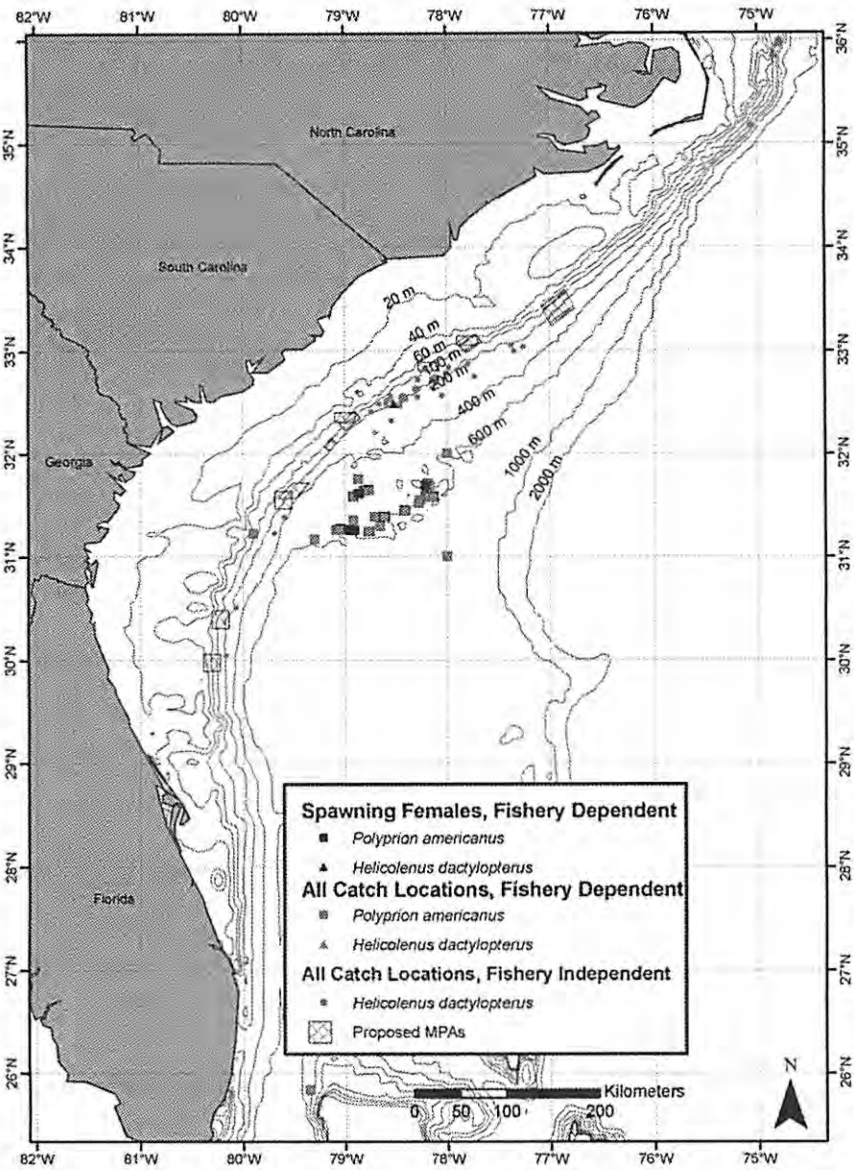


**Figure 20.** Locations of capture of blackbelly rosefish and wreckfish. See Figure 2 for additional explanation.

Red bream (*B. decadactylus*), like wreckfish and barrelfish, were collected by commercial wreckfish fishermen fishing on the Charleston Bump (Sedberry 2001). Of 16 specimens examined, eight were spawning females collected in June through September (Table 4). No spawning females were present in samples from April, May, November and December. No depth or temperature data were obtained from the commercial fishermen, but location and temperatures were similar to wreckfish catch locations.

Three additional species of grouper were also rarely collected in spawning condition. Yellowmouth grouper (*M. interstitialis*) was occasionally taken at middle- and outer-shelf reefs off of South Carolina (n = 18), where a few females (n = 9) were found in spawning condition in February, March and August off South Carolina at depths of 49 - 51 m (Tables 3-4, Figure 21). Only one bottom temperature was recorded at one spawning location (14.47° C). Rock hind (*E. adscensionis*) were collected mainly at shelf-edge reefs off of South Carolina and, of 34 examined for sex and reproductive state, five were spawning females collected during March, May and June from depths of 37 - 53 m (Tables 3-4, Figure 21). Bottom water temperatures for those collections were 20.05 - 23.96°C (n = 6). Speckled hind (*E. drummondhayi*) were distributed throughout the region on outer-shelf to upper-slope reefs in depths from 28 to 114 m, and were collected more frequently (274 examined) than rock hind (Table 3, Figure 22). Five spawning females were found off of South Carolina in May, June and September (Table 4).

In addition to the above species of grouper, we also examined gonads of seven graysby (*C. cruentata*), 18 coney (*C. fulva*) and 12 warsaw grouper (*E. nigritus*) collected throughout the region (Table 3). Several of the warsaw grouper were collected in proposed MPA sites off northern Florida and South Carolina. One spawning female was caught in May on the upper slope at a depth of 168 m (location unknown). An additional warsaw grouper examined from the database contained late vitellogenic oocytes, perhaps indicating potential spawning in the region. We collected one female coney in spawning condition in June (33.8°N, 76.8°N, 39 m), and one potential spawner in the same month with late vitellogenic oocytes. In Puerto Rico, coney spawn from December to March (Jimenez and Fernandez 2001). One female graysby examined also contained late vitellogenic oocytes, again perhaps indicating potential spawning in the region. We observed several running ripe male coney and graysby; however, male reef fishes are in spawning condition for much of the year and cannot be used to determine spawning location in the absence of females. In addition to the histological evidence of spawning cited above, we have observed courtship behavior in hogfish, *Lachnolaimus maximus*, at shelf-edge reef sites. Hogfish courtship was observed from submersible off Jacksonville, Florida on 30 July 2002 (30.4°N, 80.2°W, 56 m depth, 1846-1926 EDT) and off Charleston, South Carolina on 1 August 2002 (32.3°N, 79.0°W, 61 m depth, ~1000 EDT). Behavior was as described by Colin (1982), with the male displaying erect spines in the first dorsal fin, and rapid pelvic-fin agitations. This display was directed at one or two nearby females. Although Colin (1982) observed spawning from mid-afternoon to sunset, we did not observe actual spawning in hogfish during dives in morning and late afternoon. Bottom temperatures at the Florida site during the dive ranged from 20.90 - 20.94°C, considerably cooler than those reported by Colin (1982) in December to March in Puerto Rico (24 - 26°C). Bottom temperatures at the South Carolina site ranged from 20.47 - 22.03°C.

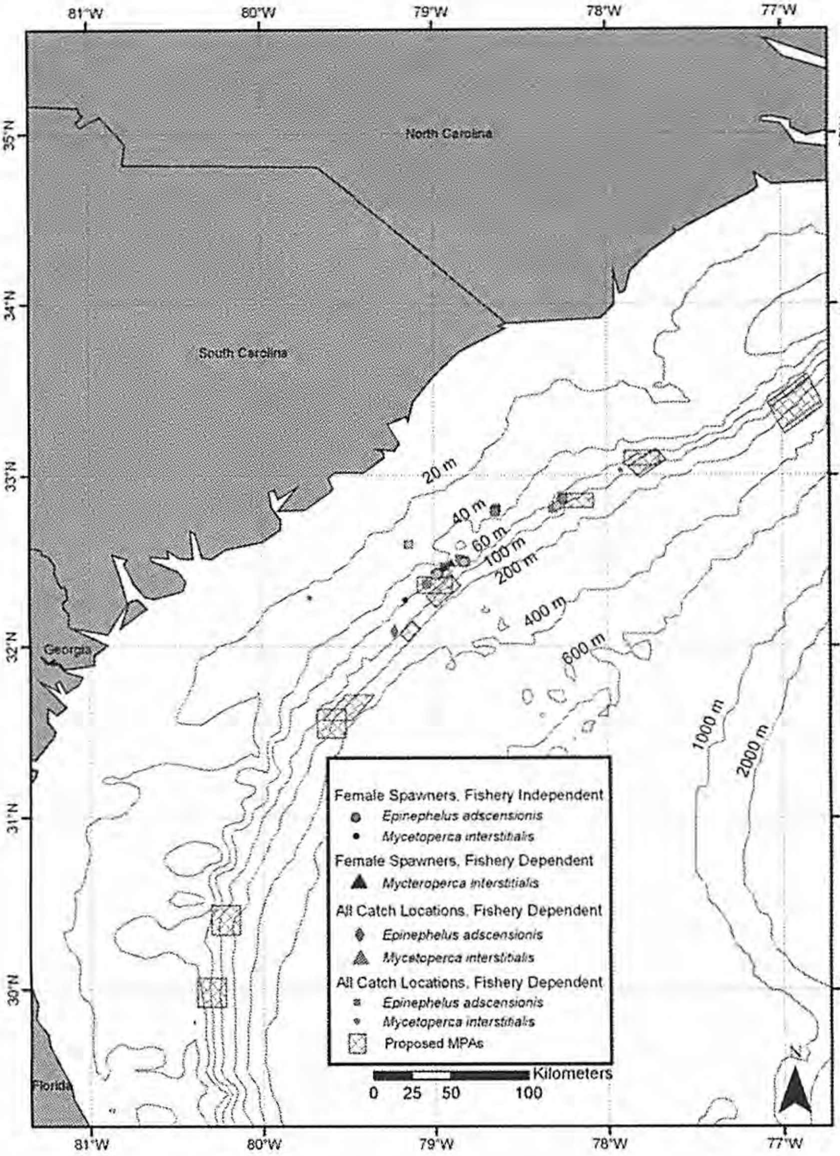


**Figure 21.** Locations of capture of rock hind and yellowmouth grouper. See Figure 2 for additional explanation.

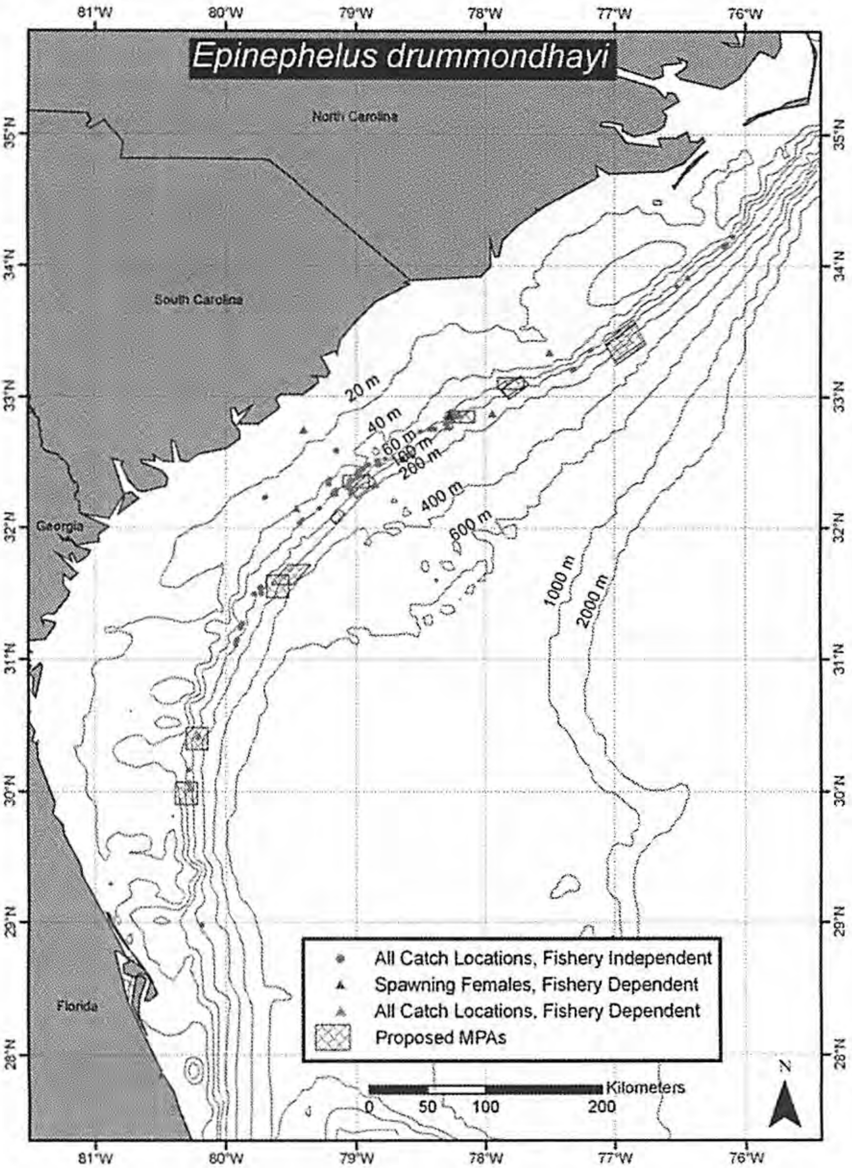


**Figure 22.** Locations of capture of speckled hind. See Figure 2 for additional explanation.

## CONCLUSIONS AND MANAGEMENT ISSUES

Spawning condition was determined for 28 species of reef fish at several phylogenetic levels, including Beryciformes (Berycidae), Scorpaeniformes (Scorpaenidae), Perciformes (Carangidae, Centrolophidae, Haemulidae, Lutjanidae, Malacanthidae, Polyprionidae, Serranidae, Sparidae) and Tetraodontiformes, and over a considerable depth and latitudinal range. In spite of some temporal and spatial sampling limitations, we determined that the species examined fall into a few groups of life history and spawning strategies.

Several species, such as small serranids, haemulids, sparids and lutjanids, spawned over protracted periods and throughout the region. Black sea bass, sand perch, tomtate, red snapper, and vermilion snapper were broadly distributed and spawned across the shelf, although vermilion snapper spawning activity seemed to be more concentrated at shelf edge reefs than the other species in this group.

Red porgy and bank sea bass also had broad distributions throughout the region, but spawning appeared to be more narrowly focused on deeper sites in the middle of the region. In the case of bank sea bass, and to a lesser extent red porgy, this may reflect sampling limitations as these both spawn in winter, when sampling is more difficult and was subsequently more confined to the waters near our laboratory.

Gag, scamp, red grouper, knobbed porgy and gray triggerfish spawned mainly at shelf-edge reefs. Gag use shallow coastal or estuarine waters as nursery areas, but make either an ontogenetic shift or spawning migration to the outer shelf. Tagging of gag has indicated a spawning migration (Van Sant et al. 1994, McGovern et al. In press). Gray triggerfish juveniles are pelagic or benthic in a variety of habitats (Martin and Drewry 1978), but apparently move to deep reefs with age and maturity. Knobbed porgy, red grouper and scamp appear to be more resident on outer-shelf reefs, where spawning occurs.

Tilefish, blackbelly rosefish, blueline tilefish, snowy grouper and yellowedge grouper are resident, at least as adults, on the upper slope. Spawning is restricted to reef (or mud in the case of tilefish) habitats on the upper slope.

Barrelfish, wreckfish and red bream live on the Charleston Bump, mainly in depths from 500 - 600 m (Sedberry et al. 2001, Popenoe and Manheim 2001, Weaver and Sedberry 2001). Spawning also occurs there, under the main axis of the Gulf Stream. Eggs, larvae and juveniles of wreckfish and barrelfish are pelagic, perhaps living at the surface for several months (Sedberry et al. 1999, Martin and Drewry 1978). It is uncertain how these fishes are recruited back to the Charleston Bump. Juvenile wreckfish are very common at the surface in the eastern North Atlantic in the months following spawning on the Charleston Bump, and wreckfish from the eastern North Atlantic are genetically identical to those from the Charleston Bump (Sedberry et al. 1999, Ball et al. 2000), indicating substantial gene flow between the regions, mediated by Gulf Stream flow.

White grunt, and to a lesser extent red grouper, were collected in spawning condition primarily in the northern part of the study area and apparently have a disjunct distribution (Zatcoff et al. 2004, Chapman et al. In prep.). They are abundant in the Caribbean and southern Florida, but are not common off northern Florida or Georgia. They appear to be more tropical species that are found only in the waters of the northern SAB that are under the influence of the Charleston Gyre. Because of the influence of Gulf Stream waters being transported onto shelf waters off northern South Carolina and southern North Carolina via the Charleston Gyre, many tropical species are recruited to this area (Powell et al. 2000).

Gag and greater amberjack appear to undertake spawning migrations to the south, with most spawning in greater amberjack apparently occurring off of southern Florida. Tagging of these species off South Carolina has indicated substantial movement to south Florida of large fish during the spawning season (Van Sant et al. 1994, McGovern et al. In press, Meister et al. In prep.).

Several rare tropical groupers (yellowmouth grouper, rock hind, speckled hind, graysby, coney, warsaw grouper) occur in the region, but it remains uncertain if spawning in most of these is occurring here or if recruitment of these fish comes from southern spawning locations. Groupers generally have long-lived larvae [31 - 66 days (Lindeman et al. 2000)], and it is certainly possible that periodic recruitment of these tropical species occurs. Some females examined appeared to be in, or approaching, spawning condition; however, it is unknown if population densities are high enough to induce spawning behavior (aggregation, harem formation) that often accompanies spawning in these tropical groupers (Jimenez and Fernandez 2001).

Although influenced by sampling limitations, there did appear to be areas within the region that are spawning grounds for several species. Shelf-edge reefs (40 - 60 m) in the middle of the SAB appeared to be particularly important. Some of these reefs coincide with areas proposed by the SAFMC as MPAs that will prohibit bottom fishing (SAFMC 2004). Proposed MPAs that encompass shelf-edge reefs off Charleston, South Carolina [SAFMC Proposed South Carolina-B MPA, Option 1 at about 32.3°N (SAFMC 2004)] included spawning grounds for bank sea bass, red grouper, gag, scamp, knobbed porgy, red porgy, vermilion snapper and gray triggerfish. Blueline tilefish were also caught in spawning condition in this proposed MPA site, but most were caught deeper, on upper slope reefs. Red snapper were also found spawning in this proposed MPA, but extensive spawning was found scattered across the shelf. Black sea bass and sand perch spawned near the South Carolina B sites, but most spawning in those two species was at scattered middle-shelf reefs. Rock hind spawned near this site and occurred in the proposed SC-B Option 1 MPA. Spawning in rock hind also occurred near Proposed South Carolina-A MPA, Option 2 at about 32.8°N, and rock hind were collected at that proposed shelf-edge MPA site. The two instances of courtship behavior observed in hogfish also took place in proposed MPA sites, one of which was South Carolina B (the other was Florida Option 1 off Jacksonville). The proposed MPA sites off South Carolina appear to be particularly important as spawning grounds for several species. Spawning occurred at one proposed South Carolina site (South Carolina-B Option 1) during all months of the year.

Gag and scamp spawning occurred in more than one proposed MPA site off South Carolina, and spawning scamp were caught in proposed MPA sites off Florida too (SAFMC Proposed North Florida MPA Option 2 at 30°N). Tomtate were found spawning at many mid- to outer-shelf sites, but only one proposed MPA site (the North Florida Option 2 site) had spawning tomtate. Vermilion snapper were found spawning in almost all of the proposed sites, the exceptions being deep (> 200 m) sites off North Carolina and Georgia.

Several species spawned mainly on upper-slope habitats. Blackbelly rosefish, snowy grouper, yellowedge grouper, and tilefish spawned on reef or mud habitat centered around 200 m. Although tilefish spawned near one of the proposed Georgia MPAs (SAFMC Proposed Georgia MPA Option 1), no spawning in any of these deepwater species was detected within the proposed MPA sites. Because protection and management of deepwater species is one of the primary objectives of the proposed MPA sites (SAFMC 2004), consideration should be given to locating a deepwater site to coincide with known spawning areas in deepwater species.

No spawning sites of greater amberjack coincided with proposed SAFMC MPA sites. However, two spawning locations were within the Florida Keys National Marine Sanctuary, but not within no-take zones in the Sanctuary. Tagging data (Meister et al. in prep.) indicate substantial movement of greater amberjack from the Carolinas to southern Florida during the spawning season. The commercial fishery for greater amberjack is closed in April (see SAFMC web site for regulations: www.safmc.net) and 56% of spawning fish were collected in April (most of those from southern Florida). This probably affords considerable protection to spawning greater amberjack.

Gag and red porgy are managed, in part, by a spawning season closure, with commercial catches limited to the recreational bag limit for gag in March and April (when 76% of spawning females were collected). Among several other restrictions, sale of red porgy is prohibited from January through April, when 88% of spawning females were collected. These closures during the peak spawning season probably afford some protection to spawning gag and red porgy.

Many species of reef fish spawn at shelf edge sites that are under the influence of the Charleston Gyre. Eggs and larvae of these species are probably entrained in this gyre. Gag larvae are most often collected in the Charleston Gyre, often several tens of kilometers offshore and over much deeper water (> 600 m) than their preferred (< 50 m) habitat (Sedberry et al. 2004). Spawning in the Charleston Gyre probably results in better survival, as early life history stages are carried off the shelf with its associated predators, and are retained in a cyclonic circulation (with upwelling at its core) that provides nutrients and eventual transported back onto the shelf toward shallow nursery areas. Such a strategy seems to be associated with the long larval period found in groupers that spawn at shelf edge sites (Lindeman et al. 2000) and that helps them utilize large gyres such as the Charleston Gyre.

Deep reef fishes of the Charleston Bump and Blake Plateau live and spawn in areas beyond those currently proposed as MPAs where bottom fishing would be prohibited. Wreckfish, however, are managed with gear restrictions (no longlines), an individual transferable quota with total allowable catch, and a spawning season closure (15 January through 15 April). Because barrelfish spawn at about the same place, and their spawning season extends into January (no data were available from February), it is likely that they are afforded some protection during spawning by regulations imposed on the wreckfish fishery. Red bream, however, spawn in summer on the Charleston Bump, when the wreckfish fishery is open and they are caught as bycatch. There is no evidence that the apparently small (but undocumented) bycatch is having a negative effect on spawning red bream, but this deserves further investigation. In addition to spawning demersal fishes on the Charleston Bump, there is some evidence that this is a spawning site for pelagic dolphin (*Coryphaena hippurus*) and swordfish (*Xiphias gladius*) as well (Govoni and Hare 2001, Sedberry et al. 2004).

Although many reef fishes important in commercial and recreational fisheries off the southeastern U.S. spawn across broad shelf areas, it is evident that some spawning is localized. Often, local spawning grounds are utilized by several species. In deciding among options for final MPA sites, consideration should be given to sites that are used as spawning grounds by several species. It is obvious that some options among the MPA sites proposed by the SAFMC contain more spawning sites for more species than do some of the other sites, and that by minor shifts in location or even orientation of the proposed closed areas, more spawning fishes could be protected. Consideration of known spawning areas and times should be an important criterion when planning time or area closures to ensure sustained fisheries.

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# The Nassau Grouper Spawning Aggregation Fishery of the Cayman Islands – An Historical and Management Perspective

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ABSTRACT

The reproductive characteristics of mass spawning at predictable times and places have made the Nassau grouper, *Epinephelus striatus*, vulnerable to over fishing. Historically in the Cayman Islands, five Nassau grouper spawning aggregations provided an important seasonal artisanal fishery for local fishermen from which fish were harvested by the thousands. In 1986, fishermen began complaining of reduced catch and size of fish taken from the fishery. Since 1987, the fishery has been monitored. Data on age, size, catch, and catch-per-unit-effort (CPUE) was collected. Fifty-two percent of fish aged were seven and eight years old, indicating full recruitment to the fishery by this age. Analyses of data show overall declines in catch, CPUE, and size. In 2001 a sixth aggregation was discovered and heavily fished. In 2002, an 'Alternate Year Fishing' law was passed to reduce fishing mortality. In 2003, an 8-year ban on fishing in all designated grouper spawning areas was implemented when it became apparent that further fishing could irreversibly compromise the viability of the 'new' aggregation. Of the six known Nassau grouper spawning aggregations sites in the Cayman Islands, three are fished out, two are in serious decline, and one, though affected by fishing, is still comparatively healthy. Additionally, two other areas were designated as potential spawning sites. The Cayman Islands case is one typical of the depletion pattern of 'boom-and-bust' Nassau-grouper aggregation fisheries seen throughout the region over the past three decades. Despite the current ban on this activity locally, our goal is to convince the local populace that this practice is unsustainable, and should permanently cease.

KEY WORDS Nassau grouper, spawning aggregation, Cayman Islands, restricted marine areas

# El Proceso de Apareamiento en las Islas Caimanes del Nassau Grouper del Punto Perspectivo Historico y de Manejamiento

Las caracteristicas de reproducción del Nassau Grouper (*Epinephelus striatus*) en tiempos y lugares predictibles los ha hecho vulnerable a la sobre pezca. En las Islas Caimanes historicamente 5 agregaciones de apareamiento del Nassau Grouper proveian una importante pezca temporal. Sin embargo en 1986, los pezcadores locales comenzarón a notar la reducción de la cantidad y el tamaño del pez obtenido.

La captura ha sido monitoriada por los ultimos 14 años , durante este tiempo los datos como la edad, tamaño, cantidad y cantidad de unidad de esfuerzo, fueron obtenidos y analizados. 52% de la edad de los peces fue 7 (26%) y 8 (25.9%) años de edad, indicaron complete recruitamiento de este grupo de edad en las pesca. Analisis de los datos señalarón todavia reduccion en las pesca, CPUE , y tamaño.

En el año 2001 una Sexta agregacion fue descubierta y violentamente pescada. En el 2002 una ley de altenar un año de pezca fue obtenidad con la idea de reducier la mortalidad. Pero cuando fue evidente que mas pescas hiban a comprometer irreversiblemente la posibilidad de sobrevivencia de la nueva argegación se implanto una nueva ley de 8 años de prohibicion de captura en todas las areas designadas de apareamiente del Nassau Grouper.

De las seis conocidas agregaciones de apareamiento del Nassau Grouper situados en las Islas Caimanes tres han desaparecidos, dos han declinado seriamente y una a pesar del impacto sigue relativamente saludable.

Las Islas Caimanes es un caso tipico de las pollaciones de explotar sobre 3 decadas la abundancia de la pesca del Nassau Grouper. A pesar de la prohibicion de la actividad pescadera local. Nuestra objective es de convencer y educar la populación local que esta practica es inconveniente y debe cesar permanentemente.

PALABRAS CLAVES: Nassau Grouper, caracteristicas de reproducción, las Islas Caimanes

## INTRODUCTION

The reproductive characteristic of aggregation spawning at predictable sites and times have made the Nassau grouper, *Epinephelus striatus* (Bloch 1792), vulnerable to overfishing. As a result, many of the known spawning aggregations of this species, are no longer viable (Sadovy and Eklund 1999).

The Cayman Islands (Grand Cayman, Little Cayman, and Cayman Brac) lie between 19°15' and 19°45'N latitude and between 79°44' and 81°27'W longitude, and Nassau grouper are relatively abundant when compared to many other locations (Patengill-Semmens and Semmens 2003). A traditional fishing culture has evolved into one economically dependent on marine tourism and finance over the past 30 years.

Historically, there were five Nassau grouper spawning aggregation sites (Tucker et al. 1993): one at the southeast corners of each of the three islands, one at the southwestern corner of Grand Cayman, and another at the southeast corner of the Twelve Mile Banks west of Grand Cayman (Figure 1). Another aggregation exists at Pickle Bank (44 nautical miles north of Little Cayman) whose political jurisdiction is undetermined. The aggregations at the eastern ends of the islands are the most well known, and have traditionally been exploited since the early 1900s with the use of small open boats and hand lines. In 1985, recognizing the importance of these three spawning areas, a general license was issued under the Restricted Marine Areas (Designation) Regulations allowing access by residents, but restricting them to fishing by hook-and-line only.

In 1986, increasing complaints from fishermen of a decline in both numbers and size of fish taken from the fishery during the last several years prompted the implementation of a monitoring program by the Department of the Environment.

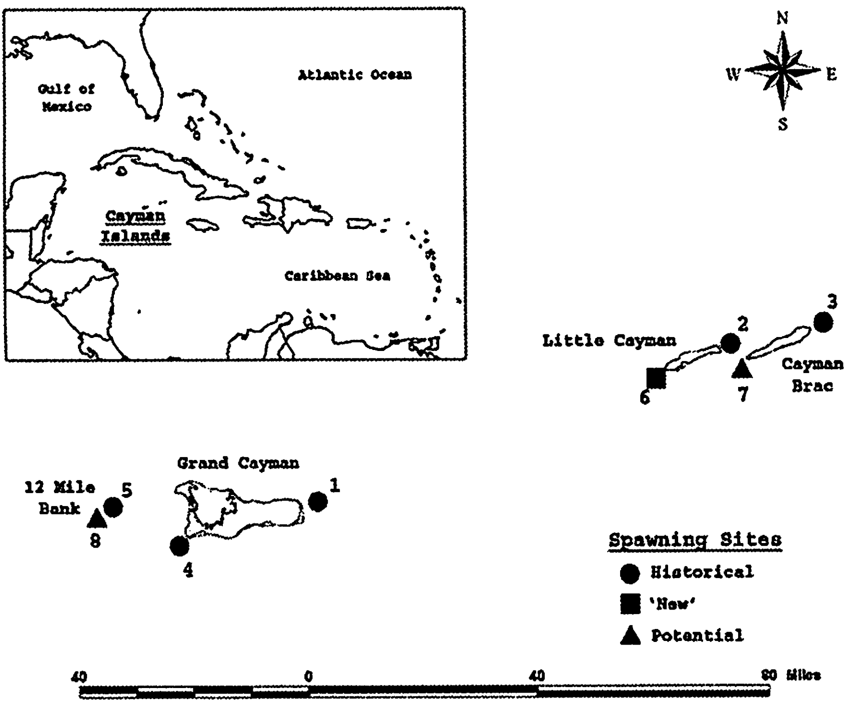


**Figure 1.** Map showing current Restricted Marine (Grouper Spawning) Areas, (1) Grand Cayman - northeast point, (2) Little Cayman - northeast point, (3) Cayman Brac - northeast point, (4) Grand Cayman -southwest point, (5) 12-Mile Bank - northeast end, (6) Little Cayman - southwest point, (7) Cayman Brac - southwest point, (8) 12-Mile Bank - southwest end.

## METHODS

From 1987 through 1992, data on catch, catch-per-unit-effort, and size, were collected during spawning season from the three main spawning sites. Catch data was recorded on a per boat basis. CPUE was determined by dividing annual catch by the number of boat trips. Total length (TL) in centimeters was measured using a graduated board.

Age data was obtained by analyzing sagittal otoliths taken from 479 fish, and the aging technique was validated in 1992 by use of captive fish injected with oxytetracycline (Bush et al 1996). Sampling of catch and size data from the three main aggregations continued through 2001. Sex and weight data was initially collected, but was discontinued due to manpower and time restraints. Data from the southwest point of Grand Cayman, Twelve-Mile Bank, and Pickle Bank was sporadic and is not reported herein.

## RESULTS AND DISCUSSION

### Fishery Data

Most grouper in the spawning aggregations (84%) are between the ages of six and 11 with 52% of the fish either ages seven (26.1%) or 8(25.9%). These two dominant year classes (seven and eight) indicate the age at full recruitment to the fishery (Figure 2). The oldest fish (29 years) exceeds the oldest age reported for Nassau grouper (Olsen and LaPlace, 1978) by 13 years. A length at age curve was generated (Figure 3) and fitted to the von Bertalanffy growth equation in order to compare the equation parameters with those published for E. striatus (Manooch 1987, Valle et al 1997). $L\infty$, average asymptotic length, = 765 $\pm$ 30 mm with 95% confidence limits; K, growth coefficient, 0.282 (per yr.); and $t_0$, theoretical age at 0 length, -0.638 yrs.; were calculated from a regression of the Ford/Walford line ($l_{t+1}$ = 140.,04 + $0.821l_t$, $r^2$ = 0.96) to where $l_t = l_{t+1}$; $l_t$ is the mean length at any given age. By restricting the ages used to calculate the von Bertalanffy growth parameters to those with a minimum of 10 fish in any age group (i.e., ages 5 - 13) a close fit of calculated and observed lengths was obtained between those ages (Table 1). Manooch (1987), Pauly and Binohlan (1996), and Valle et al (1997) summarize parameters of Nassau grouper: $L_\infty$ from 900TL -1130mm TL, with one exception (760 mm TL from NE Cuba, Claro et al 1991), K's from 0.060-0.224 (per year), and $t_0$ - 3.27 - 0.488 (year). Our calculated growth parameters differ from those published; $L\infty$ = 765 mm TL and $t_0$ = -0.638, are lower than previously published with the exception of one $L_\infty$ estimate by Claro et al 1991. Our growth coefficient K = 0.202 is slightly higher than those reported by Manooch (1987), Pauly and Binohlan (1996), and Valle (1997), with one exception, 0.224 reported by Randall (1962). The low $L_\infty$ and high K would indicate that Nassau grouper around the Cayman Islands have a high early growth rate to ages 10 or 11 but a lower terminal size than other stocks.

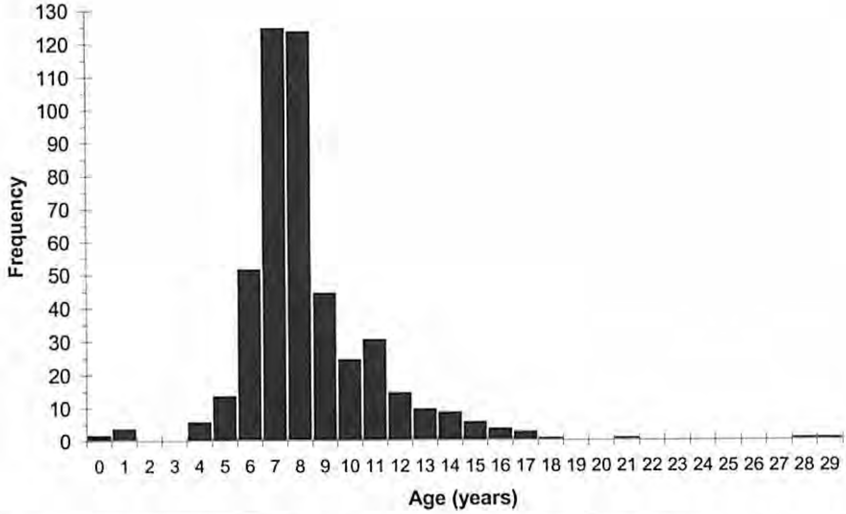


**Figure 2.** Age frequency distribution of 479 *E. striatus* from 1987 – 1992.

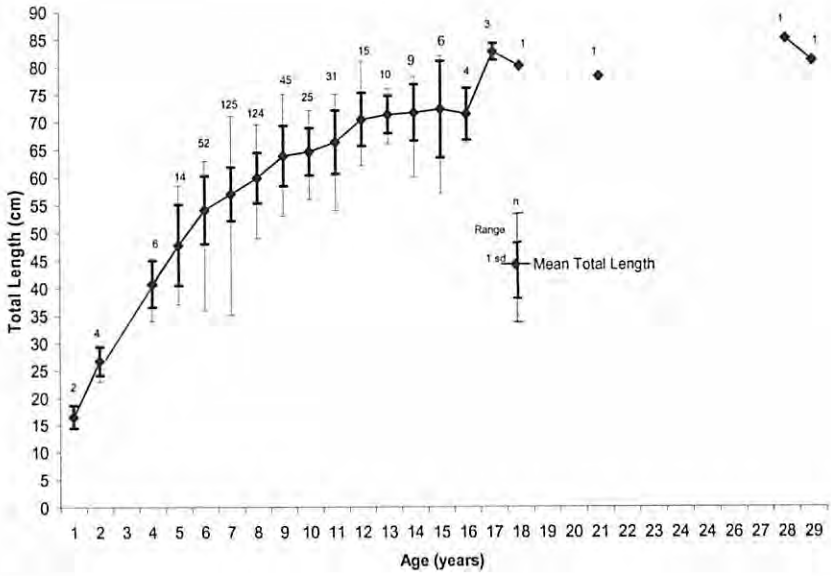


**Figure 3.** Growth curve for *E. striatus* sampled from aggregations 1987 – 1992.

**Table 1.** Age vs. Length data of 479 Nassau grouper from the Cayman Islands. Predicted mean lengths fitting the data between ages 5 and 13 to the von Bertalanffy growth equation: lt = 765[1-e-0.202(t+0.638)]

| Age years | Total Lengths (mm) | | | No. Fish | Predicted Length |
|---|---|---|---|---|---|
| | Range | Mean | Standard Deviation | | |
| 0 | 150-180 | - | - | 2 | 93 |
| 1 | 230-290 | 268 | - | 4 | 216 |
| 4 | 340-445 | 408 | 42.3 | 6 | 398 |
| 5 | 365-585 | 478 | 72.7 | 14 | 465 |
| 6 | 360-630 | 541 | 61.1 | 52 | 520 |
| 7 | 345-710 | 570 | 48.2 | 125 | 565 |
| 8 | 490-695 | 599 | 45.4 | 124 | 601 |
| 9 | 530-750 | 638 | 54,1 | 45 | 631 |
| 10 | 555-720 | 646 | 42.8 | 25 | 655 |
| 11 | 540-750 | 663 | 57.2 | 31 | 675 |
| 12 | 620-710 | 704 | 47.9 | 15 | 692 |
| 13 | 660-760 | 713 | 34.1 | 10 | 705 |
| 14 | 600-735 | 716 | 50.9 | 9 | 716 |
| 15 | 565-820 | 722 | 87.2 | 6 | 725 |
| 16 | 660-760 | 714 | - | 4 | 733 |
| 17 | 810-840 | 827 | - | 3 | 738 |
| 18 | 801 | - | - | 1 | 743 |
| 21 | 782 | - | - | 1 | 753 |
| 28 | 850 | - | - | 1 | 762 |
| 29 | 810 | - | - | 1 | 763 |

Catch, CPUE, and Size from these three spawning aggregations have declined over the 15 year period. Catch (Figure 4a) from Grand Cayman and Little Cayman during the early years of the monitoring period was in the low hundreds and has since dwindled. In Cayman Brac, while catch was in the low thousands during the initial years following the re-discovery of the spawning aggregation, it too has declined drastically in the last six years. Catch-per-unit-effort and size (Figure 4b,c) for all three islands show similar marked trends. The Little Cayman site was abandoned in 1993 when the aggregation ceased to form.

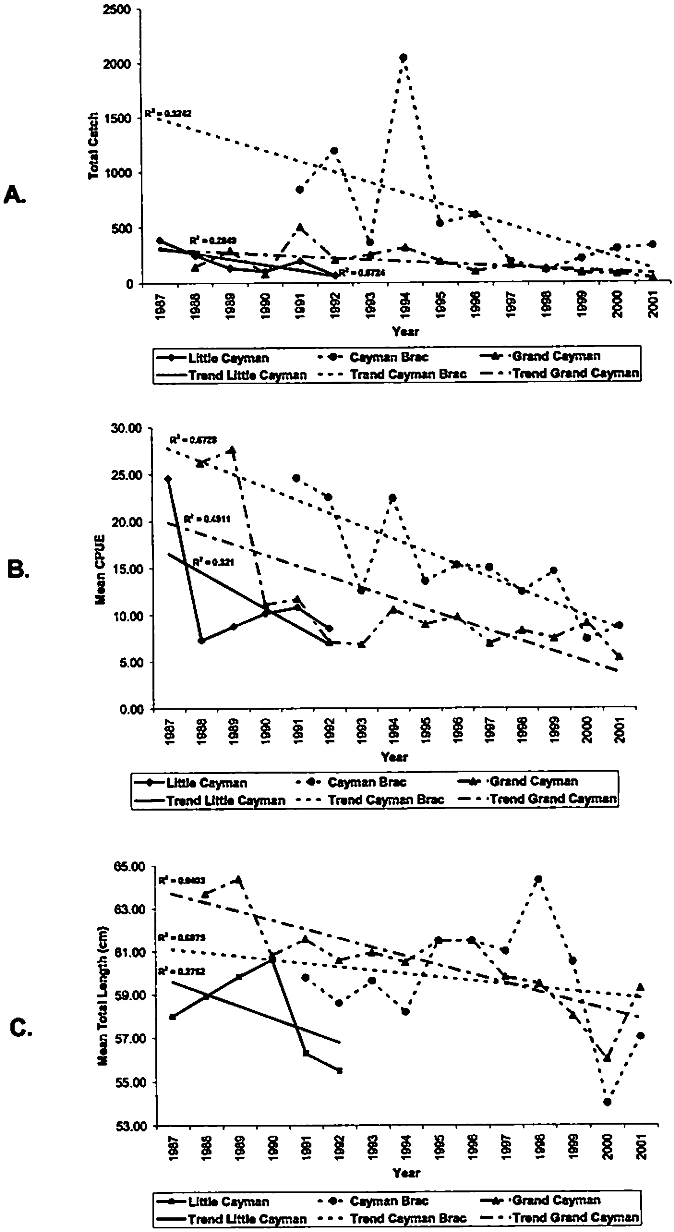


**Figure 4.** 15-year trends in (A) Annual catch, (B) Annual catch-per-unit-effort and (C) Annual size from the three northeastern grouper spawning aggregations.

### Chronology of Fishing Activity

Between 1984 and 1990, the Cayman Brac site was dormant and the fishing fleet of Cayman Brac targeted the northeast SPAG of Little Cayman (the two islands are five nautical miles apart). In 1991, an aggregation was found approximately 1.2 km north of the dormant Cayman Brac site, and has been heavily fished.

By 1993, the Little Cayman site was inactive. Continued monitoring through 2001 showed continuing declines in both catch and size of fish from the aggregations of Grand Cayman and Cayman Brac. Of the two other aggregations, located near Grand Cayman, one (Southwest site) was fished until 1990, after which it no longer formed, and the other (Twelve-Mile Bank) still yields a variable, albeit low, number of fish.

In 2001, another aggregation which (according to anecdotal reports) had not been fished since the late 1960s, was 're-discovered' at the western end of Little Cayman, and heavily fished during the 2001 and 2002 spawning season. Approximately 4,000 fish were taken from this aggregation during 20 days of fishing (Whaylen et al 2004). Pre-fishing abundance for this aggregation is estimated at over 7,000 fish. This aggregation is believed to be the last healthy spawning aggregation of Nassau groupers in the Cayman Islands.

### Chronology of Management Measures

In 1995, after the first six years of data showed a decline in all parameters, a recommendation was made to implement an 'Alternate Year Fishing' strategy in order to reduce fishing mortality by half. However, due to lack of political support, this was not implemented.

In 1998, the three main spawning areas at the eastern ends of the islands were formally demarcated as 'Restricted Marine Areas' for which access required licensing by the Marine Conservation Board (the statutory authority responsible for the administration of the Marine Conservation Law).

Following public controversy regarding the mass harvest of fish in 2001, and again in 2002, the Marine Conservation Board and the Department of Environment campaigned for support to protect the Nassau grouper spawning aggregations by holding a series of meetings with government, the watersports, and restaurant sectors of the Cayman Islands Tourism Association, as well as fishermen. Protective legislation was passed in February of 2002 (Whaylen et al. 2004). This legislation defined a spawning season of November 1 to March 31, and implemented the 'Alternate Year Fishing' law (first recommended in 1995) to reduce fishing mortality in the designated grouper spawning areas. This law allowed fishing every other year with the first non-fishing year starting with 2003, and also set a catch limit of 12 Nassau grouper per boat per day during fishing years. The law also defined one nautical mile 'no trapping' zones around each spawning site, and set a minimum size limit of 12 inches for Nassau grouper. Finally, a significant aspect of the law provided power to the Marine Conservation Board to change these restrictions to any or all of the designated spawning areas.

In mid-December of 2002, the other two of the five original spawning areas, and the new one at the west end of Little Cayman, were designated as restricted marine areas. In addition, two more areas were designated, due to their potential to accommodate spawning aggregations, and the possibility of spawning aggregations shifting. These were the southwest end of 12 Mile Bank and the southwest end of Cayman Brac, both of which have the geo-morphological and oceanographic characteristics common to such spawning areas.

With the approaching spawning season of 2004, it was realized that the new 'alternate-year-fishing' management strategy would not accomplish the goal for which it was originally intended. Our calculations showed that, despite the new catch limits, fishing during the 2004 season could compromise the viability of this relatively healthy aggregation. Assuming that fishing effort would be similar to that of 2001 and 2002, most of the estimated 3,000 surviving fish in the 'new' spawning aggregation at the west end of Little Cayman, would be removed. As a result of this, on the 29th December of 2003, the Marine Conservation Board exercised it powers to change the 'Alternate-Year-Fishing' portion of the law to an eight year ban on fishing within all designated grouper spawning areas. It was thought that this time period representing one reproductive cycle for the species, was the minimum needed to realize any benefits to replenishment.

## CONCLUSION

The Cayman Islands case is typical of the depletion pattern of 'boom-and-bust' grouper aggregation fisheries seen through out the region over the past three decades. Lack of effective management has resulted in the demise of many spawning aggregations, including some local ones, and the species is now absent in many locations.

It is important that fisheries management authorities be empowered to respond quickly to problems as the timeliness of the response is critical if it is to succeed.

The seven year delay in implementation of the alternate year strategy, combined with continued heavy fishing, almost certainly would have compromised the strategy's intended effect as reproductive stock became depleted.

The Cayman islands now have a total of eight designated grouper spawning areas covering an area of 17.56 square kilometers. Of the six known Nassau grouper spawning aggregations sites in the Cayman Islands, three are fished out, two are in serious decline , and one, though affected by two years of heavy fishing , still relatively healthy. Despite the current ban on fishing local aggregations, our goal is to convince residents that this practice is unsustainable in any measure, and should permanently cease. In the interim, we believe that the management measures implemented, along with adequate enforcement, will contribute effectively to the perpetuation of this species in the Cayman Islands.

Immediate future plans for the Little Cayman aggregation include continued in-situ monitoring, as well as a tagging and tracking project. Eventually assessments will be carried out on all known spawning aggregations sites, with a view to monitoring any replenishment or re-habilitation. Other sites possessing other locations possessing similar geo-morphological and oceanographic conditions will also be investigated.

ACKNOWLEDGEMENTS

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# Primeras Descripciones de la Agregación de Desove del Mero Colorado, *Epinephelus guttatus*, en el Parque Marino Nacional "Arrecife Alacranes" de la Plataforma Yucateca

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RESUMEN

Desde el año 2000 los primeros indicios de la ocurrencia de una agregación de desove de mero colorado *E. guttatus* en el Arrecife Alacranes fueron puestos de manifiesto en trabajos realizados con pescadores locales. A partir del 2002 y hasta el 2004, un área ubicada en el noreste del arrecife y conocido como "el sándwich" fue monitoreado mensualmente en los días previos y posteriores a la fase lunar de luna llena. La determinación de la densidad de organismos de *E. guttatus* en el sitio permitió definir que los meses de enero a marzo son los meses pico de reproducción de esta especie. La presencia de ovocitos hialinos, observados macroscópicamente, en ejemplares hembras de esta especie nos permitió confirmar la ocurrencia de agregaciones de desove en esta área particular del Arrecife Alacranes. La talla de los organismos, que fueron observados en la agregación, correspondió a ejemplares adultos y estuvieron entre los 20 y 45 cm. de longitud total. La proporción de sexos fue estimada en 1:1.3. La ocurrencia de este comportamiento reproductor fue observada, en el mismo sitio y durante los mismos meses, durante el tiempo de estudio. El área de agregación esta ubicado a una profundidad de 85 pies y presenta una cobertura dominante de corales suaves, principalmente gorgonias. Datos de la explotación pesquera de esta agregación son incluidos y discutidos en este trabajo.

PALABRAS CLAVES: Agregación de desove, mero colorado, Yucatán

# First Descriptions of a Spawning Aggregation of Red Hind, *Epinephelus guttatus*, in the National Marine Park "Alacranes Reef" on the Yucatan Platform

Since 2000, first indications of the occurrence of a spawning aggregation of red hind *E. guttatus* in the Alacranes Reef were identified through interviews with local fishermen. From 2002 through 2004, an area located in the northeast reef and known as the "sandwich" was monitored monthly during the days prior to and after the Full Moon. The determination of density of *E. guttatus* in the site allowed us to define that the months of January to March are the peak time of reproduction of this specie. The presence of hyalin oocytes, observed macrocospically, in females examples allowed us to confirm the occurrence of spawning aggregation in this particular area of the Alacranes Reef. The size of the organisms observed in the aggregation corresponded to adult organisms and were between the 20 and 45 cm. total length. The sex ratio was estimated at 1:6 male:female. Reproductive behavior was observed, in the same site and during such months, throughout the time of study. The aggregation is located at a depth of 85 feet, and it displays a dominant cover of smooth corals, mainly gorgonians. Fishing data are included and discussed in this work.

KEY WORDS: Spawning aggregation, red hind, Yucatan

## INTRODUCCIÓN

Durante su época de reproducción, los adultos de diversas especies de peces tropicales de las familias Serranidae, Lutjanidae, Caesionidae, Mugilidae, Labridae, Scaridae, Acanthuridae y Siganidae forman agregaciones en lugares específicos y periodos determinados, para liberar sus gametos. Estas agregaciones constituyen unos de los ejemplos más espectaculares de las diversas estrategias de reproducción que desarrollan los organismos presentes en los ambientes de arrecifes coralinos. Una agregación de reproducción puede ser definida como un amontonamiento de peces de una misma especie, que se juntan para emitir sus gametos, y cuya densidad o cantidad de individuos es significativamente más alta que la observada, en la misma zona de agregación, durante el periodo de inactividad sexual. Las investigaciones sobre las agregaciones de reproducción de peces son escasas por el hecho de que este tipo de estudio es generalmente difícil de realizar. A menudo son eventos efímeros que ocurren en lugares muy remotos, muchas veces cuando prevalecen condiciones climáticas desfavorables y, si suceden en zonas de fácil acceso, estas agregaciones ya desaparecieron o fueron reducidas en importancia por la pesca (Domeier y Colin 1997).

Varias especies de meros (Epinephelinae, Epinephelini) realizan migraciones de reproducción y forman agregaciones de centenares a miles de individuos durante varios días, en sitios específicos de extensión limitada, y a veces en sincronía con las fases lunares (Domeier y Colin 1997). A la fecha se ha podido comprobar la formación de agregaciones de reproducción típicas para *E. adscensionis* (Colin et al. 1987), *E. guttatus* (Colin et al. 1987; Shapiro et al. 1993a,b); Sadovy et al. 1994), *E. itajara* (Colin 1994), *E. striatus* (Smith 1972, Olsen y Laplace 1979, Colin et al. 1987, Colin 1992, Aguilar-Perera 1994, Carter et al. 1994, Sadovy y Colin 1995, Aguilar-Perera y Aguilar-Dávila 1996), *M. bonaci* (Carter 1989, Carter y Perrine 1994, Eklund et al. 2000), *M. tigris* (Sadovy y Domeier 1994) y *M. venenosa* (Bannerot en Domeier y Colin 1997). Otras especies como *M. microlepis* y *M. phenax* forman agregaciones más modestas en cuanto al número de individuos involucrados, y en áreas más extensas (Gilmore y Jones 1992, Coleman et al. 1996, Koenig et al. 1996). Algunas especies como *Cephalopholis cruentata*, *C. fulva* y probablemente *E. morio* no forman agregaciones para la reproducción (Coleman et al. 1996).

cuales estuvieron caracterizados por la presencia de gónadas pálidas, las cuales emitían esperma al someterlas a una presión leve. En 12 individuos no fue posible llevar a cabo un sexado macroscópico debido a que las gónadas estaban en estado inmaduro y de muy pequeño tamaño, estos organismos fueron catalogados como indeterminados. 43 hembras fueron identificadas debido a una avanzada maduración gonadal, caracterizada por la presencia de ovocitos opacos y hialinos a simple vista. La presencia de ovocitos hidratados, macroscópicamente, nos permitió deducir que el desove en las hembras capturadas era de manera inminente. Así con los datos anteriores se obtuvo una proporción de sexos de 1H:1.3M.

Las tallas de los organismos capturados fueron para los machos: Longitud total mínima y máxima de 34.8 y 48.5 cm., respectivamente. Las hembras tuvieron un rango de talla entre los 26.5 y 35.3 cm. de longitud total *mínima* y máxima respectivamente. Los organismos categorizados como indeterminados tuvieron una longitud total entre los 30.0 y 35.4 cm. mínima y máxima respectivamente. El análisis estadístico mostró diferencias entre la tallas, siendo los macho mas grandes que las hembras y los indeterminados, y entre estos dos últimos, el rango de tallas no presento diferencias estadísticas.

El análisis ponderal del índice gonadosómatico revelo altos valores individuales: las hembras tuvieron valores máximos y mínimos de 38.2 y 2.8% respectivos. Los valores para los machos fue de 2.76 y 0.35%, para los organismos indeterminados estos fueron los mas bajos con valores de 1 y .19 % máximos y mínimos respectivamente.

Por otro lado el análisis de la presencia de ovocitos hialinos en relación con la fase lunar nos permitió observar que los mayores porcentajes relativos del número de hembras con esta característica se presentaban en días posteriores a la fase de luna llena y más cercanos a la fase de luna nueva.

## DISCUSIÓN

El reporte de la ocurrencia de agregaciones de desove para una especie de mero, *Epinephelus guttatus*, es el primero en su tipo de descripción que se tiene para la zona del banco de Campeche. Así la determinación de un periodo de reproducción de esta especie que ocurre entre los meses de enero a marzo coincide con lo reportado para la misma especie en otra áreas del Mar Caribe; en particular, *E. guttatus* se reproduce entre enero y abril en Jamaica, Puerto Rico y Venezuela (Colin et al. 1987, Shapiro et al. 1993a,b, Sadovy 1996). Las variaciones mensuales observadas en el sitio, con un aumento bastante notorio de la densidad en los meses antes mencionados es un detalle de carácter directo que permite afirmar que efectivamente la ocurrencia de una agregación se esta dando en el área (SCRFA 2003).

En los sitios donde ocurren estas agregaciones las características de cobertura del fondo con la dominancia de pequeños parches de coral masivo y corales suaves concuerda con lo que este estudio encontró en la zona conocida como el "sándwich" (Colin et al. 1987, Shapiro et al. 1993a,b).

Se notó a través de la realización de observaciones submarinas, la formación de varios pequeños grupos de individuos de *E. guttatus* dominadas por un macho con su pequeño conjunto de hembras. También se identificaron para los ejemplares de esta especie, patrones de coloración muy similares a los descritos por Colin et al. (1987) y Shapiro et al. (1993a) para especimenes machos y hembras de *E. guttatus* observados en agregación de reproducción en Puerto Rico. Sin embargo debido a la carencia de personal y las condiciones meteorológicas de la zona de estudio no se pudo en algún momento observar algún cortejo nupcial ni tampoco emisión de gametos por parte de las organismos agregados.

A partir de del análisis macroscópico de las gónadas de los organismos capturados nos confirmo que estaban sexualmente activos y se encontraban en las etapas terminales de la vitelogénesis para las hembras o de la espermiogénesis para los machos. La presencia de un buen porcentaje de hembras con ovocitos hialinos observados a simple vista durante el periodo de mayor actividad reproductiva, nos permite determinar de manera concreta que los organismos que ocurren en esta agregación llevaran a cabo un desove inminente (SCRFA 2003).

De manera general, se conoce poco sobre la ubicación geográfica de los sitios de reproducción de los peces arrecifales de importancia comercial (Sadovy, 1996). Sin embargo con todo lo anterior y considerando la clasificación propuesta por Domeier y Colin (1997), podemos coincidir que para *E. guttatus* realiza una agregación de desove de tipo *Transitorias* ocurren en lugares ajenos al área de distribución habitual de los reproductores y implican, por parte de ellos, la realización de migraciones de una duración de varios días o semanas. Estas agregaciones se forman durante varios días o semanas consecutivos, a lo largo de un periodo de tiempo limitado a uno o dos meses del año. Así se reporta que *E. guttatus* forma agregaciones de reproducción de tipo *Transitoria*, que ocurren en sincronía con los periodos de luna llena, en Bahamas, Belice y Honduras para la primera y en Bermudas, Belice, Puerto Rico, Jamaica, y las Islas Vírgenes para la segunda (Domeier y Colin 1994).

Se ha observado frecuentemente un uso compartido de los mismos sitios de desove por parte de varias especies de meros y pargos pero en épocas del año diferentes para cada una de ellas. Tal es el caso de *E. guttatus*, *E. striatus*, *M. venenosa* y *Lutjanus synagris* en las Islas Vírgenes (Beets y Friedlander en Sadovy, 1996) o también *E. striatus*, *M. bonaci* y *L. jocu* en Belice (Carter, 1989). Al contrario, en otras regiones, como en las Bermudas, diferentes especies desovan durante la misma época pero en sitios distintos: entre 33 y 37m de profundidad para *E. striatus* y entre 18 y 27 m para *E. guttatus* (Burnett-Herkes en Thresher 1984).

Durante la formación de una agregación, la modalidad de apareamiento (por pareja o en grupos) adoptado por los organismos de una especie determinada, puede ser deducida del valor de la proporción relativa que representa el peso de los testículos en relación con el peso de los machos (i.e. IGS). Los machos de las especies que se reproducen a través de la formación de parejas presentan testículos reducidos, de poco peso, y valores de IGS bajos; mientras que los machos de las especies que desovan en grupos, presentan testículos muy desarrollados, de fuerte peso, y valores de IGS elevados. Los altos valores máximos de IGS de machos de *E. dejan* suponer que estas especies deben de desovar en grupos. Esta conclusión confirma las observaciones realizadas en otras regiones sobre *E. striatus* pero contradice lo establecido para *E. guttatus*, lo cual es considerado como una especie cuyos individuos forman parejas durante el desove (Domeier y Colin 1994). Con relación a *M. venenosa* no se dispone de reporte sobre su modalidad de apareamiento.

Es necesario la realización de estudios mas detallados sobre la ocurrencia de esta agregación de desove en el Arrecife Alacranes, además estudios más avanzados en otras áreas de la ecología pueden poder articularse con la ubicación ahora concreta en tiempo y espacio de este fenómeno natural.

Actualmente la localización precisa de los hábitats críticos donde se forman las agregaciones de reproducción así como el periodo durante el cual éstas ocurren, son informaciones de suma importancia para pretender alcanzar un manejo sustentable y la protección de especies de peces de alto valor comercial y muy vulnerable a la explotación pesquera, como son los meros.

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# Estimation of the Size of Spawning Aggregations of Red Hind (*Epinephelus guttatus*) Using a Tag-recapture Methodology at Bermuda

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ABSTRACT

The estimation of the number of fish at a spawning aggregation site by diver census can be logistically challenging. The spatial extent of the aggregation, underwater visibility, spawning time and other factors can influence the accuracy of the estimate. We use the results of an extensive tag-recapture program for red hind (*Epinephelus guttatus*) at two spatially-separated spawning aggregation sites to estimate maximum aggregation sizes. A total of three Peterson index values were derived from tag-recapture results obtained at two seasonally-protected aggregation sites from 1993-2000. The three maximum aggregation size estimates ranged from 926 to 1,153 fish. These values are compared to estimates of red hind aggregation size from two locations in the Caribbean.

KEY WORDS: *Epinephelus guttatus*, spawning aggregation size, Petersen index, Bermuda

# Valoración del Tamaño de Agregaciones de Freza de Mero Colorado (*Epinephelus guttatus*) con una Metodología del Etiqueta-recobrar en Bermudas

La estimacion del número de individuos en bancos de desove usando censos de buceo puede ser un desafío logístico. La extension especial del banco de desove, la visibilidad subacuática, el tiempo del desove y otros factores pueden influenciar la exactitud de las estimaciones. Utilizamos los resultados de un extenso programa de marcado y recaptura para mero cabrilla (*Epinephelus guttatus*) en dos sitios de desove separados para estimar los tamaños máximos de las agregaciones. Un total de tres valores del índice de Peterson fueron derivados en los dos sitios protegidos durante la epoca de desove durante el periodo 1993-2000. Las tres estimaciones del tamaño maximo de la agregación variarion entre 926 a 1,153 individuos. Estos valores se comparan con las estimaciones del tamaño de las agregaciones de mero cabrilla con otras dos localidades en el Caribe.

PALABRAS CLAVES: Mero colorado, *Epinephelus guttatus*, agregaciones de freza, etiqueta-recobrar

## INTRODUCTION

Reef fish spawning aggregations are documented throughout most of the wider Caribbean region, and there appears to be a general declining trend in landings from most known sites (Luckhurst 2004). The majority of the landings from spawning aggregation sites are of the commercially important groupers and snappers. Species from these two families comprise a significant proportion of the landings from aggregations in most countries in the region. Amongst the eight species of groupers known to form spawning aggregations in the region (Luckhurst 2003), the red hind, a medium-sized grouper, is known to form spawning aggregations in a number of countries including Bermuda (Luckhurst 1998).

Domeier and Colin (1997) defined two different types of spawning aggregations, "transient" and "resident". Groupers and snappers form "transient" aggregations with the following characteristics:

i) Fish frequently migrate long distances to the aggregation site,
ii) Aggregations typically form for only 1-3 months during the same time period each year,
iii) The duration of the aggregation ranges from only a few days to several weeks,
iv) The formation of aggregations is entrained to the lunar cycle with the full moon period appearing to be the most common aggregation time for groupers and snappers in the wider Caribbean.

Due to the economic importance of groupers and snappers to most fisheries, research to date has concentrated largely on the species in these two families. However, relatively few spawning aggregations have been scientifically evaluated. As a consequence of this paucity of quantitative information from aggregation fisheries, it is difficult to evaluate aggregation status and formulate appropriate management measures.

The estimation of fish abundance at spawning aggregation sites has been conducted mainly by divers using various visual census techniques. Shapiro et al. (1993) produced an estimate of the size of a red hind spawning aggregation in Puerto Rico while Beets and Friedlander (1998) evaluated a red hind aggregation in St. Thomas, U.S. Virgin Islands. More recently, Nemeth (2005) has been documenting the recovery of this same red hind aggregation under permanent closure.

In conducting visual counts, protocols are typically standardized to minimize error and usually involve several divers and repeated counts. However, there are still a number of problems associated with visual assessments:

i) Underwater visibility – Poor visibility limits the field of vision for diver counts.
ii) Spatial extent of aggregation – Aggregations covering large areas may preclude the ability to survey the entire site during a given dive.

iii) Depth limitations – Many aggregations occur in relatively deep water (30+ m) limiting bottom time for divers.
iv) Temporal dynamics – Many aggregations are only fully formed just before spawning occurs which is frequently approaching dusk, hence low light conditions limit the ability of divers to make accurate counts.
v) Sea conditions – It appears that spawning aggregation sites are frequently in reef locations with strong currents and often rough sea conditions, making the task of working at these sites more difficult for divers.
vi) Species behaviour - Some species swim in the water column making them easier to count while others shelter in the reef infrastructure until just prior to spawning and are not readily observed by divers.

As a result of these problems, the use of underwater video cameras has become a common means of providing a permanent record of the aggregation and different videography techniques, e.g. freeze frame, can be used to estimate the abundance of aggregating fish. This video record can then be analyzed at a later date to examine detailed fish behaviour and other features of the aggregation. Lastly, sonar scanning of aggregations has come into use in recent years to estimate abundance. This technique requires ground truth work to interpret target size and strength in order to provide reasonable estimates of aggregation abundance from sonar records.

The first research on spawning aggregations in Bermuda was conducted on the red hind from 1973 - 1975 (Burnett-Herkes 1975). This research program was initiated due to a request from commercial fishermen to take management action in the face of the overfishing of aggregations. The research involved tagging and basic biology but there was very limited data on spawning dynamics and no estimates of aggregation size were made. Sampling of the aggregations continued on an intermittent basis through the 1980s but no tagging was conducted. Following the commencement of a long-term tagging program in 1993, the initial results indicated a relatively high recapture rate of tagged fish (15.2%) at the aggregation site and the recaptured fish demonstrated site fidelity (Luckhurst 1998). This provided the opportunity to use tag-recapture data to estimate aggregation abundance. Suitable data were available for only three of the seven years of the tagging program.

In this paper, we use a Petersen index to estimate abundance of red hinds at two spawning aggregation sites at opposite ends of the Bermuda reef platform.

## MATERIALS AND METHODS

Sampling and tagging of red hinds from the northeastern (NE1) spawning aggregation site (Figure 1) was conducted during the peak spawning aggregation periods (full moon, May to July) in 1993 - 1995. At the southwestern (SW1) site (Figure 1), sampling and tagging took place during the spawning periods from 1997 - 2000.

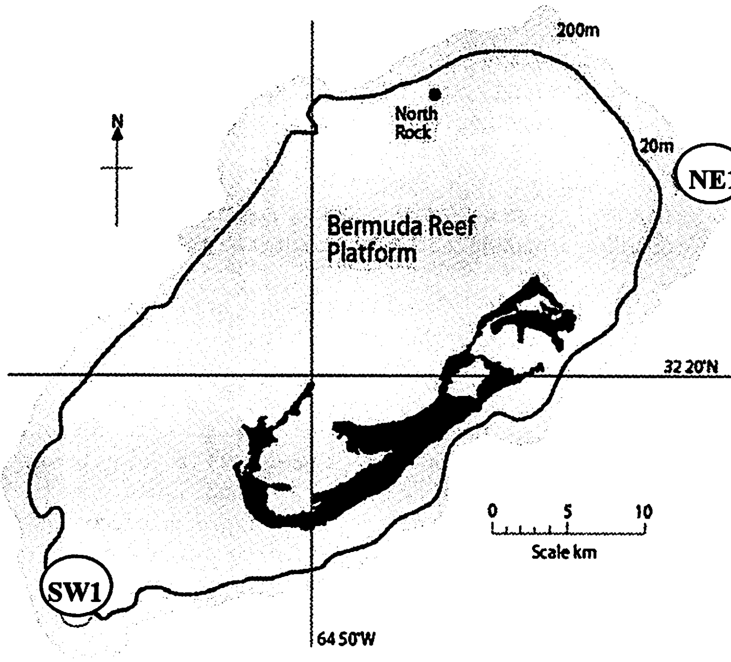


**Figure 1.** Map of Bermuda reef platform indicating locations of the two spawning aggregation sites (SW1, NE1) for red hind for which aggregation abundance values were estimated.

The details of the sampling and tagging protocol are outlined in Luckhurst (1998). It should be noted that from 1994 onward, all specimens were double-tagged with Floy T-bar anchor tags to minimize the effect of tag loss detected after the first year of tagging. To evaluate the possible increased vulnerability to predation of tagged fish upon release, the senior author observed (using SCUBA) the release, on three separate occasions of tagged fish (total of >50 fish) while stationed on the reef substrate under the research vessel. Observations were made of the behaviour upon release and tagged specimens were tracked for the first 10-15 minutes post-release. The visibility of the tags while fish were located within the reef infrastructure was also noted.

Following the theory outlined by Seber (1982), an estimate of maximum aggregation size is possible through the Peterson estimate, derived by;

$$N^* = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1 \qquad (1)$$

where $N^*$ = estimate of the number of fish in a closed population

$n_1$ = number of fish tagged and released in the first sample,

$n_2$ = number of fish obtained in the second sample

$m_2$ = number of tagged fish in the second sample.

The variance ($v^*$) of $N^*$ is given by Seber (1982);

$$v^* = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)} \qquad (2)$$

and an approximate 95% confidence interval for $N$ (the number of fish in a closed population) can be calculated by;

$$N^* \pm 1.96\sqrt{v^*} \qquad (3)$$

Before substituting experimental values into equation (1), handling mortality must be considered so that $n_1$ refers to the number returned alive to the population (Seber 1982). An element of post-release mortality of tagged fish probably occurred as a result of the invasive "winding" and tagging procedures. Mortality due to capture and "winding" was estimated from the proportion of red hinds that died while being retained in live-wells on board the research vessel or in holding tanks ashore during a 24 hour minimum observation period following capture. This time-period was selected as experience indicated it to be the most vulnerable period of captivity. Data from 1993 and 1994 indicated that the mortality rate in captivity was approximately 6%. Thus, the value substituted into equation (1) for survivorship of tagged and released fish was reduced accordingly.

## RESULTS

### Post-release Behaviour of Tagged Fish

Diving observations of tagged fish released overboard from the research vessel indicated that all marked fish behaved in a similar manner. Upon entering the water, they oriented momentarily and then swam rapidly downward to the reef substrate where they sought cover under ledges or within crevices in the reef infrastructure. Typically after 5 - 10 minutes, they left shelter and moved slowly and cautiously away remaining close to the substrate. There were no observations of attempted predation on any tagged fish.

### Aggregation Size Estimates

Suitable data from the tagging program to generate aggregation size estimates was available for only one year at the northeastern aggregation site (NE1) while two years data were available for the southwestern site (SW1) (see Figure 1). Substituting values into equation (1) for the three data sets provided estimates of aggregation size ($N^*$)(Table 1). From equations (2) and

(3), the 95% confidence limits for $N$, estimated from the variance ($v^*$) of $N^*$, are given to provide estimates of maximum aggregation size (Table 1).

Given the similarity in these abundance estimates generated from the two sites, it might be concluded that they are similar in area. However, as diving operations were not made at the sites during the sampling and tagging periods due to logistical constraints, there are no estimates of density of red hinds at the two sites during the spawning periods which could be compared. It should be recalled that both sites are seasonally closed to all fishing during the spawning period (May – August) and thus receive the same protection.

**Table 1.** Petersen Index estimates of red hind aggregation size and maximum aggregation size (using the 95% confidence interval) at two sites on the Bermuda reef platform.

| Aggregation site | Year | Aggregation size (N*) | Maximum aggregation size (95% CI) |
|---|---|---|---|
| NE1 | 1993-94 | 639 | 926 |
| SW1 | 1997-98 | 712 | 1,153 |
| SW1 | 1998-99 | 664 | 1,074 |

## DISCUSSION

Before comparing the aggregation size estimates obtained in this study with the estimates for red hinds from locations in the Caribbean, it is useful to evaluate the assumptions upon which the Peterson method is based in estimating population size ($N$), if $N^*$ is to be a suitable estimate of $N$:

*The population is closed (N is constant)* — The spawning aggregations depart from this assumption in several ways:

i) An estimate of mortality from the tagging process itself was not obtained because fish were not retained for observation after tagging. Thus, additional mortality may have occurred as a result of the tagging process (e.g. infection of wounds around the tag site). There may also have been increased vulnerability to predation as a result of tagging although initial diving observations at the time of release did not detect any. Thus, more tagged fish may have been removed through incidental mortality than estimated ($n_1$ is too high), with the net result of overestimating the aggregation size.

ii) Fishing mortality during the period between samples will remove fish from the population. In addition, recruitment probably occurred between the two sampling periods as fish attaining maturity joined the aggregation. Seber (1982) states that when both recruitment and mortality occur, $N^*$ will overestimate both the initial and final population size.

*All fish have the same probability of being caught in the first sample* — Two potential sources of bias could affect the composition of the first sample; the area sampled and the catchability of the fish. Given that the spawning aggregation sites were very limited in area (1-1.5 hectares) and the research vessel was not static in relation to the anchor site, it is probable that all portions of the aggregation site were fished. As catchability often varies with the size of the fish, a variety of hook sizes and bait types were used to reduce bias through gear selectivity. Studies on a red hind aggregation in southwest Puerto Rico demonstrated that hook and line fishing provided an adequate sampling technique both for sex ratio and size distribution within the aggregation, as determined by spearfishing (Shapiro et al. 1993).

*The second sample is a simple random sample* — Two sources of bias need to be considered here; thorough mixing of the tagged and unmarked fish between the sampling periods and the effect of tagging on catchability. Our data strongly indicate that the aggregations dispersed and reformed between sampling years thus resulting in thorough mixing of the tagged and untagged fish. Multiple recaptures of red hinds were common at both sites providing circumstantial evidence that catchability was not significantly affected by tagging.

*There is no tag loss between samples* — During the early stages of the study, tag obliteration was recorded and thus complete loss of the visible portion of the tag probably also occurred. However, all specimens were double-tagged from 1994 onward thus limiting the impact of this factor.

*All tags are reported on recovery in the second sample* — The only vessel authorised to fish at the aggregation sites during the spawning season was our research vessel. As the aggregation sites are both located in seasonally protected areas, we believe that poaching by other vessels was unlikely and all recaptures in the second sample were probably reported.

Given the above considerations, we believe that our estimates are reasonable first approximations of red hind aggregation size in Bermuda.

There are three studies of red hind spawning aggregation size from the Caribbean with which to compare our estimates. The first study was conducted in Puerto Rico by diver survey and the estimate of the size of the red hind aggregation, based on a peak density of 7.6 fish/100 m², was 745 fish (Shapiro et al. 1993). This value is very similar to our values. The second study, which was conducted in St. Thomas, U.S. Virgin Islands, yielded a mean density estimate of 4.7 fish/100 m² (Beets and Friedlander 1998) but did not provide an estimate of the aggregation size. However, this density estimate was obtained two days after peak spawning and so is undoubtedly an underestimate as red hinds appear to leave the aggregation site shortly after spawning (Shapiro et al. 1993). As there is some uncertainty concerning the actual area of the aggregation site in St. Thomas, we are unable to estimate aggregation size. Given the area of the aggregation site and density values, a simple extrapolation will produce an estimate of aggregation size. The population response of red hind to the permanent closure of this same aggregation site in St. Thomas (Red Hind Marine Conservation District) was evaluated by Nemeth (2005). He determined that the area of the red hind aggregation was considerably larger than our Bermuda estimates (1 - 1.5 hectares) and that the density of red hinds increased from 11.2 fish/100 $m^2$ in January 2000 to 24.0 fish/100 $m^2$ in 2003. As a consequence of these higher values, Nemeth (2005) estimated that the spawning population size ranged from about 26,000 to 84,000 fish. These are extraordinarily high values when compared to the other studies outlined here and may demonstrate the dramatic impact of a permanent closure of an aggregation site on the population.

The technique of mark / recapture has much potential for assessing aggregation size, particularly if simple experiments to assess tagging mortality and tag loss rates are conducted to reduce the tendency for overestimation of *N*. This technique can be a useful compliment to other methods of estimating aggregation abundance particularly when on site abundance estimation is challenging.

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# Status of a Yellowfin (*Mycteroperca venenosa*) Grouper Spawning Aggregation in the US Virgin Islands with Notes on Other Species

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ABSTRACT

Many commercially important groupers (Serranidae) and snappers (Lutjanidae) form large spawning aggregations at specific sites where spawning is concentrated within a few months each year. Although spawning aggregation sites are often considered important aspects of marine protected areas many spawning aggregations are still vulnerable to fishing. The Grammanik Bank, a deep reef (30 - 40 m) located on the shelf edge south of St. Thomas USVI, is a multi-species spawning aggregation site used by several commercially important species of groupers and snappers: yellowfin (*Mycteroperca venenosa*), tiger (*M. tigris*), yellowmouth (*M. interstitialis*) and Nassau (*Epinephelus striatus*) groupers and cubera snapper (*Lutjanus cyanopterus*). This paper reports on the population characteristics of *M. venenosa* with notes on *E. striatus* and other commercial species. In 2004, the total spawning population size of yellowfin and Nassau groupers were 900 and 100 fish, respectively. During recent years commercial and recreational fishing have targeted the Grammanik Bank spawning aggregation. Between 2000 and 2004 an estimated 30% to 50% of the yellowfin and Nassau grouper spawning populations were removed by commercial and recreational fishers. These findings support the seasonal closure of the Grammanik Bank to protect a regionally important, multi-species spawning aggregation site.

KEY WORDS: Marine protected areas, reef fish spawning aggregations, fisheries management

# La Condición de Agregaciones Reproductivas de Cuna Cucaracha y Mero Gallina: Dinámica de una Multi-especie Agregacíon Reproductiva en el USVI

Muchos meros (Serranidae) y pargos (Lutjanidae) forman agregaciones reproductivas en sitios específicos por un par de meses cada año. Aunque sitios de desove se consideran un aspecto importante de áreas marinas protegidas, muchos agregaciones reproductivas son vulnerable a la pesca. El Banco de Grammanik se usa por varias especie comercialmente importante de meros y pargos. Es un arrecife profundo (30 - 40m) localizado en el sur de los USVI y es un sitio que tiene una multi-especie agregacion reproductiva. Buzos han documentado el desove de cuna cucaracha (*Mycteroperca venenosa*), cunas (*M. tigris y M. interstitialis*), mero gallina (*Epinephelus striatus*) y el pargo guasinuco (*Lutjanus cyanopterus*). Durante años recientes, pescadores commerciales y recreativas han concentrado en la agregacíon reproductiva de cuna cucaracha. La pesca amenaza no sólo esta especie pero también el mero gallina, que se extirpó localmente en el los 1980s, pero puede ser que se recupera en este sitio. Este manuscrito describe los cambios anuales y estacionales en abundancia, la utilización del habitat, y describe las características de la población reproductiva del cuna cucaracha y mero gallina.

PALABRAS CLAVES: Áreas marinas protegidas, agregaciones de desove, las Islas Virgenes de los EEUU

## INTRODUCTION

Many commercially important groupers (Serranidae) form large spawning aggregations at specific sites and at which spawning is concentrated within a couple of months each year (e.g. red hind *Epinephelus guttatus* and Nassau grouper *E. striatus* (Colin et al. 1987), tiger grouper *Mycteroperca tigris* Valenciennes (Sadovy et al. 1994). These spawning aggregations may be the primary source of larvae that replenish the local fishery through larval retention and recruitment (Sadovy 1996).

In the late 1970s and early 1980s, unregulated fishing on grouper spawning aggregations sites throughout the U.S. Virgin Islands led to the extirpation of Nassau grouper and brought the red hind grouper population to the verge of collapse (Olsen and LaPlace 1978, Beets and Friedlander 1992). In 1990, through the recommendations of the Caribbean Fisheries Management Council and support of local fishers, two important red hind spawning aggregation sites (Red Hind Bank, St. Thomas and Lang Bank, St. Croix) were closed seasonally during spawning to protect the breeding populations of red hind. In 1999, the Red Hind Bank Marine Conservation District (MCD) was established as the first no-take fishery reserve in the USVI. Recent evidence suggests that the closure of the Red Hind Bank has been successful in protecting this spawning subsection of the population. By 1997 the average size of spawning hind had increased by over 6 cm (Beets & Friedlander, 1998). Even more impressively, the number of spawning individuals increased dramatically from 4.5 fish /100 m$^2$ in January 1997 to 23 fish /100 m$^2$ in January 2001 (Beets and Friedlander, 1998, Nemeth 2005). Similar responses to protective management measures have been shown for other species throughout the Caribbean (Bohnsack 1990). Unfortunately not all grouper spawning aggregations are afforded the necessary protection to sustain their populations.

Prior to the year 2000, the Grammanik Bank was known as a deep coral reef bank utilized by local commercial fishermen. Commercial fishermen knew of the existence of a yellowfin grouper spawning aggregation but did not harvest these fish since they were known to contain ciguatera poisoning. In February 2000, scientists at the University of the Virgin Islands first surveyed the Grammanik Bank as part of a study to compare fish populations inside and outside of the Red Hind Bank Marine Conservation District (Nemeth and Quandt 2004). Considerable attention was focused on this deep coral bank when commercial and recreational fishermen landed an estimated 10,000 pounds of yellowfin grouper within a week following the full moon in both March 2000 and 2001 (K. Turbé Personal communication). These unusually large catches of grouper were verified in monthly commercial catch reports (USVI Division of Fish and Wildlife, unpublished data). It was also reported that many of these yellowfin grouper were gravid with well developed ovaries (H. Clinton, Personal communication) and that many Nassau grouper were also caught as bycatch and sold. It was estimated that over 500 *M. venenosa* and 50 *E. striatus* were removed from the spawning aggregation each year. Following collapse of the Nassau grouper fishery in the late 1970s there has been no known spawning aggregation for this species on the shelf south of St. Thomas or St. John. Currently, a lack of enforcement at this site could mean the collapse of the yellowfin grouper and/or the delayed recovery of the Nassau grouper population which may be re-forming a potentially spawning aggregation at this site. Although the Grammanik Bank was recommended for closure as early as November 2000, the Caribbean Fisheries Management Council has only recently approved an interim seasonal closure of the Grammanik Bank from February through April 2005. The data presented in this paper provides baseline spawning population information on these vulnerable grouper species and will allow an assessment of the response of these grouper populations to the recent protective measures.

## METHODS

### Locate Primary Spawning Aggregation Site

To locate the primary spawning aggregation sites of *M. venenosa* and *E. striatus* within the Grammanik Bank, the entire bank was surveyed using scuba and underwater scooters several days before and after the full moon in March 2003 and March and April 2004. GPS coordinates were recorded by a boat following a diver-towed surface buoy to determine the area of the bank.

### Grouper Spawning Density, Fish Size, and Behavior

Diver surveys were conducted between February 2001 and August 2004. Since several species of groupers and snappers are particularly wary and tend to swim away from divers prior to being counted along a transect line (RSN, personal observations), a combination of belt transects, stationary point counts, and roving diver searches were used to accurately estimate fish densities as well as total spawning population size of all commercially important Serranids and Lutjanids. Point counts were conducted by recording all fish within a 10 m radius of a stationary diver for a period of four minutes. Belt transects were 30 m x 2 m and conducted by swimming along the linear axis of the reef while a transect tape unreeled behind the diver. The size of all fish observed along transects or point counts were estimated in 10 cm size classes. Roving diver searches were typically constrained by scuba limits at deep depths, and therefore, were conducted for periods of 15 minutes. Roving divers would swim at a constant speed and survey a 10 m wide area while towing a surface buoy. These roving dives allowed reasonably accurate estimates of total population size since divers surveyed non-overlapping areas of the narrow reef (<100 m wide) and several sequential dives could cover the entire length of the Grammanik Bank (1.69 km).

### Tagging and Population Sex Ratios

Baited Antillian fish traps and hook and line were used to collect groupers. Due to the depth from which the fish were collected, expansion of air within their gas bladders resulted in buoyancy problems and occasional embolisms. A sterilized large-bore hypodermic needle was used to extract gas from the over-inflated air bladder. Once buoyancy was restored, each fish was measured for total length (to the nearest mm) and tagged through the dorsal fin pterygiophores with a numerically-coded Floy dart tag (FT-2). Dart tags contained the following information: identification number, reward $20, University of the Virgin Islands, and a contact telephone number. The recapture location of returned tags provided information on distance travelled by fish departing the aggregation site and a detailed picture of the source of spawning groupers. Prior to release, the gender of each fish was determined by using ultrasound and by gently squeezing the body wall above the vent to extract milt and possibly eggs. Fish were released using a release cage which could be remotely opened once the cage reached the sea floor, thus minimizing mortality due to predation and ensuring re-pressurization of groupers.

## RESULTS

### Location of Primary Spawning Aggregation Sites

The Grammanik Bank lies on an East-West axis at the edge of the insular shelf south of St. Thomas, USVI (Figure 1). The bank extends 1.69 km at its longest point (between 18°11.30N, 064°57.50W and 18°11.60N, 064°56.60W). During visual surveys the northern and southern margins were clearly visible, and the bank was estimated to be less than 100 m wide for virtually its whole length. Depths on the coral reef varied between 35 and 40 m and the coral bank is bordered to the east and west by shallower (25 to 30 m) hard-bottom ridges along the shelf edge, sparsely colonized by corals, gorgonians and sponges. The bank is bordered to the north by another coral bank and to the south by the steep drop off. The primary spawning aggregation site for *M. venenosa* was discovered on April 9, 2004. It was located over colonized hard bottom approximately 300 m west of the dominant coral reef. During this same time period, we observed Nassau groupers, some with the bicolor spawning coloration and others with visibly extended abdomens. This presumed spawning aggregation site for *E. striatus* encompassed the west end of the coral reef bank to the *M. venenosa* site. A spawning site for *M. tigris* was also located at the western tip of the coral reef bank. A spawning site for *M. interstitialis* was located along the southwestern margin of the coral reef bank. Finally, the spawning site for *Lutjanus cyanopterus*, the cubera snapper,

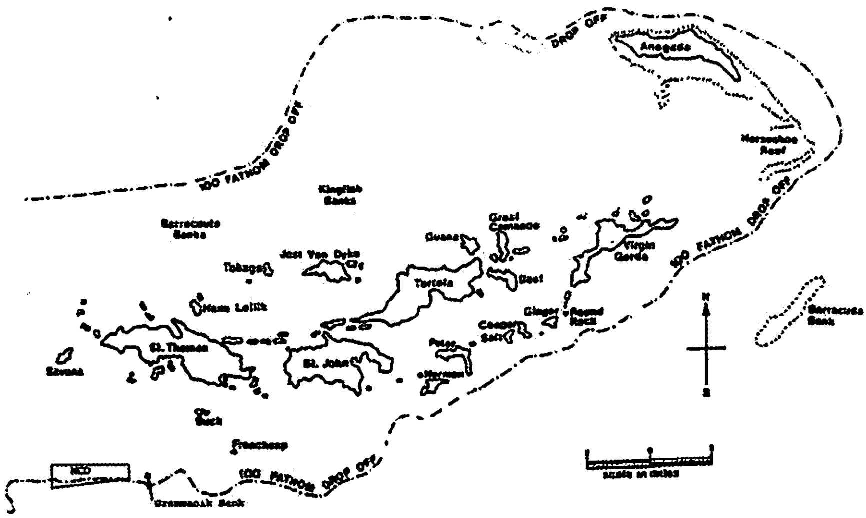


**Figure 1.** Map of the Northern Virgin Islands showing location of the Grammanik Bank (*) and the Marine Conservation District (MCD) along the southern edge of the insular platform. Dashed line shows 100 fathom depth contour.

## Grouper Spawning Density, Fish Size, and Behavior

Visual surveys (belt transects and point counts) were conducted on various dates from February 2000 to August 2004 but most were done around the full moon from February through April in each year (Table 1). Densities of commercially important groupers varied considerably between months and years (Figure 2). *M. venenosa* densities were highest in March 2003 and April 2004, *E. striatus* and *M. interstitialis* densities peaked on March 2002 and March 2003, respectively, and *M. tigris* showed high densities in April 2001 and 2004 and February 2002 (Figure 2, Table 1). From December 2002 through February 2003 the densities of *M. venenosa* and *E. striatus* were very low, and there was no evidence that these species were aggregating. While densities of most groupers remained the same throughout March 2003, the average density of *M. venenosa* increased almost fourfold (Table 1) by 19 March, one day after the full moon (Table 1). Whether this represents an overall population increase or clustering of individuals towards a single location was unknown. With the exception of *M. tigris*, all other serranids departed the Grammanik Bank aggregation site by early April 2003 (Table 1). Throughout March 2004 point counts provided fairly consistent estimates of grouper densities (Table 1). However, observations of fish behavior indicated that as evening approached groupers began to depart their daytime positions, suggesting that fish were possibly moving toward the actual spawning aggregation site. Since point counts were not effective at locating the spawning aggregation site, scooter surveys were primarily utilized throughout April 2004.

**Table1**. Grouper density (#/100m$^2$ ± SD) from belt transects and point counts on the Grammanik Bank, St. Thomas USVI, between February 2000 and August 2004. Dashed lines indicate that no data was collected using that method. N = number of transects or point counts.

| Date | Belt transects | | | | | Point counts | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | *M. venenosa* | *E. striatus* | *M. tigris* | *M. interstitialis* | N | *M. venenosa* | *E. striatus* | *M. tigris* | *M. interstitialis* |
| **2000** | | | | | | | | | | |
| 17 Feb | 6 | 0 | 0 | 0.28 ± 0.68 | 0 | - | - | - | - | - |
| **2001** | | | | | | | | | | |
| 11 Apr | 3 | 0 | 0 | 2.54 ± 2.54 | 0 | - | - | - | - | - |
| 19 Jul | 6 | 0 | 0 | 0.28 ± 0.68 | 0 | - | - | - | - | - |
| 6 Sep | 6 | 0.28 ± 0.68 | 0 | 0 | 0.28 ± 0.68 | - | - | - | - | - |
| **2002** | | | | | | | | | | |
| 1 Mar | 4 | 0 | 2.78 ± 2.54 | 2.22 ± 1.92 | 0 | - | - | - | - | - |
| 27 Mar | 15 | 0.83 ± 2.41 | 0.68 ± 2.50 | 0.28 ± 0.65 | 0 | - | - | - | - | - |
| 18 Dec | - | - | - | - | - | 6 | 0.21 ± 0.26 | 0.05 ± 0.13 | 0 | 0 |

**Table1(cont.).** Grouper density (#/100m$^2$ ± SD) from belt transects and point counts on the Grammanik Bank, St. Thomas USVI, between February 2000 and August 2004. Dashed lines indicate that no data was collected using that method. n = number of transects or point counts.

| | N | *M. venenosa* | *E. striatus* | *M. tigris* | *M. interstitialis* | N | *M. venenosa* | *E. striatus* | *M. tigris* | *M. interstitialis* |
|---|---|---|---|---|---|---|---|---|---|---|
| **2003** | | | | | | | | | | |
| 12 Feb | 8 | 0.21 ± 0.60 | 0.42 ± 0.77 | 0.42 ± 0.77 | 0.21 ± 0.59 | - | - | - | - | - |
| 4 Mar | 5 | 0.67 ± 0.91 | 0.33 ± 0.75 | 0 | 0.83 ± 1.39 | - | - | - | - | - |
| 18 Mar | - | - | - | - | - | 3 | 2.23 ± 0.32 | 0.32 ± 0.32 | 0 | 0.42 ±0.74 |
| 19 Mar | - | - | - | - | - | 7 | 2.64 ± 0.57 | 0.41 ±0.70 | 0.50 ±0.55 | 0.27 ±0.22 |
| 3 Apr | 2 | 0 | 0 | 0.83 ± 1.18 | 0 | 2 | 0 | 0 | 0.16 ±0.22 | 0 |
| 11 Dec | 8 | 0 | 0.21 ± 0.59 | 0 | 0 | - | - | - | - | - |
| **2004** | | | | | | | | | | |
| 7 Jan | 8 | 0 | 0 | 0 | 0.21 ± 0.59 | - | - | - | - | - |
| 27 Feb | - | - | - | - | - | 2 | 0.47 ±0.68 | 0.16 ±0.22 | 0 | 0.32 ±0.45 |
| 2 Mar | - | - | - | - | - | 15 | 0.32 ±0.36 | 0.06 ±0.13 | 0.13 ±0.23 | 0.08 ±0.14 |
| 3 Mar | - | - | - | - | | 5 | 0.38 ±0.35 | 0.13 ±0.28 | 0 | 0 |
| 4 Mar | - | - | - | - | - | 3 | 0.21 ±0.18 | 0.21 ±0.37 | 0 | 0 |
| 5 Mar | - | - | - | - | - | 11 | 0.32 ±0.32 | 0.20 ±0.26 | 0 | 0 |
| 7 Mar | - | - | - | - | - | 11 | 0.64 ±0.64 | 0.17 ±0.22 | 0 | 0 |
| 8 Mar | - | - | - | - | - | 6 | 0.26 ±0.24 | 0 | 0 | 0 |
| 12 Mar | - | - | - | - | - | 2 | 0 | 0 | 1.75 ±0.68 | 0 |
| 13 Mar | - | - | - | - | - | 5 | 0.25 ±0.14 | 0.13 ±0.17 | 2.80 ±1.68 | 0 |
| 12 Apr | - | - | - | - | - | 3 | 2.02 ±0.80 | 0 | 0 | 0 |

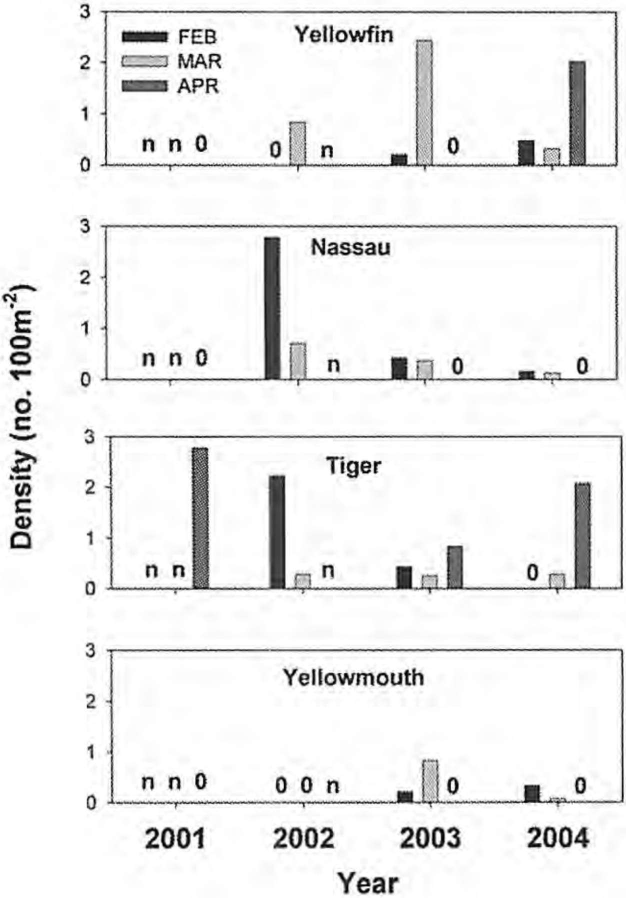


**Figure 2.** Density of four spawning grouper species: yellowfin (*Mycteroperca venenosa*), Nassau (*Epinephelus striatus*), tiger (*M. tigris*) and yellowmouth (*M. interstitialis*) for February, March and April 2001 to 2004. n = no data, 0 = no fish seen. Calculated from point counts and transects.

During roving diver surveys of the whole bank on 11 and 12 March 2003 (six days prior to the full moon), the highest density of *M. venenosa* was seen in a small (approximately 50 m$^2$) section of the bank. Other individuals were observed scattered across the reef and the total population estimate for *M. venenosa* grouper at this time, across the entire bank, was about 50 individuals. Population estimates for *E. striatus*, *M. tigris* and *M. interstitialis* for March 2003 were 5, 7 and 13 groupers, respectively.

More frequent roving diver surveys in April 2004 (full moon on April 5) improved our population estimates for *M. venenosa* and *M. tigris* (Figure 3). Total population estimates for *E. striatus* declined dramatically from March to April 2004 and may have been a result of fishing mortality from the three to five fishing boats seen on the bank each day over the course of several weeks.

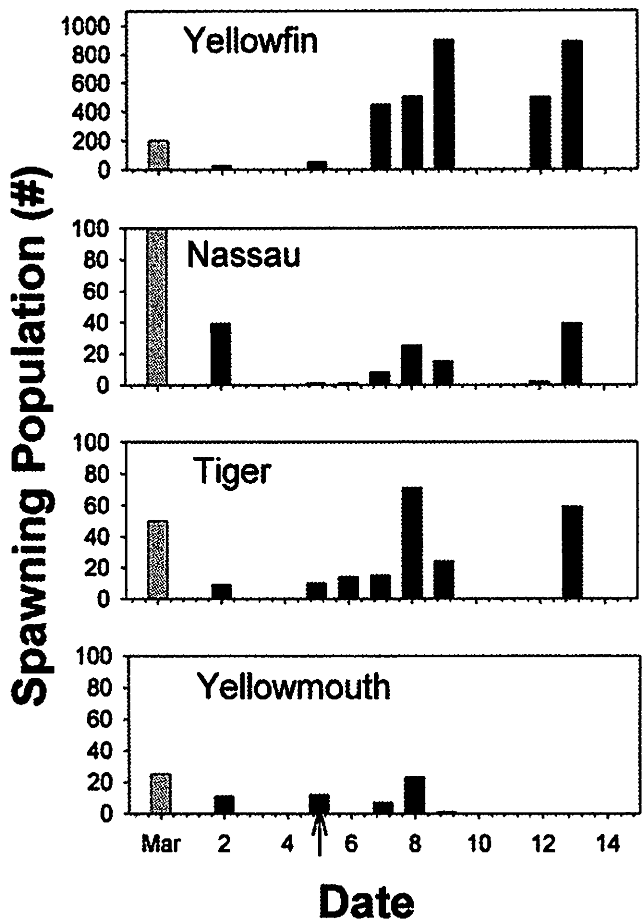


**Figure 3.** Total population size for four spawning grouper species: yellowfin (*M. venenosa*), Nassau (*E. striatus*), tiger (*M. tigris*) and yellowmouth (*M. interstitialis*) for March 11 (grey bar) and April 2-13, 2004 (black bars). The spawning aggregation sites were discovered on April 8 for *E. striatus*, *M. tigris* and *M. interstitialis* groupers and on April 9 for *M. venenosa* grouper. Full moon was on April 5, 2004.

The presumed spawning aggregations of *M. venenosa*, *M. tigris*, *M. interstitialis* and *E. striatus* were observed on April 8 to 13, 2004. During 2004, *M. venenosa* occurred in a large aggregation where about 50% to 75% of the fish were swimming two to five meters above the bottom, and the remainder swam near the bottom. Several color phases of *M. venenosa* were observed. The most common included the typical color pattern of irregular black spots on a white background. On other individuals, the dark spots were obscured on the dorsal half of the body by a deep red color. A final color pattern included fish with light colored head, white caudal fin with wide black margin and bright yellow on the margins of the pectoral fins and on the lips. Other individuals were observed with intermediate forms of these color phases. No spawning or courtship was observed for *M. venenosa*. *E. striatus* were noted in loose groupings and as pairs with one individual, presumably a male, in the bicolor phase and the other individual, presumably a female with visibly extended abdomen, displaying normal barred color pattern and resting on the bottom. At the Grammanik Bank only four of 60 *E. striatus* were seen displaying bicolor phase, but no courtship or spawning was observed. The bicolor phase male was observed either displaying laterally to the female, hovering one to two meters above the female, resting near the female on the bottom or swimming alone one to two meters above the bottom. *M. tigris* and *M. interstitialis* spawning aggregations had similar behavioral traits where about half of the individuals were hovering two or three meters above the bottom while the remainder where near the bottom among coral colonies. *M. tigris* was observed with three distinct color phases. Dominant males had pale yellow head, dark speckled body, and white patch with black spots on the ventral posterior portion of the body and base of anal fin. These fish were often observed cruising or hovering two to four meters above the bottom or displaying courtship behaviors to females which had distended abdomens. These resumed females displayed the barred color pattern typical of *M. tigris* and were typically seen swimming slowly or resting near the reef. A third color phase included smaller individuals with the typical body stripes obscured by a darkened body. These individuals were typically seen hovering two to three meters above the reef. *M. interstitialis* were observed with a bicolor phase similar to that of *E. striatus* and a lighter color phase typical of *M. interstitialis*. Both color phases were seen either resting near the bottom or hovering two to three meters above the reef. Courtship was not observed for *M. interstitialis*. Spawning was not observed for any of these grouper species.

The Grammanik Bank was surveyed for several months following the grouper spawning season in 2003 and 2004. In April 2003, one day after the full moon, more than 50 cubera snapper (*Lutjanus cyanopterus*) were observed during a roving survey. On the full moon in May 2003, divers estimated more than 300 *L. cyanopterus* on the bank. Three days following the full moon in June the population of *L. cyanopterus* on the Grammanik bank had declined to approximately 150 fish. The spawning season shifted from April to June in 2003 to June through August in 2004 (Figure 4). During the daytime several large (20 to 100 fish) roving schools of *L. cyanopterus* were observed throughout the bank with snappers most often concentrated on the northern margin of the bank. Toward evening roving schools of *L. cyanopterus* joined into one large school and fish displayed intensifying courtship interactions and spawning. Schoolmaster snapper (*L. apodus*) were also observed in large numbers in April (n = 180) and July (n = 120) 2004 but no signs of courtship or spawning was observed.

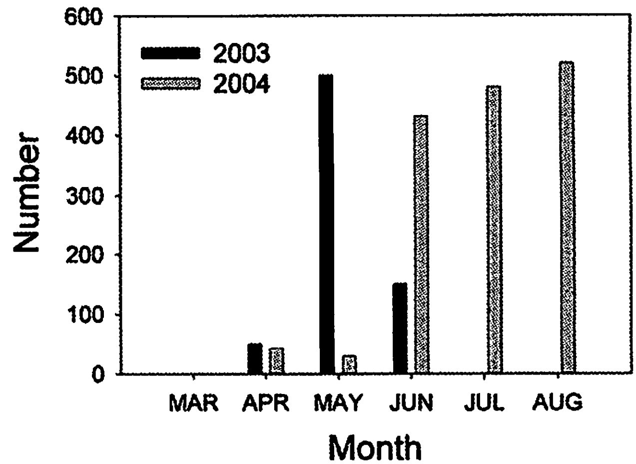


**Figure 4.** Total population size of cubera snapper (*L. cyanopterus*) spawning aggregation on the Grammanik Bank from March to August 2003 and 2004.

Size estimates of groupers from fish transects and point counts (categorized into 10 cm increments) ranged from 30 to 80 cm total length while mean lengths for *M. venenosa, E. striatus, M. tigris and M. interstitialis* were 53.2 cm, 45.6 cm, 47.0 cm and 43.7 cm, respectively. More detailed size frequency distributions and sex ratios were obtained from 28 *M. venenosa* and 62 *E. striatus* during trap and hook and line fishing. Male *M. venenosa* were significantly larger than females (ANOVA: F = 16.4, $p < 0.001$, Figure 5). Female to male sex ratio was nearly 1:1 for *M. venenosa*. The length of both sexes of *E. striatus* were nearly identical (ANOVA: F = 0.48, $p > 0.50$, Figure 5) but the female: male sex ratio was 2.4:1. Ultrasound analysis of *M. venenosa* and *E. striatus* showed that females and males of both species had well developed gonads with males of both species running ripe and females with hydrated eggs. During sampling in March 2004, two Nassau (male and female) and two male yellowfin groupers died due to air embolism. In April 2004, two additional Nassau groupers died. These last two fish were brought back to the lab and examined. The female was 55.9 cm total length and weighed 3,442 g. Its ovary weight and volume were 426 g and 410 ml, respectively. The male Nassua grouper was 64.8 cm total length and weighed 4,996 g. The weight of its testes was 322 g. A total of 23 yellowfin and 60 Nassau groupers were tagged and released on the Grammanik Bank between 8 March and 9 April, 2004. To date, no tagged groupers have been recaptured and returned to UVI for reward.

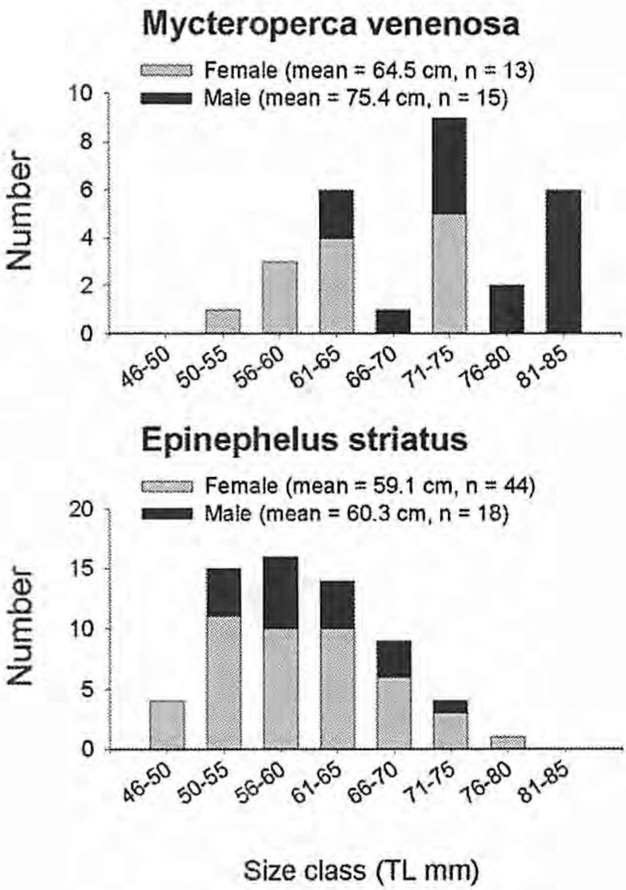


**Figure 5.** Size frequency distributions and gender for yellowfin (*M. venenosa*) and Nassau (*E. striatus*) groupers from the Grammanik Bank spawning aggregation site in April 2004.

## DISCUSSION

In March 2000 and 2001, the yellowfin grouper spawning aggregation on the Grammanik Bank was heavily targeted by local commercial and recreational fishermen. At this same time many Nassau grouper were also being caught as bycatch (K. Turbé Personal communication). It was estimated that over 500 *M. venenosa* and 50 *E. striatus* were removed from the spawning aggregation each year. Following these heavy catches, this study found that *M. venenosa* did not aggregate to spawn in 2002 but formed a small aggregation in 2003 (n = 50). These data were supported by the fact that fishermen caught almost no grouper in 2002 and very few in 2003 (RSN Personal observation). Unfortunately, it was not possible to determine if *M. venenosa* successfully spawned in either year. These low numbers, however, strongly suggest that the *M. venenosa* spawning aggregation was greatly reduced in this location during the 2002 and 2003 spawning seasons. Such a rapid reduction in numbers of fish on spawning aggregations in response to fishing pressure is not unusual (e.g. *E. striatus* grouper - Colin 1992, Sadovy and Eklund 1999) but serves to highlight the need for more responsive management action. In addition to *M. venenosa*, *E. striatus*, *M. tigris*, and *M. interstitialis* were observed on the Grammanik Bank. In 2002 small clusters of *E. striatus* possibly represented the earliest stages in the re-forming of a spawning aggregation. In March 2003, a single cluster of *E. striatus*, not previously recorded in either December or January, was present on the reef. However, there was no clear evidence (e.g. behavior, coloration) that *E. striatus* successfully spawned in 2002 or 2003 at the Grammanik Bank.

In March and April 2004, however, *M. venenosa E. striatus*, *M. tigris*, and *M. interstitialis* aggregated on the Grammanik Bank in much larger numbers than the previous two years. *M. venenosa* formed an aggregation of over 900 individuals. We are unsure why *M. venenosa* returned in such large numbers in 2004, but several possibilities exist. There are reports from fishermen that spawning aggregations of Nassua, yellowfin, and red hind in St. Croix were known to temporarily relocate to other sites if they received a lot of fishing pressure during one season (T. Daly Personal communication). For example the spawning aggregation in 2002 and 2003 may have relocated to an alternative spawning site these years in response to heaving fishing in 2000 and 2001 but returned to their historical spawning site on the Grammanik Bank in 2004. Recent data for red hind also suggests that this species may have peak spawning years that occur on a regular two-year cycle (Nemeth 2005). Thus, 2004 could have been a peak year, 2003 a low year and 2002 could have been a peak but was affected by heavy fishing in the previous two years.

*M. tigris* and *M. interstitialis* also formed spawning aggregations of 90 and 25 individuals, respectively. In contrast, *E. striatus* was observed in distinct pairs and did not form a larger aggregation (RSN Personal observation). Colin (1992) found that when *E. striatus* was present in large groups of greater than 500 fish the majority of fish within the spawning aggregation displayed the bicolor color pattern, whereas when they occurred in small spawning groups of less than 100 fish only about half were displaying the bicolor phase. *E. striatus* were typically observed in loose groupings swimming or resting near the reef. We also observed four of 60 *E. striatus* displaying the bicolor phase, but only three of these individuals seemed to be paired with a visibly gravid female. In group spawning species such as *E. striatus*, it is not known what minimum population size is needed to initiate group spawning behaviors, but the minimum aggregation size required to initiate courtship and spawning in *E. striatus* may be significantly larger than required by other haremic groupers such as red hind (*E. guttatus*) and *M. venenosa*

(Sadovy 2001). Colin (1992) recorded *E. striatus* in small groups of less than 100 fish which were spawning, but only about half were displaying the bicolor phase which typically preceeds spawning. He also found that courtship occurred in groups of only ten fish. An estimated 60 *E. striatus* were counted on the Grammanik Bank in April 2004, but courtship was seen only once, and spawning was not observed so it is possible that although an aggregation may be re-forming there may not yet be any successful spawning.

With the exception of *E. striatus*, the spawning season of all other grouper and snapper species observed on the Grammanik Bank was consistent with the reported literature from throughout the Caribbean (Sadovy et al. 1994, Claro and Lindeman 2003). Nassau typically form spawning aggregations from December through February, but have been found with ripe ovaries later in the spring as well (Olsen and LaPlace 1978, Thompson and Munro 1978, Colin et al. 1987, Colin 1992, Tucker at al. 1993, Sadovy et al. 1994, Claro and Lindeman 2003). Although *E. striatus* had previously spawned December through February in the Virgin Islands (Olsen and LaPlace 1978), spawning now seems to be following the seasonal pattern of *M. venenosa* (i.e. February to April). The seasonal shift could have two possible explanations. The historical site of the *E. striatus* spawning aggregation was located within the present boundaries of the red hind Marine Conservation District (Olsen and LaPlace 1978). Because the population "memory" of this historical aggregation site was lost when the spawning aggregation was fished to extinction in the late 1970s, the new cohort of *E. striatus* may have followed or copied the behavioral patterns and migratory routes of *M. venenosa* and *E. striatus* is just now reforming at a different location and season. The second alternative, as suggested by commercial fishermen, is that there are so many *E. striatus* at the historical spawning aggregation site that the fish showing up at the Grammanik Bank are over-flow from the historical spawning aggregation site. This alternative still needs to be verified.

The mean length (70.7 cm TL) and F:M sex ratio (1:1.1) of *M. venenosa* in this study was nearly identical to values reported by Thomson and Munro (1978) for the oceanic banks off Jamaica (mean TL = 68 cm, F:M = 1.2:1). According to Thomson and Munro (1978), these oceanic banks received relatively low fishing pressure. The similarity in length frequency and sex ratio of *M. venenosa* from unexploited oceanic banks off Jamaica in the mid-1970s and St. Thomas in 2004 may indicate that *M. venenosa* at the Grammanik Bank may be less impacted by fishing than previously thought. This would support the hypothesis that the groupers did, in fact, find an alternative spawning site during the two years when the aggregation did not form on the Grammanik Bank. Length-frequency data for *E. striatus* from this study were also similar to those reported for *E. striatus* in St. Thomas prior to its collapse and the relatively unexploited oceanic banks of Jamaica, Belize and Bermuda (Olsen and LaPlace 1978, Thompson and Munro 1978, Sadovy and Eklund 1999). The length frequency distribution also suggests that the age structure of *E. striatus* at the Grammanik Bank is dominated by four to six year old fish (Olsen and LaPlace 1978). Sex ratios from unexploited populations tend to be close to unity (Sadovy and Eklund 1999) whereas the female:male sex ratio at the Grammanik Bank was biased towards females (2.4:1) and similar to exploited populations in the Cayman Islands (Colin et al. 1987). Although the length frequency data reflects a size composition from unexploited populations, the biased sex ratio at the Grammanik Bank suggests that *E. striatus* continues to be exploited (Sadovy and Eklund 1999) as bycatch during the *M. venenosa* spawning aggregation in the Virgin Islands. This pattern may also indicate that sex ratios are very sensitive to even moderate fishing pressure on spawning aggregations. Alternatively, these biased sex ratios could also be present in the size structure of a reforming *E. striatus* spawning aggregation. As reforming aggregations have never been documented, this could just be the natural pattern and the number of males will increase as population size increases.

Continued fishing pressure on *M. venenosa* with associated catches of *E. striatus* will eliminate the likelihood that this *E. striatus* will re-form a spawning aggregation in this location. If fishing is allowed on the Grammanik Bank, the reestablishment of grouper spawning may be disrupted not only by the removal of individual fish but also by the disruption of complex behavioral patterns that are required to initiate courtship and spawning. Although the Grammanik Bank was recommended for closure as early as November 2000, the Caribbean Fisheries Management Council has only recently approved an interim seasonal closure of the Grammanik Bank from February through April 2005. Results from this study support the seasonal closure of the Grammanik Bank from February 1 to April 30, as the time period most likely to protect the yellowfin grouper spawning aggregations, and more importantly, to provide protection for a potentially reforming Nassau Grouper spawning aggregation. Future research will need to address how these commercially important species utilize the habitats within the Grammanik Bank during the spawning period but also during the entire spawning season to ensure that movement during spawning does not go beyond the proposed closure boundaries. Finally, this study also highlights the fact that the Grammanik Bank may be regionally important as a multi-species spawning aggregation site and management measures that suitably protect the spawning populations of several aggregating species of grouper and snapper that occur at this site from February through August each year will need to be evaluated.

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# A Livelihoods Analysis of Two Marine Protected Areas in Belize

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ABSTRACT

The sustainable livelihoods approach (SLA) is a fairly recent addition to the tools for evaluating management and other initiatives. Used primarily in rural development, often in the context of activities with poverty-related goals, the SLA also now appears in coastal and marine analyses. However, in the Caribbean, few coastal interventions have adopted a livelihoods perspective in their design, implementation or impact analysis. The study reported on here was one component of a larger project aimed at developing and promoting institutional arrangements for the management of marine protected areas (MPAs) in the Caribbean. Pro-poor institutional arrangements may facilitate poverty alleviation by ensuring that benefits from MPAs impact the livelihoods of the poorest stakeholders. This socio-economic analysis assesses impacts on the livelihoods of the stakeholders of two MPAs: the Hol Chan and Glover's Reef Marine Reserves in Belize. Data on demographics, capital assets and individuals' perceptions of the MPAs were collected primarily through a formal questionnaire administered to the poorest stakeholder group, the fishers. Respondents at both study sites supported the need for MPAs, but they did not want more established close to their communities. Impacts on income and business expansion have been minimal for fishers, but amenities and social services improved concurrently. Reduction of user group conflict was said to be minimal. Respondents were dissatisfied with MPA management, particularly with information flow between park authorities and user groups. Overall, Hol Chan may be moderately successful in alleviating poverty in San Pedro, whilst Glover's Reef Marine Reserve offered limited opportunity for poverty alleviation in the adjacent communities.

KEY WORDS: Belize, livelihoods, marine protected areas, socio-economic

# Un Análisis del Sustento de Dos Áreas Protegidas Marinas en Belice

El enfoque sostenible de sustentos (SLA) es una adicion bastante reciente a los instrumentos para evaluar la administracion y otras iniciativas. Utilizado principalmente en desarrollo rural, a menudo en el contexto de actividades con metas de pobrezo-relaciono, el SLA tambien ahora aparece en costero y marino analiza. Sin embargo, en el caribe, pocas en su diseno, el analisis de la implementacion o impacto. El estudio informo en aquí estaba un componente de un proyecto mas grande apunto a desarrollar y promoviendo los arreglos institutionales en pro de pobres pueden cafitar el alivio de la pobreza asegurando que beneficia de MPAs imprisiona los sustentos del tenedor de apuestas mas pobre. Este analisis socio-economica valora los dos MPAs: el Hol Chan y las Reservas de Marina de escollo de Guantero en Belice. Los datos en percepciones demograficas principales de ventajas e individuos del MPAs se reunieron principalmente por un cuestionario formal administrado al grupo mas pobre del tenedor de apuestas, los pescadores. Los demandados en ambos sitios del estudio sostuvieron la necesidad para MPAs pero para ellos no quisieron mas establido cierra a sus communidades. Los impactos en la expansion de ingresos y negocio han sido minimos para pescadores, pero los servicios y los servicios sociales mejoraron debido al MPAs. La reduccion del conflicto del grupo de usario se dijo ser minimo. Los demandados no fueron satisfechos con la administracion de MPA, especialmente con flujo de informacion entre autoridades de parque y grupos de usuario. En terminos generales, Hol Chan puede ser moderadamente exitoso en aliviar la pobreza en San Pedro, mientras Escollo de Guantero la Reserva Marina ofreciera la oportunidad limitada para el alivio de la pobreza en las comunidades adyacentes.

PALABRAS CLAVES: Belice, los sustentos, el marina protegió áreas, socioeconómica

## INTRODUCTION

The sustainable livelihoods approach (SLA) is a recent addition to the people-centred tools for policy, planning and management. Used primarily in rural development, often in the context of activities with poverty-related goals (Carney 1998), this approach is also now appearing in Caribbean coastal and marine studies (Pantin et al. 2004, Renard et al. 2000). However, few coastal interventions in the Caribbean have explicitly adopted a livelihoods perspective in their design, implementation or impact analysis.

Allison and Ellis (2001:379) define a livelihood as comprising:

> *"...the assets (natural, physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household".*

A livelihood is sustainable if it adapts to remain viable under changing circumstances. The sustainable livelihoods approach, as used in policy and planning, recognises the seasonality, diversity, complexity, uncertainty and other features of livelihood strategies in project and programme interventions. The approach attempts to remove constraints and to create an enabling environment for existing or potentially useful patterns of coping with chronic and acute livelihood problems to emerge. For example, poor people often have innovative solutions for dealing with their circumstances. Conventional interventions may unintentionally reduce their ability to cope.

Pro-poor institutional arrangements may facilitate poverty alleviation by ensuring that benefits from marine protected areas (MPAs) improve the livelihoods of the poorest stakeholders. The socio-economic analysis in this paper assesses impacts on the livelihoods of the poorest stakeholders of two MPAs: the Hol Chan and Glover's Reef Marine Reserves in Belize.

## STUDY SITES

Two MPA sites in the Belize barrier reef complex, where active management had been in place for at least five years, were selected for study: Glover's Reef Marine Reserve (GRMR), the southernmost of three atolls located 25 km east of the barrier reef, and Hol Chan Marine Reserve (HCMR) to the north end of the barrier reef (Figure 1).

### Glover's Reef Marine Reserve

GRMR, established in 1993, is the largest of Belize's MPAs (the atoll is 27 km from north to south, 10.8 km wide, encompassing an area of approximately 30,800 hectares) and was declared a World Heritage Site in 1996. It is relatively inaccessible, being 74 km southeast of Belize City and 45 km east of the mainland, where the adjacent communities of Dangriga, Hopkins and Placencia are located (Figure 1). The atoll comprises six small coral cayes, all of which are privately owned. Middle Caye is the site of the Glover's Reef Marine Research Station and visitor centre and serves as the monitoring headquarters for the Belize Fisheries Department. Three other cayes support small resorts.

The objectives of GRMR, as stated in the Glover's Reef Marine Reserve Order (Government of Belize 1993), are:

i) To maintain ecological processes;
ii) Preserve genetic diversity;
iii) Achieve sustainable yields of its resources through wise management of species and their habitats;
iv) Maintain natural areas for education and research; and
v) Provide social and economic benefits through ecologically sensitive recreation and tourism (Gibson 1988a).

To achieve these multiple objectives a zoning system has been implemented. These zones comprise a very small Wilderness Zone where no extractive or recreational activities are allowed; a Conservation Zone where non-extractive recreational activities are allowed and subsistence fishing by residents of the cayes (e.g. resort owners) under special license; a small Seasonal Closure Area (currently under indefinite closure) protecting an important grouper spawning aggregation site; and two large (covering 70% of total reserve area) General Use Zones where fishing is permitted by special license issued to fishers using the site before its designation as a MPA.

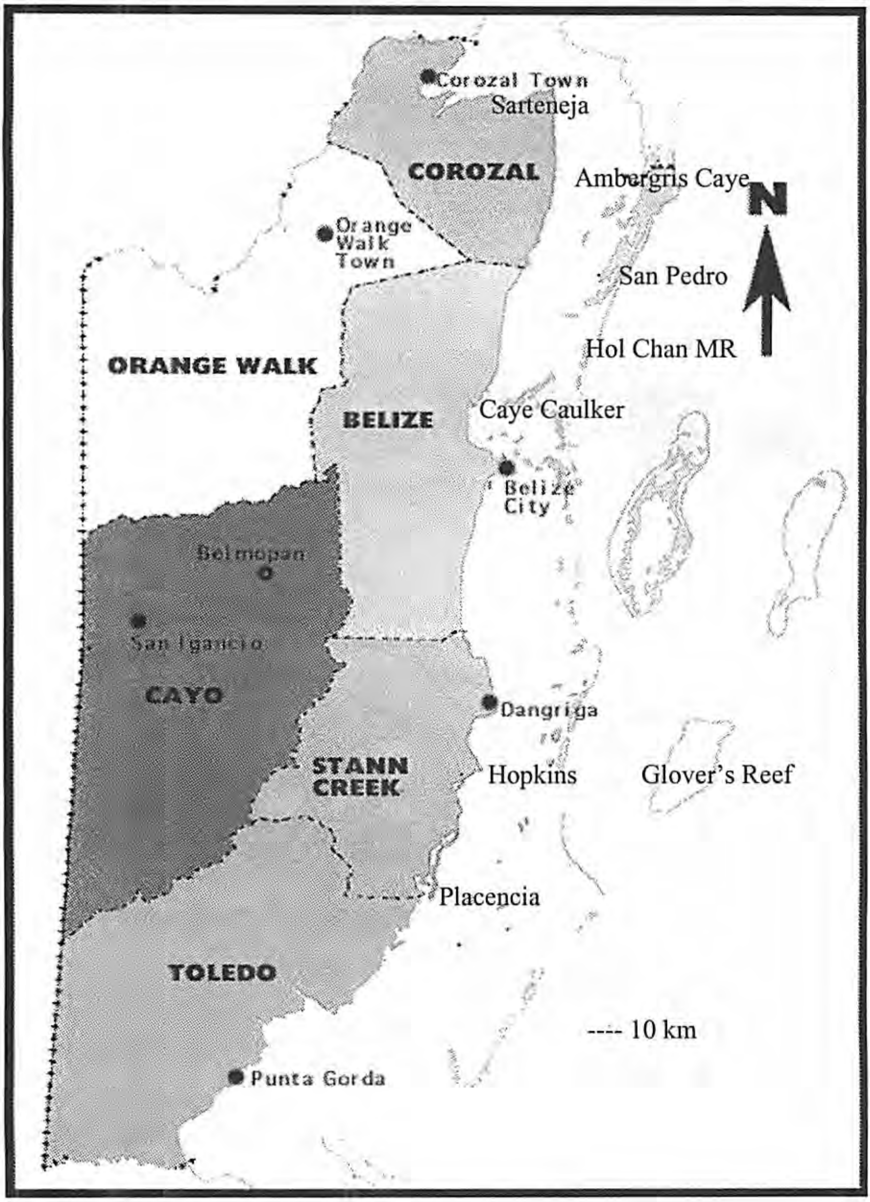


**Figure 1.** Map of Belize showing the administrative districts, the MPA study sites (Glover's Reef Marine Reserve, Hol Chan Marine Reserve) and adjacent communities (GRMR: Dangriga, Hopkins and Placencia; HCMR: San Pedro). Adapted from: http://www.belize.net/html/maps/shtml

Glover's Reef has been the traditional fishing ground and source of livelihood for the Garifuna communities of Dangriga, Hopkins and Placencia. Particularly important was the spawning aggregation site for groupers before its dramatic decline (Sala et al. 2001). An estimated 81 boats currently fish in GRMR: 24 from adjacent communities (16 from Hopkins, 8 from Dangriga, 8 from Placencia), 19 from other distant areas of Belize, and as many as 30 illegal Honduran boats.

**Hol Chan Marine Reserve**

HCMR is Belize's oldest marine reserve (established in 1987), is located off the southern tip of Ambergris Caye (Figure 1) and encompasses an area of approximately 1,116 hectares, including a section of the barrier reef, seagrass beds and coastal mangrove forest (Gibson 1988b).

There is a reserve office and visitor centre in San Pedro, Ambergris Caye managed by the Fisheries Department. The objectives of HCMR, as stated in the 2000 Hol Chan Management Plan (Young and Bilgre 2000), are to:

i) Maintain a sample coral reef in its natural state;
ii) Provide recreation and tourism services;
iii) Preserve the area for fisheries;
iv) Provide an area for education and research; and
v) Conserve genetic resources.

To achieve these multiple objectives a zoning system has been implemented. These zones comprise: a Conservation Zone (A) located over the barrier reef and well known Hol Chan Cut primarily for recreational use and conservation (no extraction of resources is allowed); a General Use Zone (B) incorporating seagrass beds where sport fishing and artisanal fishing is allowed; an Exclusive Recreational Zone (C) incorporating mangrove habitat where cutting of mangroves and disturbance of wildlife is prohibited, but sport fishing is allowed; and a Zone D incorporating Shark Ray Alley, a popular dive site, and used for catch and release sport fishing. HCMR is easily accessed by boat from Ambergris Caye (6.4 km from San Pedro) and Caye Caulker and has a very high visitor rate (over 42,000 visitors per year; BTB 2000).

The HCMR was a traditional fishing area for the community of San Pedro on Ambergris Caye, particularly for export species (conch, lobster) as well as for snapper and groupers and shallow reef fish (Carter et al. 1994). It is currently fished by an estimated 17 boats from San Pedro and has become the centre of Belize's marine-based tourism (e.g. Bonilla et al. 2000).

## METHODS

**Identification of Poorest Stakeholder Group**

The poorest stakeholder group at each MPA was identified through local key informants, using a set of pre-established livelihood/wealth indicators (i.e. food and health, capital assets, income, employment and education, together with any local indicators of wealth considered important by key informants) to judge the relative wealth of all MPA stakeholders. Using these criteria, fishers were identified as being the poorest stakeholder group at both HCMR and GRMR.

**Data Collection**

Fieldwork was conducted from 19 September to 1 November, 2001. The principal means of data collection was a formal interview survey of fishers using a questionnaire. Informal interviews and observation complemented the formal interview approach. The questionnaire was pre-tested on a small sub-sample and modified to increase local relevance before being used on the full sample of fishers. Questions were structured to obtain information on status before and after implementation of the MPA. All interviews were conducted in person and generally lasted about thirty minutes per fisher. Interviews took place at fish landing sites, and the Caribeña Fishermen's Cooperative in San Pedro for HCMR and at mooring sites and fishers' homes in Hopkins and Dangriga for GRMR fishers (Figure 1).

Since the total number of fishers in these communities was small (San Pedro: 30 fishers; Hopkins: 53 fishers; Dangriga: 19 fishers), all of the fishers who owned a boat (fisher/captain/boat owner) and who fished in the MPAs (41 fishers) were interviewed (Table 1). A further 34 informal interviews took place with persons closely associated with fishers in these communities (Table 1) and were useful for verifying data obtained from formal interviews. No questionnaires were administered to the few fishers from Placencia, or the more distant community of Sarteneja who also fish at GRMR, as a result of Hurricane Iris and impending tropical storm Michelle during the field study period. However, eight informal interviews provided supporting information

**Table 1.** Number of formal and informal interviews held with MPA fishers (boatowner/captains) and other stakeholders of the Glover's Reef and Hol Chan marine reserves

| MPA | Community | Formal Interviewees | Informal interviewees |
|---|---|---|---|
| Hol Chan Marine Reserve (HCMR) | San Pedro | 17 fishers | 5 tour guides (former fishers)<br>2 retired fishers<br>3 members of Town Council.<br>1 Manager HCMR<br>1 Secretary, Caribeña Co-operative |
| Glover's Reef Marine Reserve (GRMR) | Adjacent Communities | | |
| | Dangriga | 8 fishers | 5 Fishers (crew members)<br>3 Tour guides (x-fishers of GRMR)<br>2 Retired fishers<br>1 Manager of GR Marine Research Station<br>1 Ranger GRMR |
| | Hopkins | 16 fishers | 8 Fishers (crew members)<br>2 Members of Village Council |
| | Distant Communities | | |
| | Sarteneja | 0 | 2 Fishers (crew members)<br>2 Retired fisher |
| | Placencia | 0 | 2 Fishers (crew members)<br>2 Tour guides |

## RESULTS AND DISCUSSION

### General Biographic Data

Most fisher (owner/captain) respondents are 25 - 35 years old, have families of 4 - 6 dependents, and own their own fishing business, house, land and other assets. Around one-half (GRMR: 50%, HCMR: 54.8%) have a full primary education or higher. Over one-half the fishers (GRMR: 62.5%, HCMR: 64.7%) currently have no other sources of income other than that derived from their activities (fishing and non-fishing) in the MPAs. As such, they are highly vulnerable to changes at the MPA.

### Economic Benefits

A summary of responses to selected questions on livelihoods, economic status and changes is given in Table 1. When asked directly, the majority of fisher respondents from communities adjacent to the GRMR and HCMR did not attribute any positive economic gain to the implementation of the MPAs. Most fishers reported a decrease in income (GRMR: 83.4%, HCMR: 58.8%) following the establishment of the MPA and blamed this on the MPA, although a few did report an increase (GRMR: 16.7%; HCMR: 23.5%) which they attributed to the MPAs. The Hopkins community, in particular, appears to have suffered as a result of the seasonal closure of the grouper spawning aggregation site at the GRMR that previously provided a major part of their annual income.

However, responses to other questions illustrate that the MPAs do seem to have provided some economic benefit to the fishers. For example, most fishers also agreed that the income derived from the MPA helped them to put their children through school (GRMR 66.7%; HCMR: 76.5%). Importantly, the MPAs have enabled adaptive livelihood strategies. In particular, the MPAs have provided alternative, non-extractive employment opportunities such as tour guiding and water taxi operation for some fishers at GRMR (20.8%) and for more than half of the fishers at HCMR (60.7%), increasing resilience to fluctuations in fish availability. Fishers cite insufficient income from fishing and better prospects associated with tourism as the reasons for altering their economic activities. Opportunity to benefit through increases in capital assets have been relatively small, since many respondents at both MPAs (particularly those from San Pedro) already owned their fishing business, house, land, household appliances and transportation before the MPAs were established. Interestingly, half or more of the fishers (GRMR: 50%, HCMR: 58.8%) said that they currently have no need for additional sources of income. The fact that most reported decreased earnings as a result of MPA implementation was probably because respondents were referring only to their income from fishing. This is supported by the fact that most fishers who have taken up additional activities have seen an increase in earnings (GRMR 9 of 11 respondents; HCMR 7 of 12 respondents). Another consideration is that fishers do not generally perceive substantial economic benefits from the MPAs, partly because natural disasters (e.g. hurricanes) are reported as the primary threat to their livelihoods, and MPAs do not protect them from these impacts.

**Social Benefits**

A summary of responses to selected questions on livelihoods, social status and changes is given in Tables 2 and 3. The changes appear to have been very similar at both MPA sites, and most are attributed by fishers to the development of tourism in general, rather than directly a result of the MPAs.

Fishers were virtually unanimous in listing many public service amenity improvements (e.g. drinking water, garbage collection, sewage disposal, medical facilities, electricity, telephone communications and schools) since the establishment of the MPAs, but few saw these relating directly to the MPAs. Fishers are divided however on the issue of health benefits associated with the MPA. At GRMR, those from Dangriga saw none or were unsure, whilst 25% from Hopkins cited better recreational opportunities, greater peace and happiness, and reduced conflict. The majority from HCMR (64.7%) saw health benefits, citing a cleaner environment and better amenities. Few fishers from either MPA saw negative health impacts, although for some, increased conflict and less peace where issues.

The majority of fishers (GRMR: 66.7%, HCMR: 88.2%) recognised that the MPAs did generally benefit their communities, although this was less clear for the Hopkins community (7 of 16 did not see any benefits). However, although the vast majority of fishers were generally happy working in the MPAs (GRMR: 75%, HCMR 94.1%) and satisfied with their current quality-of-life (GRMR: 75%, HCMR: 64.7%), they were dissatisfied with the unequal distribution of benefits. At both MPA sites there was a strong perception that most of the benefits accrued to the tourism sector (particularly to tour guides in GRMR and dive operators in HCMR) with least benefits for fishers. This has resulted in fishers feeling alienated both socially and economically from other stakeholders.

**Management Issues**

A summary of management issues aired by fisher respondents is given in Table 4. Despite few benefits to themselves being attributed directly to the MPAs, most fishers (GRMR: 87.5%, HCMR: 76.5%) considered that their MPA was successful. Interestingly, the key criterion by which fishers judged the success of their MPA was conservation. This would suggest that they have seen improvements to resources within the MPAs. They were, however, almost unanimous in their desire to see improved management. Greater community participation in decision making, better enforcement of regulations, improved dissemination of information, and clearer demarcation of boundaries were the key issues for both sites. Fishers, particularly those from Hopkins and HCMR, also expressed concern over the levels of conflict in the MPAs, with management being the key source for the former and zoning for the latter. The majority of fishers from both MPAs agreed that the MPAs have had little success in decreasing conflict levels.

**Table 2.** Summary of responses to selected questions on livelihood /economic status and changes for fishers (boat owner/captains) from Glover's Reef Marine Reserve and Hol Chan Marine Reserve

| Question | Response | No. responses (% responses) | | | |
|---|---|---|---|---|---|
| | | Glover's Reef | | | Hol Chan n = 17 |
| | | Dangriga n = 8 | Hopkins n = 16 | Total n = 24 | |
| Did income from MPA help put your children through school ? | Yes | 5 | 11 | 16 (66.7) | 13 (76.5) |
| | No | 2 | 3 | 5 (20.8) | 4 (23.5) |
| | Not sure | 1 | 2 | 3 (12.5) | 0 |
| What new skills were acquired as a result of MPA? | Tour guiding | 2 | 2 | 4 (16.6) | 11 (64.7) |
| | Water taxi | 1 | 0 | 1 (4.2) | 0 |
| | None | 5 | 14 | 19 (79.2) | 6 (35.3) |
| Do you own a business? | Yes | 8 | 15 | 23 (95.8) | 17 (100) |
| | No | 0 | 1 | 1 (4.2) | 0 |
| Did you own a business before MPA? | Yes | 7 | 15 | 22 (91.7) | 15 (88.2) |
| | No | 1 | 1 | 2 (8.3) | 2 (11.8) |
| Did MPA help to acquire business? | Yes | 1 | 1 | 2 (8.3) | 3 (17.7) |
| | Not applicable | 7 | 15 | 22 (91.7) | 14 (82.3) |
| What capital assets did you have before MPA? | House | 5 | 15 | 20 (83.3) | 16 (94.1) |
| | Land | 6 | 16 | 22 (91.7) | 16 (94.1) |
| | Household items | 7 | 15 | 22 (91.7) | 16 (94.1) |
| | Motor | 5 | 4 | 9 (37.5) | 6 (35.3) |
| | vehicle/golf cart | 2 | 11 | 13 (45.8) | 5 (29.4) |
| | Bicycle | | | | |
| What capital assets do you have now? | House | 5 | 15 | 20 (83.3) | 16 (94.1) |
| | Land | 6 | 16 | 22 (91.7) | 17 (100) |
| | Household items | 7 | 15 | 22 (91.7) | 16 (94.1) |
| | Motor | 5 | 5 | 10 (41.7) | 5 (29.4) |
| | vehicle/golf cart | 2 | 12 | 14 (58.3) | 5 (29.4) |
| | Bicycle | | | | |
| Did MPA help you to acquire these? | Yes | 4 | 3 | 7 (29.2) | 1 (5.9) |
| | No | 4 | 13 | 17 (70.8) | 16 (94.1) |
| How much of your income is derived from MPA? | Small Part | 1 | 5 | 6 (25.0) | 7 (41.2) |
| | Large Part | 1 | 1 | 2 (8.3) | 4 (23.5) |
| | Very Large Part | 6 | 9 | 15 (62.5) | 6 (35.3) |
| | Not sure | 0 | 1 | 1 (4.2) | 0 |
| Other sources of income? | Yes | 3 | 6 | 9 (37.5) | 6 (35.3) |
| | No | 5 | 10 | 15 (62.5) | 11 (64.7) |
| Do you need other sources of income? | Yes | 3 | 9 | 12 (50.0) | 7 (41.2) |
| | No | 5 | 7 | 12 (50.0) | 10 (58.8) |
| What was the change in your income after MPA? | Substantial | 0 | 0 | 0 | 1 (5.9) |
| | increase | 2 | 2 | 4 (16.7) | 4 (23.5) |
| | Increase | 4 | 6 | 10 (41.7) | 1 (5.9) |
| | Substantial | 2 | 8 | 10 (41.7) | 9 (52.9) |
| | decrease | 0 | 0 | 0 | 2 (11.8) |
| | Decrease | 0 | 0 | 0 | 0 |
| | No change | | | | |
| | Not sure | | | | |
| Was MPA responsible for change in income? | Yes | 6 | 16 | 22 (91.7) | 14 (82.3) |
| | No | 2 | 0 | 2 (8.3) | 0 |
| | Not sure | 0 | 0 | 0 | 1 (5.9) |
| | Not applicable | 0 | 0 | 0 | 2 (11.8) |
| Has your economic activity changed since MPA? | Yes | 4 | 7 | 11 (45.8) | 12 (70.6) |
| | No | 4 | 9 | 13 (54.2) | 5 (29.4) |
| Why did you change economic activity? | Scarcity of fish | 0 | 0 | 0 | 2 (11.8) |
| | Insufficient | 1 | 4 | 5 (20.8) | 7 (41.2) |
| | income | 3 | 3 | 6 (25.0) | 3 (17.6) |
| | Tourism more | 4 | 9 | 13 (54.2) | 5 (29.4) |
| | income | | | | |
| | Not applicable | | | | |
| What was the change in your income from new activity? | Substantial | 0 | 2 | 2 (8.3) | 2 (11.8) |
| | increase | 3 | 4 | 7 (29.2) | 5 (29.4) |
| | Increase | 0 | 0 | 0 | 1 (5.9) |
| | Substantial | 0 | 0 | 0 | 1 (5.9) |
| | decrease | 1 | 0 | 1 (4.2) | 3 (17.6) |

**Table 3.** Summary of responses to selected questions on status and changes in quality-of-life for fishers (boat owner/captains) from Glover's Reef Marine Reserve and Hol Chan Marine Reserve

| Question | Response | No. responses (% responses) | | | |
|---|---|---|---|---|---|
| | | Glover's Reef | | | Hol Chan |
| | | Dangriga n = 8 | Hopkins n = 16 | Total n = 24 | n = 17 |
| What is your priority in life? | Food security | 0 | 1 | 1 (4.2) | 0 |
| | Housing security | 0 | 1 | 1 (4.2) | 0 |
| | Personal health | 3 | 6 | 9 (37.5) | 2 (11.8) |
| | Family well being | 5 | 6 | 11 (45.8) | 4 (23.5) |
| | Job security | 0 | 1 | 1 (4.2) | 11 (64.7) |
| | Other | 0 | 1 | 1 (4.2) | 0 |
| Are you satisfied with your quality of life? | Yes | 6 | 12 | 18 (75.0) | 11 (64.7) |
| | No | 2 | 4 | 6 (25.0) | 6 (35.3) |
| What are the main threats to your livelihood in the MPA? | Natural disasters | 6 | 5 | 11 (45.8) | 14 (43.8) |
| | Increased conflict | 0 | 0 | 0 | 3 (9.4) |
| | Management collapse | 1 | 1 | 2 (8.3) | 0 |
| | Overexploitation | 0 | 1 | 1 (4.2) | 5 (15.6) |
| | Reduction in visitors | 6 | 5 | 11 (45.8) | 7 (21.9) |
| | Others | 0 | 1 | 1 (4.2) | 3 (9.3) |
| | Unsure | 1 | 1 | 2 (8.3) | 0 |
| How do you cope with livelihood threat? | Social services | 0 | 1 | 1 (4.2) | 2 (11.8) |
| | Savings | 3 | 2 | 5 (20.8) | 6 (35.3) |
| | Loan | 5 | 9 | 14 (58.3) | 9 (52.9) |
| | Not sure | 0 | 4 | 4 (16.7) | 0 |
| What improvements have there been in amenities/social services since MPA? | Potable water | 8 | 16 | 24 (100) | 17 (100) |
| | Garbage collection | 7 | 15 | 22 (91.7) | 17 (100) |
| | Homes for the elderly | 8 | 16 | 24 (100) | 0 |
| | Polyclinics | 7 | 15 | 22 (91.7) | 17 (100) |
| | Hospitals | 4 | 3 | 7 (29.2) | 17 (100) |
| | Telephone | 8 | 15 | 23 (95.8) | 17 (100) |
| | Electricity | 8 | 16 | 24 (100) | 17 (100) |
| | Sewage | 6 | 14 | 20 (83.3) | 17 (100) |
| | Drainage | 4 | 2 | 6 (25.0) | 17 (100) |
| | Schools | 8 | 15 | 23 (95.8) | 17 (100) |
| Was improvement due to MPA? | Yes | 2 | 0 | 2 (8.3) | 1 (5.9) |
| | No | 6 | 16 | 22(91.7) | 16 (94.1) |
| Are there health benefits from the MPA? | Yes | 0 | 6 | 6 (25.0) | 11 (64.7) |
| | No | 3 | 9 | 12 (50.0) | 6 (35.3) |
| | Not sure | 5 | 1 | 6 (25.0) | 0 |
| What are the positive health benefits associated with the MPA? | Better recreation | 0 | 1 | 1 (4.2) | 0 |
| | More happiness/peace | 0 | 3 | 3 (12.5) | 0 |
| | Reduced conflict | 0 | 2 | 2 (8.3) | 0 |
| | Cleaner environment | 0 | 0 | 0 | 4(23.5) |
| | Better amenities | 0 | 0 | 0 | 7 (41.2) |
| | None | 3 | 9 | 12 (50.0) | 6 (35.3) |
| | Not sure | 5 | 1 | 6 (25.0) | 0 |
| What are the negative health impacts of the MPA? | Loss of recreation | 0 | 1 | 1 (4.2) | 0 |
| | Increased conflict | 1 | 1 | 2 (8.4) | 2(11.8) |
| | Dirtier environment | 0 | 0 | 0 | 2(11.8) |
| | Less happiness/peace | 1 | 2 | 3(12.5) | 5 (29.4) |
| | | 6 | 11 | 17 | 8 (47.0) |

Table 3. (continued)

| | | | | | |
|---|---|---|---|---|---|
| Does MPA benefit community? | Yes | 7 | 9 | 16 (66.7) | 15 (88.2) |
| | No | 1 | 7 | 8 (33.3) | 2 (11.8) |
| Are the benefits distributed equally? | Yes | 4 | 9 | 13 (54.1) | 4 (23.5) |
| | No | 4 | 7 | 11 (45.9) | 13 (76.5) |
| Which sector benefits the most? | Fishers | 1 | 0 | 1 (4.2) | 0 |
| | Dive operators | 0 | 0 | 0 | 9 (52.9) |
| | Tour guides | 3 | 7 | 10 (41.6) | 4 (23.6) |
| | None | 4 | 9 | 13 (54.2) | 4 (23.5) |
| Which sector benefits the least? | Fishers | 3 | 7 | 10 (41.6) | 13 (76.5) |
| | Tour guides | 1 | 0 | 1(4.2) | 0 |
| | None | 4 | 9 | 13(54.2) | 4 (23.5) |
| Are you happy working in the MPA? | Yes | 8 | 10 | 18(75.0) | 16(94.1) |
| | No | 0 | 4 | 4(16.7) | 1 (5.9) |
| | Not sure | 0 | 2 | 2(8.3) | 0 |

## CONCLUSIONS

The HCMR has apparently achieved some success in poverty alleviation in the adjacent community. The park has resulted in more job opportunities and stable incomes for the local community following its establishment. It has been used as a model for the establishment of other MPAs in Belize. Tourism has become the main income earning activity in San Pedro, and this has changed the social and economic structure of the community. Some of the revenue generated by the tourism industry is retained by the local community in employment, and through the purchase of local goods and services. This has improved the standard of living. Although this suggests that the park has close ties with the community and has had a positive impact, there have also been some negative impacts. The incomes of some fishers have suffered. There are also the potentially serious environmental impacts caused by coastal development and over-exploitation of resources, along with degradation due to the increased number of visitors to the MPA. It is often difficult to separate tourism development in general from MPA-specific interventions, and to say how much tourism relies on the MPA versus other elements of the tourism package.

Regarding the GRMR, the observed economic and social impacts of the MPA suggest that additional measures will need to be taken if the MPA is to contribute to poverty alleviation in adjacent communities. Urgent attention should be given to training fishers to take advantage of alternative or additional income generating opportunities in tourism (such as recreational fishing).

In concluding, it must be noted that if the GRMR and HCMR are to be used as means to derive benefits for assisting poverty alleviation there must be effective management with all stakeholders assuming responsibly for the resources and their shared uses. Only then can the economic situations, livelihoods and the quality of life of the adjacent communities be improved on a sustainable basis while the marine resources are developed rationally. If the sustainable livelihoods approach is employed as a process tool in policy, planning and management it is more likely that community-level benefits can be derived from MPAs. However, these cases demonstrate that, even if pro-poor and sustainable livelihoods approaches are not used, it is possible for some benefits to accrue.

**Table 4.** Summary of fisher (boat owner/captain) responses to selected questions on management of the Glover's Reef Marine Reserve and Hol Chan Marine Reserve

| Question | Response | No. responses (% responses) | | | |
|---|---|---|---|---|---|
| | | Glover's Reef | | | Hol Chan |
| | | Dangriga n = 8 | Hopkins n = 16 | Total n = 24 | n = 17 |
| What do you consider to be indicators of MPA success? | Conservation | 6 | 14 | 20(57.1) | 9 (25.0) |
| | More benefits to | 1 | 2 | 3(8.6) | 13 |
| | stakeholders | 2 | 1 | 3(8.6) | (36.1) |
| | Economic benefits to MPA | 2 | 0 | 2(5.7) | 4 (11.1) |
| | Enforcement of | 4 | 0 | 4(11.4) | 1 (2.8) |
| | regulations | 0 | 3 | 3(8.6) | 3 (8.3) |
| | Community participation | 0 | 0 | 0 | 5 (13.9) |
| | Research | | | | 1 (2.8) |
| | Other | | | | |
| Is the MPA successful? | Yes | 8 | 13 | 21(87.5) | 13 |
| | No | 0 | 3 | 3(12.5) | (76.5) |
| | | | | | 4 (23.5) |
| How do you receive information about the MPA? | Associations | 2 | 1 | 3(12.5) | 8 (47.1) |
| | Grape vine | 0 | 5 | 5(20.8) | 2 (11.8) |
| | MPA management | 5 | 4 | 9(37.5 | 1 (5.9) |
| | No Information | 1 | 2 | 3(12.5) | 3 (17.6) |
| | Other | 0 | 4 | 4(16.7) | 3 (17.6) |
| Your level of knowledge about the MPA | High | 0 | 2 | 2 (8.4) | 2 (11.8) |
| | Medium | 4 | 7 | 11(45.9) | 10 |
| | Low | 4 | 7 | 11(45.9) | (58.8) |
| | | | | | 5 (29.4) |
| Do you receive adequate information? | Yes | 1 | 5 | 6(25.0) | 6 (35.3) |
| | No | 7 | 11 | 18(75.0) | 11 |
| | | | | | (64.7) |
| What is level of stakeholder participation in MPA management? | High | 2 | 3 | 5(20.8) | 3 (17.6) |
| | Medium | 4 | 8 | 12(50.0) | 7 (41.2) |
| | Low | 2 | 5 | 7(29.2) | 6 (35.3) |
| | None | 0 | 0 | 0 | 1 (5.9) |
| Is there conflict in the MPA? | Yes | 3 | 11 | 14(58.3) | 12 |
| | No | 5 | 5 | 10(41.7) | (70.6) |
| | | | | | 5 (29.4) |
| What is the conflict issue? | Zoning | 0 | 1 | 1(4.2) | 7 (41.2) |
| | Resource use | 2 | 1 | 3(12.5) | 5 (29.4) |
| | Management | 1 | 9 | 10(41.7) | 0 |
| | Not applicable | 5 | 5 | 10(41.7) | 5 (29.4) |
| What effect has MPA had on conflict? | Reduced | 1 | 7 | 8(33.3) | 0 |
| | Increased | 0 | 0 | 0 | 5 (29.4) |
| | No difference | 7 | 7 | 14(58.3) | 11 |
| | Not sure | 0 | 2 | 2(8.4) | (64.8) |
| | | | | | 1 (5.9) |
| Would you like to see improvement to management? | Yes | 7 | 16 | 23(95.9) | 17(100) |
| | No | 1 | 0 | 1(4.2) | 0 |
| What improvements would you like to see in management? | Community participation | 6 | 7 | 13(15.3) | 9 |
| | Regulations/enforcement | 7 | 8 | 15(17.6) | (20.1) |
| | More benefits to | 2 | 7 | 7(8.2) | 10 |
| | stakeholders | 4 | 17 | 21(24.7) | (22.1) |
| | More information | 4 | 17 | 21(24.7) | 1 (2.2) |
| | Better demarcation of | 2 | 8 | 8(9.4) | 8 (17.8) |
| | zones | | | | 13 |
| | Other | | | | (28.9) |
| | | | | | 4 (8.9) |

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# Larval Supply and Recruitment of Coral Reef Fishes to Marine Reserves in the Upper Florida Keys, USA

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ABSTRACT

One of the primary goals of marine reserve implementation is the protection of biodiversity, current fisheries and future fish stocks. To achieve this goal, effective placement of marine reserves should ensure that incoming recruits are delivered to the protected area. Larval supply and recruitment of coral reef fishes were evaluated for both marine reserve and non-reserve sites in the upper Florida Keys. Patterns of larval supply for late-stage larvae settling to the reef were evaluated using larval light traps. Sampling efforts at two replicate reserve and non-reserve sites targeted two monthly settlement peaks during the new and third-quarter moons for each of 12 months. In addition, monthly surveys of newly-settled coral reef fishes were conducted on these reefs using SCUBA techniques. Densities of all reef fishes that had settled during the previous month (recruits < 2 cm) were quantified. Results of this study shed light on the processes influencing densities of juvenile fishes in marine reserves and non-reserve areas. Differences in larval supply and recruitment provide additional information needed to evaluate the efficacy of marine reserves.

KEY WORDS: Marine reserves, larval supply, recruitment

# El Suministro de Larvas y el Reclutamiento de Oeces Arrecifales en Reservas Marinas de los Cayos Superiores de la Florida (Florida Keys, USA)

Uno de los objetivos principales de la implementación de las reservas marinas es la protectión de la biodiversidad, las pesquerías, y el futuro de los stocks pesqueros. Para lograr este objetivo, las reservas marinas deberán asegurar una localización efectiva para que los reclutas puedan alcanzar las áreas protegidas. El suministro de larvas y el reclutamiento de peces arrecifales fueron evaluados en sitios de los Cayos superiores de la Florida (Upper Florida Keys) que son reservas y no reservas marinas. Los patrones de estadios larvales cercanos al asentamiento fueron evaluados usando trampas de luces. Los muestreos fueron efectuados en dos localidades, reservas y no-reservas, concentrados en los picos de larvas de dos meses de asentamiento durante la luna nueva y tres quartos. Investigaciones adicionales fueron llevados sobre peces arrecifales recientemente asentados usando buceo (SCUBA). Los peces arrecifales que se asentaron durante los meses anteriores (reclutas < 2cm) fueron quantificados. Resultados de este estudio brinda luces sobre los procesos que estan afectando las densidades de peces juveniles en areas que son reservas y no-reservas marinas. Las diferencias en el suministro de larvas y en el reclutamiento brindan ademas información necesaria para evaluar la eficiencia de las reservas marinas.

PALABRAS CLAVES: Cayos superiores de la Florida, reservas marinas, reclutamiento

## INTRODUCTION

The primary goals of marine reserve implementation are the protection of biodiversity, current fisheries, and future stocks from over-fishing. In order to protect future stocks, areas where marine reserves are established must receive an adequate supply of both larval and newly-settled fishes in order to ensure their sustainability. Recent literature contains frequent references to marine reserves as "sources and sinks" of reef fish larvae (e.g., Carr and Reed 1993, Roberts 2000), yet more data are needed on the supply of larvae and recruitment to reserves (Valles et al. 2001, Watson and Munro 2004). Ultimately, these data are necessary if we are to understand the dynamics of recruitment in marine reserves and the protection of local populations. Similar levels of larval supply may lead to similar levels of recruitment between reserve and non-reserve areas. Conversely, site-specific differences may lead to different rates of mortality for new recruits and subsequent differences in recruitment. Sites may also receive different levels of larval supply due to larval preferences for areas of higher coral cover or greater relief. Our null hypothesis was that there are no differences in larval supply, recruitment or diversity by protection level or site within the marine reserves located in the upper Florida Keys, USA.

## METHODS

All field research was conducted in the upper Florida Keys, (~25°N 80°W) within the Florida Keys National Marine Sanctuary (FKNMS). Established in 1997, the reserve encompasses 9515 $km^2$ of reef track, supporting a wide variety of Caribbean and Atlantic species. Within the reserve, sites are defined by varying degrees of protection. Sanctuary Protected Areas (SPAs) are marine reserves that are considered "no-take" zones, in which all collection is prohibited (Level 7; Bohnsack et al. 1999). Other areas (non-protected areas or NSPs) are restricted to general size limits, bag limits, and gear restrictions, with all forms of collection permitted except spear fishing (Level 3). To characterize the larval supply and recruitment of newly-settled reef fishes to marine reserves and non-reserve areas in the upper Florida Keys, two SPA sites (French and Molasses) and two NSP sites (Pickles and Sand Island) were sampled from May 2003 to April 2004.

Larval supply was quantified by collecting late-stage larvae settling to the reef using larval light traps (as described in Sponaugle and Cowen 1996). Relative rates of larval supply to the SPAs and NSPs were measured during the night before and the night of the new moon and the night before and the night of the third quarter moon, resulting in four days of sampling per month. These lunar phases were chosen because previous work has shown that settlement of a variety of species typically pulses during these times in the Florida Keys (Sponaugle et al., unpubl. data). During each sampling night, up to three replicate light traps were deployed at each of the four sites (two SPAs and two NPAs). Light traps were weighted to sample a depth of approximately 2 m from the surface, and then left to collect late-stage larvae overnight. Samples retrieved the next morning were immediately preserved in 95% ethanol. In the lab, fish larvae were sorted from the preserved samples and identified to lowest taxonomic classification possible using the NOAA-NMFS SEFSC larval fish identification key (Richards In press).

To evaluate recruitment, monthly surveys of all newly-settled coral reef fishes were conducted at the same sites. Censuses were conducted in areas that correspond to the habitat preferred by new recruits—the reef matrix as well as coral rubble areas. SCUBA divers censused haphazardly-placed transects by swimming along either side of the transect tape to a length of 5 m, recording any new recruits occurring within 0.5 m on each side of the tape. Fifteen surveys were conducted per habitat area within each site, resulting in a total of 30 transects per site.

To evaluate the differences in larval supply between the SPA and NSP sites, the number and diversity of reef-associated larvae were compared using ANOVA techniques. Differences were compared between sites and between protection levels. ANOVA techniques were also used to compare the difference in density of recruits and diversity of recruits by site and protection level. Diversity was measured using the Shannon-Wiener index. Upon investigation of the record of larval supply over the sampling period, a large pulse of larvae to Sand Island on October 24, 2003 resulted in a highly skewed record of larval delivery to this site. In order to investigate the patterns of larval supply during the sampling period, this pulse was removed from further analysis.

## RESULTS AND DISCUSSION

There was no significant difference in the mean numbers of larvae delivered to the four sites ($F = 2.05$, $p = 0.11$). Differences were not significant by site or protection level. Diversity of larvae, however, did differ significantly by site but not by protection level ($F = 4.07$, $p = 0.0077$). Post-hoc analysis using Fisher's LSD showed Sand Island had significantly higher diversity than Molasses or Pickles. Analysis of recruitment data yielded similar results. The density of recruits did not differ by site or protection level ($F = 2.14$, $p = 0.886$). However, the diversity of recruits was significantly different by site but not protection level ($F = 12.96$, $p = 0.000$). Post-hoc analysis using Fisher's LSD showed Sand Island had significantly lower diversity than Molasses or Pickles, and French had significantly higher diversity than Molasses or Pickles.

Upon closer inspection of the large pulse to Sand Island during the sampling period, this sample was dominated by both gerreids and haemulids. While haemulids are associated with reef areas as adults, larvae of both families settle to seagrass or mangrove habitats. Ocean color images obtained from the University of South Florida's Institute for Marine Remote Sensing (IMaRS) showed substantial movement of higher-productivity bay water along the Atlantic edge of the Keys during this period. Small pockets of water (~ 1 km) are visible in the upper Keys during the day on which the large sample was collected. Due to the relatively small sizes of these water pockets and the relatively small spatial scale over which the study sites are situated, it is possible that these oceanographic features could have led to the localized pulse in larval supply to this site.

We conclude that these four sites in the Keys did not differ significantly in either larval supply or recruitment during the sampling period. However, there were differences in diversity, though only by site. Marine reserves in the upper Keys showed no difference in larval supply or recruitment relative to non-reserve areas, and diversity did not differ by protection level. Finally, small scale oceanographic features may have played a role in the supply of larvae during this study, illustrating the importance of these features to both larval delivery and recruitment in this system.

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# Management Failures and Coral Decline Threatens Fish Functional Groups Recovery Patterns in the Luis Peña Channel No-take Natural Reserve, Culebra Island, Puerto Rico

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ABSTRACT

Target fishery species have been traditionally used as indicators of compliance and management success in no-take marine protected areas (MPAs). However, this approach has the limitation of ignoring the effects that no-take MPAs may have on the functional role of fishes at the community and ecosystem levels. The first objective of this study was to document spatial and temporal variation patterns in the structure of coral reef fish communities at the functional group level within the Luis Peña Channel No-Take Natural Reserve (LPCNR) in Culebra Island, Puerto Rico. The second objective was to test the efficiency of fish functional groups as indicators of management success in the LPCNR. There was a rapid recovery of fish communities three years following the designation of the LPCNR in 1999. Fish communities at a control fished reef located outside the reserve boundaries also showed a rapid recovery. However, management failures have resulted in poor compliance and in a recent increase in illegal fishing activities. This has resulted in a fish decline trend within core areas of LPCNR during the period of 2002 to 2004. Control sites showed the opposite trend. Also, fish communities at the reserve boundary site collapsed as a combined result of increased fishing pressure by fishers displacement after LPCNR designation and by chronic environmental degradation from areas outside reserves boundaries (i.e., large volumes of sediment- and nutrient-loaded runoff, raw sewage discharges). Chronic environmental degradation between 1997 and 2003 has been associated to a major phase shift in the community structure of coral reef benthic communities from coral to algal dominance within LPCNR. In spite of that, LPCNR has been a successful tool restoring overexploited fish communities in Culebra Island. This suggests that even with very limited efforts no-take MPAs can be successful in restoring severely depleted fishery resources. However, management failures within and outside LPCNR need to be addressed and eliminated in order to keep community support, and to restore trust and compliance.

KEY WORDS: Fish functional groups, management failure, MPAs

# La A Pérdida de Corales y la Ausencia de Cumplimiento Amenazan los Patrones de Recuperación de los Grupos Funcionales de Peces en la Reserva Natural de No-Captura del Canal Luis Peña, Isla de Culebra, Puerto Rico

Las especies objeto de pesca se han utilizado tradicionalmente como indicadoras del éxito y del cumplimiento en las áreas marinas protegidas (AMPs) de no-captura. Sin embargo, ésto tiene la limitación de ignorar los efectos que las AMPs puedan tener en el rol funcional de los peces al nivel de la comunidad y del ecosistema. Más aún, ignora el rol funcional que puede tener la integridad de los habitáculos bénticos arrecifales en el mantenimiento de las comunidades de peces. El primer objetivo de este estudio fue el de documentar los patrones de espaciales y temporales de variación en la estructura de la comunidad béntica y de peces arrecifales al nivel de los grupos funcionales. En segundo lugar, se probó la eficiencia de los grupos funcionales de peces como indicadores del éxito y cumplimiento en la Reserva Natural de No-Captura del Canal Luis Peña (RNCLP), en la Isla de Culebra, PR. Las comunidades bénticas y de peces arrecifales se monitorearon desde el 1996 utilizando transectos fijos lineales y censos visuales estacionarios aleatorios, respectivamente. Se documentó una pérdida neta de 46% en la cobertura de corales, un incremento de 683% en la cobertura de macroalgas y un 279% en la cobertura de cianobacterias. Se demostró mediante pruebas ANOSIM que dichos patrones fueron significativos a través del tiempo y a través de las zonas de profundidad. Dicho cambio de fase se ha asociado con los pulsos frecuentes de escorrentías altamente sedimentadas y cargadas de nutrientes, así como con brotes de enfermedades de corales. Las comunidades de peces dentro de las áreas núcleo de los arrecifes de coral de la RNCLP mostraron valores promedio mayores de riqueza de especies, abundancia total, biomasa total, biomasa de herbívoros totales y raspadores, y de carnívoros totales, generalistas, piscívoros y planctívoros, que en aquellos arrecifes localizados en el borde o afuera de la RNCLP. Sin embargo, la biomasa de 36% de las especies de peces ha disminuído a través de dicho período de 7 años, con 19% de éstos habiendo disminuído >50%. Se ha observado también una disminución en H'n y J'n como resultado de la dominancia en la biomasa de algunos grupos funcionales (ej. herbívoros raspadores y no desnudadores). Se sugiere que dicha dominancia puede estar influenciada por la pérdida de corales y el cambio de fase hacia la dominancia de las algas. A pesar de que algunas especies depredadoras (ej. meros, pargos) han mostrado incrementos significativos en biomasa, ninguno de los grupos funcionales de depredadores han mostrado incrementos significativos luego de la designación de la RNCLP. Dichos grupos constituyen también el objeto principal de las actividades de pesca ilegal dentro de la reserva y reflejan la ausencia significativa de éxito y cumplimiento. Los efectos de las AMPs de no-captura son altamente variables dependiendo de la escala en los que se midan. El cumplimiento inicial causó un incremento rápido en la abundancia y biomasa de muchas especies, pero la recuperación de las comunidades de peces ha fallado al nivel de la mayoría de los grupos funcionales. Estos resultados sugieren que la degradación de los

arrecifes de coral, en combinación con la ausencia de cumplimiento, pueden prevenir la recuperación de los grupos funcionales de peces. Ésto podría tener implicaciones de manejo significativas en el mantenimiento de los procesos ecológicos al nivel del ecosistema en los arrecifes de coral.

PALABRAS CLAVES: Pérdida de corales, Culebra, áreas marinas protegidas (AMPs) de no-captura

## INTRODUCTION

Fishing effects on marine ecosystems have been documented across multiple spatial and temporal scales (Jackson 1997, Jackson et al. 2001, Pauly et al. 2002). Fishing on coral reefs, often in combination with other human disturbances, such as eutrophication and disease outbreaks, has been shown to trigger long-term phase shifts in the community structure of both fish and epibenthic communities (Hughes 1994, Hawkins and Roberts 2004). It can also have profound effects at the ecosystem level (Jackson 2001), including an enormous loss of abundance and biomass of large animals, some of them undergoing extinction. Fishing can produce cascade effects affecting the abundance of marine fish populations (Pinnegar et al. 2000, Carr et al. 2002), age of maturity, size structure, sex ratio and genetic diversity of exploited species (Sobel and Dahlgren 2004). Fishing down the food web can indirectly affect marine biodiversity (Roberts 1995b, Bohnsack and Ault 1996), and as a result of bycatch, habitat degradation, by altering biological interactions (Carr et al. 2002), ecosystems structure and function and reducing the ability of reefs to recover from disturbance (Roberts 1995b, Sobel and Dahlgren 2004).

No-take marine protected areas (MPAs) have become a successful tool to help rebuild overexploited fish populations (Roberts 1994, 1995a, Roberts and Hawkins 1997, Roberts et al. 2001, Halpern 2002, Halpern and Warner 2002). Target fishery species have been traditionally used as indicators of compliance and management success in MPAs. However, this approach has the limitation of ignoring the effects that MPAs may have on the functional role of fishes at the community and ecosystem levels. Moreover, it ignores the functional role that coral reef benthic habitat integrity has on maintaining fish community structure. Functional changes in fish communities accompany structural changes at the ecosystem level, thus affecting major reef processes such as grazing, predation, competition, food web structure, energy flow, and interactions among species (Sobel and Dahlgren 2004), but also benthic processes such reef accretion and bioerosion (Roberts 1995b). Current large-scale reef crisis (i.e., Gardner 2002) requires an improved understanding of the ecological processes that underlie reef resilience (Bellwood et al. 2004). Such processes may include phase shifts in fish community structure and their relationship to modifications in their functional roles in coral reefs. The lowest fish biodiversity of the Caribbean, as compared to the Indo-Pacific region, suggests a relatively low functional redundancy and highlights the vulnerability of reef ecosystems to fish community declines. Therefore, we suggest expand traditional MPA effectiveness evaluation methods to document spatial and temporal patterns of variation in fish community structure at the functional group level.

**Why Use Fish Functional Groups?**

Interactions among species make it difficult to predict how ecological communities will respond to environmental degradation (Davis et al. 1998) or to any source of anthropogenic stress, including fishing pressure. Many coral reef fish species are highly sensitive to overexploitation and may undergo rapid local extinction. This may have cascading negative consequences for the entire ecosystem (Hughes 1994, Carr et al., 2002). Unpredictability at the population level argues for whole-ecosystem approaches to biodiversity conservation (Ives and Cardinale 2004). The sensitivity of an individual species to anthropogenic stress depends not only on the direct impact of stress on that species, but also on the indirect effects on that species caused by changes in densities of other species (Ives 1995, Ives and Cardinale 2004). For instance, fishing pressure or environmental degradation may decrease the density of competitors and/or predators of a species, thereby causing a compensatory increase in the density of that species. This may lead to wide short-term fluctuations at the population level. Functional groups have shown higher short-term stability than populations of individual species (Tilman 1996, McGrady-Steed and Morin 2000). High biodiversity will result in high functional redundancy. Functional redundancy will buffer against such short-term variations at the functional group level. However, Caribbean coral reef fish functional groups sustain a lower functional redundancy in comparison to Indo-Pacific reefs as a result of its lower fish biodiversity (Bellwood et al. 2004). Therefore, coral reef fish functional groups may be more vulnerable in the Caribbean to the effects of any anthropogenic stressor, becoming more susceptible to rapid phase shifts in community structure and ecosystem functions as a result of human exploitation or impacts. Shifting ecosystem functions will need to be assessed under any ecosystem-based fisheries management model.

Ecosystem-based fisheries management will require expanding the focus of traditional target species-oriented fish monitoring efforts to a functional-group approach. Suggested alternatives to reduce or even reverse actual fishing trends include decreasing fishing efforts by 20 - 30% and a redistribution of remaining effort across trophic levels, from large top predators to small prey species (Pauly et al. 2003). However, such an alternative will require first building up a strong database of fishing impacts on fish functional groups (i.e., trophic guilds) to help parameterize ecosystem models. Effects of chronic environmental stress will also need to be incorporated to fish monitoring efforts with proper control sites (i.e., no-take MPAs, remote reefs, etc.). This could be effectively done integrating benthic and water quality monitoring programs to fish monitoring efforts. Ecosystem-based management will also require modeling based upon a system of metrics of community structure, including diversity indices based on species richness, evenness and dominance, ordination methods applied to species composition data, and aggregate indicators of ecosystem status such as biomass size spectra (Babcock and Pikitch 2004).

The first objective of this study was to document spatial and temporal variation patterns in the structure of coral reef fish communities at the functional group level within the Luis Peña Channel No-Take Natural Reserve (LPCNR) in Culebra Island, Puerto Rico (PR). Second, we tested the efficiency of fish functional groups as indicators of management success in the LPCNR.

## METHODS

### Study Sites

Studies were carried out within the LPCNR, in Culebra Island, PR (Figure 1). Culebra is located at approximately 28 km off the northeastern coast of PR. The reserve was declared in 1999 and full descriptions of its marine communities, species inventories, ecological status assessments and threats from anthropogenic activities can be found elsewhere (Hernández-Delgado 2000, 2003a,b, 2004a,b, Hernández-Delgado and Sabat 2000, In press, Hernández-Delgado et al. 2000, Hernández-Delgado and Rosado-Matías 2003). Data was collected in 1996, 1998, 1999, 2002, 2003 and 2004 from Carlos Rosario Beach – CRO - (core area of LPCNR), and in 1999, 2002, 2003 and 2004 from Punta Melones – PME - (boundary area) and Punta Soldado – PSO - (control site outside). Sampling was conducted at two depth zones: I (<5 m), II (5-15 m). Data from year 1999 was collected prior to the LPCNR fishing prohibition in September 30, 1999.

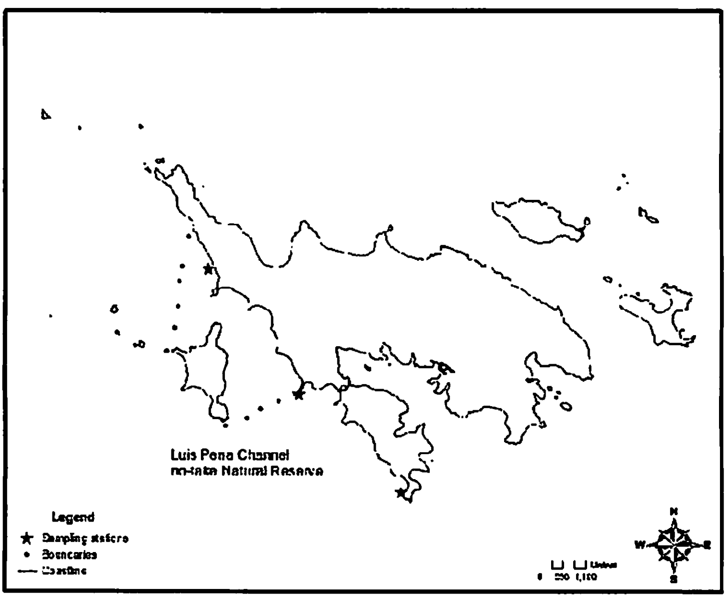


**Figure 1.** Study sites within LPCNR. From north to south: 1) Carlos Rosario Beach, 2) Punta Melones, and 3) Punta Soldado (control site outside LPCNR).

**Data Collection**

Fish community was sampled following a factorial design with time, sites, and depth zones as main factors. Data on fish species richness, abundance, and size estimates were collected at each site during the months of August and September of each year using the fish stationary visual census technique (Bohnsack and Bannerot, 1986). Size data (fish fork length) was used to calculate biomass following Bohnsack and Harper (1988) and Bohnsack (Unpub. data). Weight-length relationships were calculated by fitting a regression line to the equation: log W= log a + b log L, which is equivalent to the equation W = aLb, where W is weight in grams, L is length in mm, and *a* and *b* are constants. Basic information of the fish community structure included species richness, abundance, species diversity index (H'n), evenness (J'n), biomass, and standing stock biomass. Also, provided was information about abundance and biomass at the family/subfamily level and at the trophic group level, including herbivore guilds (i.e., non-denuders, browsers, scrapers), carnivore guilds (i.e., generalist, piscivores, planktivores), omnivores, and detrivores. Also, it provided the same type of information on target fishery species guilds. Only species richness, abundance, H'n, J'n and biomass data of functional groups were analyzed during this study.

**Statistical Analysis**

Spatio-temporal variation in community parameters at CRO was analyzed by means of one-way ANOVA using time and depth zones as main factors. No interaction analysis was carried out due to differences in the number of replicate samples per depth zone and per year. Two separate analyses were conducted for all years (1996-2004) and for the LPCNR designation year (1999) vs. 2004. A two-way ANOVA was used to test for spatio-temporal variation in community parameters among sites (MPA core, MPA boundary, control outside), year and depth zones. Post-hoc analysis was conducted using Tukey's comparison of means (Zar 1984). Data on species richness and abundance was √-transformed, while data on proportions was arcsin-(√)-transformed (Zar 1984). Data on biomass was $\log_{10}$-transformed (Zar 1984).

Individual coral reef fish functional group community matrices were compiled and imported into PRIMER ecological statistics software package (Clarke and Warwick 2001) for multivariate analysis. Mean fish functional group biomass proportion values were square root-transformed in order to appropriately weight the less abundant categories. Mean data from each year and depth zone at CRO, and from each site, year and depth zone were classified with hierarchical clustering using the Bray-Curtis group average linkage method (Bray and Curtis 1957) and then ordinated using a non-metric multidimensional scaling (MDS) plot (Clarke and Warwick 2001). Spatio-temporal variation patterns in community structure were tested using PRIMER's multivariate equivalent of an ANOVA called ANOSIM, which means "analysis of similarities" (Clarke 1993, Clarke and Warwick 2001). Both, global and pairwise tests were carried out by means of ANOSIM. All tests were based on 5,000 permutations and had no built-in assumptions about the data distribution. The key fish functional groups responsible for spatial variation in community structure between groups of years, sites, and depth zones were determined using PRIMER's SIMPER routine (Clarke and Warwick 2001).

## RESULTS

### Spatio-temporal Variation in Fish Communities at CRO: 1996-2004

There was an overall increase in the mean value of most community parameters at CRO after the LPCNR designation in 1999 (Figure 2). Fish abundance, H'n, J'n, fishery target species density, as well as total biomass, herbivore, browser, scraper, total carnivore and piscivore biomass, and the percent biomass of fishery target species showed significant temporal increases at CRO following MPA designation (Table 1). However, post-hoc analysis revealed that most of the differences were documented between years 2002-2003 and years previous to the LPCNR designation in 1999. Fish species richness, total abundance, abundance of fishery target species, total biomass, and fishery target species standing stock biomass declined between 2002 and 2004. A similar trend was documented in the mean biomass values of total herbivores, browsers, scrapers, total carnivores, piscivores, planktivores and shallow-water omnivores (Figure 3). No significant differences were documented in many parameters when year 2004 was compared to years during the period of 1996 to 1999. Scraper herbivore and piscivore biomass were significantly higher in shallow-water habitats when data was pooled across years (Table 1).

### Spatio-temporal Variation in Fish Communities at CRO: 1999 vs. 2004

Total abundance, total biomass, total carnivore, generalist and piscivore biomass, and fishery target species standing stock biomass showed significantly higher mean values five years after the LPCNR designation (Figures 2 and 3, Table 1). Generalist carnivore biomass was significantly higher in deep-water habitats, while piscivore biomass was significantly higher in shallow-water habitats.

### Magnitude of Changes at CRO

The magnitude of change in total fish abundance during the first five years of the LPCNR no-take designation was dramatic, reaching up to 378% in shallow-water habitats and 235% in deeper waters (Table 2). Total biomass increased during the first three years a magnitude of 508% and 521%, respectively, but declining to only 188% and 206%, respectively, after five years. A similar pattern occurred with total herbivore, browser, and scraper biomass. Scraper herbivores constitute an important part of the Culebra Island reef-associated and showed a 521% and 354% increase in mean biomass in shallow and deeper habitats, respectively, during 2002. These plummeted to only 102% and 49% in 2004. A similar trend was documented for all carnivore groups, including piscivores. These showed a dramatic 1,392% and 1,105% increase in mean biomass after three years. After five years this increase was cut down nearly in half (Table 2).

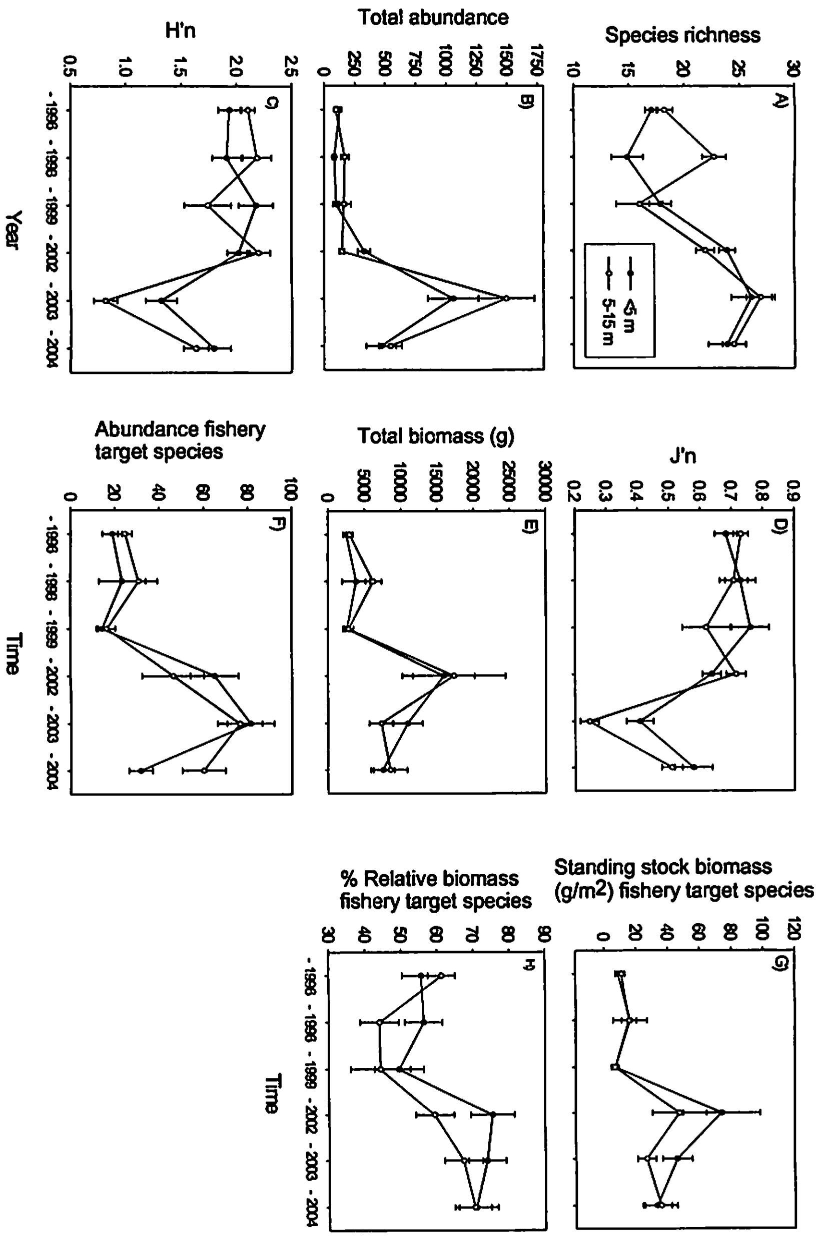


**Figure 2.** Fish community parameter changes through time at Carlos Rosario Beach (LPCNR core area): A) Species richness, B) Abundance, C) H'n, D) J'n, E) Total biomass, F) Abundance fishery target species, G) Standing stock biomass fishery target species, and H) % Relative biomass fishery target species. Mean± one standard error.

**Table 1.** Significant changes documented in fish community parameters through time (1996-2004) and between 1999 and 2004. Figures are *p* values from ANOVA.

| Parameters | All years (Time)[a] | All years (Depth)[a] | 99 vs 04 (Time)[b] | 99 vs 04 (Depth)[b] |
|---|---|---|---|---|
| Species richness | 0.0691 | 0.4910 | 0.1127 | 0.6594 |
| Abundance | 0.0024 | 0.5317 | 0.0329 | 0.1585 |
| Species diversity index (H'n) | 0.0428 | 0.5890 | 0.3127 | 0.2707 |
| Species evenness (J'n) | 0.0127 | 0.3134 | 0.1541 | 0.2112 |
| Total biomass | 0.0015 | 0.4820 | 0.0185 | 0.2019 |
| Total herbivore biomass | 0.0060 | 0.8598 | 0.1411 | 0.9892 |
| Non-denuder herbivore biomass | 0.1881 | 0.7256 | 0.3919 | 0.9602 |
| Browser herbivore biomass | 0.0271 | 0.6345 | 0.3652 | 0.8712 |
| Scraper herbivore biomass | 0.0006 | 0.0472 | 0.1720 | 0.5943 |
| Total carnivore biomass | 0.0056 | 0.2644 | 0.0025 | 0.0099 |
| Generalist carnivore biomass | 0.0792 | 0.0881 | 0.0130 | 0.0175 |
| Piscivore biomass | 0.0002 | 0.0032 | 0.0104 | 0.0303 |
| Planktivore biomass | 0.3005 | 0.0898 | 0.1067 | 0.1070 |
| Omnivore biomass | 0.2253 | 0.7878 | 0.7784 | 0.8362 |
| Fishery target species density | 0.0062 | 0.3075 | 0.1492 | 0.3611 |
| Fishery target species standing stock biomass | 0.0009 | 0.3459 | 0.0196 | 0.7116 |
| Percent biomass fishery target species | 0.0251 | 0.1186 | 0.0753 | 0.4563 |

[a] D.F.= time (5,11), depth (1,11).
[b] D.F.= time (1,3), depth (1,3).

**Table 2.** Magnitude of changes documented in fish community parameters in Carlos Rosario Beach between 1999 and 2004.

| Parameters | 1999 vs 2002 <5 m | 1999 vs 2002 5-15 m | 1999 vs 2004 <5 m | 1999 vs 2004 5-15 m |
|---|---|---|---|---|
| Species richness | 34% | 37% | 34% | 53% |
| Abundance | 235% | -10% | 378% | 235% |
| Species diversity index (H'n) | -7% | 26% | -18% | -6% |
| Species evenness (J'n) | -16% | 15% | -24% | -18% |
| Total biomass | 508% | 521% | 188% | 206% |
| Total herbivore biomass | 404% | 957% | 70% | 131% |
| Non-denuder herbivore biomass | 103% | 24% | 14% | 112% |
| Browser herbivore biomass | 290% | 2,384% | 35% | 306% |
| Scraper herbivore biomass | 521% | 354% | 102% | 49% |
| Total carnivore biomass | 642% | 313% | 223% | 226% |
| Generalist carnivore biomass | 442% | 200% | 209% | 224% |
| Piscivore biomass | 1,392% | 1,105% | 694% | 750% |
| Planktivore biomass | 28% | 174% | -36% | -27% |
| Omnivore biomass | 12% | -44% | -47% | 292% |
| Fishery target species density | 355% | 181% | 122% | 265% |
| Fishery target species standing stock | 934% | 581% | 366% | 413% |

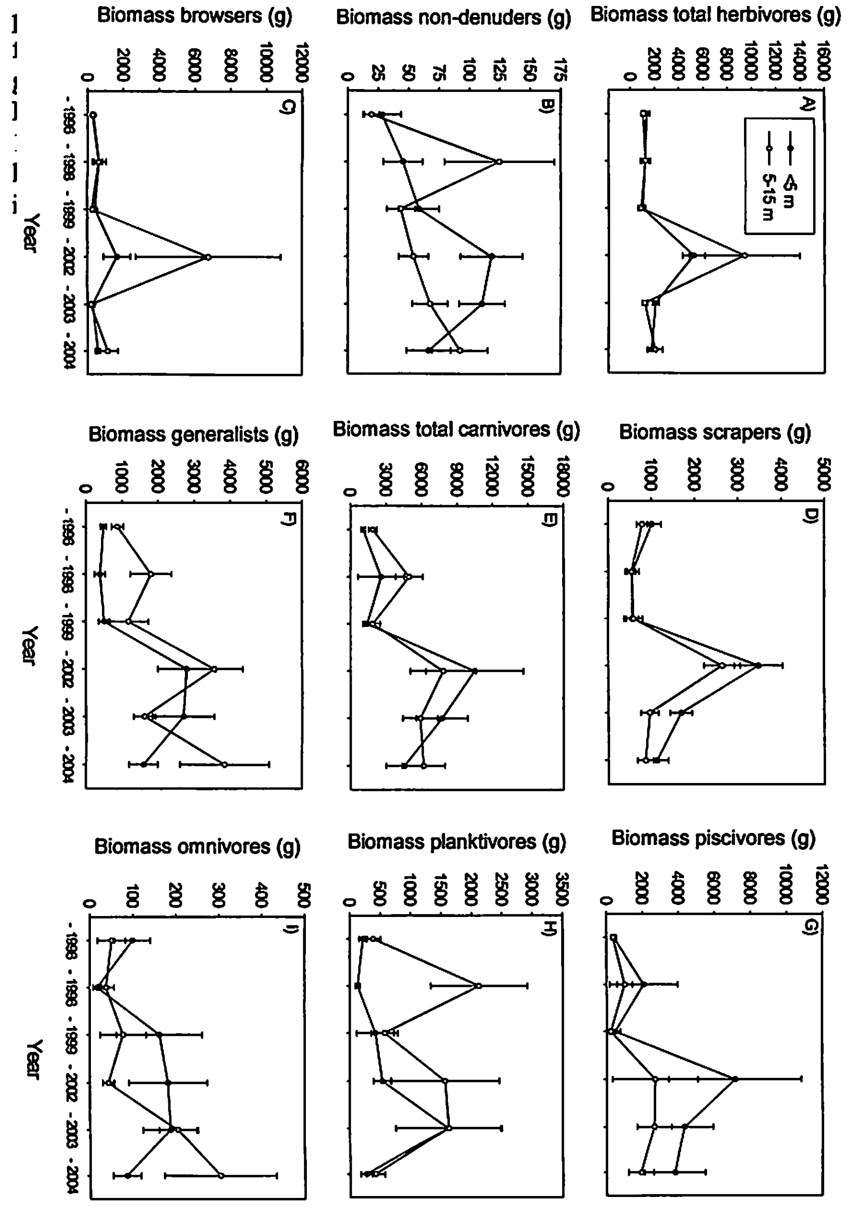


**Figure 3.** Fish functional group biomass changes through time at Carlos Rosario Beach (LPCNR core area): A) Total herbivores, B) Non denuders, C) Browsers, D) Scrapers, E) Total carnivores, F) Generalists, G) Piscivores, H) Planktivores, and I) Omnivores. Mean± one standard error.

### Multivariable Analysis at CRO

There was a highly significant difference in fish community structure at the functional group level among years at CRO, particularly between year pairs 1996 and 2002, 1996 and 2003, and between 1999 and subsequent years following LPCNR designation (Table 3). No significant difference was documented between years 1996 and 2004. A low stress (0.07) MDS analysis revealed six different cluster patterns of years and depth zones at CRO when using the 20% dissimilarity cut-off level, with two of them grouping years 1996 and 1999, and years 2003 and 2004, respectively (Figure 4a). Years 1998 and 2002 grouped independently. These patterns suggest that fish communities were becoming significantly different, mostly three years after the LPCNR designation, but a reversal pattern has occurred during 2003 and 2004, leading to a stage close to where they were before the LPCNR designation. No significant patterns were documented between depth zones (Table 3), but a significant interaction effect was documented between years and depth zone as a result of the effect of the variable years.

**Table 3.** ANOSIM analysis of spatio-temporal changes in fish community structure at Carlos Rosario Beach[1].

| Factors | Global R | Significance |
|---|---|---|
| *Global test* | | |
| Year | 0.600 | 0.2% |
| Depth | -0.013 | 42.9% NS[2] |
| Year x Depth | 0.065 | 0.2% |
| *Pairwise test* | | |
| 1996 vs. 1998 | 0.014 | 31.0% NS |
| 1996 vs. 1999 | 0.056 | 15.8% NS |
| 1996 vs. 2002 | 0.068 | 4.1% |
| 1996 vs. 2003 | 0.122 | 1.6% |
| 1996 vs. 2004 | -0.001 | 46.8% NS |
| 1999 vs. 2002 | 0.159 | 0.7% |
| 1999 vs. 2003 | 0.221 | 0.1% |
| 1999 vs. 2004 | 0.098 | 4.0% |

[1]Based on 5000 permutations.
[2]NS= Non-significant (values <5% are considered significant).

### Community Structure at CRO

The annual percent contribution of total herbivore biomass increased from 51% in 1996 to 62% in 1999, but declined to 46% in 2003 (Table 4). However, it increased back to 59% in 2004. Non-denuders annual percent contribution increased from 10% in 1996 to 18% in 1998 and stabilized at 17% from 1999 to 2004. Browsers have shown fluctuations associated to the behavior of large acanthurid fish schools. However, they have remained largely unchanged through the study. Similarly, annual percent contribution of scraper herbivores has remained unchanged during the study. The annual percent contribution of total carnivore biomass declined from 44% in 1996 to 35% in 1999, but increased to 41% in 2002. However, it declined back to 38% in 2004. Percent contribution in generalist carnivores was declining during the two years previous to the LPCNR designation. Three years later there was an increase, followed by another decline in successive years. Percent contribution of generalist carnivores during 2003 and 2004 was even lower than that of 1999. Piscivore annual percent contribution was 10% in 1996 and declined to 6% in 1998, increasing back to 11% in 2003 and 2004. Planktivores have shown large fluctuations through time, while omnivores percent contribution has increased from a lowest 3% in 1999 to 13% in 2004.

**Table 4.** Percent contribution of fish functional group biomass to community structure per year at Carlos Rosario Beach.

| Functional group | 1996 | 1998 | 1999 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|
| *Herbivores* | | | | | | |
| Non-denuders | 10 | 18 | 17 | 17 | 17 | 17 |
| Browsers | 20 | 17 | 23 | 9 | 11 | 22 |
| Scrapers | 21 | 22 | 22 | 22 | 18 | 20 |
| *Carnivores* | | | | | | |
| Generalists | 21 | 17 | 18 | 20 | 17 | 16 |
| Piscivores | 10 | 6 | 7 | 7 | 11 | 11 |
| Planktivores | 13 | 15 | 10 | 14 | 9 | 11 |
| *Omnivores* | 5 | 5 | 3 | 11 | 17 | 13 |

SIMPER indicator group analysis showed that changes in the biomass of different fish functional groups were significant causing temporal variation patterns in CRO depending on the temporal scale (Table 5). Planktivores caused the most significant change in community structure between 1996 and 1998, while non-denuders where the most important between 1996 and 1999. Browsers were the most important group between 1996 and 2002, and 2002 and 2004, while piscivores did so between 1996 and 2003, and between 1996 and 2004, respectively. They were also the most significant factor influencing temporal variation in community structure between years 1999 and 2003, and years 1999 and 2004. Overall, mean dissimilarity between 1999 and 2002 was 32%, but declined to only 21% between 1999 and 2004. This suggests that 2004 fish communities at CRO were more similar to 1999 fish communities than 2002 communities were.

**Spatio-temporal Variation in Fish Communities: MPA Core Zone, Boundary and Control Site**

Overall, fish communities were significantly different at the LPCNR core zone (CRO) and in the control site (PSO) when compared to the boundary zone (PME), where fish communities have shown a dramatic decline since 1999 (Table 6). All community parameters were significantly different among sites, with the exception of total herbivore, browser and omnivore biomass, and fishery target species density (Table 7). Post-hoc analysis showed that both, CRO and PSO had significantly higher mean values in most parameters when compared to PME. All community parameters were also significantly different among years, with the exception of scraper herbivore, total carnivore, generalist, piscivore, and planktivore biomass. Post-hoc analysis showed that both, CRO and PSO had significantly higher mean values in most parameters after the LPCNR designation. The opposite was observed at PME. No significant differences were documented between depth zones, with the exception of browser herbivores that showed a significantly higher biomass in shallower habitats. There were significant site x year interactions in all parameters, with the exception of non-denuder herbivore, piscivore, planktivore and omnivore biomass, and in fishery target species density. Site x depth interactions were non-significant, with the exception of percent biomass of fishery target species. All year x depth interactions were non-significant.

**Table 5.** SIMPER test of indicator functional groups at Carlos Rosario Beach.

| Factors | Group | P Biomass Factor A | P Biomass Factor B | % contrib.. |
|---|---|---|---|---|
| 1996 vs. 1998 | Planktivores | 0.03 | 0.11 | 23.12% |
| D=24.92% | Non-denuders | 0.03 | 0.10 | 19.09% |
| | Piscivores | 0.01 | 0.06 | 17.17% |
| 1996 vs. 1999 | Non-denuders | 0.03 | 0.06 | 23.57% |
| D=12.42% | Omnivores | 0.05 | 0.08 | 22.18% |
| | Planktivores | 0.03 | 0.05 | 15.03% |
| 1996 vs. 2002 | Browsers | 0.02 | 0.32 | 25.95% |
| D=37.49% | Piscivores | 0.01 | 0.18 | 20.02% |
| | Generalists | 0.03 | 0.15 | 14.16% |
| 1996 vs. 2003 | Piscivores | 0.01 | 0.13 | 24.01% |
| D=28.35% | Planktivores | 0.03 | 0.16 | 23.75% |
| | Non-denuders | 0.03 | 0.11 | 15.80% |
| 1996 vs. 2004 | Piscivores | 0.01 | 0.11 | 25.96% |
| D=24.09% | Generalists | 0.03 | 0.13 | 21.40% |
| | Non-denuders | 0.03 | 0.10 | 17.54% |
| 1999 vs. 2002 | Browsers | 0.03 | 0.32 | 27.04% |
| D=33.76% | Piscivores | 0.01 | 0.18 | 21.89% |
| | Scrapers | 0.04 | 0.21 | 18.58% |
| 1999 vs. 2003 | Piscivores | 0.01 | 0.13 | 29.03% |
| D=23.11% | Planktivores | 0.05 | 0.16 | 21.85% |
| | Generalists | 0.04 | 0.10 | 14.07% |
| 1999 vs. 2004 | Piscivores | 0.01 | 0.11 | 29.47% |
| D=20.94% | Generalists | 0.04 | 0.13 | 20.65% |
| | Omnivores | 0.08 | 0.13 | 15.29% |
| 2002 vs. 2004 | Browsers | 0.32 | 0.06 | 28.41% |
| D=21.60% | Scrapers | 0.21 | 0.07 | 19.11% |
| | Omnivores | 0.08 | 0.13 | 13.82% |

**Table 6.** Mean community parameters per site, year and depth zone.

| **Parameters**[a] | **Site** | **99 I** | **99 II** | **02 I** | **02 II** | **03 I** | **03 II** | **04 I** | **04 II** |
|---|---|---|---|---|---|---|---|---|---|
| Species richness | CRO | 18 | 16 | 24 | 22 | 26 | 27 | 24 | 24 |
| | PME | 19 | 22 | 21 | 27 | 18 | 21 | 21 | 20 |
| | PSO | 17 | 21 | 29 | 28 | 28 | 31 | 30 | 31 |
| Abundance | CRO | 97 | 163 | 327 | 145 | 1057 | 1495 | 465 | 541 |
| | PME | 255 | 281 | 157 | 248 | 143 | 183 | 130 | 126 |
| | PSO | 69 | 117 | 287 | 505 | 266 | 523 | 405 | 412 |
| Species diversity index (H'n) | CRO | 2.18 | 1.75 | 2.02 | 2.20 | 1.32 | 0.81 | 1.79 | 1.63 |
| | PME | 1.33 | 1.74 | 2.43 | 2.47 | 2.16 | 2.41 | 2.49 | 2.42 |
| | PSO | 2.27 | 2.08 | 2.48 | 2.13 | 2.33 | 1.73 | 2.35 | 2.11 |
| Species evenness (J'n) | CRO | 0.76 | 0.62 | 0.64 | 0.71 | 0.41 | 0.25 | 0.58 | 0.51 |
| | PME | 0.49 | 0.57 | 0.80 | 0.75 | 0.75 | 0.79 | 0.82 | 0.82 |
| | PSO | 0.83 | 0.73 | 0.74 | 0.65 | 0.70 | 0.50 | 0.69 | 0.61 |
| Total biomass* | CRO | 2.61 | 2.78 | 15.9 | 17.3 | 10.9 | 7.31 | 7.51 | 8.54 |
| | PME | 10.2 | 10.3 | 3.15 | 4.76 | 1.85 | 2.95 | 1.35 | 1.32 |
| | PSO | 2.82 | 4.93 | 3.35 | 8.50 | 2.79 | 3.54 | 6.15 | 5.81 |
| Total herbivore biomass* | CRO | 1.04 | 0.94 | 5.24 | 9.44 | 2.09 | 1.21 | 1.76 | 2.06 |
| | PME | 4.70 | 5.47 | 1.47 | 1.31 | 0.79 | 1.34 | 0.74 | 0.53 |
| | PSO | 1.51 | 1.16 | 1.60 | 3.66 | 1.21 | 1.12 | 2.82 | 2.82 |
| Non-denuder herbivore biomass | CRO | 58 | 49 | 118 | 54 | 110 | 68 | 66 | 92 |
| | PME | 51 | 57 | 100 | 139 | 88 | 234 | 70 | 150 |
| | PSO | 155 | 208 | 342 | 319 | 191 | 218 | 259 | 202 |
| Browser herbivore biomass | CRO | 420 | 286 | 1640 | 6739 | 292 | 179 | 568 | 1102 |
| | PME | 3553 | 3665 | 429 | 560 | 276 | 391 | 161 | 127 |
| | PSO | 148 | 187 | 342 | 2544 | 227 | 374 | 1190 | 1857 |
| Scraper herbivore biomass | CRO | 560 | 608 | 3480 | 2644 | 1690 | 966 | 1129 | 867 |
| | PME | 1098 | 1754 | 939 | 616 | 424 | 711 | 510 | 257 |
| | PSO | 1183 | 763 | 917 | 794 | 791 | 525 | 1366 | 758 |
| Total carnivore biomass* | CRO | 1.41 | 1.83 | 10.5 | 7.83 | 7.73 | 5.89 | 4.55 | 6.17 |
| | PME | 3.95 | 3.69 | 1.56 | 3.35 | 1.01 | 1.50 | 0.52 | 0.75 |
| | PSO | 1.14 | 2.72 | 1.61 | 4.58 | 1.50 | 2.29 | 3.19 | 2.79 |

**Table 6 (cont.).**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Generalist carnivore biomass | CRO | 515 | 1153 | 2793 | 3553 | 2696 | 1616 | 1593 | 3840 |
| | PME | 2783 | 2632 | 888 | 1753 | 741 | 1044 | 370 | 504 |
| | PSO | 699 | 1133 | 1172 | 2577 | 1144 | 1161 | 1836 | 2375 |
| Piscivore biomass | CRO | 479 | 216 | 7148 | 2710 | 4326 | 2645 | 3803 | 1913 |
| | PME | 1123 | 1016 | 663 | 1580 | 247 | 435 | 107 | 240 |
| | PSO | 101 | 426 | 195 | 1704 | 253 | 892 | 992 | 312 |
| Planktivore biomass | CRO | 417 | 541 | 534 | 1564 | 1616 | 1629 | 268 | 417 |
| | PME | 48 | 41 | 13 | 19 | 22 | 17 | 42 | 11 |
| | PSO | 342 | 1156 | 210 | 297 | 106 | 240 | 360 | 108 |
| Omnivore biomass | CRO | 162 | 90 | 182 | 43 | 187 | 205 | 85 | 303 |
| | PME | 1550 | 1145 | 118 | 91 | 52 | 114 | 89 | 27 |
| | PSO | 185 | 1058 | 135 | 265 | 79 | 127 | 146 | 195 |
| Fishery target species density | CRO | 0.08 | 0.09 | 0.37 | 0.26 | 0.46 | 0.43 | 0.18 | 0.34 |
| | PME | 0.09 | 0.24 | 0.31 | 0.41 | 0.35 | 0.41 | 0.28 | 0.25 |
| | PSO | 0.09 | 0.14 | 0.50 | 0.45 | 0.47 | 0.21 | 0.74 | 0.57 |
| Fishery target spp. standing stock biomass | CRO | 7.15 | 7.09 | 73.9 | 47.4 | 46.1 | 26.8 | 33.3 | 35.8 |
| | PME | 20.6 | 20.1 | 13.5 | 20.4 | 7.1 | 11.3 | 4.5 | 5.0 |
| | PSO | 9.7 | 9.9 | 10.2 | 20.1 | 10.2 | 12.9 | 20.3 | 16.5 |
| Percent biomass fishery target species | CRO | 50% | 44% | 75% | 59% | 74% | 67% | 71% | 70% |
| | PME | 36% | 38% | 66% | 71% | 66% | 67% | 55% | 64% |
| | PSO | 56% | 42% | 49% | 46% | 63% | 56% | 57% | 61% |

*Values x Kg.

**Table 7.** Significant spatio-temporal changes in fish community parameters through time (1999-2004). Figures are *p* values from ANOVA.

| Parameters[a] | Site | Year | Depth | Site x Year | Site x Depth | Year x Depth |
|---|---|---|---|---|---|---|
| Species richness | 0.0027 | 0.0020 | 0.1354 | 0.0295 | 0.2458 | 0.6791 |
| Abundance | 0.0034 | 0.0027 | 0.0959 | 0.0027 | 0.5780 | 0.5278 |
| Species diversity index (H'n) | 0.0034 | 0.0134 | 0.1201 | 0.0129 | 0.0811 | 0.6909 |
| Species evenness (J'n) | 0.0038 | 0.0241 | 0.0581 | 0.0055 | 0.1488 | 0.6858 |
| Total biomass | 0.0008 | 0.0130 | 0.0645 | 0.0005 | 0.1989 | 0.3638 |
| Total herbivore biomass | 0.1360 | 0.0185 | 0.6211 | 0.0036 | 0.9562 | 0.5084 |
| Non-denuder herbivore biomass | 0.0005 | 0.0384 | 0.4242 | 0.5054 | 0.0665 | 0.5604 |
| Browser herbivore biomass | 0.3560 | 0.0043 | 0.0430 | 0.0007 | 0.2529 | 0.0982 |
| Scraper herbivore biomass | 0.0160 | 0.0511 | 0.0970 | 0.0112 | 0.4732 | 0.4542 |
| Total carnivore biomass | 0.0015 | 0.0680 | 0.0616 | 0.0068 | 0.3009 | 0.7964 |
| Generalist carnivore bio-mass | 0.0286 | 0.1526 | 0.0314 | 0.0059 | 0.9770 | 0.3489 |
| Piscivore biomass | 0.0070 | 0.0900 | 0.4018 | 0.0558 | 0.0987 | 0.5949 |
| Planktivore biomass | 0.0000 | 0.1361 | 0.5157 | 0.0690 | 0.2589 | 0.1655 |
| Omnivore biomass | 0.6140 | 0.0480 | 0.6808 | 0.1127 | 0.3344 | 0.7984 |
| Fishery target species den-sity | 0.1578 | 0.0009 | 0.5429 | 0.1250 | 0.3038 | 0.2424 |
| Fishery target species standing stock biomass | 0.0009 | 0.0108 | 0.5636 | 0.0018 | 0.2125 | 0.8538 |
| Percent biomass fishery target species | 0.0000 | 0.0000 | 0.4043 | 0.0000 | 0.0375 | 0.0995 |

[a] D.F.= time (2), year (3), depth (1), site x year (6), site x depth (2), year x depth (3), error (6).

### Multivariable Analysis of Sites

There was a highly significant difference in fish community structure at the functional group level among sites (Table 9). Fish communities at CRO were significantly different than both, PME and PSO. PME was significantly different than PSO. No significant differences were documented among years and between depth zones. However, a pairwise ANOSIM test documented significant differences between 1999 and 2002 when pooling all sites, and between 1999 and 2004. MDS analysis (stress=0.16) revealed seven different cluster patterns of sites, years and depth zones when using the 20% dissimilarity cut-off level, with a large group composed by PME and PSO, and a close group composed by CRO-1999 and CRO-II-2004 (Figure 4a). Clusters follow a gradient of change through time after the LPCNR designation, but also reflect a dramatic reversal in fish community structure at PME and the early signs of reversal at CRO.

### Magnitude of Changes Within and Between Sites

There were dramatic within-site changes in community structure five years after the LPCNR designation (Table 8). Species richness increased by a factor of 41% and 61% at CRO and PSO, respectively, while fish abundance increased by a factor of 287% and 339%, respectively. However, abundance declined by 52% at PME. Total biomass increased by 198% at CRO and by 54% at PSO, but declined by 87% at PME. Browser herbivore biomass increased by 137% at CRO and by 810% at PSO, but declined by 96% at PME. Generalist carnivore biomass increased by 226% at CRO and by 130% at PSO, but plummeted by 84% at PME. Piscivores showed a similar decline at PME, but increased by 147% at PSO and by 722% at CRO. Fishery target species standing stock biomass increased by 392% at CRO and by 276% at PSO, but declined by 77% at PME.

Between-site differences in year 2004 were also significant for most parameters, particularly when CRO and PSO were compared to PME (Table 8). For example, CRO showed higher mean values when compared to PME in factors such as fish abundance (293%), total biomass (501%), and mean biomass of browsers (480%), scrapers (160%), total carnivores (744%), generalists (522%), piscivores (1547%), planktivores (1192%) and omnivores (234%), as well as in fishery target species standing stock biomass (631%). Differences were less pronounced between CRO and PSO, but CRO showed higher fish abundance (23%), total carnivore biomass (79%) and piscivore biomass (338%). However, CRO showed a slightly lower (6%) fishery target standing stock biomass than at the control PSO. PME showed dramatically lower mean values for most of the parameters when compared to PSO (Table 8), suggesting a fish community collapse.

**Table 8.** Magnitude of changes documented in fish community parameters within and between sites between 1999 and 2004[1].

| Parameters | CRO | PME | PSO | CRO v PME 2004[2] | CRO v PSO 2004[3] | PME v PSO 2004[4] |
|---|---|---|---|---|---|---|
| Species richness | 41% | 0% | 61% | 15% | -21% | -33% |
| Abundance | 287% | -52% | 339% | 293% | 23% | -69% |
| Species diversity index (H'n) | -13% | 60% | 3% | -30% | -23% | 9% |
| Species evenness (J'n) | -21% | 55% | -11% | -34% | -16% | 26% |
| Total biomass | 198% | -87% | 54% | 501% | 34% | -78% |
| Total herbivore biomass | 93% | -75% | 111% | 50% | -32% | -55% |
| Non-denuder herbivore biomass | 48% | 104% | 27% | -28% | -66% | -52% |
| Browser herbivore biomass | 137% | -96% | 810% | 480% | -45% | -91% |
| Scraper herbivore biomass | 71% | -73% | 9% | 160% | -6% | -64% |
| Total carnivore biomass | 231% | -83% | 55% | 744% | 79% | -79% |
| Generalist carnivore biomass | 226% | -84% | 130% | 522% | 29% | -79% |
| Piscivore biomass | 722% | -84% | 147% | 1547% | 338% | -73% |
| Planktivore biomass | -28% | -49% | -69% | 1192% | 46% | -89% |
| Omnivore biomass | 54% | -96% | -73% | 234% | 14% | -66% |
| Fishery target species density | 206% | 61% | 470% | -2% | -60% | -60% |
| Fishery target species standing stock biomass | 392% | -77% | 276% | 631% | -6% | -87% |
| Percent biomass fishery target species | 50% | 61% | 20% | 18% | 19% | 0.8% |

[1]Annual means.
[2]Relative magnitude of CRO compared to PME.
[3]Relative magnitude of CRO compared to PSO.
[4]Relative magnitude of PME compared to PSO.

**Table 9.** ANOSIM analysis of spatio-temporal changes in fish community structure.

| Factors | Global R | Significance |
|---|---|---|
| *Global test* | | |
| Site | 0.402 | 0.0% |
| Year | 0.079 | 11.9% NS[2] |
| Depth | 0.004 | 40.0% NS |
| Site x Year | 0.403 | 0.9% |
| Site x Depth | 0.382 | 0.0% |
| Year x Depth | -0.073 | 77.4% NS |
| *Pairwise test – Site* | | |
| CRO vs. PME | 0.640 | 0.1% |
| CRO vs. PSO | 0.483 | 0.1% |
| PME vs. PSO | 0.166 | 2.4% |
| *Pairwise test - Year* | | |
| 1999 vs. 2002 | 0.280 | 2.6% |
| 1999 vs. 2003 | 0.200 | 7.4% NS |
| 1999 vs. 2004 | 0.256 | 2.6% |
| 2002 vs. 2003 | -0.030 | 52.4% NS |
| 2002 vs. 2004 | -0.189 | 99.4% NS |
| 2003 vs. 2004 | -0.061 | 65.4 NS |

[1]Based on 5000 permutations.
[2]NS= Non-significant (values <5% are considered significant).

## Community Structure per Site, Year and Depth Zone

Herbivores had a 38% biomass contribution at CRO, with 51% at PME and 49% at PSO, when data was pooled across time (Table 10). Carnivores had a 51% biomass contribution at CRO, with 35% at PME and 37% at PSO, when pooled across time. Omnivores showed little fluctuations among sites. Non-denuders were proportionally higher at PSO (23%) and PME (20%). Browsers, scrapers and generalists did not fluctuate much among sites. Piscivores (16%) and planktivores (19%) were proportionally higher at CRO. Herbivores percent contribution increased overall from 43% in 1999 to 50% in 2004. Non-denuders showed also a large increase from 14% to 20%. Carnivores did not fluctuate much overall through time, but piscivore percent contribution increased from 9% in 1999 to 14% in 2002. However, declined to 11% in 2004. There were not many differences between depth zones overall, but herbivores were proportionally more abundant in shallow water, while carnivores were more abundant in deep habitats.

SIMPER indicator group analysis showed that planktivores were the most significant functional group causing differences in fish community structure between CRO and PME, and between PSO and PME (Table 11). Piscivores were the most significant group explaining differences between CRO and PSO. CRO and PME showed the highest mean dissimilarity between sites (32%). Omnivores were the most significant group explaining differences between 1999 and subsequent years. Piscivores explained most of the differences between 2002 and 2004, while planktivores explained most of the variation between shallow and deep habitats.

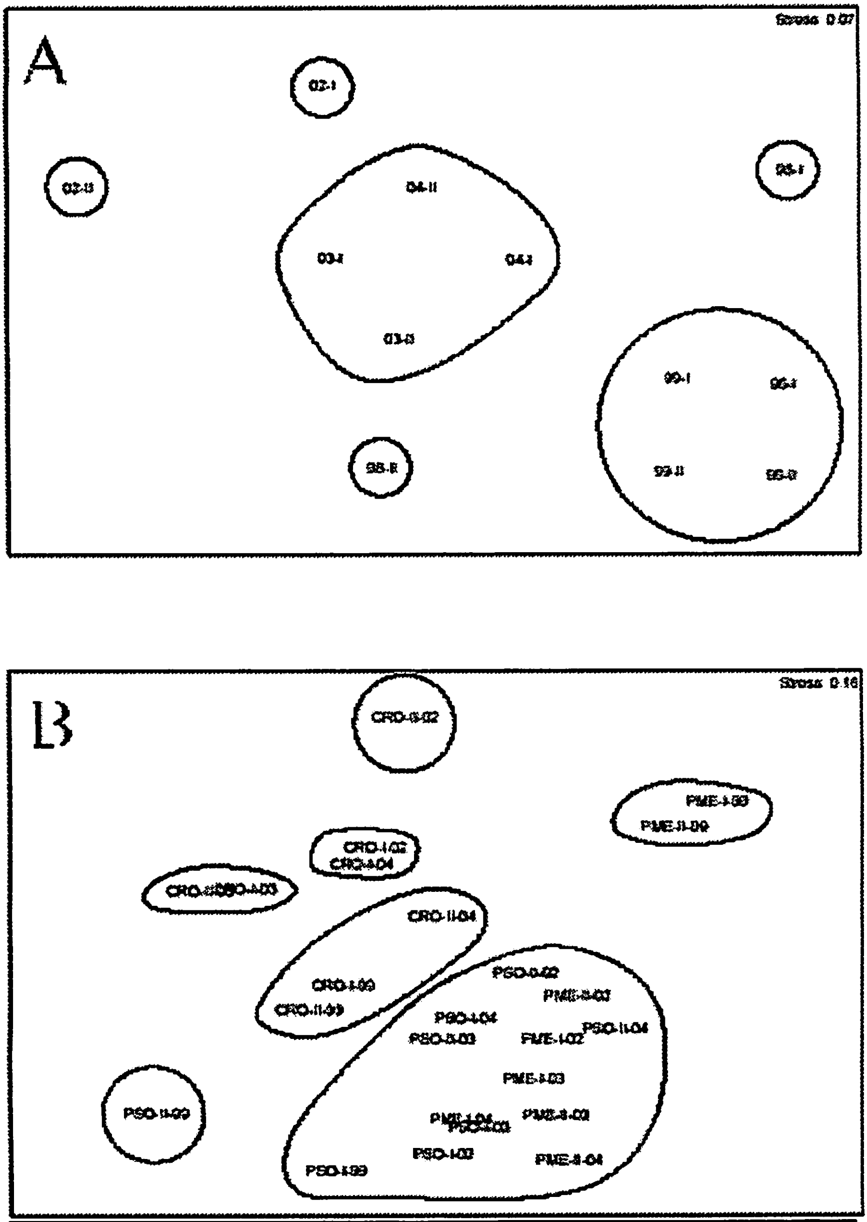


**Figure 4.** Multi-dimensional scaling plots of fish community structure changes: A) Temporal variation patterns in Carlos Rosario Beach, B) Spatio-temporal variation patterns (reserve, boundary, control outside sites). Circles show groupings based on a 20% dissimilarity cut-off level.

**Table 10.** Percent contribution of fish functional group biomass to community structure per site, year and depth zone.

| Functional group | CRO | PME | PSO | 99 | 02 | 03 | 04 | I | II |
|---|---|---|---|---|---|---|---|---|---|
| *Herbivores* | | | | | | | | | |
| Non-denuders | 12 | 20 | 23 | 14 | 17 | 20 | 20 | 18 | 18 |
| Browsers | 10 | 13 | 10 | 11 | 14 | 11 | 13 | 12 | 12 |
| Scrapers | 16 | 18 | 16 | 18 | 18 | 17 | 17 | 19 | 16 |
| *Carnivores* | | | | | | | | | |
| Generalists | 16 | 17 | 16 | 15 | 18 | 17 | 17 | 16 | 18 |
| Piscivores | 16 | 12 | 8 | 9 | 14 | 12 | 11 | 11 | 13 |
| Planktivores | 19 | 6 | 13 | 14 | 8 | 10 | 9 | 10 | 10 |
| *Omnivores* | 11 | 14 | 14 | 19 | 11 | 13 | 13 | 14 | 13 |

**Table 11.** SIMPER test of indicator functional groups for sites, year and deptb zones.

| Factors | Group | P Biomass Factor A | P Biomass Factor B | % contrib.. |
|---|---|---|---|---|
| CRO vs. PME D=32.31% | Planktivores | 0.09 | <0.01 | 28.21% |
| CRO vs. PSO D=25.53% | Piscivores | 0.09 | 0.02 | 22.76% |
| PME vs. PSO D=25.84% | Planktivores | <0.01 | 0.04 | 20.83% |
| 1999 vs. 2002 D=28.39% | Omnivores | 0.11 | 0.02 | 19.53% |
| 1999 vs. 2003 D=26.66% | Omnivores | 0.11 | 0.02 | 23.32% |
| 1999 vs. 2004 D=27.42% | Omnivores | 0.11 | 0.02 | 23.83% |
| 2002 vs. 2004 D=25.47% | Piscivores | 0.07 | 0.04 | 20.53% |
| Depth I vs. Depth II | Planktivores | 0.03 | 0.05 | 19.78% |

## DISCUSSION

### Effects of the LPCNR Designation on Fish Communities

Our study showed six important things:

i) Fish communities were significantly overexploited by fishing activities before the LPCNR designation;
ii) There was a rapid increase in species richness, total abundance and biomass of most functional groups, including piscivores during the first three years after the LPCNR designation;
iii) Since 2002 there has been a decline in biomass of fishery target species groups within the core areas at CRO;
iv) In spite of that trend, core areas of the LPCNR supported higher biomass of most of the fishery target species groups in comparison to boundary areas;

v) Fish communities at the boundary area of PME suffered a severe decline between 1999 and 2004; and
vi) There was a significant increase in biomass of most functional groups at the control site at PSO comparable to core areas within LPCNR.

Rapid recovery in fish communities within the LPCNR and control sites outside was outstanding and comparable to previous reports in the Caribbean (Helpern et al. 2002). For example, Roberts and Hawkins (1994) reported a total biomass slightly above 4.1 kg/count two years after an MPA designation in St. Lucia and a biomass of 1.8 kg/count at a control site outside. Roberts (1995a) reported a total biomass of 3.5 kg/count four years after an MPA designation in Saba and a biomass of 1.9 kg/count at a control site outside. Biomass increased to 4.5 kg/count within the MPA and to nearly 4.0 kg/count outside six years after the MPA designation. In our study, total biomass three years after the LPCNR designation increased from an annual mean of 2.7 kg/count at the moment of designation to 16.6 kg/count within the core area of CRO. Biomass increased from 3.9 kg/count in 1999 to 5.9 kg/count in 2002 at a control site PSO. But five years after designation, total biomass declined at CRO to 8.0 kg/count, while biomass at PSO remained at 6.0 kg/count. The magnitude of the total biomass decline within the core area of the LPCNR was 52% only within two years, while at the same time biomass remained virtually unchanged at the control site subjected to fishing. A nearly similar pattern was documented within many of the individual functional groups. However, the most dramatic fish community collapse occurred at the boundary site of PME. Mean total biomass was 10.5 kg/count in 1999, but plummeted to 1.3 kg/count in 2004, a magnitude of 87%. These observations suggest that three factors might have affected fish communities:
i) Illegal fishing activities within the LPCNR;
ii) Environmental degradation in the boundary area at PME; and
iii) A combination of both.

Artisanal fishing was eliminated and recreational fishing was significantly reduced after the designation of the LPCNR during the first three years. However, there has been a systematic increase in the presence of poachers within the LPCNR since year 2002. These include mostly off-island recreational spearfishers, and recreational and artisanal hook and line fishers (Hernández-Delgado 2004b). Also, there has been recent increase in illegal fishing activities, including shark long-lines, queen conch, topshell, and octopus poaching (Hernández-Delgado 2004b). Local residents have also documented for the first time several localized juvenile fish and invertebrate massive kills in rocky shores within and outside LPCNR, which might suggest the recent introduction of chemicals during fishing activities by off-island residents. But most of the fishing pressure documented at CRO has been recreational spearfishing from off-island private yacht operators (Hernández-Delgado Pers. obs.). Fishing can have rapid negative effects on the community structure of coral reef fishes (Roberts and Polunin 1993, Russ and Alcalá 1998) and benthic habitats (Hawkins and Roberts 2004). The effect of spearfishing pressure reflected on a decline in mean sizes of target fishery species such as red hind, *Epinephelus* *guttatus*, graysby, *Cephalopholis* cruentatus, schoolmaster, *Lutjanus apodus*, dog snapper, *Lutjanus jocu*, and yellowtail snapper, *Ocyurus chrysurus* (data not shown). It has also reflected in catch and release data of *E. guttatus* at several sites within the LPCNR that has consistently showed a declining trend in mean abundance and size (López and Sabat Unpub. data). Moreover, fishery target species standing stock biomass at CRO increased from 7.1 g/m$^2$ at CRO in 1999 to 60.7 g/m$^2$ in 2002, a magnitude of 755%. These values were comparable to those reported by Polunin and Roberts (1993) but low to those reported by Roberts and Polunin (1994) from Hol-Chan. However, standing stock biomass at CRO declined to 34.5 g/m$^2$ in 2004, a magnitude decline of 43% within only two years. Meanwhile, standing stock biomass of fishery target species at PSO control site increased from 9.8 g/m$^2$ in 1999 to 36.8 g/m$^2$ in 2004, a magnitude of 276%. Recreational boats rarely frequent PSO, suggesting that recreational spearfishing pressure from private yacht operations is lower at this site in comparison to CRO. Rapid recovery at the control site outside the LPCNR may also suggest a possible combined effect of high recruitment and a possible fish spillover effect. If suitable habitats exist, mobile species will search for resources outside of the MPAs, leading to export of biomass to areas which are fished (Sánchez-Lizaso 2000).

On the other hand, PME has also shown a dramatic increase in fishing pressure immediately after the LPCNR designation due to a fishing effort displacement effect. Fishing has been mostly by hook and line from the shore and boat anglers, and by recreational spearfishers. But this site has also suffered severe environmental degradation resulting from sediment- and nutrient-loaded runoff from the urban area of Culebra. Nemeth and Nowlis (2001) showed that sediment-loaded runoff lead to coral decline in St. Thomas. Culebra Island has experienced extensive development during the last few years (Hernández-Delgado 2004a,b), exposing large areas of land to erosion without the required controls. Hernandez-Delgado and Sabat (in press) documented a 46% decline in coral cover, a 683% increase in macroalgal cover and a 279% increase in cyanobacterial cover within 1997 and 2003 at LPCNR. ANOSIM tests showed this trend to be highly significant through time and among depth zones. This phase shift was associated to the long-term cumulative effects of frequent highly sediment- and nutrient-loaded runoff pulses and coral disease outbreaks. Subsequently, Hernández-Delgado (unpub.data) has documented a close relationship between runoff pulses and disease outbreaks and mortality events in Acroporid corals. As a result, dead coral surfaces were rapidly occupied by algae. Thus, recent high coral mortality has resulted in a significant phase shift in benthic community structure from coral to algal dominance that could explain in part the rapid increase in non-denuder herbivore biomass (Pomacentridae). Most pomacentrids are highly territorial and can interfere with significant reef processes such as tissue regeneration in corals (Hernández-Delgado 2000) and bioerosion rates (Risk and Sammarco 1982). Similarly, Jones et al. (2004) documented a major decline in fish communities in Papua New Guinea following coral decline. Therefore, it is suggested that the observed phase shift in fish community structure at PME has been the combined result of fishing pressure and environmental degradation. This further suggests that management failures in combination with coral decline have con-

**Management Failures**

There has been an increasing concern for the ecological effects of non-compliance associated to management failures in MPAs (Kritzer 2004). Caribbean-wide surveys have shown that MPA effectiveness and compliance levels are directly related to the capacity of managing institutions (Appeldoorn and Lindeman 2003). Non-compliance usually results in illegal harvesting activities that can dissipate the potential benefits of management regulations (Gigliotti and Taylor 1990). Illegal fishing activities within the boundary and core zones of LPCNR have been the direct result of management failures by the PR Department of Natural and Environmental Resources (PRDNER), as well as by other co-enforcing agencies.

Several aspects regarding management failures can be mentioned:

i) There was only a part-time management officer at LPCNR for the period of 2001 to 2003, and there has been none in Culebra since then;
ii) Boundary buoys were placed in 2002 but vandalized or dislodged by strong currents in 2003 and not placed back for over a year;
iii) There has never been continuous patrolling and law enforcement;
iv) Sporadic patrolling has been conducted by local fishermen that have no legal authority;
v) There is no management plan in place;
vi) There is no educational and outreach program in place;
vii) There is no coordination among enforcing agencies or between agencies and stakeholders;
viii) Scientific information has not been translated into management action; and
ix) Fishing pressure has shifted from artisanal to recreational and not much attention has been paid to recreational fishing effects.

Also, we identified combined natural resource management failures by public and private sectors outside the boundaries of LPCNR but that are negatively affecting the reserve. These included:

i) Major land clearing activities on steep slopes;
ii) Lack of compliance with erosion and sedimentation control regulations;
iii) Lack of enforcement of these regulations by Municipal and State government agencies;
iv) Illegal beach land clearing;
v) Continuous illegal pumping of sediment-loaded waters from public project sites to coastal waters;
vi) Construction and/or expansion of private and public dirt roads on steep slopes without any erosion control measure; and
vii) Illegal raw sewage discharges to coastal waters.

Environmental degradation outside LPCNR boundaries has been identified as a major concern for the conservation of coral reef and seagrass benthic communities within LPCNR (Hernández-Delgado, 2004a,b). This study showed that fish communities at the PME boundary zone have been largely affected.

## CONCLUSIONS

There was a rapid recovery of fish communities three years following the designation of the LPCNR. Control fished reefs located outside the reserve boundaries also showed a rapid recovery in fish communities. However, management failures have resulted in poor compliance and in a recent increase in illegal fishing activities. This has resulted in a fish decline trend within core areas of LPCNR during the period of 2002 to 2004. Control sites showed the opposite trend. Also, fish communities at the reserve boundary site collapsed as a combined result of increased fishing pressure by fishers displacement after LPCNR designation and by chronic environmental degradation. In spite of that, LPCNR has been a successful tool restoring overexploited fish communities in Culebra Island. This suggests that even with very limited efforts no-take MPAs can be successful in restoring severely depleted fishery resources.

MPA effectiveness can be limited by low institutional and community capacity for management (Jameson et al. 2002), leading to management failure. Management failure can result in declining community support and lack of compliance with management measures, including fishing prohibition (Coleman et al. 2004). User surveys have also shown that the lack of an educational and outreach program, combined with the lack of boundary buoys demarcation and the absence of enforcing personnel, prevented most off-island recreational navigators to know the exact location of the LPCNR and the existing fishing prohibition (Hernández-Delgado et al. Unpub. data). Management failures can also have profound effects on the success of a no-take MPA in achieving its goals and objectives (Coleman, et al. 2004). Those effects could be even more negative on the perception of the public. Furthermore, environmental degradation can magnify those effects. Therefore, there is a need to account for these variables through the development of a management plan that should involve local stakeholders, the academia, NGOs, etc.

Specific management recommendations include:

i) Promote stronger coordination and collaboration among Federal, State, Municipal, academic, non-governmental agencies and community stakeholders;
ii) Increase local public education and outreach;
iii) Enforce existing LPCNR no fishing regulations and laws governing resource extraction;
iv) Reduce the effects of fishing on the boundaries of the LPCNR;
v) Build research and analytical capacity in the PRDNER;
vi) Promote management-oriented research in the PRDNER;
vii) Integrate a water quality monitoring component to existing coral reef epibenthic and fish communities monitoring programs;
viii) Develop an ecosystem-based model for the design of a long-term ecological monitoring network;
ix) Develop a management plan;
x) Integrate stakeholders into a participatory management model;
xi) Recognize and incorporate knowledge of the community;
xii) Reduce or eliminate land-derived pollution from coastal development

xiii) Enforce existing regulations and laws governing erosion and sedimentation controls; and
xiv) Improve and maintain coastal water quality.

Management failures within and outside LPCNR need to be addressed and eliminated in order to keep community support, and to restore trust and compliance.

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# *Oculina* Banks Restoration Project: Description and Preliminary Assessment

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ABSTRACT

Deep-water coral reefs are impacted by a number of anthropogenic activities, primarily destructive fishing practices. In some locations, the coral framework has been reduced to such an extent that it no longer fulfills its original ecological function. Large-scale restoration of damaged reefs is neither logistically nor economically feasible, but habitat restoration may be viable in small ecologically significant areas. The *Oculina* Banks off the south eastern coast of Florida have been so severely damaged over the past 20 years that much of the coral has been reduced to rubble with no infrastructure. The framework coral, *Oculina varicosa* is a broadcast spawning species, which annually produces many dispersive larvae, however, there is no evidence of re-colonization of denuded areas. It is possible that the rubble does not provide suitable substrate for planular settlement or that repeated impact from illegal trawling destroys any newly established colonies. Between 1996 and 2001, restoration modules were deployed in the Experimental *Oculina* Research Reserve (EORR) a small (315 $km^2$) area of the *Oculina* Banks. In total, 281 large and 450 small modules were deployed (some with coral transplants) in various configurations. Coral transplants have survived and limited recruitment of new colonies had been observed in the older modules. It takes several years before recruits reach sufficient size that they can be positively identified with ROV and submersible cameras. Commercially important predaceous fish species have been observed in association with the large modules and small fish have taken up residence inside them. The restoration project will be assessed whenever possible for coral transplant survival and growth, coral recruitment, and habitat function for important fish species.

KEY WORDS: Coral, restoration, deepwater

# *Oculina* Deposita Proyecto de la Restauración: Descripción y Gravamen Preliminar

Los filones coralinos profundos son afectados por un número de actividades anthropogenic; sobre todo prácticas destructivas de la pesca. En algunas localizaciones, se ha reducido el marco coralino hasta tal punto que satisface no más de largo su función ecológica original. La restauración en grande de filones dañados es ni logísticamente ni económicamente factible, pero la restauración del habitat puede ser viable en áreas ecológico significativas pequeñas. El Oculina ejerce la actividad bancaria de la costa del este del sur de la Florida se ha dañado tan seriamente sobre los últimos 20 años que mucho del coral se ha reducido al escombro sin la infraestructura. El coral del marco, varicosa de Oculina es una especie de freza de la difusión, que produce anualmente muchas larvas dispersivas, sin embargo, no hay evidencia de la recolonizacio'n de áreas denuded. Es posible que el escombro no proporciona el substrato conveniente para el establecimiento planular o que el impacto repetido de pescar con red barredera ilegal destruye a cualquier colonia nuevamente establecida. Entre 1996 y 2001, los módulos de la restauración fueron desplegados en la reserva experimental de la investigación de Oculina (EORR) un área pequeña (315 $km^2$) de los bancos de Oculina. Un total de 260 módulos grandes y 450 pequeños fue desplegado (algunos con los trasplantes coralinos) en varias configuraciones. Los trasplantes coralinos han sobrevivido y el reclutamiento limitado de nuevas colonias había sido observado en los módulos más viejos. Toma varios años antes tamaño del alcance de los reclutas de suficiente que pueden ser identificados positivamente con ROV y las cámaras fotográficas sumergibles. Las especies predaceous comercialmente importantes de los pescados se han observado en la asociación con los módulos grandes y los pescados pequeños han tomado la residencia dentro de ellos. El proyecto de la restauración será determinado siempre que sea posible para la supervivencia y el crecimiento coralino del trasplante, el reclutamiento coralino y habitat funcione para la especie importante de los pescados.

PALABRAS CLAVES: *Oculina*, Deposita Proyecto de la Restauración

## INTRODUCTION

The Ivory Tree Coral, *Oculina varicosa* (Lesueur, 1820), occurs at depths between 5 m and 100 m on the Atlantic coast of Florida. It is facultatively zooxanthellate and can tolerate a wide range of environmental conditions including low temperature, high turbidity and low light levels. The shallow populations have been reported as far north as South Carolina, and as far south as the Florida Keys and the Caribbean, however the taxonomy of the Oculinidae of the Western Atlantic is somewhat confused (Dr. S. Cairns Pers. comm.), so the distribution descriptions may be incorrect.

In deep water, *O. varicosa* forms massive bushes of fragile colonies, creating continuous tracts of reef on the slopes and tops of pinnacles, similar in structure to deep-water *Lophelia* reefs. The deep *Oculina* bioherms are the only known monospecific coral banks that occur on the North American continental shelf at less than 200 m depth. Similar bioherms of *Lophelia pertusa* and *Enallopsammia profunda* exist in deeper waters at the base of the Florida Hatteras Slope and the Blake Plateau (Reed 2000). All of these deep-water 'reef-building' corals have a similar growth pattern, which is unlike that of typical shallow water species. As the colony increases in diameter, the tangled outer branches block water flow to the core of the colony, and the inner branches of the colony die. Bioerosional processes weaken the dead coral branches, which eventually break and the colony falls apart. The outer living branches continue to grow, and new recruits may colonize the exposed dead core. As this process continues over thousands of years, these mounds and pinnacles can reach tens of meters in height, with the live coral forming a cover over the unconsolidated dead coral debris below.

The deep shelf-edge *Oculina* reefs form natural spawning grounds for commercially important populations of gag (*Mycteroperca microlepis*) and scamp (*M. phenax*) grouper. They also serve as nursery grounds for juvenile snowy grouper (*Epinephelus niveatus*), and feeding grounds for these and many other commercial fish species including black sea bass (*Centropristis striata*), red grouper (*E. morio*), speckled hind (*E. drummondhayi*), Warsaw grouper (*E. nigritus*), amberjack (*Seriola* sp.), red porgy (*Pagrus pagrus*) and red snapper (*Lutjanus campechanus*) (Gilmore and Jones 1992). Apart from the valuable fisheries species, the deep-water reefs also support very rich communities of invertebrates; faunal diversity on the *Oculina* banks is equivalent to that of many shallow tropical reefs. Over 20,000 individual invertebrates were found living among branches of 42 small *Oculina* colonies, yielding more than 350 different species (Reed and Hoskin 1987, Reed and Mikkelson 1987, Reed 2000), many of which are important food sources for animals at higher trophic levels. These unique deep-water *Oculina* reefs exist only on the shelf edge off eastern Florida, and stretch over 90 nautical miles (167km) from Fort Pierce to Daytona (Avent et. al 1977, Reed 1980).

Three different fisheries have operated in the *Oculina* Banks area over the past three decades: a trawl fishery for rock shrimp (*Sicyonia brevirostris*), a trawl and dredge fishery for calico scallops (*Argopecten gibbus*) and a hook and line fishery for reef fish (Koenig et al. 2000). Both the rock shrimp and calico scallop fisheries began in the early 1970s (Allen and Costello 1972, Kennedy et al. 1977, Oleson 1982). The scallop fishery collapsed in the late 1980s (Stimpson 1989) and the reef-fish fishery increased in the early 1980s, especially at Jeff's Reef.

In 1984, the South Atlantic Fishery Management Council designated 315 km$^2$ of the deep *O. varicosa* banks as a Habitat Area of Particular Concern (HAPC), because of their importance to the life histories of many commercially valuable species. This area was closed to trawling, dredging, long-lining, and trapping (Federal Register 49 FR 29607). In 1994, the status of the same area was changed to the Experimental *Oculina* Research Reserve (EORR), which closed the area to all bottom fishing for a period of 10 years, and in 1995 the use of anchors and grapples was prohibited in the reserve. The EORR and a designated control (fished) area were mapped in 1995 with SIS side scan sonar, and visually surveyed using an ROV and the Clelia submersible (Harbor Branch Oceanographic Institution). Analysis of the side scan information showed that terrain that supported *O. varicosa* thickets (high-relief, high-backscatter) comprised just 3% of the EORR, although small *O. varicosa* colonies were also found in surrounding low-relief high-backscatter areas (Koenig et al. 2000, Scanlon 1999). Much of the *Oculina* habitat had been severely degraded or destroyed since the initial surveys in the 1980s, although the Jeff's Reef area was still intact and healthy. The coral structure on parts of Chapman's Reef and Steeple had been damaged, and Sebastian Pinnacles and Twin Peaks were covered with small pieces of coral rubble. Fish communities had also changed from the diverse assemblages of economically important species observed in the early surveys. In 1995, the abundance of these species had declined (Koenig et al. 2000) and the dominant species had shifted from grouper species, particularly scamp (*Mycteroperca phenax*), to small non-fishery species, such as red barbier (*Hemanthius vivanus*) and roughtongue bass (*Holanthius martinicensis*). Spawning aggregations of gag and scamp observed on Jeff's and Chapman's Reef either had disappeared completely or been reduced to a few small individuals.

By 1998, efforts were underway to amend the *Oculina* HAPC even further. SAFMC was mandated by a 1996 amendment to the Magnuson-Stevens Fishery Management Act to describe and identify essential fish habitat (EFH), including adverse impacts on such habitat, in order to minimize damage to EFH resulting from fishing activities. In addition, the agency was required to identify other actions that encourage the conservation and enhancement of EFH (Magnuson-Stevens Act, 1996). On July 14th, 2000, the OHAPC regulations were expanded to include the known extent of the *Oculina* Banks (Federal Register 50 CFR 622). The rule retained the western and southern boundaries of the existing OHAPC, moved the northern boundary 68.5km to 28°30' north latitude, and moved the eastern boundary to the 183 m contour (Figure 1). Furthermore, two satellite HAPCs (10 km$^2$) were established: Area 1 was bounded by 28°30'N, 28°29'N, 80°00'W and 80°03'W and Area 2 was bounded by 28°17'N, 28°16'N, 80°00'W and 80°03'W Restrictions in the expanded reserve prohibit:

i) Use of a bottom long-lines, bottom trawls, dredges, pots, or traps;
ii) Use of anchors, anchor and chain, or grapple and chain; and
iii) Fishing for rock shrimp or possession of rock shrimp in or from the area.

In 2001, the *Oculina* Banks were re-visited as part of NOAA's Office of Ocean Exploration Islands in the Stream cruise, using the Clelia submersible and Phantom S4 ROV for habitat surveys. Analysis of video transects taken along ridge features within the EORR (7,645 m) indicated that most of the habitat (90%) was comprised of unconsolidated rubble, with small areas (4%) of scattered coral colonies and intact (6%) coral habitat. Jeff's Reef and the western ridge of Chapman's Reef are the only remaining areas of live thicket habitat and together they cover approximately eight hectares. Video transects (2014 m) of ridges taken outside the EORR showed only unconsolidated rubble with occasional small colonies of live *O. varicosa*. Sparsely distributed small colonies of *O. varicosa* were also observed on low relief rocky substrate.

Some of these colonies were dead but standing. Historical coral sites (Reed 1980) were re-visited during the 2001 cruise, although there was uncertainty about some of the exact site locations, none of areas surveyed had intact coral habitat and most had been reduced to rubble. The exact causes of these extensive areas dead coral are undetermined. Impact from commercial and sport fishing is evident. Submersible and ROV surveys have shown evidence of extensive damage apparently due to bottom trawls, and because the *Oculina* habitat is at the edge of the Florida Current, bottom hook and line fishing requires heavy weights that may also damage the coral beds. Fishing lines have often been found among the coral and a large ball of long-line was observed on the reefs in 2001. Damage to the *Oculina* habitat has reduced the highly complex structure of standing coral heads to low relief, low complexity rubble substrate which may not be suitable for larval settlement. Very little natural recovery has been observed in the damaged areas. This may be due to lack of successful larval recruitment or by repeated impact from trawling.

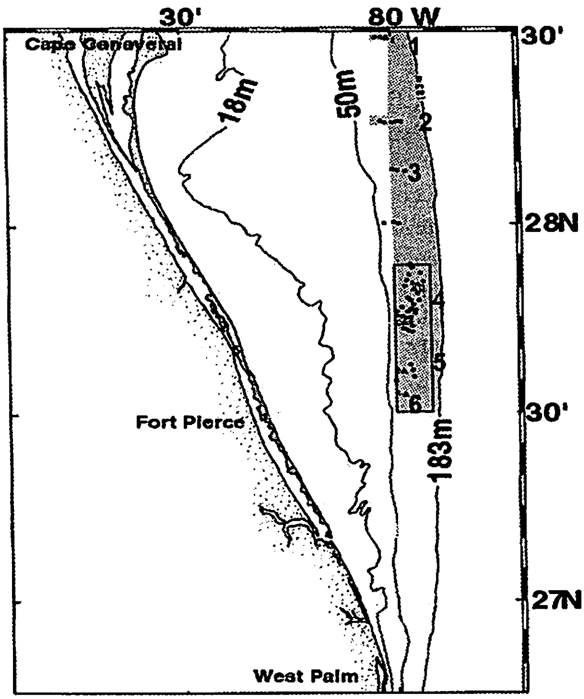


**Figure 1.** Chart of the Oculina Banks OHAPC showing dive areas visited in 2001: 1. Cape Canaveral, 2. Cocoa Beach, 3. Eau Gallie, 4. Sebastian Pinnacles, 5. Chapman's Reef, 6. Jeff's Reef. Dots are historic dives sites visited in the 1970s and 80s. The shaded area defines the expanded OHAPC boundary and the smaller inset box is the EORR and the original (1984) OHAPC boundary.

Despite regulations that have been in place for two decades, there is substantial evidence that illegal trawling still occurs in the OHAPC (Koenig 1997, Authors' Pers. obs.). In 2002, the SFMC recognized a need for increased protection for the OHPC and passed the rock shrimp FMP amendment 5 (Federal Register: 50 CFR 622.9) in January 2003. This requires the use of an approved vessel monitoring system (VMS) by rock shrimp vessels and requires the operator to have an operator permit, effective July 2003. The Florida Fish and Wildlife Conservation Commission (FFWCC) have also acquired a 20 m vessel, which now regularly patrols the *Oculina* Banks for illegal fishing activity.

**Restoration**

Despite evidence that trawling is at least partially responsible for the habitat degradation, we know almost nothing about natural senescence or mortality of *O. varicosa* colonies. Similar areas of dead coral have also been observed in deepwater *Lophelia pertusa* reefs (540 - 870 m) off the coast of Florida (Reed 2000), where there are no records of a trawl fishery. There are also areas of standing dead *O. varicosa* colonies, which have obviously not been impacted directly with fishing gear. Natural phenomenon such as protracted upwelling, benthic storms, or disease may be responsible for this mortality, but the cause is currently unknown. Dead colonies apparently fulfill a similar function to the live coral because they provide structure for invertebrates and fish, but when the coral framework is reduced to unconsolidated rubble, abundance and diversity of associated fauna declines and grouper spawning aggregations are lost (Koenig et al. 2000).

Artificial structures (shipwrecks) off St. Augustine and Jacksonville to in the northern region of the OHAPC are covered with *Oculina* colonies (Koenig Pers. obs.), however very few new colonies were observed at damaged sites during habitat surveys. This observation prompted a restoration effort with the objective of supplying appropriate settlement substrate for coral larvae and habitat for fish species. A pilot project was initiated in 1996 by Dr. Koenig (NMFS/FSU), who deployed eight concrete structures with live coral transplants attached in the EORR. The transplants were still alive the following year, so the project was expanded and 48 more blocks were deployed in 1997 and 1998. A larger scale restoration effort was undertaken in 2000 and 2001. This paper describes the projects and presents preliminary results.

**Objectives**

i) To rehabilitate fish habitat in destroyed areas by simulating *O. varicosa* coral heads with artificial reef structures seeded with *Oculina* fragments,
ii) To restore coral habitat destroyed by mobile fishing gear through transplantation of *O. varicosa* fragments to denuded areas, and
iii) To evaluate the efficacy of different restoration methods within the OHAPC.

METHODS

**Restoration Modules**

Between 1996 and 1998, 56 restoration modules or 'reefblocks' (81.3cm x 81.3cm x 71.1cm) were constructed from 18 concrete cinder blocks and deployed in groups at various locations within the in the EORR.

The first large scale restoration effort was initiated in 2000 when experimental coral transplant structures were deployed in Sebastian Pinnacles, a badly degraded region of the EORR. Two types of restoration units were utilized: reefballs and reefdisks. Reefballs were perforated hemispherical concrete structures (www.reefball.org) approximately 1 m in diameter, 0.7 m high and weighing 180 kg (Figure 2). Reefballs were chosen to simulate *O. varicosa* colonies and provide fish with benthic structure similar to natural coral heads. A small colony of live coral was attached to each reefball with the anticipation that the coral fragments would eventually overgrow the structure and form the foundation for coral recolonization. Corals were attached to the reef balls with cable ties and a quick-setting cement mixture approximately five minutes prior to deployment and were covered with seawater-saturated paper towels to avoid dehydration on deck. The reefballs were deployed in an experimental design to investigate the effect of cluster size and internal complexity on association of fish populations.

**Figure 2.** Reefballs with attached coral transplants and additional internal complexity created by vexar mesh. Floats help slow descent rate and can be used to locate reefballs for surveys

In addition to the reefballs, experiments using much smaller and simpler 'reefdisks' (Figure 3) were deployed in the same area of the EORR. Reefdisks were concrete paving disks (0.3 m diameter) with a vertical PVC posts (0.4 m). A coral fragment ('small' or 'large') was attached to the top of each post using cable ties. This experiment tested the effect of fragment size on transplant survival and growth, since smaller fragments require less coral and therefore lower impact on donor sites. These disk clusters also represented coral 'nurseries' where small pieces of adult colony are used to seed recovery of the damaged area. Raising the fragments off the substrate ensured that they were not buried in sediment before they could become established colonies.

Coral fragments were collected on scuba by members of the Association of Underwater Explorers (AUE divers) from an unidentified wreck at 90 m and from the 'Cites Service Empire' wreck at 64 m. Corals were maintained in chilled re-circulating aquaria until needed.

**Figure 3.** Reefdisks with 'large' coral fragments attached and ready for deployment

**Module Deployment**

In 1996, eight reefblocks were deployed during this pilot study, four at Jeff's Reef (intact coral habitat) and four at Sebastian Pinnacles (coral rubble). Live *O. varicosa* was attached PVC posts at each of the upper corners of the block.

In 1997, an additional 24 reefblocks were placed at four different locations. Jeff's Reef (27°32.55'N, 79°58.74'W) and Chapman's Reef (27°36.51'N, 79°59.07'W) were in intact coral habitat, whereas Sebastian Pinnacles (27°50.02'N, 79°57.70'W) and Steeple Pinnacle (27°43.57'N, 79°58.72'W) consisted of dead coral and coral rubble. The blocks were deployed in two clusters of three at each location, one cluster with live *O. varicosa* transplants and the other without.

In 1998, 24 reefblocks were deployed in the same locations and configuration as was used in 1997. The blocks had an additional piece of PVC on the float line so that the blocks could be identified by year of deployment during future survey cruises.

In 2000, a stern mounted hydraulic winch and a quick release hook was used to deploy the reefballs, which were also fitted with drag boards attached with biodegradable line. The boards ensured that released reefballs remained in an upright position during decent and settlement on the bottom. In total, 105 reefballs were deployed in clusters of 5, 10, and 20 at each of three locations in the Sebastian Pinnacles area of the EORR. This experiment was designed to test the effect of different reefball cluster sizes on rehabilitation of coral and fish habitat. In addition to the reefballs, 450 small reefdisks were also deployed in three replicate groups of 25 reefdisks for each of two treatments (large and small fragments) in the same three damaged areas of Sebastian Pinnacles.

In 2001, a total of 120 reefballs were deployed in six clusters of 20 on the tops of pinnacle ridges at Sebastian Pinnacles. All reefballs had coral transplants attached as before and in addition, half of the reefballs contained internal complex structure created by vexar mesh to try to mimic the internal microhabitat of coral colonies and attract some of the smaller fish such as red barbier and roughtongue bass that are common in coral thickets. Replicate clusters of reefdisks were also deployed, as described for 2000.

## RESULTS

### Reefblocks

In 1997, an ROV was used to locate and survey three of the reefblocks at each site. In each case, the coral transplants were alive and appeared to have grown. There was also evidence of growth on the surface of the reefblocks but this could not be positively identified as coral. Fishing lines were wrapped around all of the modules deployed in 1996, strongly suggesting that bottom fishing intensity was high within the reserve. Additionally, a 'downplaner' (used by trolling fishermen to get bait closer to the bottom) was hanging on the side of one of the *Oculina* transplant modules, indicating that fishermen were targeting bottom-associated species (grouper and snapper) rather than pelagic species in the closed area. The continuation of bottom fishing in the reserve will clearly affect conclusions concerning the use of Marine Fisheries Reserves as management tools.

In 1999, a reefblocks were surveyed at Jeff's reef using the Clelia submersible. Coral was alive and growing but some transplants were missing. New coral recruits were observed on a reefblock on the north side of Jeff's reef (27°32.6020'N, 79°58.7521'W), and a snowy grouper was seen next to the structure. In 2000, ROV surveys of the reefballs showed that, in addition to providing support for the coral transplants and larval settlement substrate, these structures provided artificial fish habitat. Many fish species were found around these structures, and a scamp spawning aggregation appeared to be associated with one of the clusters in Sebastian Pinnacles. Thus, the fish population was locally enhanced when structural complexity was increased through the deployment of the reefblocks. In 2001, insufficient numbers of reefblocks were observed to draw any statistical conclusions regarding transplant survival, coral recruitment or fish assemblages associated with these structures, but in 2003, several coral colonies were observed on a reefblock deployed in 1998 using a Phantom ROV. The Largest colony was 810 cm in diameter and ~ 3 years old, assuming a growth rate of 1.6 - 2 cm/yr (Reed 1981). More than one distinct size class was observed, indicating that larval recruitment may be episodic.

**Reefballs and Reefdisks**

Reefballs and reefdisks deployed in 2000 were observed in 2001 using the Clelia submersible. Reef fish abundance and species composition around reefballs was much greater than over the surrounding dead habitat (Koenig et al. In review). These species included groupers, snappers and amberjack as well as the smaller fish species that are commonly found associated with healthy coral (Table 1). Observation of economically important species associated with the reefballs was particularly encouraging. The data show very little difference between number of species and total abundance of fish associated with the clusters of 10 and 20 but did show much fewer fish associated with the smallest cluster size. Distribution of economically important fish associated with the reefballs show similar trends (Figure 4). Courtship-type behavior was observed between scamp grouper associated with some of the reefball clusters, but spawning-season surveys are required to determine the extent of their function as aggregation sites. Male gag grouper were also observed in the vicinity of the reefballs. Submersible surveys of the reefballs and reefdisks showed that two of the reefdisk clusters were missing and only broken pieces of PVC remained. The PVC was broken rather than detached from the concrete bases indicating strong mechanical impact. In the vicinity of the missing reefdisk clusters were apparent trawl tracks in the rubble. Of the 40 reefdisks surveyed that still had transplants, 50 - 60% was alive, but fragment growth could not be scored with the available camera resolution. Most of the reefballs (75%) deployed in 2000 still had attached coral fragments and ~25% of these were alive. A preliminary conclusion is that coral fragments attached to the reef balls and disks can survive, but very small fragments (< a few cm) suffered higher mortality than larger transplants.

**Table 1.** Reef fish associated with three replicate clusters (1500 m$^2$) of reefballs (* economically important species)

| Common name | Species name | 5 reefballs/cluster | | 10 reefballs/cluster | | 20 reefballs/cluster | |
|---|---|---|---|---|---|---|---|
| | | N | % total | N | % total | N | % total |
| Greater amberjack* | *Seriola dumerili* | | | 109 | 37.72 | 100 | 41.32 |
| Roughtongue bass | *Holanthias martinicensis* | 7 | 41.18 | 120 | 41.52 | 53 | 21.9 |
| Red barbier | *Hemanthias vivanus* | | | 1 | 0.35 | 25 | 10.33 |
| Almaco jack* | *Seriola rivoliana* | | | 20 | 6.92 | 20 | 8.26 |
| Scamp* | *Mycteroperca phenax* | 3 | 17.65 | 15 | 5.19 | 14 | 5.79 |
| Wrasse | *Labridae* | | | 1 | 0.35 | 10 | 4.13 |
| Blue angelfish | *Holocanthus bermudensis* | | | 3 | 1.04 | 5 | 2.07 |
| Reef butterflyfish | *Chaetodon sedentarius* | | | 4 | 1.38 | 3 | 1.24 |
| Red snapper* | *Lutjanus campehanus* | | | 6 | 2.08 | 2 | 0.83 |
| Snowy grouper* | *Epinephelus niveatus* | 2 | 11.76 | 1 | 0.35 | 1 | 0.41 |
| Speckled hind* | *E. drummondhayi* | | | | | 3 | 1.24 |
| Tattler | *Serranus pheobe* | 1 | 5.88 | | | 2 | 0.83 |
| Red porgy* | *Pagrus pagrus* | 2 | 11.76 | | | 2 | 0.83 |
| Puffer | *Canthigaster rostrata* | | | | | 1 | 0.41 |
| Queen angelfish | *Holocanthus ciliaris* | | | | | 1 | 0.41 |
| Bank butterflyfish | *Chaetodon aya* | 1 | 5.88 | 2 | 0.69 | | |
| Short bigeye | *Pristigenys alta* | | | 2 | 0.69 | | |
| Cardinalfish | *Apogon pseudomaculatus* | | | 2 | 0.69 | | |
| Spiny Soldierfish | *Corniger spinosus* | | | 2 | 0.69 | | |
| Sharpnose puffer | *Canthigaster rostrata* | | | 1 | 0.35 | | |
| Bank seabass* | *Centropristis ocyurus* | 1 | 5.88 | | | | |
| Yellowtail reef fish | *Chromis enchrysurus* | | | | | | |

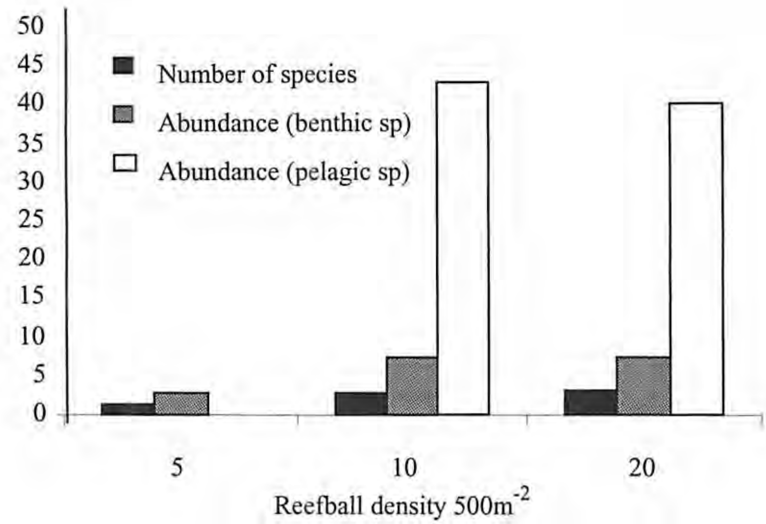


**Figure 4**. Economically important fish associated with reefball clusters of 5, 10 and 20 deployed on coral rubble at Sebastian Pinnacles in the EORR

DISCUSSION

Although reef restoration projects are common in shallow water environments, this attempt to restore a deepwater coral ecosystem is the first of its kind and preliminary results are promising. Coral transplants show moderately good survival rates, which may be increased with improved handling techniques, and several new coral colonies have been observed on the older structures. The reefballs were surveyed approximately one year after deployment, which was too soon to assess coral recruitment as colonies would have been too small to identify using submersible or ROV cameras. Recruitment of coral larvae may be episodic and variable since different distinct colony size classes were seen on one of the early reefblocks. If this is the case, it may take several years before recruitment success can be assessed. The number of fish species and total fish abundance were enhanced by the deployment of reefballs on the badly damaged Sebastian Pinnacles site. Hopefully, these structures will provide interim habitat for fisheries species until the *Oculina* habitat can recover. The restoration structures will continue to be monitored as funding allows for coral recruitment and growth and for development of associated fish communities.

Surveillance and enforcement of regulations in remote areas is difficult and expensive. However, surveillance of fishing activity, particularly at night when shrimp trawlers operate, has been minimal at best. A list of trawling violations in the OHAPC were obtained from the Office of General Council for Enforcement and Litigation, NOAA, NMFS, SER*O*. Since 1984, arrests for poaching occurred on 21 July 1993, 2 October 1994, 19 November 1994, and

19 January 2000, but levels of illegal activity are considerably higher than the arrest records indicate. The trawler caught in 2000 was one of three working in the OHAPC at the time and was captured after a half-hour chase (J. Reed, personal communication). The typical penalty to trawlers caught poaching in the OHAPC is confiscation of their catch, which is obviously insufficient to deter them

The recently initiated VMS systems allow full-time monitoring of commercial vessels therefore the level of surveillance in the OHAPC has recently been increased but compliance to regulations by the user groups is vital for effective resource protection. Although large-scale commercial fisheries, such as trawlers, have direct and devastating impacts on the coral habitat, small repetitive impacts from uninformed recreational fishermen may also have long-term consequences to the health of these reefs. Acceptance of the OHAPC regulations by the different user groups may be motivated through education of the public and fishing community on the value and fragility of the coral habitat.

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# Preliminary Characterization of a Mid-shelf Bank in the Northwestern Gulf of Mexico as Essential Habitat of Reef Fishes

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ABSTRACT

The continental shelf of the northwestern Gulf of Mexico has many, widely scattered, high-relief, bathymetric features (or banks) that represent important naturally occurring aggregation areas for exploited fish species (especially snappers and groupers). While a few of these banks are protected and monitored as national marine sanctuaries (e.g., Flower Garden Banks), most are unprotected and poorly studied. Here, we present initial results of a study of one such bank, Sonnier Bank, where we are developing survey approaches with sidescan sonar, seismic devices, SCUBA, ROV (remotely operated vehicle), and fish traps. Sonnier Bank appears as a ring of topographic peaks, covering approximately 12.6 $km^2$. At the shallowest depths (< 30 m) we have observed a diverse community of unexploited reef fishes associated with millepora coral and sponges. In this shallower environment, rock hind (*Epinephelus adscensionis*) were the dominant serranid. The deeper (45 to 60 m) bathymetric features of Sonnier Bank had the greatest numbers of exploited reef fish species. Sidescan and ROV surveys identified these areas as more gradually sloping with large pieces of rubble (1 to 4 m in diameter). Notable aggregations of vermilion snapper (*Rhomboplites aurorubens*), red snapper (*Lutjanus campechanus*), and gray snapper (*L. griseus*) were present, and yellowmouth grouper (*Mycteroperca interstitialis*) and graysby (*Cephalopholis cruentata*) were also observed. Our ongoing efforts include the calibration of a laser array for measuring distances with ROV video/ images, and comparisons of fish counts and measurements between divers and the ROV. The development of approaches with ROV may be an effective way to quantify and monitor commercially important snappers and groupers in these deeper, structurally-complex habitats.

KEY WORDS: Visual survey, ROV, Sonnier Bank

# Caracterización Preliminar como Habitat Esencial de Peces de Arrecife en un Banco Continental de Profundidad Intermedia en el Noroeste del Golfo de México

La plataforma continental en el noroeste del Golfo de México poseé muchas estructuras de alto relieve batimétrico (bancos) muy dispersas que representan importantes sitios de congregación de muchas especies comercialmente importantes (particularmente huachinangos y meros). Mientras que un número limitado de estos bancos son protegidos y monitoreados como santuarios marinos nacionales (e.g., Flower Garden Banks), la mayoría no reciben protección y son poco estudiados. Aquí presentamos los resultados iniciales del estudio de uno de estos bancos, el Banco Sonnier, en el cual estamos desarrollando técnicas de monitoreo que incluyen el sonar lateral, aparatos sísmicos, buceo autónomo, sumergible de control remoto (ROV), y trampas de peces. El Banco Sonnier asemeja un anillo de picos y ocupa aproximadamente 12.6 km$^2$. En su profundidad mínima (< 30 m) hemos observado una diversa comunidad de peces de arrecife no explotados asociados con corales *millepora* y esponjas. En esta profundidad menor, el serranido mas abundante es el *Epinephelus adscensionis*. En el Banco Sonnier, el mayor número de especies comercialmente importantes están asociadas con estructuras batimétricas de mayor profundidad (45 a 60 m). El sonar lateral y el monitoreo con ROV identifica estas areas como zonas con pendientes mas pronunciadas en el que se encuentran grandes estructuras (1 a 4 m de diámetro). Ahí se congregan gran numero de *Rhomboplites aurorubens*, *Lutjanus campechanus*, y *L. griseus*, así como *Mycteroperca interstitialis* y *Cephalopholis cruentata*. Actualmente estamos calibrando un grupo de lasers con el objetivo de utilizar las imagenes obtenidas con el ROV para medir distancias, asi como realizando comparaciones entre los censos de peces obtenidos por varios buzos y mediante el ROV. El desarrollo de tecnologías associadas con el ROV puede eventualmente convertirse en una forma efectiva para censar y monitorear especies comercialmente importantes de huachinangos y meros en estas aguas mas profundas y estructuralmente complejas.

PALABRAS CLAVES: Plataforma continental, habitat esencial de peces de arrecife, Golfo de México

## INTRODUCTION

The continental shelf of the northwestern Gulf of Mexico is dominated by low-relief, soft-sediment environments that are punctuated by small, high-relief, hard-substrate areas. These hard bottom features are often associated with salt diapers (or salt-domes) and are called banks (Rezak et al. 1985). Banks associated with the mid-shelf and shelf edge support diverse communities (Rezak et al. 1985, Dennis and Bright 1988) and are important naturally occurring aggregation areas for exploited fish populations. With the exception of the Flower Garden Banks National Marine Sanctuary, most of the banks in the northwestern Gulf of Mexico are unmonitored, and their importance as essential fish habitat is unquantified (Asch and Turgeon 2003, Coleman et al. 2004a). Part of the problem has been that the biota of these habitats is not easily sampled with conventional survey gears (e.g., otter trawls). In addition if these habitats might later be designated as marine protected areas, the use of sampling approaches that perturb sessile benthic communities would not be desirable.

We are currently studying one mid-shelf bank in the northwestern Gulf of Mexico, Sonnier Bank (approximate location: 28°20'N, 92°27'W), to evaluate it as essential habitat of coral and reef fish species and to develop survey approaches with SCUBA and ROV (remotely operated vehicles) that can be applied to monitor other similar banks in this region. The biota of Sonnier Bank has been described by Rezak et al. (1985), and high-resolution bathymetry has recently been mapped with multi-beam sonar (Beaudoin et al. 2002) (Figure 1). To date, we have conducted side-scan sonar surveys of Sonnier Bank to characterize benthic habitats (results are not presented here), and we have initiated SCUBA and ROV assessments of one of the main bathymetric peaks. For this preliminary data, our objectives are:

i) To evaluate the precision of visual surveys for quantifying abundance of exploited fish populations,
ii) To compare current sessile benthic community composition with that observed two decades ago (see Rezak et al. 1985), and
iii) To estimate age-structure of species that were sampled from this peak with hook-and-line.

## METHODS

Sonnier Bank appears as a ring of siltstone, claystone, and sandstone outcroppings. We conducted two initial surveys of the highest peak, which crests at a depth of approximately 18 m. Our first trip, 9-11 August 2004, was abandoned prematurely due to hurricane Bonnie; therefore, the results presented here are primarily from our second trip, 24-27 August 2004.

The SCUBA visual survey approach followed Bohnsack and Bannerot's (1986) method where target fish species observed in an imaginary cylinder of radius 7.5 m were counted. The cylinder was visualized by the divers by setting out 15 m lengths of line on the bottom. Due to the fish identification experience of the divers and our desire to maximize the number of cylinder counts, target species were limited to four families: Serranidae, Lutjanidae, Haemulidae, and two genera of Carangidae (*Seriola* and *Caranx*). These fish families were chosen because they represent major groups of exploited fish populations in this region. Diving was conducted with nitrox (oxygen enriched air) to maximize time at depth for divers, and count durations were limited to five minutes per cylinder to maximize the number of cylinder counts per dive. We selected the uppermost area of the peak with depths ranging from 18 to 29 m, and we distributed sampling locations evenly across the peak, covering an area of approximately 0.006 $km^2$ (n = 33).

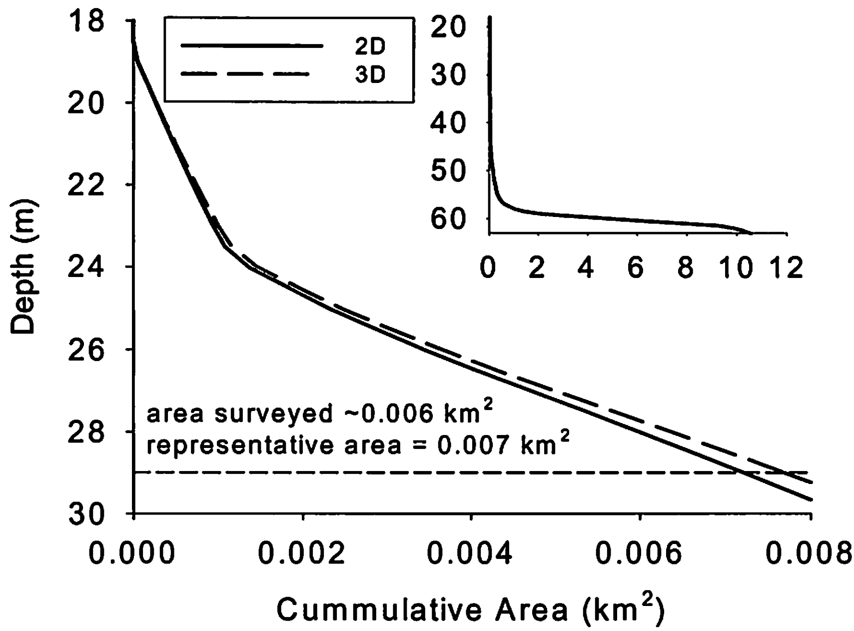


**Figure 1.** Hypsographic plot of depth on cumulative area (both 2-dimensional and 3-dimensional area, as denoted in the key). Horizontal dashed line represents maximum depth of SCUBA visual surveys, and inset plot shows hypsographic function for the entire bank. These plots were calculated from the bathymetry data of Beaudoin et al. (2002). The steepness of the highest peaks is emphasized by the divergence of the 2-dimensional and 3-dimensional cumulative areas. In the inset plot, these two functions are essentially the same, demonstrating that the high-relief peaks represent a very small fraction of the entire bank.

On selected dives, the locations of the cylinder counts were marked temporarily with a small float that was tethered to a lead weight. Between dives, an ROV with forward- and down-looking digital camera was deployed to record a video survey of the area that was marked previously during the SCUBA operations. The markers also helped divers minimize cylinder overlap. Our approach with the ROV was to follow the markers, searching the area around each marker. The video was subsequently analyzed and we counted target species that were identified in the video transect. We also fabricated a laser array that was mounted on the ROV. Three lasers were arranged to allow us to measure the distance of objects from the ROV (two red lasers in parallel and one green laser at an angle). As part of our development of this ROV survey approach, we plan to use the lasers to quantify the size of the search area, but for this paper we report only observations on the reactions of fish to the lasers. For comparison with the SCUBA visual survey results, counts of target species from the video transects were normalized to the number of marked areas that were searched.

The species composition of the sessile benthic community was assessed by divers using a standard 1 $m^2$ frame (quadrat) with lines that divided the quadrat into 100 squares. Each square, or cell, was 100 $cm^2$. The quadrat was placed on the bottom, and the diver counted the number of cells in which each species was observed. On each dive, a starting location was haphazardly chosen for the first quadrat, and the locations of subsequent quadrats were determined by swimming a random distance and direction from the previous location.

The age-structure of reef fish populations has been shown to vary significantly between reefs, and this phenomenon may have implications for understanding population dynamic responses to exploitation (e.g., Gust et al. 2002). We were interested in developing information on age-structure of fish populations at Sonnier Bank; therefore, with hook-and-line, we collected otolith samples from several species. We then counted annuli in otolith thin-sections, using standard otolith preparation and light microscopy techniques (see Panfili et al. 2000).

To evaluate the SCUBA visual survey approach, we conducted a re-sampling exercise to estimate the relationship between sample size and standard error of mean counts. We simulated sample sizes of 2, 5, 10, 20, 60, 100, and 500 to estimate standard error, and for each sample size, the data were re-sampled 10000 times with replacement. Count data are typically treated as a Poisson variable, but with this large number of re-sampling iterations, presumably the arithmetic mean and variance will properly describe the re-sampled distribution as per the central limit theorem. We modeled a power function between standard error and sample size to interpolate standard errors of intermediate sample sizes. To evaluate the sensitivity of our cylinder count approach for detecting changes in abundance, we determined the minimum detectible difference (given a 5% chance of Type-I error and 90% chance of detecting a difference; see Zar 1984, p. 135) across ranges of sample size (from 5 to 50) and density (from 0.25 to 2 times the observed mean count).

We were also interested whether depth and/or the person making the count had any significant effect on the count. For this exercise we conducted a Poisson regression of observed species count on person with depth as a covariate. There was significant over dispersion in our data; therefore, we scaled the covariance matrix by the deviance (Kleinbaum et al. 1998). We set a significance level of alpha = 0.05 prior to statistical hypothesis testing.

## RESULTS

Out of our target groups, five species were regularly observed during the SCUBA surveys: Atlantic creolefish (Serranidae: *Paranthias furcifer*, n = 1,823), tomtate (Haemulidae: *Haemulon aurolineatum*, n = 315), rock hind (Serranidae: *Epinephelus adscensionis*, n = 128), gray snapper (Lutjanidae: *Lutjanus griseus*, n = 118), and vermilion snapper (Lutjanidae: *Rhomboplites aurorubens*, n = 73). From Carangidae, three species targeted by recreational anglers were regularly observed, greater amberjack (*Seriola dumerili*, n = 18), crevalle jack (*Caranx hippos*, n = 33), and horse-eye jack (*Caranx latus*, n = 4), and these were combined into a single category (i.e., large jacks) for the analyses. Other species from target groups (though some are important exploited populations) were present only in small numbers or in single groups and were not included in the analyses. These latter species were, bar jack (*Caranx ruber*, n = 45), lane snapper (*Lutjanus synagris*, n = 20), cottonwick (*Haemulon melanurum*, n = 8), mahogany snapper (*Lutjanus mahogoni*, n = 7, though this identification is unverified), graysby (*Epinephelus cruentata* , n = 6), Rainbow Runner (*Elagatis bipinnulata*, n = 4), dog snapper (*Lutjanus jocu*, n = 2), yellowtail snapper (*Ocyurus chrysurus*, n = 2), ceasar grunt (*Haemulon carbonarium*, n = 2, though this identification is unverified), and red snapper (*Lutjanus campechanus*, n = 1).

The highest densities observed during SCUBA visual surveys were for Atlantic creolefish followed by tomtate and rock hind (Table 1). The surveyed depths ranged from 16 to 32 m with a mean of 23 m, and most counts were made at depths <29 m (only one count was made at 32 m). In the Poisson regression, there were no significant depth trends for any of the species, though there was a slight increase in mean count with depth for all species (in Table 1) except rock hind. In addition for all species, there were no interactions between depth and diver, and there were no significant differences between the four divers. Note that there was one outlying observation, a single large school of tomtate (n = 160), and this was not included in the Poisson regression analysis. This outlier was included in the re-sampling analysis.

**Table 1.** Mean counts (and 95% C.L.s) from visual surveys and ROV video surveys for selected species.

| | *SCUBA Visual Survey*[a] | | | *ROV*[b] |
|---|---|---|---|---|
| | *Mean* | *Lower C.L.* | *Upper C.L.* | |
| Atlantic creolefish | 54.6 | 38.4 | 77.6 | 3.8 |
| tomtate | 4.6 | 2.9 | 7.2 | 1.9 |
| rock hind | 3.8 | 3.0 | 4.9 | 1.0 |
| gray snapper | 3.4 | 1.9 | 6.1 | 0.8 |
| vermilion snapper | 2.2 | 1.0 | 4.9 | 0.2 |
| large jacks | 1.7 | 0.9 | 3.3 | 0.1 |

[a]Estimates from Poisson regression (*n* = 33).
[b]Count from video per number of marked areas that were searched (n = 28).

As expected, the standard errors estimated from the re-sampling procedure declined with sample size, and the highest standard errors were observed for Atlantic creolefish and tomtate (Figure 2). High standard errors for these species reflected frequently observed aggregations of Atlantic creolefish and the one large school of tomtate that was recorded. A large school of tomtate was also reported by two other divers, but it was not inside the survey cylinders and was not counted. For counts of rock hind, gray snapper, vermilion snapper, and large jacks there was little improvement in standard error by increasing sample size from 20 to 50 (Figure 2). Due to the low overall frequencies of observations of large jacks and vermilion snapper, these species were not included in the minimum detectable difference calculations. Based upon the estimated minimum detectable differences, the SCUBA visual surveys would be most sensitive at detecting changes in abundance of the most stationary species (rock hind) and the most abundant species (Atlantic creolefish). Increases in sample size and/or increases in abundance improved detection, and with respect to observed mean counts and our sample size of 33, the density would have to decline by 66% for rock hind and 88% for Atlantic creolefish before we would detect a statistical difference in mean cylinder count (Figure 3). For gray snapper and tomtate, the proportional declines would have to be much larger: 1.6-fold and 1.8-fold, respectively (Figure 3).

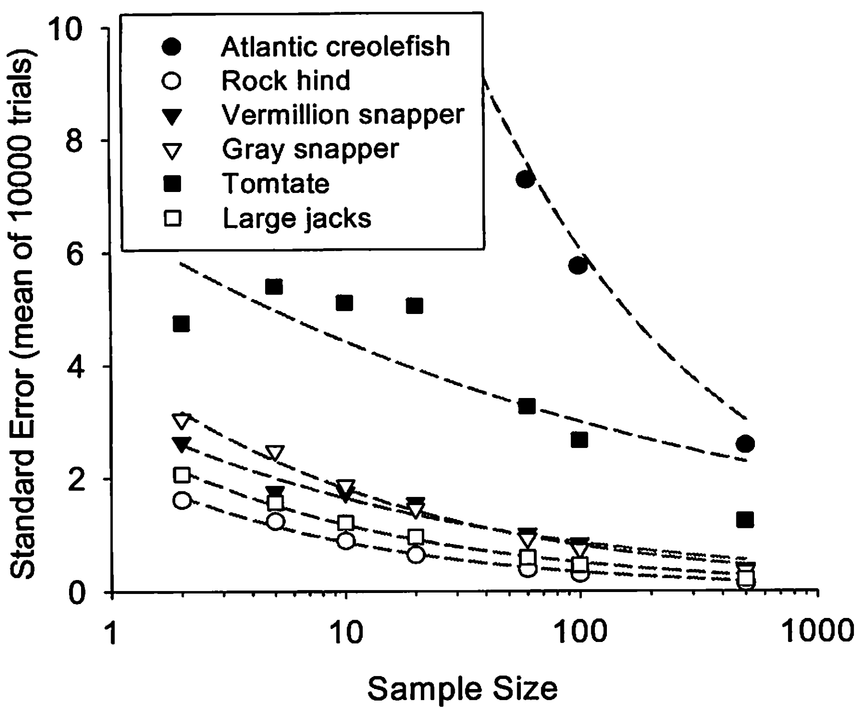


**Figure 2.** Re-sampling analysis results showing standard error as a function of sample size for selected species observed at Sonnier Bank. Dashed curves show power functions that were fitted to the data.

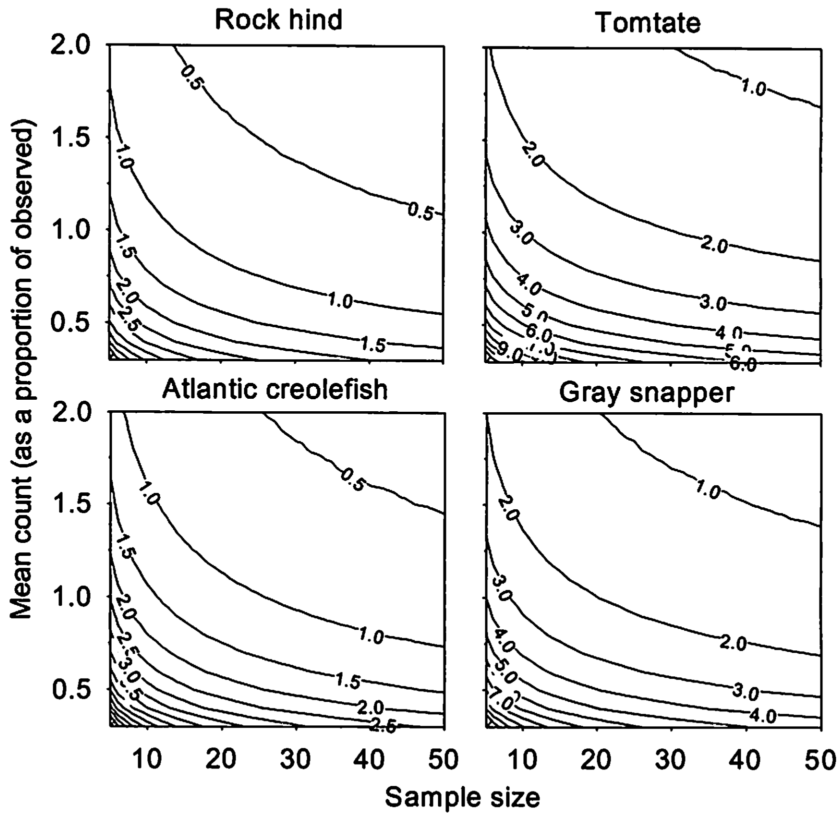


**Figure 3.** The minimum detectable difference (plotted as a proportion of the mean count) as a function of mean count and sample size for selected species observed at Sonnier Bank.

Though the rank order of abundance of target species was the same between SCUBA visual surveys and ROV video transects, the counts per marked area from the ROV were many times lower (Table 1). These differences were due, at least in part, to a smaller search area and limited field of view with the ROV. We are currently working on an approach to better quantify search areas with the ROV in order make better comparisons with SCUBA visual surveys. In general, the behavior of the fish in the video recordings was similar to that observed by the divers. In addition, there was a notable reaction of some fishes to the spot projected by the green laser. For example, damsel fishes (primarily *Stegastes* spp.), bluehead wrasse (*Thalasoma bifasciatum*), and smaller rock hind frequently attacked the green laser spot when it was projected on the bottom while close to the ROV (< 4 m), and on one occasion, a rock hind was observed to eat a juvenile bluehead that was attracted to the laser spot.

The substrate of the surveyed peak was completely encrusted with sessile benthic organisms, and no bare substrate was observed. Previously, the benthic community of this area was described as a *Millepora*-sponge community (Rezak et al. 1985), and this characterization was still accurate for our surveys, twenty years later. From 40 quadrat surveys with depths ranging from 17 to 27 m, the dominant benthic organisms were fire coral (*Millepora alcicornis*), several species of sponges (primarily *Agelas clathrodes*, *Ircinia strobilina*, and *Neofibularia nolitangere*), and crustose coralline algae (Figure 4). Notably, some bleached *Millepora* was observed, and this phenomenon was not reported by Rezak et al. (1985).

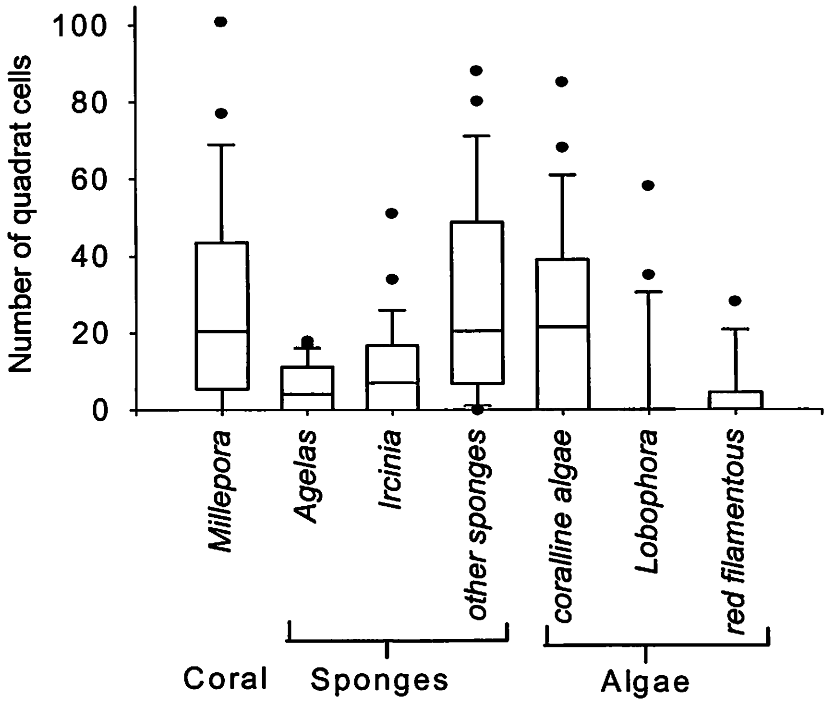


**Figure 4.** Incidence of major benthic organisms observed at Sonnier Bank and quantified with quadrats (see text). The box plots give median, 10$^{th}$, 25$^{th}$, 75$^{th}$, and 90$^{th}$ percentiles for each taxonomic group, and the dots represent outliers.

Some of the same species observed with SCUBA and ROV were captured with hook-and-line for otolith analysis (Figure 5). The assigned ages, based upon annulus counts, showed overlapping distributions for most of the species, with ages typically between 4 and 10 years. For all the species, younger ages are believed to be present based upon diver observations of smaller individuals, but the gear selected for larger fish. There were two notably old fish: one tomtate that was 19 years old and one Atlantic creolefish that was 26 years old. There was nothing particularly unusual about these individuals (e.g., with respect to morphology), except that it was unusual to catch Atlantic creolefish with hook-and-line.

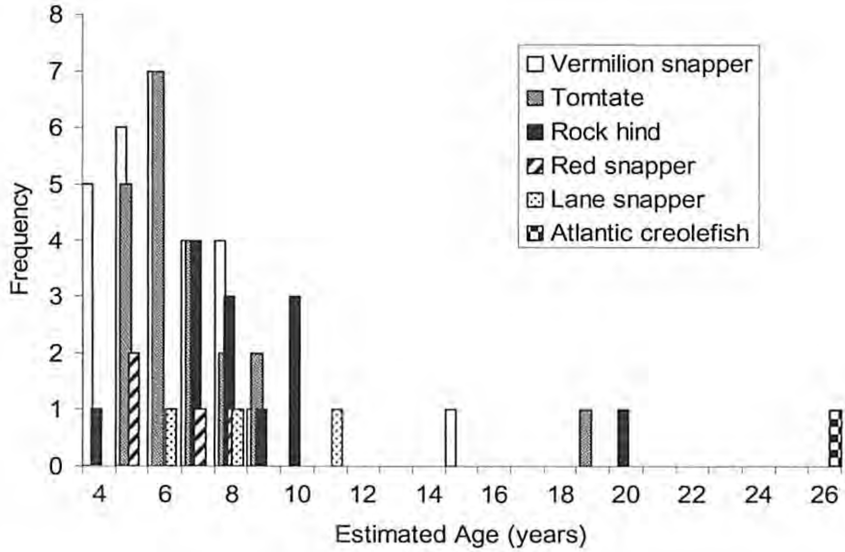


**Figure 5.** Age-distribution of species captured by hook-and-line at Sonnier Bank. Ages were determined by annulus counts from thin sections of otoliths.

## DISCUSSION

The results of this preliminary data analysis indicated that a target sample size for SCUBA surveys of around 30 cylinder counts provided reasonable precision (s.e. < 2) for estimating abundance of low density species (< 4 per cylinder). Though this essentially represents most of the area of Sonnier Bank that is accessible for SCUBA surveying, it is a level of sampling that could reasonably be conducted on a regular basis. The two most abundant species, tomtate and Atlantic creolefish, exhibited high variability, and increases in sample size indicated substantial improvements in precision across the range of simulated sample sizes up to 500. Such large sample sizes are unreasonable for conducting SCUBA surveys, but at least for high abundance species like Atlantic creolefish, we expect to be able to detect moderate to large changes in abundance with the same level of sampling.

The two species, which we predict our SCUBA survey approach would have the greatest sensitivity to detect changes in abundance, were rock hind and Atlantic creolefish, and of these only rock hind would be expected to have significant exploitation from commercial or recreational fishing. Due to recent concern in the Gulf of Mexico about the impacts of recreational fishing (Coleman et al. 2004b), we posed the question — What does the minimum detectable difference at a sample size of 30 (cylinder counts) reflect in terms of numbers of rock hind removed by fishing? Given a total survey area of ~7,000 $m^2$ and a minimum detectable difference of 2.5 rock hind per cylinder (cylinder area = 176 $m^2$), anglers would have to catch approximately 100 rock hind. Current federal regulations limit recreational catch of rock hind to five per person per day; therefore, if each angler catches her limit, we would detect the change in abundance after approximately 20 angler trips. This amount of effort might be masked in the short term because rock hind from adjacent areas can move to replace those that are caught. Still, the equivalent (or greater) fishing effort of 20 angler trips where bag limits are reached is a highly plausible level of fishing that could take place during typical monitoring intervals (monthly or bi-monthly).

Our explorations of deeper areas (>30 m) around this main peak with the ROV, indicated that densities of lutjanids (most notably, *L. griseus*) and tomtate increased substantially, approaching similar levels to that observed for Atlantic creolefish on the crest of this peak and in accordance with the increasing (but non-significant) depth trend in the Poisson regression analysis. These deeper areas that are not accessible by SCUBA are clearly more important for the majority of exploited fish populations at Sonnier Bank, and our future efforts will concentrate on quantifying these populations by developing approaches with the ROV. Though the laser spots seem to attract or antagonize some smaller fish, the effects were most evident in the immediate vicinity of the ROV, and we have not seen any indications that this effect will bias counts of species from our target groups. Ongoing efforts to better quantify the search area of the ROV with the laser array will be a crucial part of this work.

Some other observations from these initial surveys that warrant additional study were:

i) The bleached patches of *Millepora* coral that were either not observed or recorded previously by Rezak et al. (1985), and
ii) The presence of unusually old tomtate and Atlantic creolefish.

These fish may merely represent coincidental captures of unusually old individuals. We are not aware of any published information documenting such high longevity for tomtate, and further we are not aware of any ageing information on Atlantic creolefish. From the few samples of otoliths that we have collected from other species, the age-structure of these populations is not well defined, but appears to be comparable to other published information from the Gulf of Mexico and northwestern Atlantic. The development of age-structure data will be important for predicting population level responses to exploitation or different management actions that may affect fish populations at Sonnier Bank.

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# Monitoring of Tropical Shallow-water Fish Communities around the EcoEléctrica Liquefied Natural Gas Import Terminal and Co-generation Plant in Guayanilla Bay, Puerto Rico

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ABSTRACT

One of the permit conditions for the operation of the EcoElectrica co-generation plant at Guayanilla Bay Puerto Rico requires a monitoring program to assess the long–term impacts of the Intake and Discharge waters of its cogeneration plant to marine communities surrounding the area. Among the principal goals of the EcoElectrica's biological monitoring program plan was to ensure that thermal effluents produced by the EcoElectrica Discharge Station are not creating an impact to marine organisms on nearby locations. Thus, the aim of this study is to determine if there is any environmental impact on the fish fauna near the Discharge Station by comparing fish species composition, diversity, abundance and health condition between the Intake and Discharge Stations of EcoElectrica cogeneration plant.

Fish communities from the Intake and Discharge Stations at the EcoElectrica LNG terminal pier were sampled in October/December 2001, February/March 2002, September 2002, and February 2003. Reef fish assemblages were recorded using three complementary sampling methods: stationary point count method, fish traps, and beach seine net. Results from multivariate tests at different sampling periods showed significantly distinct fish communities among stations with little variation among sampling periods. The Discharge Station had a higher abundance of fish and number of species per point count than the Intake Station. The families Pomacentridae, Haemulidae, and Gerreidae accounted for most of all families observed on all methods combined within the Intake Station whereas in the Discharge Station the families Haemulidae, Lutjanidae, Chaetodontidae, and Gerreidae were the most abundant families recorded.

The dusky damselfish, *Stegastes fuscus*, the french grunt *Hamulon flavolineatum* and the silver jenny, *Eucinostomus gula* were among the most abundant species. No gross external morphological symptoms (e.g. presence of ulcers tumors color aberrations) were found on fish caught within stations. The preliminary results of this study indicate that apparently no potential environmental hazards have been found to affect fish populations near the Discharge Station.

KEY WORDS: Fish assemblages, recruitment, disturbance

# Monitoreo de las Comunidades de Peces Tropicales en Áreas Someras Alrededor de la Planta Ecoeléctrica de Licuado y del Terminal de la Importación del Gas Natural y de la Planta de la Cogeneración en la Bahía de Guayanilla, Puerto Rico

Una de las condiciones del permiso NPDES para operar el terminal de importación de gas natural licuado y la planta de cogeneración de EcoEléctrica, situada en la bahía de Guayanilla, Puerto Rico, requiere un programa de monitoreo biológico para evaluar los impactos a largo plazo de las aguas provenientes de las estaciones de la descarga (Discharge Station) y de la toma de agua (Intake Station) a las comunidades marinas cercanas al área. Uno de los objetivos principales del plan del programa de monitoreo biológico de EcoEléctrica es asegurar que los efluentes termales producidos por la zona de descarga no están creando un impacto adverso a los organismos marinos en las localidades cercanas a la planta. El propósito de este estudio es determinar si hay algún impacto ambiental en las comunidades de peces aledañas a la zona de la descarga, comparando la abundancia, diversidad, condición y composición de especies de peces de arrecife entre las estaciones de descarga y de toma de agua de EcoEléctrica.

Las comunidades de peces de las estaciones de la toma de agua y de la descarga de EcoEléctrica fueron monitoreadas en Octubre/Diciembre 2001, Febrero/Marzo 2002, Septiembre 2002 y Febrero 2003 mediante el uso de censos visuales de puntos estacionarios, nasas y chinchorro de arrastre. Los resultados de las pruebas multivariadas muestran que las comunidades de peces son significantemente distintas entre estaciones, pero con poca variación entre periodos de muestreo. La estación de descarga tuvo significantemente una mayor diversidad y abundancia de peces que la estación de la toma de agua. Las familias Pomacentridae,Gerreidae y Haemulidae componen la mayoría de las familias de peces observadas por todos los métodos de muestreo combinados en la estación de la toma de agua mientras que la comunidad de peces en la estación de la descarga está compuesta en su mayoría de las familias Haemulidae Lutjanidae y Chaetodontidae.

La damisela obscura *Stegastes fuscus*, el ronco amarillo *Haemulon flavolineatum* y la mojarra pequeña *Eucinostomus gula* fueron de las especies más abundantes. No se encontraron lesiones físicas (presencia de ulceras tumores, manchas etc.) en las especies capturadas en las zonas de estudio. Los resultados preliminares del estudio indican que aparentemente no se ha encontrado ningun problema ambiental que haya afectado las poblaciones de peces cerca de la descarga.

PALABRAS CLAVES: Las comunidades de peces, problema ambiental, terminal de importación de gas natural licuado

## INTRODUCTION

During the last 30 years, Puerto Rico has experienced a rapid industrialization and subsequent increase in demand for electrical power (Lopez 1979). This demand has led to the construction of several fossil fuel and thermoelectric power plants, all of which were located in coastal areas and used seawater for associated cooling processes. During the cooling process, cooling water temperatures become elevated and the water is subsequently discharged back into the sea. However, concerns for the thermal impact of heated effluents on surrounding environments fostered several studies on the effects of thermal pollution on marine organisms (Lopez 1979). Extensive bibliographies concerning the effects of temperature on fish and other organisms have been published by Coutant (1971, 1974). However, these studies have largely concerned themselves with temperate or subtropical fish communities while few have examined tropical fish communities.

A benthic finfish-monitoring program was initiated on October 2001 as a complementary study to the EcoElectrica's Biological Monitoring Program Plan (BMPP). One of the permit conditions for the operation of the EcoElectrica co-generation plant requires a monitoring program to assess the long–term impacts of the Intake and Discharge waters of its cogeneration plant to marine communities surrounding the area. Among the principal goals of the study was to ensure that thermal effluents produced by the EcoElectrica Discharge Station (Sta.) are not creating an impact to marine organisms on nearby locations. Thus, the aim of this study is to determine if fish species composition, diversity, abundance and health condition differs between the Intake and Discharge Sta. of EcoElectrica cogeneration plant. The program will produce technical data that should prove very useful in designing and constructing other land development proposals. In addition, the program should, provide guidance in setting mitigation policy and designing mitigation requirements.

## METHODS

### Sampling

The fish communities around the Intake and Discharge Sta. (Figure 1) at the EcoElectrica LNG terminal pier were sampled using visual census, fish seine nets, and fish traps from October 2001 to December 2001, from February 2002 to March 2002, September 2002 and February 2003. For each station, a 5 x 5 m grid pattern was produced over a habitat map provided by Vicente & Associates. This numbered grid was the basis for selecting point count and trap survey sites.

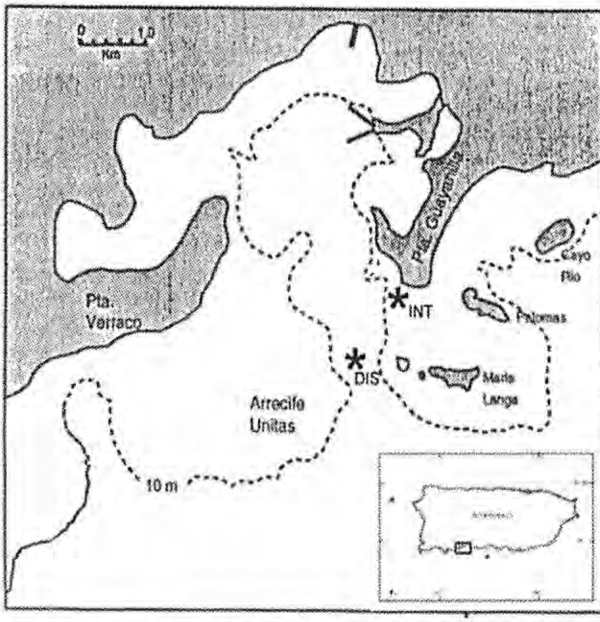


**Figure 1.** Location of Intake and Discharge Sta. in Guayanilla Bay, PR.

At each of the ten points randomly selected in each station, one diver using the Stationary Point Count Visual Census (Bohnsack and Bannerot 1986) recorded major habitat category type, fish species in that habitat category, number of fish present for each species, and size categories of fish observed to the nearest 5 cm. For each station, five fish traps hauling sites were also randomly selected. Fish traps used in this study were chevron-shape (91cm x 45.72 cm) with 3.8 cm bar mesh. Traps were unbaited and fished for 24 hours. Finally, three beach seine hauls were conducted at each station. The beach seine net measured 9.14 m x 1.2 m, had weights and floats attached. The net mesh size was 1.3 cm stretch mesh. All fish caught in the fish traps and in the seine net were identified, enumerated, and measured (SL) to the nearest millimeter, and released at the point of capture. The general conditions of the fish sampled were determined based on gross external morphological symptoms (i.e. presence of ulcers tumors, color aberrations).

Data from visual census were analyzed using cluster analyses and non-metric multi-dimensional scaling statistical techniques to describe the variation between species abundance and composition at each location and at each period. Abundance and presence/absence data from each location and at each period were analyzed using the Bray-Curtis similarity measure. One-way analyses of similarity (ANOSIM) tests were used to test the hypothesis that fish assemblages from the two locations and three periods were similar. Variations of abundance, number of species per census, diversity and evenness index between stations were examined by Mann-Whitney test (Sokal and Rohlf 1981).

## RESULTS

### Stationary Point Count Visual Census

Thirty visual census point counts were made at the Intake Sta. intercepts and at the Discharge Sta. intercepts (Figure 1). For the Intake Sta., 303 fishes were observed representing 20 species and 11 families (see Table 1a). The dusky damselfish *Stegastes fuscus* accounted for 72 % of fish observed. The most frequently observed fish at all Intake fish point counts was the dusky damselfish *Stegastes fuscus* (97 %). The families Pomacentridae and Haemulidae accounted for 78 % and 13 % of all families observed in the Intake Sta. fish.

**Table 1a.** Abundance of species per family recorded by visual census at Intake Station

| Species | Family | Abundance | Percent | Frequency of occurrence |
|---|---|---|---|---|
| *Stegastes fuscus* | Pomacentridae | 217 | 71.6 | 97.5 |
| *Haemulon flavolineatum* | Haemulidae | 22 | 7.3 | 7.5 |
| *Anisostremus virginicus* | Haemulidae | 12 | 4.0 | 10.0 |
| Total Number of Fish | | 303 | | |
| Total Number of Species | | 20 | | |

Only species with >4% of abundance.

For the Discharge Sta., (Table 1b) 287 fishes were observed representing 43 species and 18 families. The french grunt, *Haemulon flavolineatum* accounted for 15 % of fish observed. The most frequently observed fish in all Discharge fish point counts were the dusky damselfish, *Stegastes fuscus* (47 %). The families Haemulidae and Lutjanidae accounted for 23 % and 19 % of all families observed in the Discharge Sta.

**Table 1b.** Abundance of species per family recorded by visual census at Discharge Station

| Species | Family | Abundance | Percent | Frequency of occurrence |
|---|---|---|---|---|
| *Haemulon flavolineatum* | Haemulidae | 61 | 15.4 | 17.5 |
| *Stegastes fuscus* | Pomacentridae | 44 | 11.1 | 47.5 |
| *Lutjanus griseus* | Lutjanidae | 28 | 7.1 | 10.0 |
| *Thalassoma bifasciatum* | Labridae | 27 | 6.8 | 17.5 |
| *Lutjanus apodus* | Lutjanidae | 26 | 6.6 | 20.0 |
| *Acanthurus bahianus* | Acanthuridae | 20 | 5.1 | 20.0 |
| *Myripristis jacobus* | Holocentridae | 20 | 5.1 | 25 |
| *Stegastes partitus* | Pomacentridae | 18 | 4.5 | 30.0 |
| Total Number of Fish | | 396 | | |
| Total Number of Species | | 43 | | |

Only species with >4% of abundance.

The Discharge Sta. had higher number of fish and number of species per point count than the Intake Sta. (Figures 2 and 3). Species diversity (H') (Figure 4) and evenness (Figure 5) was also higher in the Discharge Sta. Mann-Whitney rank sum test showed that the mean number of species and the diversity index (H') were significantly higher ($p < 0.001$) in the Discharge Sta. Results of the percentage similarity of species composition and fish densities between stations indicated a low similarity in species composition (32 %). There were only 16 species shared between stations. Average linkages clustering of mean abundance of species among stations and sampling periods showed two distinct groups with little variation among sampling dates (Figure 6). This pattern was confirmed by multidimensional scaling analyses and produced a low Kruskall stress value 0.01 indicating that the data was a good fit for the model (Figure 7). Two-way ANOSIM test confirmed that differences among stations were significant ($p < 0.003$) but there were no differences among sampling periods ($p > 0.05$).

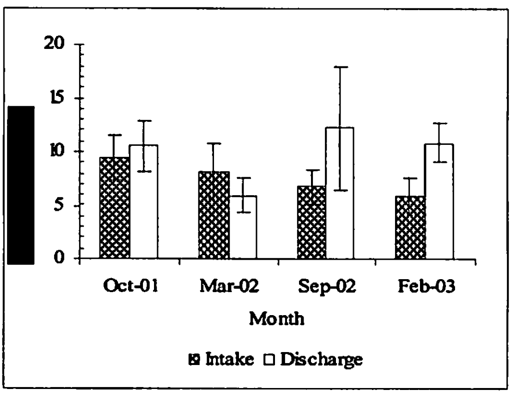


**Figure 2.** Mean number of fish per point count by site and sampling month.

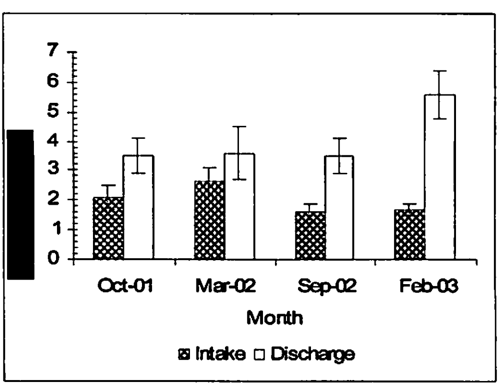


**Figure 3.** Mean number of species / point count by site and sampling month.

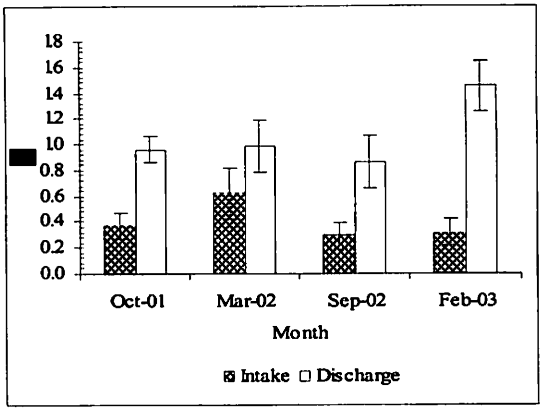


**Figure 4.** Mean Shannon-Weaver Diversity Index per point count by site and sampling month.

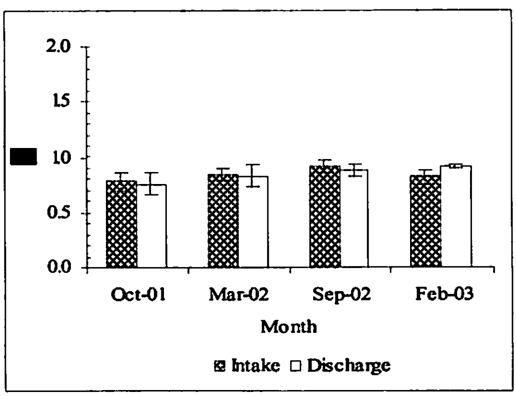


**Figure 5.** Mean Pielou Evenness Index per point count by site and sampling month.

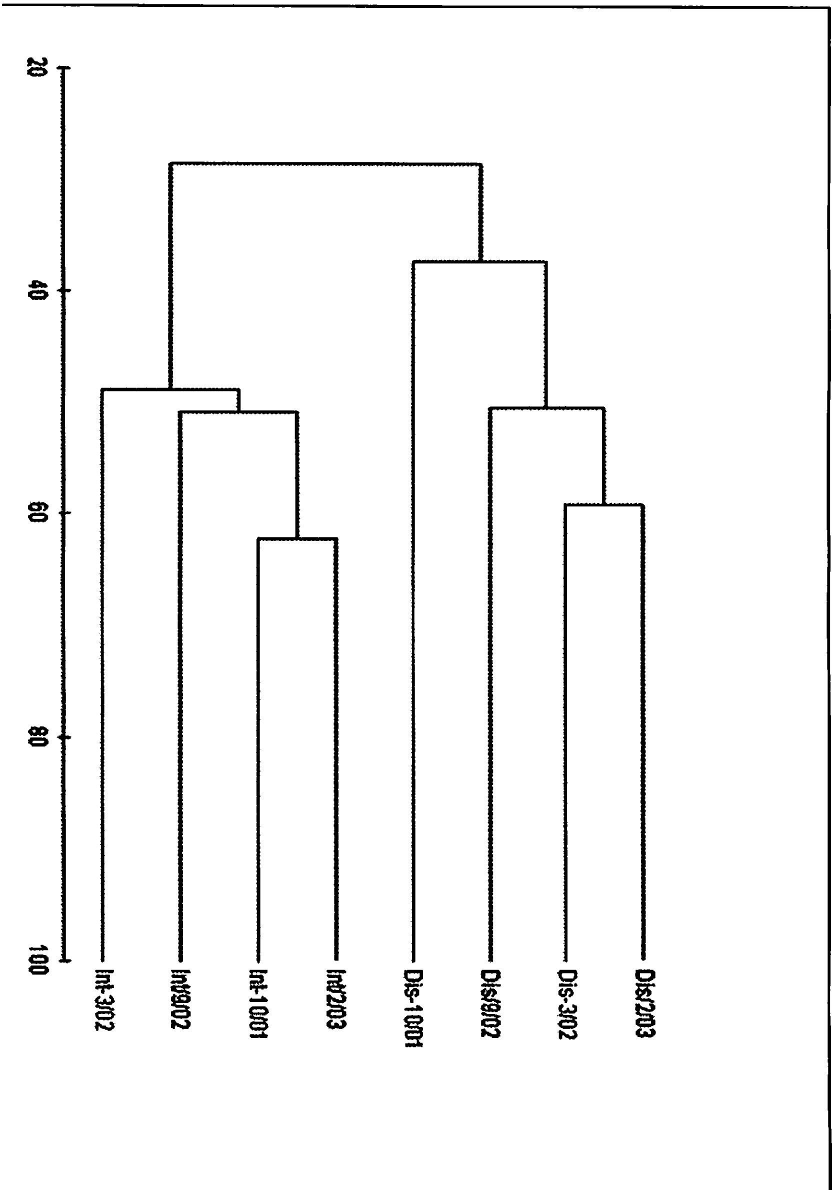


**Figure 6.** Cluster analysis of similarities of fish fauna among stations per date.

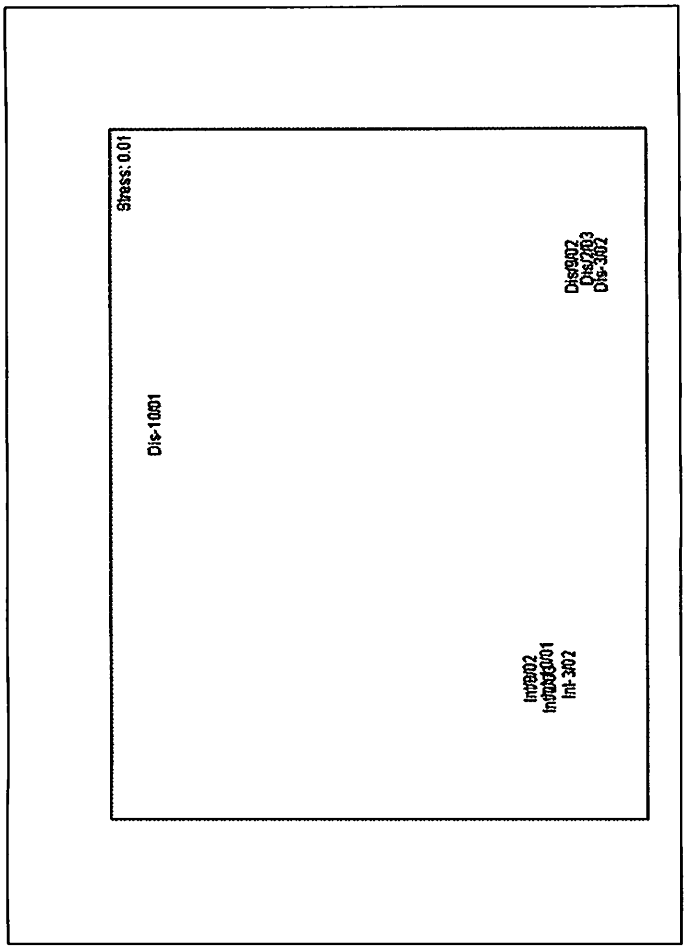


**Figure 7.** MDS ordination of fish fauna among station per date.

Length frequencies for economically important species within stations are shown in Figures 8, 9, 10, and 11. *Haemulon flavolineatum, H. plumieri, Ocyurus chrysurus* recruit (< 5cm TL) densities were highest on the Discharge Sta. while larger individuals (> 15cm TL) were rare on both stations during these sampling periods.

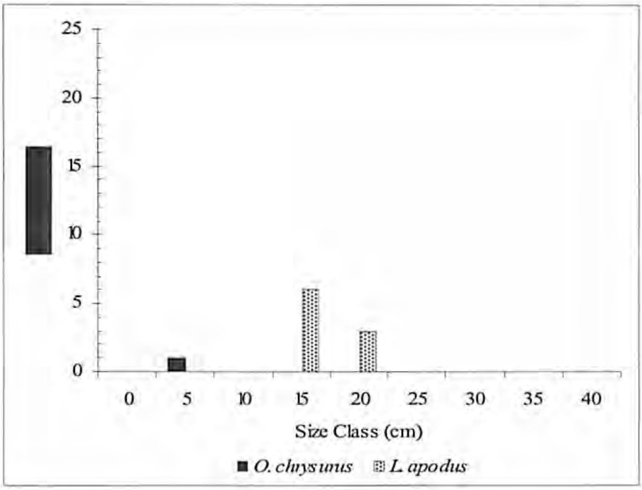


**Figure 8.** Size class distribution of lutjanid species observed on visual census in the Intake Station.

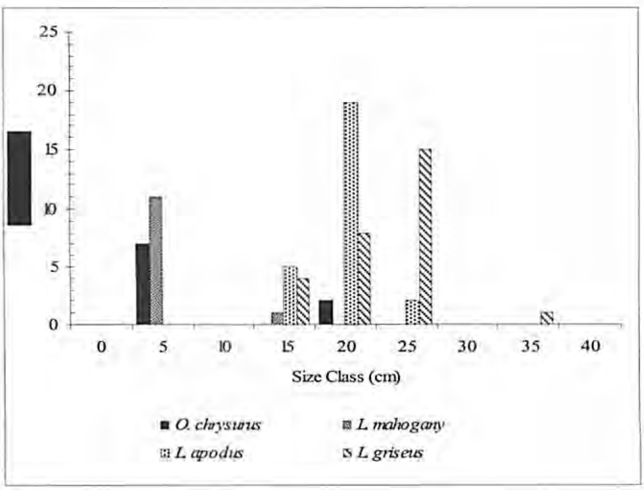


**Figure 9.** Size class distribution of lutjanid species observed on visual census in the Discharge Station.

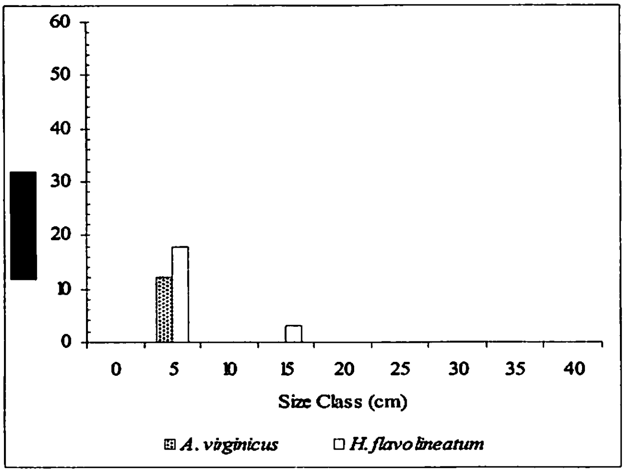


**Figure 10.** Size class distribution of haemulid species observed on visual census in the Intake Station

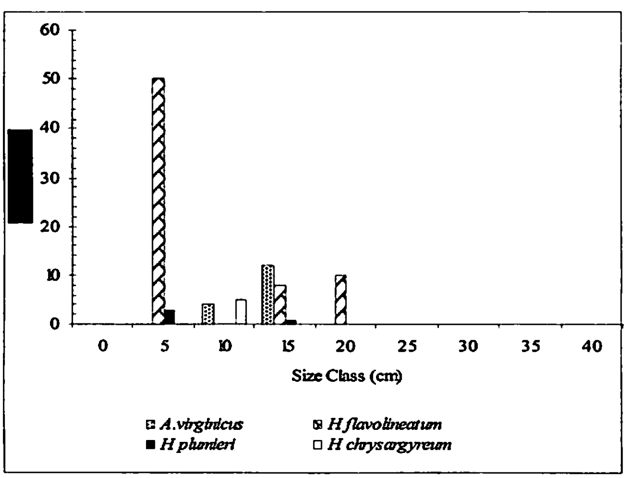


**Figure 11.** Size class distribution of haemulid species observed on visual census in the Discharge Station

### Fish Traps

In the Intake Sta., the most abundant fish was the banded butterflyfish *Chaetodon striatus* (Table 2a). At the Discharge Sta. (Table 2b), the banded butterflyfish *Chaetodon striatus*, and the squirrelfish *Holocentrus adcenscionis*, accounted for 52 % of the total catch. The Discharge Sta. had higher number of fish and species caught per trap-haul than the Intake Sta. (Figures 12 and 13). Mean standard lengths and mean fish sizes at sexual maturity are shown in Table 2a and 2b. Results suggest that in general, *Haemulon album*, *Sparisoma chrysopterum*, and *Lutjanus apodus* caught on traps were smaller than their mean size at sexual maturity. No gross external morphological symptoms (e.g. presence of ulcers tumors color aberrations) were found.

**Table 2a.** Abundance and mean standard lengths (mm) of species caught by fish trap hauls at Intake Sta.

| Species | Abundance | Percent | Mean Length (SE) | Maturity | Reference |
|---|---|---|---|---|---|
| *Chaetodon striatus* | 2 | 50.0 | 147.2(21.6) | 132 | Aiken (1983) |
| *H. aurolineatum* | 1 | 25.0 | 215.0 | 130 | Billings & Munro (1974) |
| *H. plumieri* | 1 | 25.0 | 195.0 | 165-210 | Roman Cordero (1991) |
| Total No. of Spp. | 3 | | | | |
| Total No. of Fish | 4 | | | | |

**Table 2b.** Abundance and mean standard lengths (mm) of species caught by fish trap hauls at Discharge Sta.

| Species | Abundance | Percent | Mean Length (SE) | Maturity | Reference |
|---|---|---|---|---|---|
| *Chaetodon striatus* | 14 | 35.0 | 114.5(1.5) | 132 | Aiken (1983) |
| *Holocentrus adcencionis* | 6 | 17.6 | 222.6(10.1) | 145 | Wyatt (1983) |
| *Haemulon plumieri* | 5 | 14.7 | 215.0(5.3) | 165-210 | Roman Cordero (1991) |
| *Chaetodon capistratus* | 4 | 11.8 | 103.5(5.3) | 88.0 | Aiken (1983) |
| *Chaetodon ocellatus* | 3 | 8.8 | 133(8.3) | 139 | Aiken (1983) |
| *Lutjanus apodus* | 3 | 8.8 | 223(11.1) | 250 | Thompson & Munro (1983) |
| *Acanthurus bahianus* | 2 | 5.9 | 179.5(0.5) | 111.0 | Reeson (1983) |
| *Sparisoma chrysopterum* | 2 | 5.9 | 215.0 | 235 | Figuerola et al. (1998) |
| Total No. of Spp. | 9 | | | | |
| Total No. of Fish | 40 | | | | |

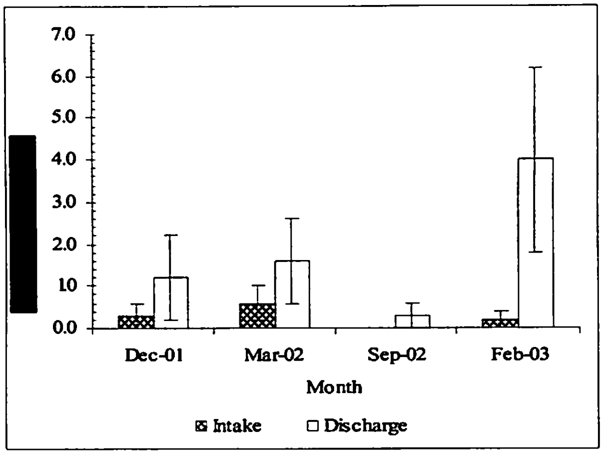


Figure 12. Mean number of fish caught by traps at Intake and Discharge Sta.

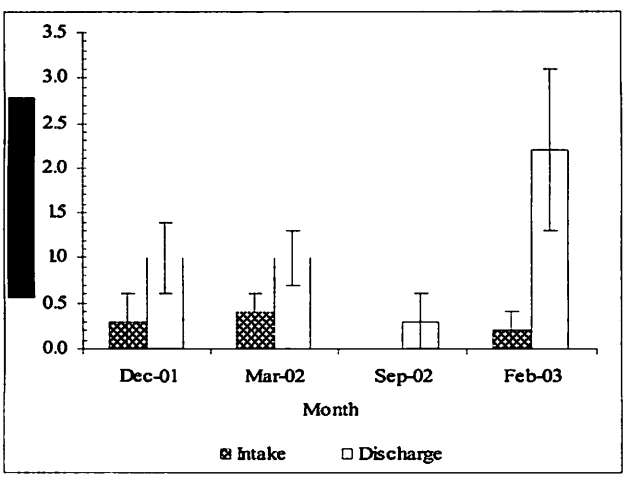


Figure 13. Mean number of species caught by traps at Intake and Discharge Sta.

**Beach Seine**

In the Punta Guayanilla Sta., the white sprat, *Harengula clupeola,* accounted for 19 % of seine catches (Table 3a). In the Maria Langa Sta. the silver jenny *Eucinostomus gula,* accounted for 43 % of the catches (Table 3b). Mean standard lengths and mean fish sizes at sexual maturity (length at which 50 % of the population become mature for the first time) are shown in Table 3a. The mean catch per seine haul for Punta Guayanilla within all sampling dates ranged from 5 to 23 fish per seine haul whereas for Maria Langa it ranged from 4.3 to 30.3 fish per seine haul (Figure 14). Mean number of species caught per seine haul for Punta Guayanilla within all sampling dates ranged from 1.3 to 6 species per seine haul whereas for Maria Langa it ranged from 2.3 to 2.6 species per seine haul (Figure 15). Results here suggest that, in general, most species of snappers, grunts as well as other fishes such as the permit *Trachinotus falcatus* and the doctorfish *Acanthurus chirurgus*, caught on seine nets were smaller than their mean size at sexual maturity. No gross external morphological symptoms were found.

**Table 3a.** Abundance of species per family by seine net-hauls at Pta. Guayanilla.

| Species | Abundance | Percent | Mean Length (SE) | Maturity | Reference |
|---|---|---|---|---|---|
| *Eucinostomus gula* | 30 | 18.99 | 71.3 (4.2) | N/A | N/A |
| *Harengula clupeola* | 27 | 17.09 | 81 (1.6) | N/A | N/A |
| *Trachinotus falcatus* | 19 | 12.03 | 40.5 (1.8) | 486 | Crabtree et al. (2002) |
| *Anchoa lyolepis* | 18 | 11.39 | 54 (2.1) | N/A | N/A |
| *Acanthurus bahianus* | 11 | 6.96 | 50.3 (2.4) | 155 | Reeson (1983) |
| *Pseudupeneus maculatus* | 10 | 6.33 | 62.6 (1.7) | 185 | Munro (1983) |
| Total No. of Spp. | 21 | | | | |
| Total No. of Fish | 158 | | | | |

Only species with >4% of abundance.

**Table 3b.** Abundance and mean standard lengths (mm) of species caught by seine net-hauls at Maria Langa.

| Species | Abundance | Percent | Mean Length (SE) | Maturity | Reference |
|---|---|---|---|---|---|
| *Haemulon flavolineatum* | 83 | 41.92 | 57.9 (1.0) | 160 | Billings & Munro (1974) |
| | 46 | 23.23 | 60.6 (4.2) | N/A | N/A |
| **Eucinostomus gula** | | | | | |
| *Ocyurus chrysurus* | 28 | 14.14 | 80.7 (2.3) | 248 | Figuerola et al (1998) |
| *Haemulon sciurus* | 14 | 7.07 | 41.56 (2.75) | 200 | Billings & Munro (1974) |
| Total No. of Spp. | 16 | | | | |
| Total No. of Fish | 198 | | | | |

Only species with >4% of abundance.

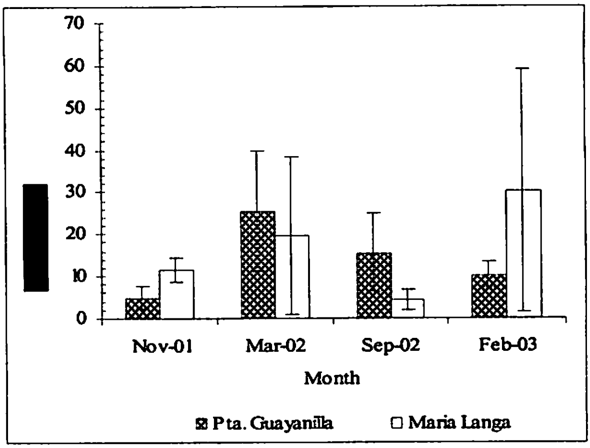


Figure 14. Mean number of fish caught by seine nets at Pta. Guayanilla and Maria Langa Sta.

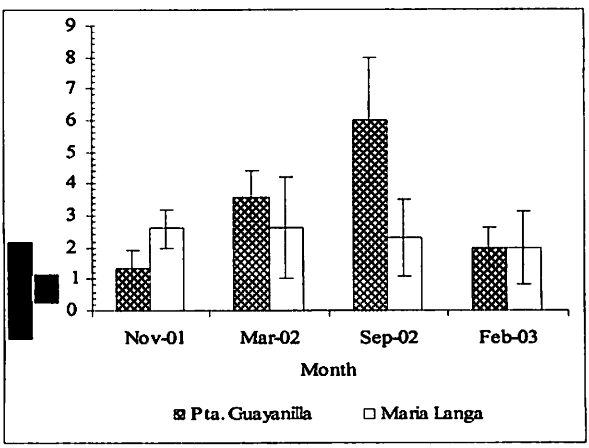


Figure 15. Mean number of fish caught by seine nets at Pta. Guayanilla and Maria Langa Sta.

## DISCUSSION

Fish communities from the Intake and Discharge Stations around the EcoElectrica LNG Plant differed in community structure. Our results from the Stationary Point Counts Visual Census show that the fish fauna had a very low index of similarity (32 %). Both stations have few species in common. Almost all the fish species composition on the Intake Sta. were dominated by one or two species of damselfishes. This lowered the diversity and the evenness indexes for the Intake Sta. In contrast, species richness values on the Discharge Sta. doubled the ones on the Intake Sta. Furthermore, species composition on the Discharge Sta. was more evenly distributed between Lutjanids, Labrids, and Haemulids. Results from the multivariate tests at different sampling periods also showed distinct fish communities among stations with little variation among sampling periods.

The differences in fish among stations may be attributed to interacting factors such as increased sedimentation, abundance of food resources, and structural heterogeneity in habitats. Several studies have found significant positive correlations between living coral cover, coral species diversity, and abundance of reef fishes (Gladfelter and Gladfelter 1978, Galzin et al. 1994). Furthermore, other studies found that fish biomass increased with structural heterogeneity of reef substratum (Carpenter et al. 1981). Previous benthic studies at the Discharge and the Intake Sta. found higher vertical relief, species diversity and live coral cover in the discharge than in the Intake Station (Castro and Garcia 1996). It is likely that the higher structure complexity in the Discharge Station offers more shelter to many reef fish near the discharge area.

Light availability may be an important component of feeding success, thus influencing on the habitat quality for nearshore fishes (McFarland 1991). Previous work on the effects of turbidity (with associated changes in light intensity) indicated that reductions in prey contrast, foraging efficiency, reactive distance, and visual range, reduce feeding success (McFarland 1991, Duffy- Anderson and Able 1999). Poor light conditions in areas under heavy sedimentation may have similar effects especially if fishes rely on vision to acquire food. The use of vision as the principal means of capturing prey is common and available evidence suggest that planktivorous fishes, such as grunts, are visual feeders (McFarland 1991). Data on sedimentation levels on the Intake and Discharge Sta. suggest that in general the Intake Sta. receives more heavy sedimentation than the Discharge Sta. (Vicente & Associates unpublished data). Therefore, light conditions may give a possible explanation on fish distribution among areas. However, while it seems likely that visually feeding fishes would be unable to feed in darkened under pier environments around heavy sedimentation, we cannot exclude the possibility that there was less food available on the Intake Sta. It may be that juvenile fishes around the Intake are able to successfully consume prey in darkened habitats but that food availability was too low to support good growth rates. Evidence of higher potential prey food availability around the Discharge Sta. comes from the higher abundance of zooplankton around this area, thus supporting complex trophic food webs on this station (Garcia 2002).

Although availability of food may be a factor in habitat selection, evidence suggests that predator avoidance may be important for juvenile fishes. One interesting finding was that the recruit phase of certain economically important reef fishes, such as the yellowtail snapper *Ocyurus chrysurus* and mahogany snapper *Lutjanus mahogany,* were found on algal patches, small patch reefs, and limited rubble areas surrounded by mud habitats in the Discharge Sta.; recruits of the french grunt *Haemulon flavolineatum* were found on isolated small patch reefs near the Intake Sta. It appears that these species use these nearshore sites as nursery areas as a refuge from predators in spite of the influence of natural gas plant effluents.

Comparisons of our field data with previous studies are complicated by differences in sampling gear, precise location of collection, and historical changes in habitat. In general, however, it appears that many of the same fishes have continued to dominate Guayanilla Bay nearshore habitats over the last 25 to 30 years. For example, Martin and Patus (1973), and Kimmel (1979) reported mojarras (Gerreidae), jacks (Carangidae), and the sea bream *Archosargus rhomboidalis* (Sparidae) as very common in their gill net collections. About 20 years later during the environmental studies preceding the construction and operation of a liquid natural gas thermoelectric power plant in Guayanilla Bay, these same fish families predominated at all seine collections whereas butterflyfish, grunts and the sea bream *A. rhomboidalis* dominated the fishtrap catches (EcoElectrica 1999). Finally, comparing our visual census results with previous fish censuses at the Intake and Discharge Sta. during the preoperational phase of the LNG thermoelectric power plant (Castro and Garcia 1996) we found similar fish faunas at both stations with minor differences in their species relative abundance.

The three methods used to sample nearshore habitats yield satisfactorily although somewhat different results due to biases inherent in each method. Fish traps tended to under represent certain species (such as *Stegastes fuscus*) that apparently avoided traps or were small enough to pass through the trap mesh and not to be caught. However, traps allowed accurate standard length measurements of the most abundant species. Baitfish such as the silver jenny, and small snooks were more abundant in seine net catches than in transects and fish traps. However, seines were limited to areas adjacent to the shore without rocky and hard bottom substrates. The visual census method can provide a list of species in an area. It is also possible to collect some length frequency information based on visual estimates of fish size. However, visual estimates are not as accurate as actually measuring each fish. Nevertheless, by utilizing these three methods at the same time, a more complete view of the finfish community can be achieved than from any one method alone. Results here also document the importance of these nearshore habitats for juvenile fishes. Most fish sampled by beach seine nets were smaller in size then their mean size at sexual maturity (for beach seine catches see Tables 3a, 3b) suggesting that seagrass beds around Punta Guayanilla and Maria Langa have an important nursery value for many reef fish inhabitating these nearshore areas.

This report is a product of a preliminary baseline study initiated to determine our state-of-knowledge about the impacts of Discharge/Intake effluents of EcoElectrica LNG Plant. It has demonstrated that there are some statistically significant differences between fish assemblages at Intake and

Discharge Sta. at the community level. The collection of data to explain the mechanisms for increased abundance of fish at the Discharge Sta. was beyond the scope of this study, however, we suggest that a number of mechanisms including reduced siltation, increased food abundance, and structural complexity, may be responsible for differences in fish fauna among stations. Identifying the level of current knowledge, areas of uncertainty, and future research needs could provide a more consistent review and evaluation of development proposals, and decrease potential impacts to threatened marine communities if the information is utilized in the course of permit review and assimilated into regulations.

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# Univariate and Multivariate Assessment of the Relationships Between Benthic Flora and Coastal Fish Communities of The Bahamas

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ABSTRACT

We completed surveys of coastal fish communities and benthic flora at different study sites, seasons, and years to identify differences in fish communities as well as to determine the features of the benthic flora that were most responsible for the observed differences in fish community composition. Fish communities were significantly different at different sites, seasons, and sample sequences (site-season-year combinations). Multivariate analyses identified cover of specific species and functional forms of benthic flora as the major factors determining species abundances. Total flora cover and seagrass cover were more important in influencing species and trophic group biomasses than abundances. Univariate analyses also highlighted the effects of total flora cover and cover of various functional groups on the number of species, diversity, and mean total biomass. In general, univariate analyses tended to provide stronger (more significant) results than multivariate analyses. We conclude that there is a strong relationship between benthic flora and fish community composition, and that different floral parameters affect different aspects of coastal fish communities.

KEY WORDS: Fish communities, benthic flora, benthic interactions

# Análisis Univariante y Multivariante de las Relaciones Entre Macroalgas/Hierba Marinas y Agregaciones de Peces en Habitates Costeros de Las Bahamas

Realizamos muestreos en comunidades de peces costeros y flora bentónica en diferentes localidades, estaciones y años, con los objetivos de determinar las diferencias entre las comunidades de peces y tambien que características de la flora bentónica presentan un mayor efecto sobre las comunidades de peces. Las comunidades de peces fueron significativamente diferentes en las distintas localidades, estaciones y la secuencia de muestreo (*i.e.* las combinaciones sitio-estación–año).El análisis multivariado identifico a la cobertura de especies y el grupo funcional de la flora bentónica como los principales factores que determinan la abundancia de especies. El total de cobertura vegetal y de *Thalassia testudinum* tuvo mayor importancia afectando la biomasa de especies y grupos tróficos. Análisis univariados enfatizan los efectos de la cobertura vegetal total y las coberturas de *Thalassia testudinum* y *Batophora oerstedii* sobre las abundancias totales, biomasas y diversidad. En general, los análisis univariados tienden a ser mas fuertes (*i.e.* mas significativos) que los análisis multivariados. Concluimos que hay una fuerte relación entre la flora bentónica y la composición de la comunidad de peces, y que diferentes parámetros afectan diferentes aspectos de la comunidad de peces costeros.

PALABRAS CLAVES: Macroalgas, hierbas marinas, peces, análisis, Bahamas

## INTRODUCTION

Habitat structure and complexity have been considered to be some of the primary factors that influence marine, estuarine, and freshwater fish communities worldwide (Huston 1979, Crowder and Cooper 1982, Roberts and Ormond 1987, McClanahan et al. 2000, Able et al. 2002). Coastal habitats, by their very nature, are influenced by oceanic and terrestrial influences, and consequently are shaped by a variety of terrestrial and aquatic characteristics (both abiotic and biotic) that can directly determine habitat quality, structure, and complexity, and indirectly determine fish community composition.

The first objective of this study was to determine the differences in fish communities at different coastal sites of Andros Island, The Bahamas. We then investigated how differences in the benthic flora contributed to observed differences in fish communities. By comparing fish communities to a suite of floral characteristics, we determined which features are most important in influencing fish communities. We predicted that fish community structure was not random and could be at least partially explained by some measures of floral composition. Because different habitat characteristics may influence different aspects of a fish community (e.g. diversity, species densities, or size spectra), we analyzed a variety of dependent variables commonly used to describe fish community composition. At a multivariate level, we analyzed individual species' abundances and biomasses, while at a univariate level, we analyzed Shannon-Weiner diversity, total abundances, number of species, and mean total biomass.

Some characteristics of an environment can likely target specific types of fish more than others. For example, the availability and types of flora may influence the occurrences of herbivores more than invertebrate feeders or piscivores. Thus, we hypothesized that floral-related differences in fish communities might also be detected at trophic group levels of analyses.

## MATERIALS AND METHODS

### Study Sites

Four study sites located along a 16 km stretch of coastline of eastern North Andros were incorporated into this study. SC1 and SC2 were spatially the closest (< 1 km apart), but varied in their physical properties. See Nero & Sealey (In press) for details of the study sites. Sites were visited in the summers of 2003 and 2004 and the winter of 2004, except for site SC2, which was only sampled in 2003.

**Beach Seining**

Beach seining followed standard seine protocol, and was completed with a seine net that was 20 m long and 1.5 m high, with a 1.2 m wide central pocket. The sampling schedule included a minimum of 15 seine events at each site in order to incorporate natural variability due to different tides and times of day (Nero & Sealey, In press).

Species and total abundances were recorded. In cases where large schools of atherinids were caught, these individuals were identified down to the family level (referred to as Atherinidae spp.), and their abundances were estimated. Fish were measured on a gridded tray and their lengths were then applied to standard length-weight relationships to obtain biomass estimates.

**Environmental Data**

Benthic flora variables were measured at each site once per sample sequence. Point intercept analysis was used to obtain cover estimates for each flora species. Each species was also assigned a functional group based on its morphology, and cover of each functional group was obtained by summing the cover of all representative species in that functional group. Presence/absence surveys of macroalgae and seagrass were used to determine Shannon-Weiner diversity.

**Data Analysis**

Analyses included univariate approaches (using SYSTAT v 10.2 and PRIMER v 5) and multivariate approaches (using PRIMER v 5). Analyses were based on abundance and biomass datasets, with data being analyzed first at the species level, then at the trophic group level. Species were sorted into trophic groups using PRIMER's 'aggregate' function and a master taxonomy list which assigned each species to a trophic level. Species were categorized as herbivores, primary predators (feeding mainly on small invertebrates), and secondary predators (feeding on large invertebrates and fish).

All data were fourth-root transformed, which allowed the estimated abundances of schooling silversides (Atherinidae) to be properly considered. Cluster analyses were used to identify outliers (defined as being less than 20% similar) to each data set. These outliers reflected minimal to no catch and were most likely due to poor seining or weather conditions; consequently, these outliers were omitted from future analyses. ANOSIM, PRIMER's multivariate equivalent to ANOVA, was used to test for effects of site, season, and sample sequence on individual seine events. The SIMPER routine identified the main species/trophic groups responsible for differences.

In order to address the influences of benthic flora features on the fish communities, data were averaged to yield one estimate per site and sampling sequence. Averaging of the data was completed using PRIMER's 'average' function. Environmental features, which represented conditions for each site at each sampling season/year, could then be matched to fish communities for each site/sampling year. Thus, there were 10 final data points, representing

Summer 2003, Winter 2004, and Summer 2004 for three sites (SC1, SH5, and BS2), and a Summer 2003 survey for site SC2, which could not be re-sampled in 2004 due to time constraints.

PRIMER's BIOENV routine identified the key benthic flora variables that best explained the variation in abundances and biomasses of species and trophic groups. Backward stepwise multiple regression was used to test for the effects of the various benthic features on univariate measurements of fish diversity, number of species, number of individuals, and mean total biomass. Correlation analysis (data not presented) verified that none of these dependent univariate variables was correlated to any other dependent variable.

## RESULTS

### Variability in Seine Events

ANOSIMS on individual seine events showed significant effects of site, season and sample sequence (significance = 0.1% for each) on fish species abundances and biomasses. Trophic group abundances were affected only by sample sequence (significance = 0.1%), while trophic group biomasses were only affected by site (significance = 4.2%).

SIMPER helped identify the sources of differences between different sites, and the species that accounted for differences in species abundances and biomasses are summarized in Table 1. It was often the case that the species that contributed to pairwise differences in abundances were not the same species that contributed to pairwise differences in biomasses. For example, BS2 was distinguished from SC2 by a higher abundance of *Eucinostomus melanopterus*, but higher biomasses (and larger individuals) of *Albula vulpes* and *Sphyraena barracuda*.

### Averaged Site and Sample Sequence Values

Typically, fish community diversity (Figure 1a) at any given site tended to be higher in the winter sample sequence than in the two summer seasons. However, SC1 showed very little difference in fish diversity between Winter 2004 and Summer 2004. The fish community at BS2 had the highest diversity in Summer 2003 and Winter 2004, but the SC1 fish community was most diverse in Summer 2004. A similar pattern of increased biomass (Figure 1b) at winter was also observed, except again for site SC1, where there was little difference between Winter 2003 and Summer 2004. One seine event in Summer 2004 at SC1 resulted in over 600 mixed jacks being collected; this unusually high seine event is likely responsible for the inflated mean biomass for Summer 2004. In most cases, the error bars are very large, especially for biomass estimates, indicating a very high degree of variability among individual seines.

**Table 1.** Results of SIMPER analyses for pairwise comparisons of sites. Percent values represent the average dissimilarity between the two sites. Cells above the diagonal represent analyses completed on species biomasses, while cells below the diagonal represent analyses completed on species abundances. Species listed represent those which contributed to the top 50% of pairwise dissimilarity. Species in bold were more abundant or had higher biomass at the site above the cell, while species not in bold were more abundant or in higher biomass at the site to the left of the cell.

| | BS2 | SC1 | SC2 | SH5 |
|---|---|---|---|---|
| **BS2** | | 82.52%<br>***Trachinotus goodei***<br>*Albula vulpes*<br>***Trachinotus falcatus***<br>*Eucinostomus melanopterus* | 74.59%<br>***Trachinotus goodei***<br>*Albula vulpes*<br>*Sphyraena barracuda*<br>***Gerres cinereus*** | 80.87%<br>***Trachinotus goodei***<br>*Sphyraena barracuda*<br>*Eucinostomus melanopterus*<br>*Albula vulpes* |
| **SC1** | 75.58%<br>*Atherinidae spp.*<br>*Trachinotus falcatus*<br>*Trachinotus goodei*<br>***Eucinostomus melanopterus*** | | 64.58%<br>*Trachinotus goodei*<br>*Trachinotus falcatus*<br>***Gerres cinereus***<br>***Eucinostomus melanopterus*** | 66.48%<br>*Trachinotus goodei*<br>*Trachinotus falcatus*<br>***Eucinostomus melanopterus*** |
| **SC2** | 62.10%<br>*Atherinidae spp.*<br>*Trachinotus goodei*<br>***Eucinostomus melanopterus***<br>*Gerres cinereus* | 62.22%<br>***Atherinidae spp.***<br>***Trachinotus falcatus***<br>***Trachinotus goodei***<br>*Eucinostomus melanopterus* | | 66.75%<br>*Trachinotus goodei*<br>*Eucinostomus melanopterus*<br>*Gerres cinereus*<br>*Strongylura notata* |
| ***SH5*** | 72.05%<br>***Eucinostomus melanopterus***<br>***Sphyraena barracuda***<br>*Atherinidae spp.*<br>*Trachinotus falcatus* | 64.16%<br>***Atherinidae spp.***<br>***Trachinotus falcatus***<br>***Trachinotus goodei***<br>***Albula vulpes*** | 60.75%<br>***Eucinostomus melanopterus***<br>*Atherinidae spp.*<br>*Trachinotus goodei*<br>*Harengula humeralis* | |

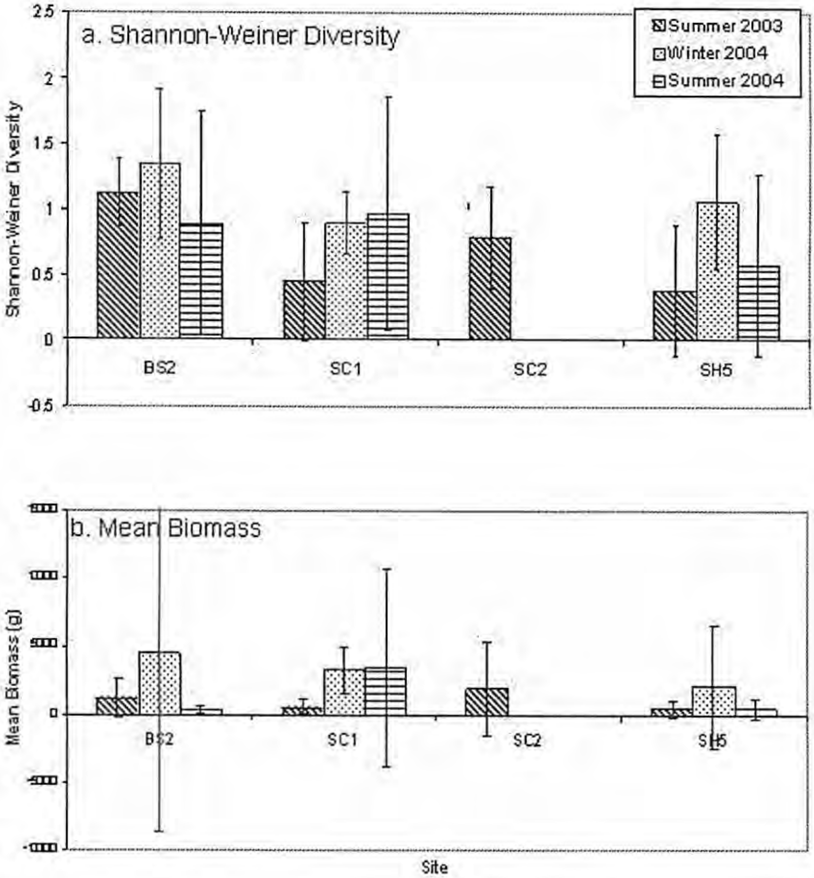


**Figure 1.** Values of mean a) Shannon-Weiner Diversity and b) Total biomass at the different site and sample sequence combinations. Error bars represent the 95% confidence interval. SC2 was only sampled in Summer 2003.

The two-dimensional MDS plot (Figure 2) indicated that species abundances show strong seasonal and site influences. The plot shows that communities from the same site (e.g. BS2) but different sample sequences are very similar, but in other cases (e.g. SC1 and SH5), fish communities from the sample sequence but different sites are more similar. In particular, there is a noticeable separation between the Winter 2004 communities and all summer communities of those sites. The MDS plot indicates that the BS2 fish community is most unlike those of the other sites.

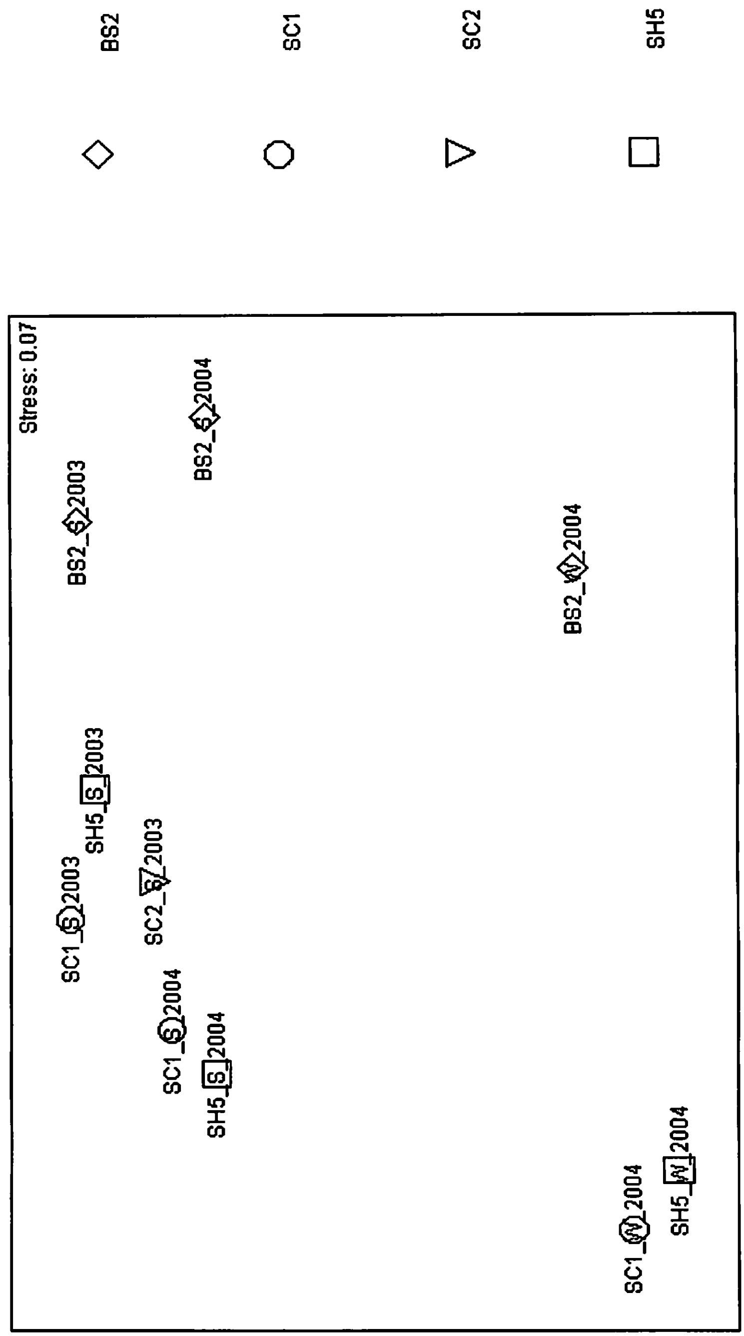


**Figure 2.** MDS plot based on abundances of fish species averaged for each site and sample sequence combination. Seasons are denoted as S (Summer) or W (Winter).

**Relationships between Benthic Flora and Fish Communities**

BIOENV provided the five best models for each fish parameter, and the strongest influences are summarized in Figure 3. For fish species abundances, each of the five best models explained a moderate degree of variation, with values of Spearman's rank correlation, $\rho_s$, ranging from 0.457 to 0.465. Cover of *Batophora oerstedii* and the branching functional group were the most common variables included in the best models, although cover of *Udotea spp.* and *Dasycladus vermicularis* were also important factors influencing species abundances.

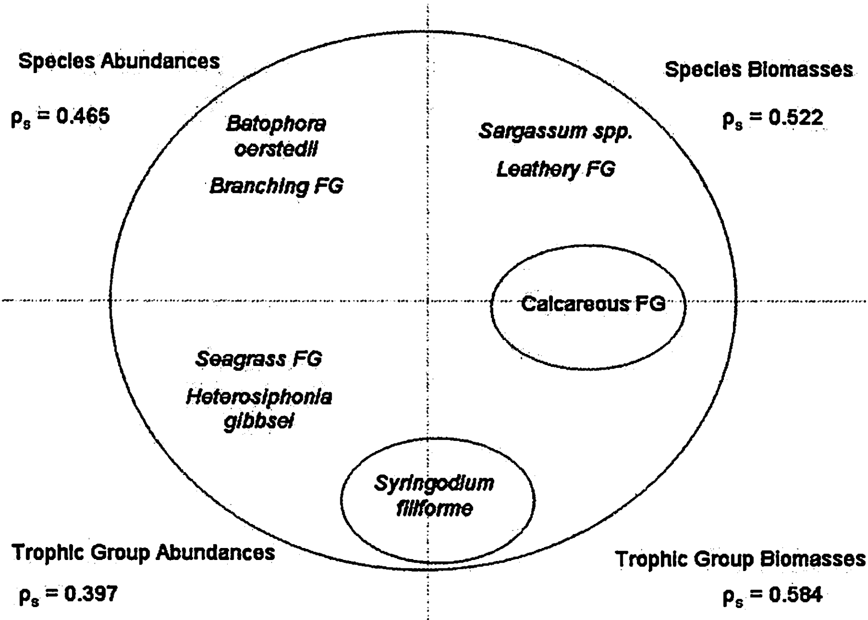


**Figure 3.** Representation of benthic flora features' effects on fish species and trophic groups abundances and biomasses. Factors that affect a single parameter are included only in that parameter's quadrant, while factors that affect more than one parameter are included in circles that span all affected parameters.

BIOENV analyses showed that the cover of *Sargassum spp.*,the calcareous functional group, and the leathery functional group were most influential in affecting fish species biomasses. *Dasycladus vermicularis* and filamentous functional group were also commonly included in the best models. The five best models had Spearman's rank correlation coefficients ranging from 0.495 to 0.522.

Cover of *Syringodium filiforme, Heterosiphonia gibbesei*, and the seagrass functional group were included in each of the five best BIOENV models explaining patterns in trophic group abundances. The five best models had $\rho_s$ values ranging from 0.386 to 0.397. Cover of *Dictyota spp.* and *Chondria spp.* were also included in several of the models.

BIOENV models that determined relationships between benthic flora features and trophic group biomasses were highly variable. The top five models had Spearman's rank correlation coefficients that ranged from 0.560 to 0.584, and included 10 different species. The features common to all five top models were cover of *Syringodium filiforme* and the calcareous functional group, although cover of the turf functional group and *Laurencia* spp. was also important.

Multiple regression analyses, summarized in Table 2, investigated the effects of benthic flora factors on univariate dependent variables. The total number of individuals was not significantly influenced by any of the independent variables investigated. Cover of different species and functional groups affected different parameters, although overall cover of benthic flora was also often incorporated into the models.

**Table 2.** Results of stepwise backward multiple regression analyses. Variables were omitted one by one until only significant variables remained in the model.

| Parameter | Significant Variables | *p* value | $R^2$ value |
|---|---|---|---|
| Number of Species | Flora diversity | 0.019 | 0.935 |
| | Flora cover | 0.001 | |
| | *Halodule wrightii* cover | 0.016 | |
| | Turf cover | 0.001 | |
| | *Batophora oerstedii* cover | 0.001 | |
| Number of Individuals | No significant variables | n/a | n/a |
| Shannon-Weiner Diversity (at the species level) | Flora cover | 0.003 | 0.990 |
| | *Thalassia testudinum* cover | 0.006 | |
| | Branching algae cover | 0.006 | |
| | *Laurencia intricata* cover | 0.000 | |
| | Calcareous algae cover | 0.000 | |
| Mean Total Biomass | Flora diversity | 0.041 | 0.733 |
| | Calcareous algae cover | 0.020 | |

## DISCUSSION

There were clear distinctions in the types, numbers, and biomasses of fish associated with each site. The fish communities from BS2, which was characterized by having benthic flora assemblages most unlike those of other sites, were the most disparate, and included many unique species, such as *Sphoeroides testudinus*, *Sphoeroides spengleris*, and *Hippocampus erectus*. We conclude that there is a direct link between the environmental features and the fish community at a site. Furthermore, we conclude that different specific benthic features affect different aspects of fish communities. Species and trophic group abundances were most influenced by species and/or functional groups that were characteristically tall and/or complex (e.g. seagrasses and branching algae). Species and trophic group biomasses tended to be most influenced by the cover of tougher morphologies, such as leathery and calcareous morphologies. In general, analyses of the environmental data showed strong effects of benthic flora characteristics on univariate parameters (high $R^2$ values) and moderate effects on multivariate parameters (moderate Spearman's Rank Coefficient values).

In our studies, some species, such as *Eucinostomus melanopterus* and Atherinid spp. were ubiquitous, but their relative abundances and/or biomasses varied greatly and contributed to a great deal of the variation between different sites. *Albula vulpes*, for example, was observed at all sites, and in fairly similar abundances. However, the individuals observed at BS2 samples were *much* larger adults, compared to the smaller, post-recruitment sized individuals observed at all other sites. Benthic flora features at sites SC1, SC2, and SH5 may be more favorable to recently settled *Albula vulpes*, while benthic flora features of BS2 may provide better resource for adults.

Relationships between flora and fishes tended to be stronger in analyses completed at the fish species level than at the trophic group level. Such results suggest that studies of responses of fish communities to environmental features are best understood at species levels, rather than at broader, taxa-reducing scales. Reducing 41 species down to only three trophic groups may have accounted for the decrease in occurrence and/or strength of relationships between benthic flora and fishes. Furthermore, since different species have different reproductive, dietary, and behavioral patterns, it can be expected that responses to different environmental and temporal states will be detected at the species level. In our study, the species that would most likely be affected by changes in the benthos are herbivores and invertebrate feeders, which rely on the benthos for a direct or indirect food supply. However, because there were many species that were reduced down to these two groups, it is possible that natural species-level variations clouded out trophic group responses. Ideally, analyzing the data at the trophic-group level would provide insight into how coastal fish communities respond to resource availabilities (i.e. availability of flora for herbivores or invertebrates for primary predators), but our analyses provided less than optimal results. To provide more meaningful results, future studies of such trophic group responses should incorporate a finer scale of trophic level assignments and/or more frequent sampling of fishes and environments.

The weakest relationship was that between benthic flora and trophic group abundances, whose BIOENV analysis has the lowest Spearman's rank coefficient value of 0.397. Past work has shown that abundances of various trophic groups on reefs are significantly influenced by flora assemblage composition (McClanahan et al. 2001) and coral cover and topographic complexity (Connell and Kingsford 1998). However, responses of fishes on reefs (which consist mainly of adult fishes on a consolidated substrate) may be quite different than responses of fishes in coastal habitats (which are typically composed of sub-adult individuals in an unconsolidated substrate dominated by benthic flora).

Although it is a common notion that diversity begets diversity, our univariate analyses lead us to conclude that this is not necessarily always the case. Our results suggest that benthic flora cover, and not flora diversity, was much more important in influencing fish diversity. Parker et al. (2001) also determined that indices of epifaunal diversity were more strongly related to total plant surface area than to plant diversity. We believe that there are very few species-specific qualities that determine the resource-providing abilities of different flora species. Thus, parameters that measure some aspect of total flora abundance (e.g. benthic flora cover) or cover of similar morphologies (e.g. branching floral forms) are probably better predictors of fish diversity.

Overall, the values of Spearman's Rank Coefficients for the various BIOENV routines were relatively low. Thus, it is possible that the environmental factors investigated were not the most important in influencing fish communities, and that other site-specific factors not considered by this study, (such as temperature, prey densities, and wave energy), may be more critical than those addressed here. Additionally, as concluded by a similar study (Hovel et al. 2002), it is possible that processes operating at larger spatial scales, such as regional storm events and larval delivery by currents, may be a source of influence on coastal fish community composition. This is likely the case, since nearshore habitats are commonly occupied by young recruits (Mateo and Tobias 2001) that rely at least partially on oceanographic influences for long-distance transport to settlement sites (Underwood and Keough 2001).

The combination of multivariate and univariate analyses helped to elucidate the benthic factors most affecting various aspects of fish communities. In some cases, the two types of analyses stressed the effects of different floral features. For example, univariate analyses commonly highlighted the role of total floral cover in shaping fish communities, but this feature was not important in any of the multivariate analyses. Conversely, the multivariate analyses featured the importance of many floral species or functional groups that were not highlighted by univariate analyses. In this case, multivariate analyses alone probably gives a better understanding than do univariate analyses alone, but omission of either type of analysis leads to an incomplete picture of the wide array of factors that may influence the composition of fish communities.

In conclusion, we have demonstrated that there is a clear link between the benthic floral composition of a site and that site's fish community. The relationships between flora and fauna are not easily discerned, however, because different aspects of the flora influence different univariate and multivariate fish parameters. Our results indicate that fish are responsive to their habitat, suggesting that changes in the benthos due to natural (e.g. storms) or anthropogenic (e.g. eutrophication or sedimentation) activities can affect fish community composition.

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# Status of *Acropora palmata* Populations off the Coast of South Caicos, Turks and Caicos Islands

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ABSTRACT

This study is the first detailed assessment of *A. palmata* populations of the Turks and Caicos Islands. A total of 203 individual colonies and 62 thickets were tagged on five shallow reefs. Depth, percentages of living tissue, recent mortality and old skeleton were estimated. Presence of disease and predatory snails was noted, and disease spread and grazing rates of the snails estimated. Colonies were found in depths of 0.2 - 4 m. Living tissue for individual colonies (75.9% ± 2.2 SE) was significantly greater than for thickets (58.6% ± 3.6) and in both cases exceeded old skeleton (individuals: 22.7% ± 2.1 SE, thickets: 38.0% ± 3.4 SE). Percentage of recent mortality was very low (individuals: 1.3% ± 0.3 SE, thickets: 3.4% ± 0.7%). We found WBD (n = 2), white pox disease a (WPDa) (n = 7) and white pox disease b (WPDb) (n = 14) with greatly varying spreading rates. The WBD infected colonies showed an atypical spread from the top of the branch towards the base. *Coralliophila abbreviata* and *C. caribaea* affected 3.7 - 54.7% of the populations (grazing rate: 4.29 $cm^2$/day/snail ± 1.16 SE). South Caicos' *A. palmata* populations are still in good condition, though increasing human disturbances combined with disease and predatory snails may threaten these populations.

KEY WORDS: *Acropora palmata*, assessment, Turks and Caicos Islands

# Estado de las Poblaciones de *Acropora palmata* en la Costa sur de South Caicos, las Islas Turks & Caicos

Durante nuestra investigación marcamos un total de 203 colonias individuales y 64 arbustos (que constituyen varias colonias) de arrecifes someros. Estimamos la profundidad, el porcentaje de tejido vivo y muerto de cada colonia. La presencia de la enfermedad del blanqueo y de caracoles depredadores fueron también anotadas. Estimamos también la tasa de cambio de la difusión de la enfermedad del blanqueo y la tasa de consumos de tejido por parte de los caracoles. Las colonias se encuentran en profundidades entre 0.2 - 4 m. El porcentaje de tejido vivo en las colonias fue de 75.85% (± 2.17 SE) y fue mayor que en los arbustos (58.59% ± 3.63). En ambos casos excede el esqueleto (colonias individuales: 22.73% ± 2.07 SE, arbustos: 38.03% ± 3.38 SE). El porcentaje de mortalidad reciente fue muy bajo (colonias individuales: 1.33% ± 0.26 SE, arbustos: 3.38% ± 0.72%). Encontramos varias enfermedades: WBD (n = 2), WPDa (n = 7) y WPDb (n = 14). Una de las colonias infectadas mostraba una atípica forma de difundirse desde la cabeza del coral hacia la base. Los caracoles *Coralliophila abbreviata* y *C. caribaea* afectaron entre 3.7 y 54.7% de la población de coral. Su tasa de consumo se coral se estimo en 4.29cm$^2$/dia/caracol ±1.16 SE). La población del sur de la isla de Caicos de *A. palmata* esta aun en buenas condiciones. Sin embargo el aumento del disturbio por actividades humanas y la depredación por caracoles puede amenazar estas poblaciones en el futuro.

PALABRAS CLAVES: *Acropora palmata,* estado de las poblaciones, Islas Turks & Caicos

## INTRODUCTION

The Caribbean elkhorn coral (*Acropora palmata*) is one of the main reef-building coral species of the Caribbean and Florida reef tract (Lirman 2002). Colonies prefer exposed reef crest and fore reef environments in depths of less than 6 m (Adey and Burke 1976), although isolated corals may occur to a depth of 18 m (Bruckner 2002). It is the largest of the acroporids with colonies growing up to 3 m in diameter (Bruckner 2002). The three-dimensional shape of this coral species makes it essential for creating habitat for many reef fish and other reef associated organisms (Gladfelter and Gladfelter 1978, Lirman 1999, 2002). The growth of detached fragments in between periods of disturbances creates dense thickets (Adey and Burke 1976). Thicket formation reduces wave energy from offshore and protects seagrass, mangrove habitats and coastline (Bruckner 2002). The loss of thickets results in major losses of reef function and biodiversity (Bruckner 2002). In areas where storm disturbances are low, only isolated colonies occur because of decreased fragmentation (Dustan 1977).

In many areas, the characteristic "*Acropora palmata* zone" has been transformed into rubble fields with a few, isolated living colonies (e.g. Weil et al. 2002). In the early 1970s, *A. palmata* populations were relatively healthy, but subsequent declines were observed in the 1970s to 1980s and again through the 1990s (Kramer 2002). Over the last three decades, the Caribbean has experiences losses of 95% or more of the once dominating *A. palmata* populations (Precht et al. 2002). Paleontological studies show acroporids dominated coral reefs communities throughout the Caribbean from the Pleistocene to the end of the 1970s, suggesting the present mortality rates are without precedent in the Holocene Epoch (Mesolella 1967, Jackson 1992). In most cases, *A. palmata* populations are being affected by a number of different stresses simultaneously resulting in a decreased ability to regenerate (Aronson et al. 2002). In 1999, *A. palmata* was added together with *A. cervicornis* to the Candidate Species List of the Endangered Species Act by National Oceanic and Atmospheric Administration (NOAA)'s National Marine Fisheries Service (Bruckner 2002), and a status review report put together by NOAA Fisheries, Protected Resources Division is expected in March 2005 (J. Moore Pers. comm.).

Until recently White Banding Disease (WBD) was considered the dominant cause of *A. palmata* mortality throughout the Caribbean (Aronson and Precht 2001). The paleontologically unprecedented outbreaks of WBD have led many to speculate anthropogenic stressors are the heart of the disease outbreaks, but no direct evidence of this has yet been found (Richardson 1998, Aronson and Precht 2001). Colonies infected by WBD show a distinctive white band moving from the base to the branches of the colony (Gladfelter 1982). First documented in 1996, the highly contagious and rapidly spreading White Pox Disease (WPD) now rivals WBD as the leading cause of disease related *A. palmata* mortality (Patterson et al. 2002). It has been suggested that WPD is caused by a common human fecal enterobacterium, *Serratia marcescens* (Patterson et al. 2002).

Predation by snails is also a cause of significant concern, as they can quickly consume large quantities of coral (Baums et al. 2003a). In the past few decades, 10 - 20% of *A. palmata* populations have been observed to be infested by the corallivorous snail *Coralliophila abbreviate* in the Florida Keys (Baums et al. 2003a). Additionally, feeding rates as high as 9 $cm^2$/snail/day have been calculated, indicating that snails have the potential to seriously affect the viability of *A. palmata* (Baums et al. 2003a).

The Turks and Caicos Islands (TCI) have low human population pressure when compared to many other Caribbean islands, and the one study that has been done in the area describes the reefs to be in generally good condition (Riegl et al. 2003). Around the east and south-east side of South Caicos and along the west side of Long Cay, healthy looking colonies and even thickets of *A. palmata* have been observed. The aims of this research project are to collect baseline data of *A. palmata* populations on the reefs around South Caicos and Long Cay and to determine their health status. We expect that *A. palmata* populations on reefs around South Caicos are in very good condition without significant signs of disease and snail predation.

## MATERIALS AND METHODS

### Study Sites, Depth and Density Estimation

Five different reefs off the coast of South Caicos, TCI, were selected to determine the *A. palmata* population (Figure 1). Shark Alley and Cox Development are fringing reefs. Admirals Aquarium, Tuckers and South End Long Cay are patch reefs.

All research was conducted snorkeling during March and April 2004. The depth the colonies were found in was measured using the base of the colony as a reference point. To estimate density of the different reefs, the size of each reef monitored was measured using 30 m measure tapes that were run in straight lines along the edges of the total reef area (rectangular areas) and divided by the number of colonies found in these areas.

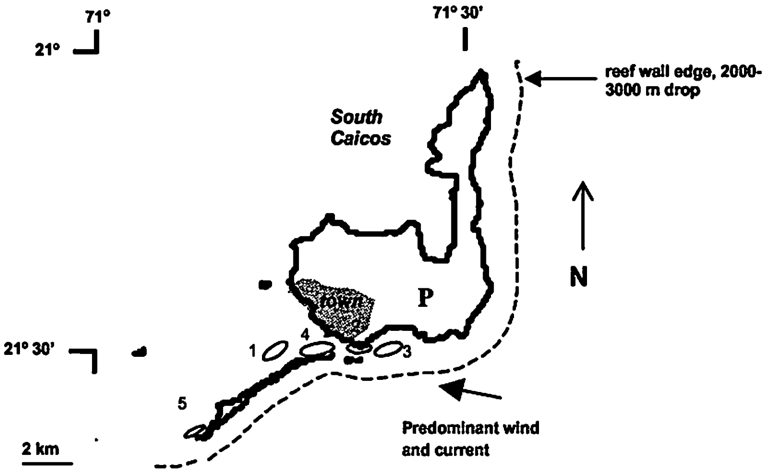


**Figure 1.** Map of South Caicos with the study sites (1 = Admirals Aquarium, 2 = Cox Development, 3 = Tuckers, 4 = Shark Alley, 5 = South End Long Cay) and showing the predominant wind and current direction.

### Health Status

Each colony measured was tagged using a numbered aluminum tag hammered into dead substrate close to the base of the colony. During most of the study period, the sea was very rough. Hence, we were not able to include all colonies in the study since some were too difficult to survey without damaging corals. Smaller individuals may be slightly under-represented because, due to time constrains, we focused on larger colonies to cover a greater survey area. Living tissue, recent mortality, and old dead skeleton of each tagged colony were visually estimated. Areas of recent mortality were evident as white bare skeleton, whereas old dead areas were covered with algae.

### Diseases and Their Spread

Each tagged colony was observed for disease. Colonies that showed signs of disease were tagged with a cable tie (if possible it was placed on dead skeleton) as a reference point. Calipers were used to measure the width and length, to the closest millimeter, of either the total recently dead area killed off by WBD or the width and length of each individual pox for White Pox Disease a (WPDa). The course of White Pox Disease b (WPDb) was monitored by counting the number of pox present on one colony and recounting them when revisited. The colonies were revisited one to three times during the study period to calculate the rate the disease proceeded.

### Predatory Snails and Their Grazing Rates

Pilot observations showed that the main predators of *A. palmata* of South Caicos' reefs were the two corallivorous snails *Coralliophila abbreviata* and *C. caribaea*. If corallivorous snails were observed on tagged colonies, the quantity of the snails was visually estimated. Individual snails were collected, the species noted, and siphonal length measured to the nearest millimeter using a caliper to determine the size distribution. Some randomly selected snail infested colonies were revisited to estimate approximate rates of grazing. Cable ties were tied at the bases of grazed branches (if possible on dead areas) to determine a reference point. Grazing activity was then calculated measuring the distance from the cable tie to the furthest boundary of living tissue and grazed area and the width of the grazed area to the nearest millimeter using a caliper.

### Statistical Analysis

A one-way ANOVA was conducted when data was homogenous (Levene's test) and normal (normal probability plot of residuals), or a non-parametric Kruskal Wallis ANOVA median test was used.

## RESULTS

### Density and Depth

We surveyed 203 individual colonies and 62 thickets consisting of 280 individual colonies (Table 1). The five reefs surveyed differed in size. We did not measure the reef area of South End Long Cay due to time and weather constrains. The density of *A. palmata* individual colonies, thickets, and total colonies varied between the sites (Table 1). Colonies and thickets were found in very shallow areas on all reefs ranging from 0.2 to 0.5 m. At South End Long Cay, and Admirals Aquarium, colonies were found down to 1 m, whereas at Tuckers colonies were observed down to 4 m depth. The mean depth of *A. palmata* individual colonies and thickets was 1.2 m (± 0.04 SE).

### Health Status

Overall, individual colonies and thickets combined had 72.7% (± 1.9 SE) living tissue, 25.5% (± 1.8 SE), old dead skeleton, and 1.8% (± 0.3 SE) recent mortality. There was a significant difference between these three categories (Kruskal-Wallis: $H(1, n = 813) = 505.205$, $p < 0.001$).

We also found significant differences between colonies and thickets in the amount of living tissue (ind. colonies 75.8% (± 2.2 SE), thickets 59% (± 3.7 SE)), old dead skeleton (ind. colonies 22.7% (± 2.1 SE), thickets 36.8% (± 3.4 SE)), and recent mortality (ind. colonies 1.3% (± 0.3 SE), thickets 3.5% (± 0.7 SE)) (Kruskal Wallis: living tissue $H(1, n = 265) = 18.825$, $p < 0.001$; old dead skeleton $H(1, n = 265) = 17.863$, $p < 0.0001$, recent mortality $H(1, n = 265) = 17.044$, $p < 0.0001$).

**Table 1.** Area (m²) of reefs, number of individual colonies, thickets with individual colonies in parentheses, total number of individual colonies and thickets' individual colonies) surveyed and density (colonies/m²) of only individual colonies, thickets and total colonies. Admirals = Admirals Aquarium, Cox = Cox Development, Shark = Shark Alley, SELC = South End Long Cay.

| site | area m² | individual colonies | thickets (colonies) | total colonies | density (colonies/m²) |
|---|---|---|---|---|---|
| Admirals | 900 | 6 | 0 | 6 | 0.007 |
| Cox | 8,360 | 85 | 24 (99) | 184 | 0.01/0.003/0.02 |
| Shark | 9,273 | 50 | 31 (146) | 196 | 0.005/0.003/0.02 |
| Tuckers | 28,215 | 50 | 4 (27) | 77 | 0.002/0.0002/0.003 |
| SELC | - | 12 | 3 (8) | 20 | - |
| total | - | 203 | 62 (280) | 483 | - |

Individual colonies at all sites had more living tissue than old dead skeleton, whereas thickets showed much more variation (Figure 2a,b). For thickets at Cox Development and Shark Alley living tissue was significantly greater than old dead skeleton (Kruskal-Wallis: Cox Development $H$ (1, n = 48) = 9.932, p = 0.0016; Shark Alley $H$(1, n = 62) = 3.895, p = 0.048), whereas at Tuckers Reef old dead skeleton equals the amount of living tissue (Kruskal-Wallis: $H$(1, n = 12) = 1.283, p = 0.257) (Figure 2b). Shark Alley and Tuckers showed highest percentage of recent mortality (Figure 2b). Admirals was the only site that had 100% living tissue. South End Long Cay did not show any recent mortality.

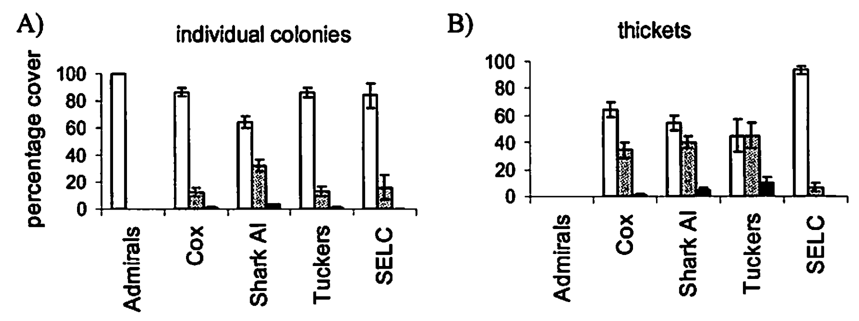


**Figure 2.** Percentage living tissue, old dead skeleton and recent mortality of a) individual *A. plamata* colonies and b) *A. plamata* thickets for each site. Error-bars represent standard errors. white = living tissue, grey = old dead skeleton, black = recent mortality.

### Diseases

Across all sites 11.5% of the individual colonies were found to be infected with WBD (0.5%), WPDa (4.3%), WPDb (6.7%), and WBD and WPDa at the same time (0.5%). Of all thickets 6.3% were observed to have either WPDa (4.7%) or WBD (1.6%). Shark Alley was the only site where WBD occurred, WPDb was observed at Cox Development and Tuckers and WPDa was found at Admirals Aquarium, Cox Development and Shark Alley. The percentage of diseased colonies at the different sites ranged from 0% to 17.9%. At South End Long Cay, none of the tagged colonies were infected by disease. The two colonies that were found with WBD at Shark Alley were in relatively close proximity to each other. Both instances of WBD exhibited atypical spread patterns. On one colony the band appeared to have initially followed a normal spread pattern (from the base to the branches). However, once the end of the second branch was reached, the disease appeared to have spread to the tip of a neighboring branch. The other colony also showed this atypical spread pattern, starting at the tip of the branch and working its way down the branch. Visual surveys showed that WPDb tended to be found on colonies within close proximity to other WPDb colonies; this trend was not nearly as strong with WPDa. The atypically WBD showed a mean spreading rate of 2.80 $cm^2$/day (± 0.8 SE, n = 3) and a maximum rate of 5.47 $cm^2$/day. At Shark Alley, WPDa showed a higher progress rate (1.83 cm/day, ± 0.54 SE, n = 13) compared to Admirals Aquarium (0.09 cm/day, ± 0.03 SE, n = 4) and Cox Development (0.20 cm/day, n = 1). WPDb spreading rate was similar between Cox Development (0.54 cm/day, ± 0.71 SE, n = 4) and Tuckers (0.67 cm/day, ± 0.54 SE, n = 6). At Tuckers two colonies with WPDb had decreasing numbers of pox, whereas at Cox Development the numbers of pox on one colony did not change, though two colonies showed first increasing numbers and then decreasing. All other colonies of these sites and the other reefs showed increasing numbers of pox.

### Predatory Snails and Their Grazing Rates

Predatory snails, *C. abbreviata* and *C. caribbaea*, were found on 21% of the individual colonies and 28% of the thickets across all sites. Most often there were less than 10 snails followed by 10 - 19 snails per colony or thicket (Table 2). One individual colony and one thicket had more than 50 predatory snails grazing on its tissue (Table 2).

**Table 2.** Number of predatory snails found on individual colonies and thickets.

| | number of snails | | | | | | |
|---|---|---|---|---|---|---|---|
| | <10 | 10-19 | 20-29 | 30-39 | 40-49 | 50+ | total |
| individual colonies | 23 | 13 | 3 | 3 | 0 | 1 | 43 |
| thickets | 8 | 5 | 2 | 2 | 0 | 1 | 18 |
| total | 31 | 18 | 5 | 5 | 0 | 2 | 61 |

Snail infestation differed between the reefs and the individual colonies and thickets (Figure 3). At Cox Development only individual colonies were found with predatory snails, whereas at South End Long Cay snails were only observed on thickets. These infestations accounted for less than 10% of the individual colonies and thickets at each site, respectively (Figure 3). Of all sites, colonies at Shark Alley were infested most heavily by predatory snails whereas no snails were found at Admirals Aquarium. At Shark Alley and Tuckers snails of the species *C. abbreviata* were collected to look at the frequency distribution. The smallest snail measured was 2 mm and the largest 35 mm in length. There was no difference in the size distribution between the two sites (one-way ANOVA: $F$ (1, 164) = 0.132, p = 0.716; Tuckers: mean = 17.2 mm ± 0.5 SE; Shark Alley: mean = 17.35 ± 1.3 SE). The mean grazing rate was 4.29 cm/snail/day (± 1.2 SE) for all sites combined. There was no significant difference in the grazing rate between the reefs (one-way ANOVA: $F_{2,12} = 0.026$, p = 0.801; Tuckers: 2.7 cm/snail/day ± 0 SE, n = 2; Shark Alley: 4.99 cm/snail/day ± 1.6 SE, n = 8; Cox: 3.8 cm/snail/day ± 2.0 SE, n = 5).

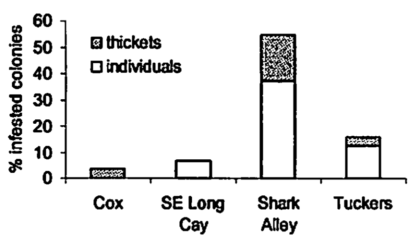


**Figure 3.** Percentage colonies infested with predatory snails (*C. abbreviata* and *C. caribbaea*) for total individual colonies and thickets per site. The percentage of both categories was calculated from the total number of individual colonies and thickets per site combined. For sample sizes see table 2.

**Predatory Snails and Disease Incidences**

Only six of all 280 individual colonies and thickets were found to be infected by diseases while simultaneously being grazed on by predatory snails (Table 3). Five of these colonies were found at Shark Alley, where more than 50% of the colonies that we surveyed were found with snails. The remaining snail and disease infected colony was found at Tuckers, where nine more colonies were found with only snails. Hence, there does not seem to be a relationship between disease infection and snail predation.

Table 3. Number of colonies and thickets combined for each site with presence or absence of disease and/or snails.

| | Admirals | Cox | Shark Al | SELC | Tuckers |
|---|---|---|---|---|---|
| total | 6 | 109 | 81 | 15 | 56 |
| healthy | 1 | 98 | 34 | 15 | 38 |
| disease, no snails | 1 | 7 | 5 | 0 | 9 |
| disease, snails | 0 | 0 | 5 | 0 | 1 |
| snails only | 0 | 4 | 42 | 0 | 8 |

## DISCUSSION

### Density and Depth

A study conducted in the Florida Keys found *A. palmata* density ranging from 0.01 to 0.07 colonies/m among different regions (Chiappone et al. 2002). These values differed from our findings (0.0002-0.01 colonies/m). These discrepancies may be caused by an underestimation of colonies in our study, since due to weather limitations and time constrains, some fragments and smaller colonies were ignored. Furthermore, Chiappone et al. (2002) used transects, while we measured total area of the reefs where we surveyed the *A. palmata* populations. Considering that the predominant habitat of *A. palmata* are shallow outer reef slopes exposed to wave action (Vernon 2000), our results may be an underestimation of *A. palmata* density when compared to Chiappone et al. (2002). In the past, most *A. palmata* populations throughout the Caribbean were mainly composed of dense thickets, but now individual colonies are more prevalent (Bruckner 2002). We found both individuals and thickets on the reefs. Because thickets develop during periods between storms (Adey and Burke 1976), the thickets we observed on the reefs off South Caicos may have grown due to the fact that the last hurricane hit the TCI over 14 years ago. Since the high growth rate of *A. palmata* is 5 - 10 cm per year (Adey and Burke 1976), 14 years may be a long enough time period to grow extensive thicket populations.

The depth range of *A. palmata* around South Caicos varied from 0.2 - 3.5 m. However, *A. palmata* grows ideally in depths of 5 - 6 m (Bruckner 2002). Shallow depths could potentially inhibit the growth of *A. palmata* because of the increased risk of sub-aerial exposure and high sea surfaces temperatures, which can cause bleaching and eventually coral mortality. Despite this, we found large, healthy populations in depths less than 5 m. This may be due to the absence of bleaching events in the TCI over the last decades. However, there is no data available supporting this hypothesis.

### Health Status

Overall, the *A. palmata* populations of South Caicos are in relatively healthy condition compared to populations at other locations. The amount of live tissue of *A. palmata* colonies in this study ranges from 65% to 100% per site with an average of around 80%. In contrast, a study performed in the Florida Keys, USA found approximately 60% live coral tissue (Miller et al. 2002). Generally, the TCI reefs show very little signs of being negatively impacted from human activities (Spalding et al. 2001). However, there is cause to worry as three hotel construction sites on South Caicos may increase sedimentation to the surrounding waters, and *A. palmata* is very intolerant to sediment pollution as it causes death of the underlying tissue (Rogers 1983). An increased development can also induce eutrophication that increases algal growth competing with corals for space (Lapointe 1997). To date, finfish is not the targeted seafood of the South Caicos fishermen; however, this is expected to change as tourism increases. Intensive fishing in the area could negatively affect the *A. palmata* populations because as herbivorous fish populations decline, algal biomass increases and out-competes the corals (Steneck 1988). In the South Caicos area, fishing can also directly induce negative effects on corals when illegal chemicals such as bleach are used or when lines, nets, plastic bags or other materials get wrapped around the colony branches.

**Disease Abundance**

Despite the fact that the reefs of the TCI have been reported to be almost pristine (Riegel et al. 2003), we found WBD, WPDa, and WPDb affecting *A. palmata* colonies. Only colonies at South End Long Cay, the site that is furthest away, showed no diseases. Hence, it is possible that the *A. palmata* colonies closer to South Caicos are more affected by human activities.

WBD was only found on two colonies at one of the five sites. Both colonies were in close proximity to each other, which might suggest that their incidence is related. The progression of the band between branches on one of the two infected colonies also suggests that the disease may be contagious. To date there are no instances of WBD on *A. palmata* spreading from the tip of the branch to the base. This was only reported from WBD Type II infected colonies of *A. cervicornis* (Ritchie and Smith 1998). While the mean rate of spread per day (2.80 ±0.81 SE $cm^2$/day) of WBD found during this study is close to the maximum rate of expansion (2.06 $cm^2$/day) reported by Davis et al. (1986), the maximum rate of spread found at Shark Alley was much higher. The atypical progression may be the reason for the increased spread rate.

The mean rate of lesion expansion of WPDa was lower than that reported by Patterson et al. (2002) in the Florida Keys. Our results concur with the findings of Patterson et al. (2002) concerning high variability in tissue loss between colonies. However, we also found high variability within colonies. Patterson et al. (2002) found WPD highly contagious within and among reefs. We support their findings, since all WPD incidences we report were found on the four reefs that were within close proximity of each other. The site that was the most remote (South End Long Cay) had no diseases present. This might show a very high frequency of between reef WPD spread. However, of the individual types of WPD we found that WPDa does not appear to have a high within reef rate of transmittance, whereas WPDb is found exclusively in colony clusters, thus exhibiting a very high rate of dispersion.

**Snail Predation**

The data collected on *C. abbreviata* populations and their grazing rates were similar to those of a study performed in the Florida Keys. According to Baums et al. (2003b), 20% of *A. palmata* populations were infested with snails on the reefs surveyed in 1999, compared to a mean of 24.8 % snail infestation for all locations in this study. Our result for average snail size was 17.7 mm, slightly smaller than the mean size of 21.1 mm for low-density *A. palmata* stands and 26.0 mm for colony thickets reported by Baums et al. (2003b). The mean grazing rate of 3.83 $cm^2$/snail/day ($\pm$ 0.67 SE) that we found in this study was similar to consumption rates reported from the Florida Keys (Baums et al. (2003b) - 4 $cm^2$/snail/day , Miller (2001) - 3.37 $cm^2$/snail/day ).

The presence of snails may pose a significant threat to South Caicos *A. palmata* populations. With a mean grazing rate of 3.83 $cm^2$/snail/day ($\pm$ 0.67 SE), one snail can consume approximately 115 $cm^2$ coral tissue in a month. Snail infestation on South Caicos ranges from 0% to 54.7% at different sites and more than 50 snails can be present on one single colony. Hence, large populations of *C. abbreviata* have the ability to consume large quantities of coral tissue in relatively short time. However, no relationship was found between disease incidences and predatory snails.

## CONCLUSIONS

While the present condition of *A. palmata* populations in South Caicos is good compared to other Caribbean islands, the presence of diseases and snail predation is cause for concern. Studies show that *A. palmata* diseases occur in the end stages of stress induced synergistic effects (Harvell et al. 2001, Richardson 1998, Antonius 1981). It is believed that stressed corals have weakened defense mechanisms and are therefore more susceptible and vulnerable to diseases (Richardson 1998, Harvell et al. 2001, Aronson and Precht 2001). Hence, considering the remoteness of South Caicos' reefs and the relatively low anthropogenic stressors they are facing, it is quite surprising that we observed such a high occurrence of WBD, WPDa and WPDb on these reefs. South Caicos' *A. palmata* populations could potentially be at high risk of mortality, especially when observed snail predation, disease, and potential anthropogenic threats are combined. However, other more global, natural stressors such as global warming have also been linked to *A. palmata* degradation through incidences of bleaching and increased water temperature (Antonius 1981, Richardson 1998, Harvell et al. 2001, Aronson and Precht 2001, Patterson et al. 2002, Gardner 2003). Patterson et al. (2002) reports a causal linkage between bleaching and disease related mortality due to increased opportunistic infections. They further speculate that the increased frequency and intensity of future bleaching events, due to global warming, may lengthen the disease season. However, there are no long-term data neither on coral cover and the status of *A. palmata* populations nor on the temperature of the surrounding water that may explain why South Caicos' *A. palmata* populations experience diseases. Furthermore *C. abbreviata* and *C. caribbaea* infestations are worrying, especially because they have been found on the reefs that have been severely impacted by tropical storm Jeanne in September 2004. Many fragments broken and laying on the benthic substrate are easy prey for snails which may limit the fragments survival rate. This has been reported from Jamaican reefs after hurricane Allen in 1980 (Knowlton et al. 1981). Generally, the reefs can be protected from direct anthropogenic stress, but natural impacts such as hurricanes and storm events, as well as mortality caused by disease is beyond management possibilities. Abundance of predatory snails may be controlled by collecting and eliminating these (Miller 2001). However, the question remains how many snails can *A. palmata* populations withstand? Populations at other locations have been observed to experience periods of decline and rebound, and snail population dynamics fluctuates from year to year (Miller et al. 2002).

This type of survey is very important because it serves as baseline data for future comparisons. Studying the status, trends, and threats of *A. palmata* populations is important for conservation efforts. While our results define the current status of *A. palmata*, studies in the future can be compared to this data to determine if the populations remain stable, increase or decline, and whether changes in disease occurrence or *C. abbreviata* populations affect the status of the coral population. However, if significant disease outbreaks and snail predation are being observed, how can we protect South Caicos *A. palmata* populations?

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# Determining the Trophic Relationships among Flora and Fauna within *Sargassum* Mat Communities Using Fatty Acids

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ABSTRACT

Trophic relationships among organisms associated with floating *Sargassum* in the northwest Gulf of Mexico was assessed using fatty acids. Nineteen groups were selected as representatives of the *Sargassum* community including 4 autotrophs, 8 invertebrates, 5 juvenile fishes, and 2 adult fishes. Spatial and temporal variability in polyunsaturated fatty acid (PUFA) signatures of selected taxa (*Sargassum fluitans* [autotroph], *Leander tenuicornis* [primary heterotroph], *Balistes capriscus* [secondary heterotroph]) was examined to quantify natural variation within these dietary tracers. Although PUFA signatures varied seasonally for all three taxa, no differences were detected between samples collected in year 2000 and 2001 or from different sample locations in the northwest Gulf. PUFA signatures made up 16.3 - 62.3% of the total fatty acid composition of main autotrophs present in the pelagic environment (particulate organic matter [POM], epiphytic algae, *Sargassum fluitans, S. natans*), and PUFA profiles of selected primary producers were distinct. Specifically, levels of 20:5*n-3* and 22:6*n-3* were higher in POM than *Sargassum spp.* or epiphytic algae (*Cladophora sp.*). Dominant PUFA in the tissue of invertebrate and vertebrate consumers were 18:2*n-6*, 20:4*n-6*, 20:5*n-3*, 22:5*n*-3, 22:6*n*-3 and multivariate analyses indicated that PUFA signatures of all consumers were highly similar to POM. As a result, heterotrophs utilizing the *Sargassum* complex may rely heavily on phytoplankton production rather than production by *Sargassum* or associated epiphytic algae.

KEY WORDS: *Sargassum*, trophic relationships, fatty acids

# Determinación de las Relaciones Tróficas entre Fauna y Flora en las Comunidades de *Sargassum* Usando Ácidos Grasos

Las relaciones tróficas entre organismos asociados al *Sargassum* flotante en el noroeste del Golfo de México fueron evaluadas mediante ácidos grasos. Diecinueve grupos fueron seleccionados como representativos de la comunidad de *Sargassum*. Estos incluyeron 4 autótrofos, 8 invertebrados, 5 peces juveniles y 2 peces adultos. La variación espacial y temporal en el registro del ácido graso polinosaturado (PUFA) de los taxa selecionados (*Sargassum fluitans* [autótrofo], *Leander tenuicornis* [heterótrofo primario], *Balistes capriscus* [heterótrofo secondario]) fue examinada para cuantificar las variaciones naturales en estos indicadores dietéticos. A pesar de que existieron variaciones estacionales en los 3 taxa, no se detectaron diferencias entre las muestras colectadas en los años 2000 y 2001, ni entre las diferentes localidades muestradeas en el Golfo. Los registros de PUFA contribuyeron del 16.3 al 62.3% del total de la composición de ácidos grasos en los principales autótrofos presentes en ambientes pelágicos (material orgánica particulada [POM], algas epifíticas, *Sargassum fluitans* y *S. natans*) donde los perfiles de PUFA fueron distintos entre los productores primarios. Especialmente, los niveles de 20:5*n-3* y 22:6*n-3* fueron más altos en POM que en *Sargassum spp.* o algas epifiiticas (*Cladophora sp.*). Los PUFA dominantes en los tejidos de invertebrados y vertebrados fueron 18:2*n-6*, 20:4*n-6*, 20:5*n-3*, 22:5*n*-3, 22:6*n*-3, donde un análisis multivariado indicó que los registros PUFA de todos los consumidores fueron muy similares al POM. Como resultado, los heterotrofos que utilizan el conglomerado de *Sargassum* parecen depender fuertemente en la produción fitoplantónica y no en la produción de *Sargassum* o algas epifíticas asociadas.

PALABRAS CLAVES: *Sargassum*, relaciones tróficas, ácidos grasos

## INTRODUCTION

Due to inherent problems associated with conventional measures of diet (*e.g.*, gut content analysis), considerable effort has been afforded to the development of alternative approaches (*e.g.*, stable isotopes, fatty acids) to identify trophic links and determine food web structure within marine systems (Fry and Sherr 1988, Iverson et al. 1997). Although stable carbon and nitrogen isotopes have been used extensively to identify source(s) of primary production has provided important insights on feeding histories of marine fauna, primary producers and secondary consumers often have similar isotopic signatures, thus limiting the usefulness of the approach for examining trophic relationships. In recent years, fatty acid signatures have increasingly been used as natural dietary tracers for a variety of aquatic organisms including invertebrates, fishes, sea turtles, and marine mammals (*e.g.*, Fraser et al. 1989, Graeve et al. 1994, Iverson et al. 1997, Kirsch et al. 1998), and the approach has been shown to overcome deficiencies often associated with stable isotope analysis (Kiyashko et al. 1998, Kharlamenko et al. 2001). Due to biochemical limitations in marine organisms, polyunsaturated fatty acids (PUFAs) are rarely modified and cannot be synthesized *de novo* (Raclot et al. 1998, Hastings et al. 2001, Graeve et al. 2002, Gurr et al. 2002). Therefore, PUFAs in marine consumers are obtained exclusively from dietary sources and useful for reconstructing feeding histories (*e.g.*, Iverson et al. 1997, Graeve et al. 2002).

*Sargassum* is a pelagic, brown algae that dominates a section of the western North Atlantic known as the Sargasso Sea and is present throughout the Caribbean and Gulf of Mexico (Butler et al. 1983). Two species of *Sargassum, S. fluitans and S. natans,* support a large diversity of marine invertebrates and vertebrates, including several commercially, recreationally, and ecologically important fishes (*e.g.*, *Balistes capriscus, Caranx crysos, Seriola dumerili, Coryphaena hippurus, Acanthocybium solandri*) (Dooley

1972, Bortone et al. 1977, Settle 1993). Although *Sargassum* is recognized as essential fish habitat (EFH) by the National Marine Fisheries Service (SAFMC 1998), the role of *Sargassum* has yet to be determined, and data regarding trophic relationships of associated fauna is clearly needed to fully understand its importance within pelagic ecosystems.

In the present study, we examined the feeding ecology of fauna associated with free-floating, pelagic *Sargassum* mats in the northwest Gulf of Mexico using PUFAs. Results of a previous study utilizing stable isotopes (Rooker et al. 2004) indicated that organic matter supplied to heterotrophs inhabiting the mat community might not originate from either *Sargassum* species. However, due to similarities in isotopic signatures of associated autotrophs (phytoplankton and epiphytic algae), this study did not assess the relative importance of producers other than *Sargassum*. Therefore, the aim of the present study was to use fatty acid signature analysis to trace source(s) of primary production to consumers using the *Sargassum* complex and to determine feeding histories of associated fauna. Specific objectives of the present study were to:

i) Characterize PUFAs of autotrophs and consumers, and
ii) Relate PUFAs of community flora and fauna to determine trophic relationships.

## METHODS

### Sample Collection

Samples were collected from three sites within the northwestern Gulf of Mexico, including one inshore and two offshore sites stratified into a northern and southern region (Figure 1). The inshore and offshore sites were < 30 nm and > 30 nm from shore, respectively. Collections were conducted monthly from May through August in 2000 and 2001. *Sargassum* mats were chosen at random within each region during each collection. A 20 m (L) x 3.3 m (H) purse seine with 1,000 mm mesh was deployed around individual mats to collect community flora and fauna. Larger fishes were collected by hook and line opportunistically at each sample site. Samples of POM were collected from seawater pre-filtered through a 125 mm sieve then collected in a 25 mm sieve (to reduce the risk of sample contamination) before being filtered onto 0.7 mm Whatman glass fiber filters for analysis. Samples for zooplankton were collected from seawater in a 125 mm sieve before being filtered onto 0.7-mm Whatman glass fiber filters for analysis. Epibiota (including flora and fauna) were removed from thallus, blades, and pneumatocysts of *Sargassum* using forceps.

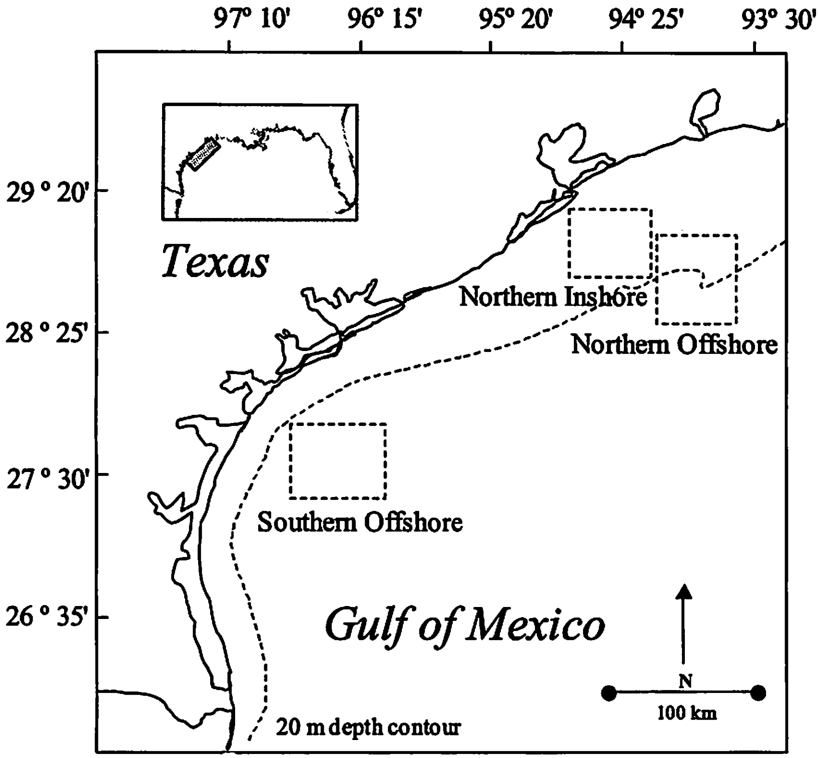


Figure 1. Location of sampling sites in the northwestern Gulf of Mexico

**Sample Preparation and Analysis**

Whole samples of autotrophs, invertebrates, and juvenile fishes, and lateral muscle tissue from adult fishes were homogenized thoroughly with blenders and mixing mills. Lipid was then extracted in duplicate aliquots in chloroform:methanol (2:1; v:v) after Folch et al. (1957) as modified by Iverson et al. (2001). Fatty acid methyl esters were prepared by transesterification directly from ≤ 100 mg of pure extracted lipid (filtered and dried over anhydrous sulfate), with 0.5 N sulfuric acid in methanol plus dichloromethane following the Hilditch procedure. Analysis of methyl esters was run using temperature-programmed gas chromatography on a Perkin Elmer Autosystem II Capillary FID Gas Chromatograph fitted with a 30 m x 0.25 mm internal diameter column coated with 50 % cyanopropyl polysilohexane (0.25 mm film thickness, J&W DB-23, Folsom, CA, USA) and linked to a computerized integration system (Turbochrome 4 software, PE Nelson). Identification of fatty acids and isomers was determined by calibrating gas chromatography data with known standards (Nu Check Prep., Elysian, MN, USA). Individual fatty acids were converted to mass percent of total fatty acids using conversion factors from Ackman (1972) after accounting for the contribution of BHT.

**Statistical Analyses**

Multivariate analysis of variance (MANOVA) and analysis of variance (ANOVA) were used to examine differences in composition of PUFA signatures and individual PUFAs, respectively among autotrophs and consumers. Tukey's honestly significant difference (HSD $\alpha = 0.05$) test was used to determine significant differences between groups. Normality and homogeneity of variances were verified using Kolmogorov–Smirnov and Bartlett tests, respectively. Fatty acid data were arcsine-transformed before analyses of variance were run to correct for their binomial distribution (percentages) (Zar 1998). Principal components analysis (PCA) was used to examine distance relationships among autotrophs and subsequent consumers based on PUFA signatures. Factors were extracted using a correlation matrix with minimum eigenvalues of 1.0.

## RESULTS

Sixty-seven individual fatty acids were identified during analysis. The five PUFAs (18:2*n-6* [linoleic acid], 20:4*n-6* [arachidonic acid, AA], 20:5*n-3* [eicosapentaenoic acid, EPA], 22:5*n-3* [docosapentaenoic acid, DPA], and 22:6*n-3* [docosahexaenoic acid, DHA]), were used to assess temporal and spatial variation within the system and determine trophic relationships of the associated community fauna to reduce the number of variables because they were 1) the most abundant and 2) were found to be indicators of diet in previous studies of estuarine and marine consumers (Turner 2004). Further uses of 'PUFA signatures' were based upon these five fatty acids.

Nineteen groups were selected as representatives of the *Sargassum* community including four autotrophs, eight invertebrates, five juvenile fishes, and two adult fishes (Table 1). Although sixty-seven individual fatty acids were identified in the present study, analyses were limited to select PUFAs since marine organisms have extremely limited ability to modify these fatty acids. PUFAs comprised the largest % composition of all fatty acid groups in most of our samples (16.3 – 62.3% of the total fatty acid composition). Furthermore, the five most abundant PUFAs made up 54.1 – 95.9% of the PUFAs and 9.6 – 44.9% of the total fatty acid composition of the samples processed and were used exclusively for further characterization of trophic relationships.

**Spatial and Temporal Variation**

Spatial and temporal variation in PUFA signatures was investigated at three distinct levels in the *Sargassum* mat community: autotroph (*S. fluitans*), primary heterotroph (*Leander tenuicornis*), secondary heterotroph (*Balistes capriscus*) as part of another study (Turner 2004). Although no significant differences were detected between samples collected in 2000 and 2001, and among three sampling regions (northern inshore – NI, northern offshore – NO, and southern offshore - SO), significant seasonal differences in PUFA signatures were identified for *S. fluitans* and *Balistes capriscus*, (but not *L. tenuicornis*) using MANOVA. Therefore, to ensure that seasonal variation in PUFA signatures did not confound our characterization of trophic relationships, only samples from May and June 2000 collected from the northern offshore sampling region (NO) were used for further assessments.

**Table 1.** Representative species of the *Sargassum* community. All specimens collected from Northern Offshore location during May[a] or June[b] 2000. Length represents total length for fishes, carapace length for shrimps, and carapace width for crabs.

| Species | n | Length (mm) |
|---|---|---|
| *Cladophora sp.* (green epiphytic algae)[a] | 10 | n/a |
| *Sargassum fluitans* (brown algae)[a] | 36 | n/a |
| *Sargassum natans* (brown algae)[a] | 24 | n/a |
| POM[ab] | 25 | n/a |
| Zooplankton[a] | 15 | n/a |
| *Membraniporum sp.* (bryozoan)[a] | 6 | n/a |
| *Algaophenia latecarinata* (hydroid cnidarian)[a] | 6 | 8.2-12.5 |
| *Spirorbis sp.* (serpulid polychaete)[a] | 6 | 1.1-2.3 |
| *Latruetes fucorum* (hippolytid shrimp)[a] | 12 | 8.2-15.5 |
| *Leander tenuicornis* (palaemonid shrimp)[a] | 12 | 20.5-36.0 |
| *Portunus sayi* (portunid crab)[a] | 12 | 17.0-38.5 |
| *Scyllaea pelagica* (nudibranch gastrpod)[a] | 12 | 57.3-76.1 |
| *Balistes capriscus* (gray triggerfish)[a] | 27 | 60.5-98.9 |
| *Caranx crysos* (blue runner)[a] | 18 | 46.2-57.7 |
| *Histrio histrio* (sargassum fish)[a] | 19 | 65.5-90.1 |
| *Stephanolepis hispidus* (planehead filefish)[a] | 20 | 65.2-91.4 |
| *Seriola dumerili* (greater amberjack)[a] | 20 | 91.5-145.0 |
| *Coryphaena hippurus* (dolphinfish)[ab] | 9 | 330.0-486.5 |
| *Acanthocybium solandri* (wahoo)[a] | 3 | 1035.0-1115.0 |

### Autotrophs

Significant differences in PUFA signatures of four autotrophs were identified (MANOVA, $p < 0.001$). Levels of 18:2*n-6*, 20:4*n-6*, 20:5*n-3*, and 22:6*n-3* were significantly different (ANOVA, $p < 0.001$) among autotrophs, although levels of 22:5*n-3* were similar in all autotrophs sampled ($p = 0.094$). Tukey's HSD tests indicated that levels of 20:5*n-3*, 22:5*n-3*, and 22:6*n-3* were found in significantly higher concentrations in POM than in *S. fluitans*, *S. natans*, or *Cladophora sp.* (Figure 2).

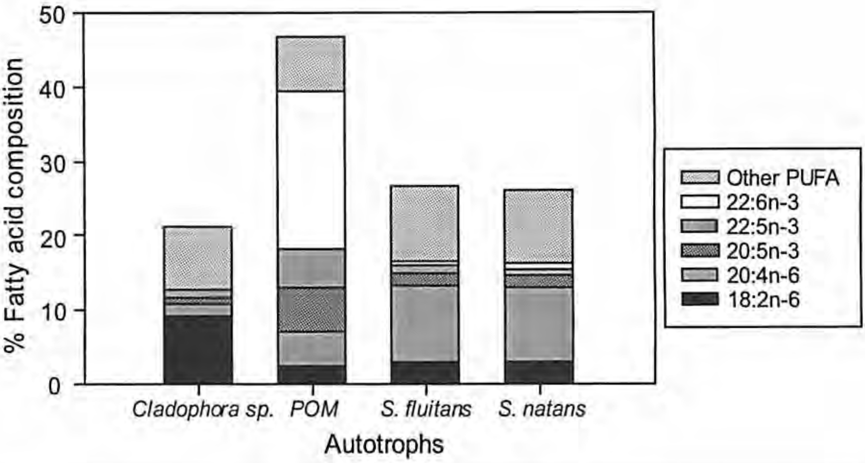


**Figure 2.** Percent composition of five abundant polyunsaturated fatty acids (PUFAs) within autotrophs. Mean values are reported for 18:2*n-6*, 20:4*n-6*, 20:5*n-3*, 22:5*n-3*, 22:6*n-3*,and of all other PUFAs.

## Invertebrates

PUFA signatures of eight invertebrates included in the present study were significantly different (Figure 3A; MANOVA, $p < 0.001$), and ANOVA results indicate that levels of all PUFAs were significantly different among taxa examined. Levels of 18:2*n-6* were significantly different among invertebrates (ANOVA, $p < 0.001$), but Tukey's HSD test showed that overall significant differences were driven by differences among three groups: crustaceans (*Leander tenuicornis*, *Latruetes fucorum*, *Portunus sayi*), epibionts-nudibranch (*Membraniporum sp.*, *Spirorbis sp.*, *Algaophenia latecarinata*, and *Scyllaea pelagica*) and zooplankton. Similar trends were observed for thrree of the other four individual PUFAs ( 20:4*n-6*, 20:5*n-3*, and 22:6*n-3* (ANOVA, $p < 0.001$) were significantly different in invertebrates overall. Levels of 22:5*n-3* (ANOVA, $p < 0.001$) were also significantly different among invertebrates, but Tukey's HSD test showed that significant differences described by ANOVA results were driven by differences between two groups: crustaceans-epibionts-nudibranch and zooplankton.

## Fishes

Significant differences in PUFA signatures of fish taxa were also observed (Figure 3B; MANOVA, $p < 0.001$). Univariate contrasts indicated 18:2*n-6*, 20:4*n-6*, 20:5*n-3*, and 22:6*n-3* were significantly different among fishes (ANOVA, $p < 0.001$), while no effect was observed for 22:5*n-3* (ANOVA, $p = 0.336$).

Tukey's HSD tests indicated that levels of 18:2*n-6*, 20:4*n-6* and 22:6*n-3* were not significantly different among species within two groups: *Caranx crysos*, *Seriola dumerili*, *Coryphaena hippurus*, *Acanthocybium solandri* and *Balistes capriscus*, *Stephanolepis hispidus*, *Histrio histrio*. Tukey's HSD tests for the PUFA 20:5*n-3* revealed significant differences between three groups: *C. crysos* and *S. dumerili*, *C. hippurus* and *A. solandri*, and *B. capriscus*, *S. hispidus*, *H. histrio*.

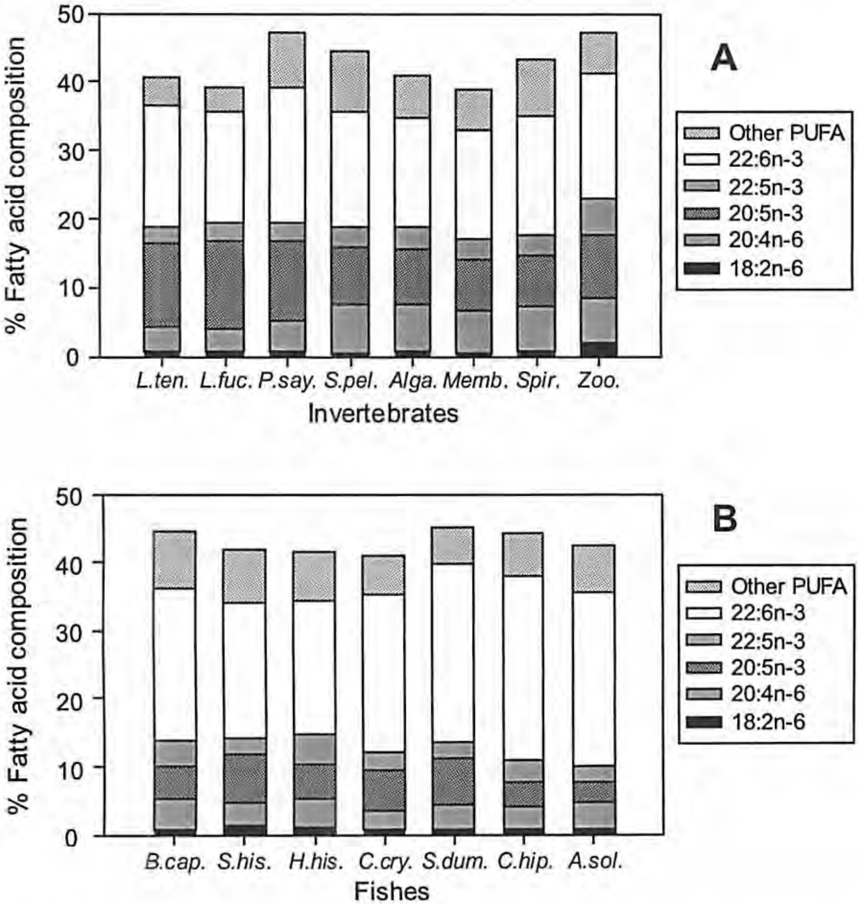


**Figure 3.** Polyunsaturated fatty acid (PUFA) data for invertebrates included in the present study including 18:2*n-6*, 20:4*n-6*, 20:5*n-3*, 22:5*n-3*, 22:6*n-3*,and of all other PUFAs. In Fig. 3A, mean values of percent composition are reported for *L. ten.* = *Leander tenuicornis*, *L. fuc.* = *Latruetes fucorum*, *P. say.* = *Portunus sayi*, *S. pea.* = *Scyllaea pelagica*, *Alga.* = *Algaophenia latecarinata*, *Memb.* = *Membraniporum sp.*, *Spir.* = *Spirorbis sp.*, Zoo. = zooplankton. In Fig. 3B, mean values of percent composition are reported for *B. cap.* = *Balistes capriscus*, *M. his.* = *Stephanolepis hispidus*, *H. his.* = *Histrio histrio*, *C. cry.* = *Caranx crysos*, *S. dum.* = *Seriola dumerili*, *C. hip.* = *Coryphaena hippurus*, *A. sol.* = *Acanthocybium solandri*.

**Trophic Interactions**

Levels of PUFA signatures of consumers were closely related to levels found in POM, while significantly different from quantities found in either *Sargassum* species or *Cladophora sp.* (Figures. 2, 3A, and 3B; MANOVA, p < 0. 001). PCA was performed using averaged individual PUFA values including all autotrophs, invertebrates, and fishes, and over 68% of the variation in composition of PUFA signatures could be explained by principal components 1 and 2. Scatterplots of components 1 and 2 revealed similarities among individual invertebrates and fishes with POM and separation from other autotrophs (Figure 4).

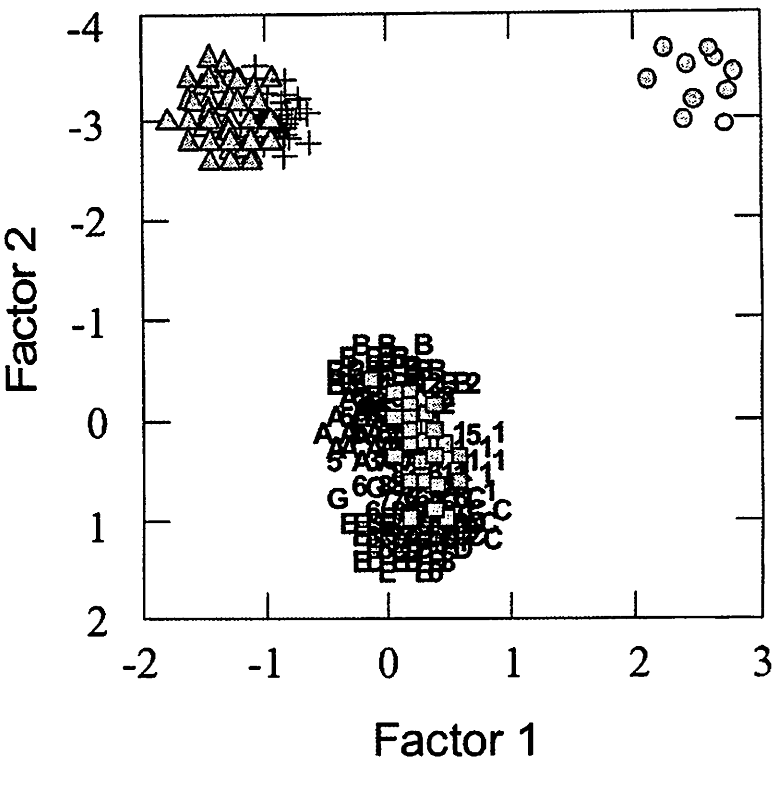


**Figure 4.** Factor scores plot of principal components analysis based upon polyunsaturated fatty acid (PUFA) signatures of autotrophs (■-POM, ▲-*Sargassum fluitans*, + - *Sargassum natans*, ●-*Cladophora sp.*), invertebrates (1-zooplankton, 2- *Membraniporum sp.*, 3- *Spirorbis sp.*, 4- *Algaophenia latecarinata*, 5- *Scyllaea pelagica*, 6- *Leander tenuicornis*, 7- *Latruetes fucorum*, 8- *Portunus sayi*), and fishes (A- *Stephanolepis hispidus*, B- *Balistes capriscus*, C- *Histrio histrio*, D- *Caranx crysos*, E- *Seriola dumerili*, F- *Coryphaena hippurus*, G- *Acanthocybium solandri*) in the *Sargassum* community.

## DISCUSSION

Results suggest that PUFA signatures of POM were significantly different than signatures of *Sargassum spp.* or *Cladophora sp.*, and contained high levels of PUFAs including 20:5*n-3*, 22:5*n-3*, and 22:6*n-3*, while levels of 18:2*n-6* and 20:4*n-6* were more abundant in macroalgae. These results were not unexpected since concentrations of long-chain PUFAs (20:5*n-3*, 22:5*n-3*, 22:6*n-3*) are found in many phytoplankton species, although levels of these fatty acids are often minimal or absent in macroalgae (Herbretau et al. 1997, Graeve et al. 2002). Phytoplankton is typically the largest component of POM, though smaller amounts of bacteria and non-living particles are present (Hama 1999), and it often contains substantial amounts of long-chain PUFAs like 20:5*n-3* and 22:6*n-3* (Pedersen et al. 1999, Graeve et al. 2002). As previously reported, large concentrations of long-chain PUFAs including 20:5*n-3*, 22:5*n-3*, and 22:6*n-3* are often found in diatoms, dinoflagellates, and haptophytes (Harrington et al. 1970, Henderson et al. 1988, Pedersen et al. 1999). Conversely, macroalgae typically contain very low quantities of long-chain PUFAs, especially 22:6*n-3* (Herbretau et al. 1997, Graeve et al. 2002). Therefore, PUFA signatures of phytoplankton in POM are most likely contributing to signatures found in the *Sargassum* food web indicating that phytoplankton is the likely source of organic matter in this complex.

Organic matter incorporated into invertebrates and fishes appears to have originated from phytoplankton in POM rather than *Sargassum spp.* or *Cladophora sp.* based upon PUFA signatures. High levels of long-chain PUFA signatures, apparently derived from phytoplankton, were identified in all zooplankton, microinvertebrate, macroinvertebrates, and fishes included in the present study. For example, copepods, the most abundant marine zooplankton in pelagic waters, are highly associated with *Sargassum* and typically feed upon diatom and dinoflagellate species (Yeatman 1962, Cowles et al. 1988, Xu and Wang 2001). As a result, food chains utilizing organic matter from marine phytoplankton tend to be exceptionally enriched in levels of 20:5*n-3* and 22:6*n-3* (Sargent 1978, Pedersen et al. 1999, Domiazon et al. 2000).

Although *Sargassum* does not appear to directly contribute nutrients to the food web, it may play important roles in nutrient recycling, aggregation mechanisms, as substrate, and increasing habitat complexity in pelagic environments. This is seemingly facilitated by similar oceanographic factors involved with "clumping" *Sargassum* and may, in addition, accumulate large concentrations of phytoplankton in these characteristically oligotrophic areas, ultimately shaping the composition of organic matter in this system (Carpenter 1970, Dooley 1972, Stoner and Greening 1984, Woodcock 1993). Additionally, by contributing byproducts of photosynthetic processes, *Sargassum* appears to be an important component in nutrient cycling of the pelagic environment (Shoener and Rowe 1970). *Sargassum* also serves as a substrate for other macro algae, including large amounts of *Cladophora sp.*, which often covers portions of whole *Sargassum* plants. Furthermore, drifting macrophytes add to habitat complexity in many surface waters, facilitate redistribution of organisms in pelagic environments, and could affect survival of species that depend upon them for food and refuge (Kingsford 1995). Similarly, by increasing the complexity of the pelagic environment *Sargassum* may bring about redistribution of organisms and augment survivorship by providing protection from predators and improving food availability during early life stages in several fishes.

In summary, high concentrations of PUFAs found in POM more closely match levels in higher trophic groups of the *Sargassum* community than signatures of *Sargassum fluitans, S. natans,* or *Cladophora sp.*, suggesting that phytoplankton is the major source of organic matter entering this food web. Organic matter incorporated into invertebrates including crustaceans, nudibranch, epibionts, and zooplankton, appears to have originated from phytoplankton in POM based upon PUFA signatures. PUFA signatures of juvenile and adult fishes in the complex are similar to prey taxa and thus utilization of *Sargassum* mats is in part may be linked to their value as feeding grounds.

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# Montego Bay to Ocho Rios in One Hour at the Cost of Essential Fish Habitat

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ABSTRACT

Between March and August an estimated million land crabs (*Cardisoma guanhumi*) leave their burrows and become subject to one of Jamaica's most socially universal fishery. Boys, women and men search at night with flaming torches for crabs which are caught by hand. The fishery requires no boats, no seamanship skills and no special equipment, only a bag, some twine, a glass bottle, kerosene and a rag. The typical catch during a "fishing trip" of 2-4 hrs is 18-80 crabs by a group of 2-7 people. The crabs are caught along roads bordering low lying coastal areas and wetlands. They are sold along the road alive for about $J500 to $800 for about a dozen crabs. The net value to a single fisher is higher than typical fin fishers who must venture out for longer periods with a higher capital investment to catch dwindling catches. The crabs can reach 13 cm in carapace width, but the mean size measured 7.3cm. Females are smaller and more are required to make a saleable bundle. Until the construction of the north coast highway in 2002 linking Montego Bay with the northern Jamaican tourist destination town of Ocho Rios there were was no sign of declining catches. The completion of the road will see the development of a modern, paved road replacing the narrow, winding and pot holed road that previous served the area. Transit time between the Montego Bay airport and Ocho Rios will be cut in half. Already the fishers are reporting it is harder to find crabs as there is less essential habitat as the construction of the road further destroys mangrove communities, shore line habitats, wetlands and essential habitat for the land crab. This fishery represents another example how valuable natural resources are being destroyed thereby shifting economic value to another sector of society.

KEY WORDS: Land crabs, *Cardisoma guanhumi*, Jamaica

# Montego Bay a Ocho Ríos en Una Hora a Expensas del Hábitat Esencial del Cangrejo

Se estima que entre los meses de marzo y agosto alrededor de un millón de cangrejos abandonan sus cuevas para ser expuestos a una de las pesquerías más sociales en Jamaica. Niños, mujeres y hombres se dedican a buscar cangrejos (*Cardisoma guanhumi*) durante la noche con antorchas de fuego, a los cuales capturan con sus manos. Esta pesca no requiere embarcación o equipo especial, ni destrezas o conocimiento en navegación, tan solo se necesita un saco o bolsa, alambre, una botella de cristal, queroseno y un pedazo de tela. La captura típica durante un "viaje de pesca" que dure de 2 a 4 horas, por un grupo compuesto de 2 a 7 personas es de18 a 80 cangrejos. Los cangrejos son capturados en los caminos que bordean áreas costeras bajas y en áreas pantanosas. Los mismos son vendidos vivos en los caminos o carreteras a un precio entre J$500 y $J800 la docena. El valor neto para un pescador de cangrejo es mayor que para un típico pescador de peces de aleta, el cual se tiene que aventurar al mar por un período de tiempo mas largo y hacer una inversión mayor para poder pescar. El cangrejo puede alcanzar 14 centímetros de ancho en su caparazón, pero la mayoría de los cangrejos capturados tenían una medida aproximada de 9.1 centímetros hombres. Los pescadores dicen que la pesca de cangrejo era estable antes de la construcción de la carretera en la costa norte que une a Mongeto Bay con Ocho Ríos, destino turístico en el norte de Jamaica, en el año 2002. Al completar este proyecto de construcción se contará con una moderna carretera pavimentada la cual reemplazará el camino angosto de tierra lleno de hoyos que existía anteriormente. El tiempo de recorrido entre el aeropuerto de Montego y Ocho Ríos se reducirá a la mitad. Sin embargo, la construcción de esta nueva carretera a tenido impacto sobre los mangles, las áreas pantanosas y las áreas que bordean la playa las cuales son áreas de hábitat de esta especie. Los pescadores de esta especie están reportando que se les hace más difícil encontrar cangrejos. La merma de esta pesquería representa otro ejemplo del impacto negativo a causa del desarrollo a los valiosos recursos naturales, sustituyendo los valores económicos de un sector de la sociedad a otro.

PALABRAS CLAVES: *Cardisoma,* Jamaica, hábitat esencial

## INTRODUCTION

The government of Jamaica embarked on construction of a north coast road improvement program in 2001 between the tourist centers of Negril, Montego Bay and Ocho Rios. By straightening, grading, widening and providing a smooth road surface traveling time will be greatly reduced. However, one of the consequences of this on-going effort is the filling in of more wetland and the further destruction of mangroves.

Mangrove forests once covered some 75 percent of the coastlines of tropical and sub-tropical countries, but some 35 percent of the world's mangroves are already gone. In the Americas, mangrove forests are being cleared at a faster rate than the tropical rainforests. These mangroves and adjacent lands are important habitats for many land crabs.

This paper will examine the effect that the road improvement program is having on coastal wetlands and mangrove communities and the land crab fishery.

### The Fishery

Land crabs, (*Cardisoma guanhumi*) (termed pond crabs by British Virgin Islanders and *jueyes* by people from Puerto Rico and Santo Domingo) are gray crabs that live in a network of holes found in low-lying areas near mangrove swamps, salt ponds, wetlands and marshes. These crabs are traditionally harvested by people inhabiting coastal areas throughout the Caribbean. In Jamaica, the crab fishery requires no boats, no seamanship skills, and no special equipment - only a bag, some twine, a glass bottle, kerosene, and a rag. It is Jamaica's most socially universal fishery with boys, women, and men all participating.

Although the fishery is common around Jamaica, there are no published reports documenting it. It is also ignored in commercial fisheries reports for the US Virgin Islands (Kojis 2004) or only briefly mentioned in Puerto Rico fisheries reports where it is and not considered a significant fisheries species, although 6,327 lbs were recorded landed in Puerto in 2001 (Matos-Caraballo (2004).

Between March and August, numerous land crabs leave their burrows at night to mate and feed. May appears to be the main month of this nighttime activity. It is also often the month with the highest rainfall as the inter-tropical convergence zone passes over Jamaica at this time.

The crabs emerge from their burrows mainly at night to feed and mate. Crab hunting usually takes place on the waning moon when the moon rises late. Groups of boys, women, and men search at night with flaming torches for crabs which are caught by hand. Catching crabs at night is called "torching," a name which comes from the days before kerosene bottles were used instead. Then torches were made out of an oily wood, aptly named torchwood or in later years would be made out of a piece of cut up truck or automobile tire tied to a stick. Today, the torch is commonly kerosene in an old bottle blocked by an old rag. The use of flashlight is uncommon.

## MATERIAL AND METHODS

Thirty two people out collecting crabs were surveyed between March and July 2004. They were asked several questions about the duration of their effort, the number of crabs they had caught and were expecting to catch. Ethnographic interviews were conducted with ten older fishers. They were asked if they thought it was easier to find crabs now than before. Random surveys of roadside vendors were used to assess the cost of road side sales.

A total of 22 crabs (14 male and 8 female) were weighed and carapace width measured using a vernier calipers.

The road from the Montego Bay airport to Ocho Rios was driven and qualitative observations were made at locations where road construction was having the greatest impact on crab habitats and mangrove communities.

## RESULTS

The typical catch during a "fishing trip" of two to four hours is 18 - 80 crabs by a group of 2 - 7 people. Crab fishers are not usually reef fishers. They are typically youth and a few solitary "old timers". Occasionally, people in cars would be cruising the back roads looking for crabs to catch. The crabs are caught along roads bordering low lying coastal areas and wetlands. They are sold along the road alive for about $J500 to $J800 (J$62 = US$1.00 Nov.

2004) for eight to a dozen crabs. Females are smaller and more are required to make a saleable bundle. Although gravid females were observed being caught, they were not observed being sold. The crabs can reach 15cm in carapace width, but the mean size measured was 9.1cm for males and 8.4cm for females. The power relationship was significant for both male (Figure 1) and for female crabs (Figure 2).

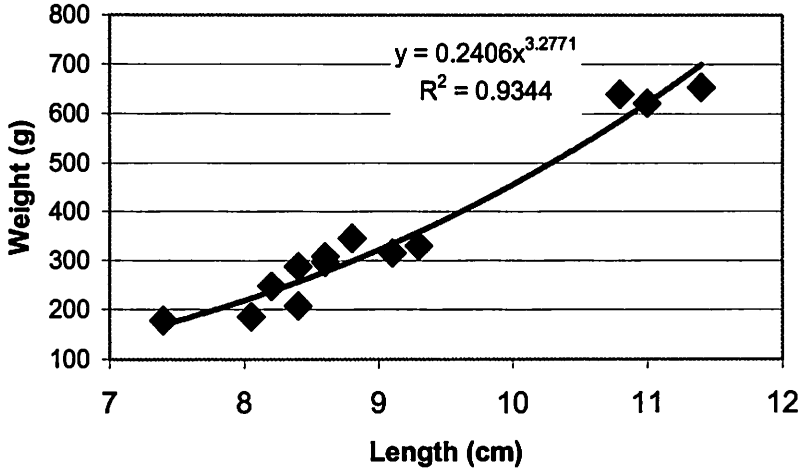


Figure 1: Length weight relationship for male crabs. N = 14.

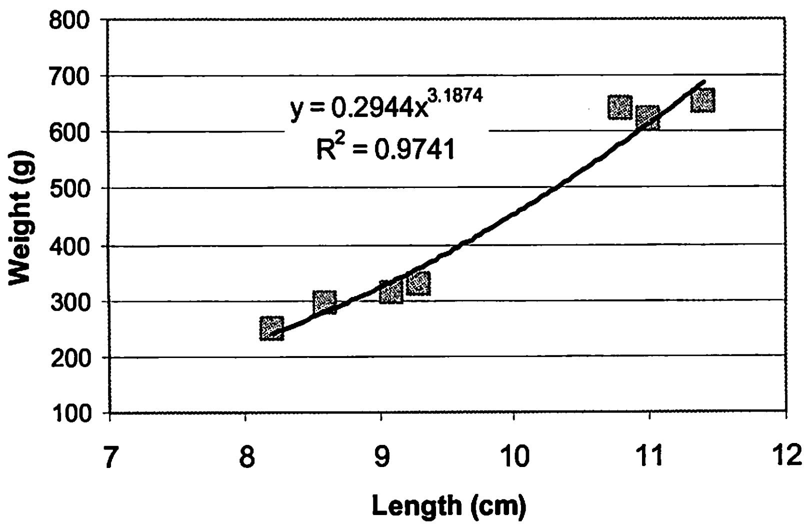


Figure 2: Length weight relationship for female crabs. N = 8.

## DISCUSSION

Until the construction of the north coast highway linking Montego Bay with the northern Jamaican tourist destination town of Ocho fishers stated that there was no sign of declining catches. However, fishers are reporting it is harder to find crabs as there is less essential habitat as the construction of the road further destroys mangrove communities, shore line habitats, wetlands, and essential habitat for the land crab and further reduces the already diminished nursery capability of along the north coast of Jamaica (Quinn and Kojis 2004).

A socio economic comparison between the crab fishery and reef fishery is difficult. The reef fishery is centered on a specific beach where the fishers return and their catch can be counted, measured and weighed – usually in the daytime. In contrast, there are diffuse groups of crab fishers and it not possible to survey all or be there to survey their catch at the end of a fishing trip. It is estimated that during the initial weeks of the crab season a person will earn between US$15 and US$40 per collecting expedition. Per person return diminished with larger groups. The net value to a crab fisher is higher than typical reef fishers who must venture out for longer periods with a higher capital investment to catch dwindling catches and then sell the fish before they go bad.

While the market price of the crabs varies seasonally with their availability, the crabs do not quickly perish and can be sold several weeks after they were caught. In contrast the reef fish are not iced and must be sold that day. In 2001, Sary *et al* (2003) estimated that the reef fisher earned between US$13 (line fishing) and US$29 (trap fishing) per trip. The figure does not include the substantial start up costs which range from US$800 to US$8000, depending upon whether a new or second hand boat and engine are bought (Polunin *et al*, 2000).

Networks of marine protected areas work for people, fish and crabs. More are needed and should include coastal wetlands to help safeguard biodiversity and secure food resources. However, the protection of essential habitat is not enough. The land crab is over exploited on some islands of the Caribbean. Puerto Rico has adopted management measure for crabs that include minimum size, closed areas in territory controlled land, closed season from July 15 to October 15, gear restrictions, and export report requirements.

The establishment of fisheries management regulations is hampered by enforcement difficulties. In a country where homicides and violent crimes are at record highs, there is little support for the implementation and enforcement of fishery regulations. Most of the fishers are underemployed youth and would not be able to pay fines. However, a set of management guidelines with an environmental awareness program is advised. Fishers should recognize that they should not take juvenile crabs or crabs bearing eggs. Meetings with fishers and school youth are advised.

For centuries mangrove forests were considered by many as useless swamps, and many mangroves have been cleared to make way for development. This attitude has not changed in Jamaica as roads are constructed to facilitate the movement of people from the Montego Bay airport to tourist centers. While an environmental assessment was completed and the requisite culverts installed to meet the reporting standards, the net effect is a loss of essential crab habitat. This fishery represents another example how valuable sustainable natural resources are being diminished in trade-offs that shift economic value from the subsistence sector of society to other sectors of Jamaican society.

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# Exploring Temporal and Spatial Variability in Nekton Community Structure in the Northern Gulf of Mexico: Unraveling the Potential Influence of Hypoxia

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ABSTRACT

The northern Gulf of Mexico supports substantial commercial and recreational fisheries. While landings have remained strong throughout recent years, the seasonal formation of hypoxic bottom waters is a threat to long-term sustainability of regional fisheries production. Because nekton are mobile, the greatest threat to fisheries resources is likely to be the effects of reduced oxygen on habitat quality, potentially forcing movement of individuals away from favorable habitat as well as altering migration pathways. As a basis for understanding potential effects of hypoxia on nekton in the northern Gulf of Mexico, we explored temporal and spatial patterns of community structure in coastal Louisiana and Mississippi. We defined community structure in terms of relative densities of sixty-six species that were either abundant, of commercial and/or recreational importance, or thought to be especially susceptible to hypoxia. Several fisheries-independent data sources were summarized to generate yearly density summaries by season (summer and fall), bathymetry (inshore, nearshore and offshore), and alongshore zones (central Louisiana and eastern Louisiana/Mississippi). Differences in community structure were most pronounced bathymetrically; densities of most species varied significantly among depths. Alongshore differences were less prominent, and were primarily driven by higher densities of bay anchovy in the eastern zone as well as higher densities of Atlantic croaker and commercially important macroinvertebrates in the central zone within inshore waters. Seasonal differences in community structure were most evident in nearshore zones as well as inshore in central Louisiana, areas historically prone to the formation of hypoxic waters. Although no substantial long-term changes in community structure were detected, temporal coverage of these data sets (1982 - 2000) may be inadequate to identify temporal alterations due to a shifted baseline. Future efforts that expand the spatial and temporal coverage of these analyses, incorporate environmental variability, and focus on areas especially susceptible to hypoxia are recommended.

KEY WORDS: Gulf of Mexico fisheries; hypoxia; nekton community structure

# Explorando la Variabilidad Temporal y Espacial de la Estructura Comunitaria en el Norte del Golfo de México: Revelando la Influencia Potencial de la Hipoxia

El norte del Golfo de México mantiene pesquerías comerciales y recreacionales substanciales. Mientras los desembarques pesqueros han permanecido fuertes en los últimos años, la formación estacional de hipoxia en las aguas del fondo continúa siendo una amenaza para la sostenibilidad a largo plazo de la producción pesquera regional. Debido a la movilidad del necton, la mayor amenaza para los recursos pesqueros parece ser el efecto de la concentración reducida de oxígeno sobre la calidad del hábitat, potencialmente forzando a individuos a alejarse del hábitat favorable, así como alterando pasos migratorios. Como una base para comprender los efectos potenciales de la hipoxia sobre el necton en el norte del Golfo de México, exploramos patrones temporales y espaciales de la estructura comunitaria en las costas de Louisiana y Mississippi usando PRIMER. Definimos estructura comunitaria en términos de densidades de 66 especies que fueran ya sea abundantes, de importancia comercial y/o recreacional, o consideradas especialmente susceptibles a la hipoxia. Varias fuentes independientes de datos fueron resumidas para generar resúmenes anuales de densidad por estación (verano y otoño), batimetría (litoral interno, litoral y mar abierto) y a lo largo de las costas (centro de Louisiana y este de Louisiana/Mississippi). Diferencias en la estructura comunitaria fueron más pronunciadas batimétricamente; densidades de la mayoría de especies variaron substancialmente entre profundidades. Las diferencias a lo largo del litoral fueron menos pronunciadas, y principalmente dirigidas por las densidades altas de anchovieta en la zona este, así como densidades altas de corbina y macroinvertebrados comercialmente importantes en la zona oeste. Diferencias estacionales en la estructura comunitaria fueron más evidentes en las zonas del litoral interno y del litoral del centro de Louisiana, áreas históricamente propensas a la formación de aguas hipóxicas. Aunque no se detectaron cambios drásticos en la estructura comunitaria a largo plazo, la cobertura temporal de estos datos (1982-2000) puede ser inadecuada para identificar una estructura comunitaria alterada, debido al desfase de la línea base. Se recomiendan esfuerzos futuros que expandan la cobertura espacial y temporal de estos análisis, que incorporen la variabilidad ambiental y que se enfoquen en áreas especialmente susceptibles a la hipoxia.

PALABRAS CLAVES: Estructura communitaria, hipoxia

## INTRODUCTION

The "Fertile Fisheries Crescent," an area extending from Mississippi to eastern Texas and encompassing the region of the northern Gulf of Mexico directly influenced by discharge from the Mississippi River (Gunter 1963), is characterized by an abundance of fisheries resources that is partially driven by the prolific primary production common to the region (Houde and Rutherford 1993, Grimes 2001, Nixon and Buckley 2002). Commercial and recreational fishery landings within coastal Louisiana have exceeded those from other U.S. Gulf states in terms of biomass and value over the past several decades, and currently represent close to seventy percent of the total commercial harvest within U.S. Gulf waters (Chesney et al. 2000). During the same time frame total commercial landings within Louisiana waters have steadily increased, and as of 1996 the total bycatch produced by the various fisheries in Louisiana exceeded total fishery landings for any other Gulf state.

While moderate levels of nutrient enrichment are generally thought to enhance fisheries productivity, the input of excess nutrients, or nutrient over-enrichment, may be detrimental to fisheries resources. Scientists have long been aware of a zone of high productivity near the mouth of the Mississippi River (Riley 1937); enhanced primary production in shelf waters near the mouth of the river is positively correlated with influxes of nutrients into the Gulf of Mexico in association with seasonal peaks in freshwater discharge (Justic et al. 1993, Lohrenz et al. 1997). Over the past half century, riverine nutrient concentrations within Mississippi River waters have increased significantly due to altered land-use practices, resulting in eutrophication along the continental shelf (Turner and Rabalais 1991, Turner and Rabalais 1994, Rabalais et al. 1996). The enhanced primary productivity, coupled with strong stratification along the coast, leads to the seasonal formation of a large zone of hypoxic ($\leq 2$ mg/l $O_2$) bottom water along the Louisiana-Texas coast (Rabalais et al. 1996, Wiseman et al. 1997). Typically occurring in depths of 5 – 30 m, the areal extent of hypoxic waters has increased from 8,000 – 9,000 $km^2$ during the late 1980s to 16,000 – 20,000 $km^2$ in the late 1990s (Rabalais et al. 1996, Rabalais and Turner 2001).

The seasonal occurrence of hypoxic bottom waters in the northern Gulf of Mexico has the potential to adversely affect demersal fishery resources. In the Black Sea, long-term changes in fish abundances have been linked to eutrophication and hypoxia (Daskalov 2003), while in the northern Gulf of Mexico, abundances and distribution of penaeid shrimp and groundfish are negatively related to the relative size of the mid-summer hypoxic zone (Renaud 1985, Zimmerman and Nance 2000). Although the occurrence of hypoxia can lead to direct mortalities of sessile organisms (Burnett and Stickle 2001), most highly-mobile nekton are capable of leaving regions when dissolved oxygen concentrations drop to hypoxic levels (Breitburg et al. 2001, Rabalais et al. 2001). For most fishes and motile macroinvertebrates, the greatest threat of hypoxia is likely to be the effect of reduced oxygen on habitat quality, potentially forcing the movement of individuals away from favored habitat as well as altering migrations. While recent studies have focused on the distribution of selected species (Craig 2001) as well as overall demersal biomass (Craig et al. 2001) in relation to hypoxia, little work has focused on the effects of hypoxia on community structure in the northern Gulf of Mexico.

We explored spatial and temporal patterns in nekton community structure within coastal waters off Mississippi and Louisiana as an initial step towards understanding the potential influence of hypoxia on their patterns of distribution and abundance. Community-level analyses were conducted (1) to identify spatial differences in community structure, both alongshore and in association with changing bathymetry, and (2) to identify seasonal as well as long-term changes in community structure within given spatial zones. When differences in community structure were detected, additional analyses were conducted to identify specific taxa whose densities contributed to observed differences. Combined, these results provide valuable insight into temporal and spatial variability in community structure as well as potential community-level responses to hypoxia in the northern Gulf of Mexico.

## MATERIALS AND METHODS

The northern Gulf of Mexico study area included waters off the coasts of Louisiana and Mississippi that are directly influenced by inflow from the Mississippi River (Figure 1). A total of six separate spatial zones were defined to explore spatial patterns of community structure, and these zones were constructed to account for regional hydrology as well as the occurrence of hypoxia. The study area was bisected into two alongshore zones by the Mississippi River; the central Louisiana (CLA) zone extended from the mouth of the river westward to Vermilion Bay while the eastern Louisiana/ Mississippi zone (ELA/MS) extended from the mouth of the river eastward to the Mississippi/Alabama border. Three bathymetric zones (inshore: 0 – 5 m; nearshore: 5 – 25 m; offshore: 25 – 200 m) were defined based upon areas most frequently influenced by the seasonal formation of hypoxia (Rabalais and Turner 2001).

To examine temporal and spatial patterns of community structure in the coastal waters off Louisiana and Mississippi we assembled fisheries-independent trawl data collected by the Louisiana Department of Wildlife and Fisheries (LDWF), the Mississippi Department of Marine Resources (MDMR), and the Southeast Area Monitoring and Assessment Program (SEAMAP). Because the offshore SEAMAP data is collected as part of summer and fall groundfish surveys, comparisons among areas were restricted to data collected from June through November only. For each data source, catch-per-unit-effort (CPUE) values were calculated (number 1000 $m^{-2}$) for sixty-six species that were selected because of their abundance, commercial and/or recreational importance, or perceived susceptibility to hypoxia. Mean CPUE values were calculated in a 2 X 3 X 2 X 19 array of alongshore zones, bathymetric zones, seasons (summer: June – August; fall: September – November) and years (1982 – 2000). When combining data from multiple sources (inshore zones only), mean CPUE values were weighted by the relative sampling effort (proportion of total area sampled) of each data source within the specified spatial zone.

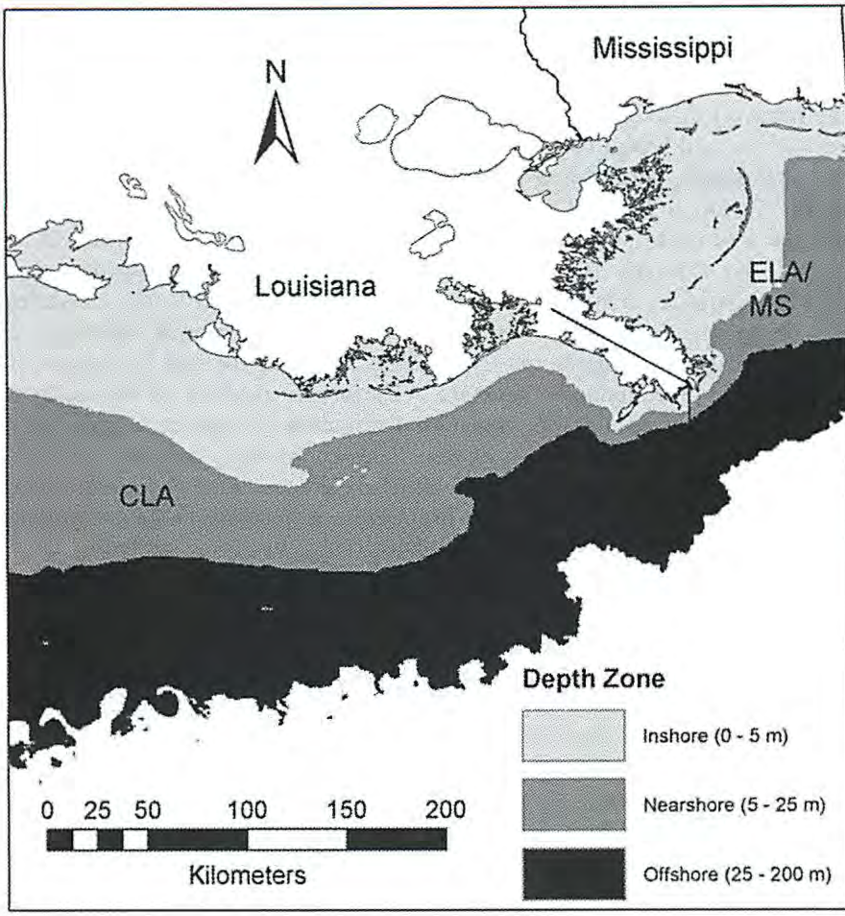


**Figure 1.** Study area off of Louisiana and Mississippi. Alongshore zonations (CLA: central Louisiana; ELA/MS: eastern Louisiana and Mississippi) were designated based on influence of Mississippi River plume. Bathymetric zonations (Inshore; Nearshore; Offshore) were established to isolate the Nearshore region, which is most frequently prone to hypoxia.

Spatial and temporal comparisons of community structure were conducted using the PRIMER software package (Clarke and Warwick 2001, Clarke and Gorley 2001). To minimize confounding effects and simplify interpretation of results, spatial comparisons (alongshore and bathymetric zones) were conducted seasonally, while temporal comparisons incorporating both seasonal and time-interval components (I: 1982 – 1985, II: 1986 – 1990, III: 1991 – 1995, IV: 1996 – 2000) were conducted separately for each of the six spatial zones. Ordination among samples was examined using non-metric multidimensional scaling (MDS) based upon Bray-Curtis similarities (Bray and Curtis 1957) that were calculated using square-root transformed CPUE data. For each MDS plot, stress values indicated that the amount of distortion resulting from compressing the relationships among data points to two dimensions was acceptable (i.e., as long as values did not exceed 0.3).

Spatial (alongshore zone X bathymetric zone) and temporal (season X time interval) differences in community structure were tested separately in a two-way crossed layout using the analysis of similarity (ANOSIM) procedure, a non-parametric permutation procedure applied to the Bray-Curtis similarity matrix. Testing of the null hypothesis of no difference in community structure involved a series of steps. Initially, the value of a test statistic R was calculated for the observed data based upon ranked similarities within groups and ranked similarities among groups, adjusted to range from 0 to 1. Next, a series of permutations ($n = 999$) were conducted in which sample labels were randomly distributed among observed values based on the null hypothesis of no difference in community structure. The observed value of R was then compared with the resulting permutation distribution to calculate a probability value. When significant differences were detected, pairwise post-hoc comparisons were conducted using the Bonferroni adjustment. Due to limitations of permutation testing, the examination of R values is generally more useful than that of p-values, and can identify whether groups were well separated ($R > 0.75$), were clearly separated but overlapped somewhat ($0.75\ ^3\ R > 0.5$), or were barely separable ($R < 0.25$).

The contribution of each species to observed between-group differences was calculated using the similarity percentages (SIMPER) routine. For between-group differences (i.e., between pairs of spatial zones), the contribution of each species to Bray-Curtis dissimilarities was calculated. Bray-Curtis dissimilarities are analogous to similarities, with the exception that values range from 0 (completely similar) to 100 (completely dissimilar). Contributions were calculated by taking into account both the contribution of each species as well as the variability in overall contribution to observed dissimilarities. Due to the large number of potential comparisons, SIMPER analyses were only conducted when either significant differences were detected in ANOSIM results or the comparisons involved seasons and/or spatial zones for which hypoxic conditions are common. For the sake of brevity, only the top five species contributing to observed between-group differences were reported.

## RESULTS

Distinct spatial groupings were evident seasonally (Figure 2). All three bathymetric zones were clearly separated during both seasons, while distinct separation between alongshore zones was only evident within inshore and offshore zones, primarily during fall. Community structure differed significantly among bathymetric zones during both summer (ANOSIM: $R = 0.93$, $p < 0.001$) and fall months (ANOSIM: $R = 0.94$, $p < 0.001$). Pairwise comparisons between bathymetric zones, averaged across both alongshore zones, indicated that community structure differed among all three zones during both summer (ANOSIM: $R\ ^3\ 0.84$) and fall (ANOSIM: $R\ ^3\ 0.92$). Although there was some overlap, community structure also differed significantly between alongshore zones during both summer (ANOSIM: $R = 0.40$, $p < 0.001$) and fall (ANOSIM: $R = 0.48$, $p < 0.001$).

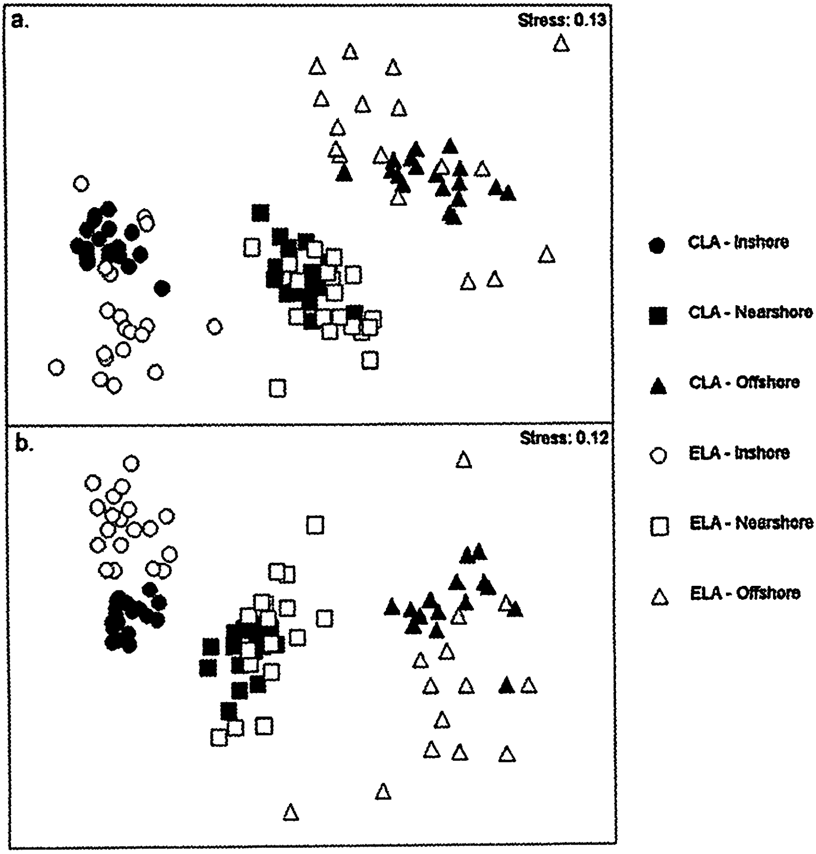


**Figure 2.** Spatial patterns of community structure based on non-metric multidimensional scaling for a) summer (June – August) and b) fall (September – November), respectively. Symbols represent alongshore (CLA: central Louisiana; ELA: eastern Louisiana and Mississippi) and bathymetric (Inshore: 0 – 5 m; Nearshore: 5 – 25 m; Offshore: 25 – 200 m) zonations.

Dissimilarity between bathymetric zones was high during summer, ranging from 59.0 to 80.7% (Table 1). The greatest dissimilarity was between inshore and offshore zones, and was characterized by higher abundances of *Anchoa mitchilli* within inshore zones as well as higher abundances of *Stenotomus caprinus* and *Serranus atrobranchus* within offshore zones. Nearshore and offshore communities also differed significantly, with higher abundances of *Trachypenaeus similis* and *Peprilus burti* within nearshore zones. Dissimilarity between inshore communities of central Louisiana and eastern Louisiana/Mississippi were comparable during both summer (46.3%) and fall (41.3%; Table 2). During both seasons, differences between the two zones were characterized by higher abundances of *M. undulatus* and penaeid shrimp in central Louisiana as well as higher abundances of *A. mitchilli* and *A. hepsetus* in eastern Louisiana/Mississippi.

**Table 1.** Bray-Curtis dissimilarity values between bathymetric zones during summer (June – Aug) in coastal Louisiana and Mississippi. Values reported include total dissimilarity (Tot.Dis), average abundance (Avg.Abund, in number 1000 $m^{-2}$), average dissimilarity (Avg.Dis), ratio of average dissimilarity to standard deviation of similarity (Dis/SD) and the percent contribution to the total dissimilarity (%).

| Bathymetric Zones | Tot.Dis | Taxon | Zone I Avg.Abund | Zone II Avg.Abund | Avg.Dis | Dis/SD | % |
|---|---|---|---|---|---|---|---|
| Inshore - Nearshore | 64.0 | *A. mitchilli* | 21.7 | 0.1 | 5.9 | 1.1 | 9.2 |
| | | *S. caprinus* | 0.2 | 9.5 | 5.1 | 2.6 | 7.9 |
| | | *T. similis* | 0.1 | 5.1 | 3.2 | 1.4 | 5.0 |
| | | *P. burti* | 0.2 | 5.6 | 3.0 | 1.2 | 4.7 |
| | | *M. undulatus* | 4.2 | 3.8 | 2.5 | 1.2 | 4.0 |
| Inshore - Offshore | 80.7 | *A. mitchilli* | 21.7 | 0.0 | 9.0 | 1.3 | 11.1 |
| | | *S. caprinus* | 0.2 | 5.8 | 5.2 | 1.6 | 6.4 |
| | | *M. undulatus* | 4.2 | 5.3 | 4.3 | 1.2 | 5.4 |
| | | *S. atrobranchus* | 0.0 | 2.5 | 3.9 | 2.0 | 4.8 |
| | | *A. hepsetus* | 3.6 | 0.0 | 3.9 | 1.1 | 4.8 |
| Nearshore - Offshore | 59.0 | *T. similis* | 5.1 | 1.1 | 4.0 | 1.3 | 6.8 |
| | | *M. undulatus* | 3.8 | 5.3 | 3.5 | 1.1 | 5.9 |
| | | *S. caprinus* | 9.5 | 5.8 | 3.3 | 1.4 | 5.6 |
| | | *P. burti* | 5.6 | 1.8 | 3.1 | 1.1 | 5.2 |
| | | *C. similis* | 2.9 | 0.3 | 3.1 | 1.7 | 5.2 |

**Table 2.** Bray-Curtis dissimilarity values between alongshore zones within inshore waters (0 – 5 m depth) during summer (June – Aug) and fall (Sep – Nov). Values reported include total dissimilarity (Tot.Dis), average abundance (Avg.Abund, in number 1000 $m^{-2}$), average dissimilarity (Avg.Dis), ratio of average dissimilarity to standard deviation of dissimilarity (Dis/SD) and the percent contribution to the total dissimilarity (%).

| Season<br>Alongshore Zones | Tot.Dis | Taxon | Zone I<br>Avg.Abund | Zone II<br>Avg.Abund | Avg.Dis | Dis/SD | % |
|---|---|---|---|---|---|---|---|
| Summer | | | | | | | |
| CLA – ELA/MS | 46.3 | *A. mitchilli* | 3.9 | 39.5 | 8.0 | 1.4 | 17.3 |
| | | *A. hepsetus* | 0.3 | 6.9 | 4.1 | 1.5 | 8.9 |
| | | *M. undulatus* | 7.0 | 1.5 | 3.5 | 1.3 | 7.5 |
| | | *C. chrysurus* | 2.0 | 1.5 | 1.8 | 1.0 | 3.9 |
| | | *F. aztecus* | 3.1 | 1.2 | 1.8 | 1.7 | 3.8 |
| Fall | | | | | | | |
| CLA – ELA/MS | 41.3 | *A. mitchilli* | 3.8 | 23.8 | 6.8 | 1.8 | 16.6 |
| | | *M. undulatus* | 5.3 | 0.9 | 3.1 | 1.3 | 7.6 |
| | | *A. hepsetus* | 0.4 | 4.5 | 2.8 | 1.0 | 6.7 |
| | | *C. chrysurus* | 2.0 | 3.3 | 2.4 | 1.4 | 5.8 |
| | | *L. setiferus* | 3.3 | 1.2 | 1.7 | 1.6 | 4.2 |

Clear seasonal groupings were evident for most spatial zones, although there was little evidence of long-term changes in community structure (Figure 3). Seasonal differences were most distinct throughout central Louisiana and the nearshore zone within eastern Louisiana/Mississippi. Among seasonal comparisons, R-values ranged from 0.23 to 0.77, and there was evidence of strong seasonal differences in community structure (ANOSIM: $R > 0.52$) for all spatial zones except inshore and offshore zones within eastern Louisiana/ Mississippi. Community structure did not differ strongly among time intervals for any of the six spatial zones (ANOSIM: $R \leq 0.45$). Nevertheless, subtle long-term changes in community structure may have occurred in inshore zones of central Louisiana (ANOSIM: $R = 0.45$, $p < 0.001$) and eastern Louisiana/ Mississippi (ANOSIM: $R = 0.43$, $p < 0.001$). Within these two inshore zones, pairwise comparisons among time intervals indicated that community structure during the first time interval (1982 – 1985) differed from all other time intervals (1986 – 1990; 1991 – 1995; 1996 – 2000) for both central Louisiana (R $^3$ 0.52) and eastern Louisiana/Mississippi (R $^3$ 0.73).

Seasonal patterns in community structure within the nearshore zone were similar for both central Louisiana and eastern Louisiana/Mississippi (Table 3). Observed differences were driven primarily by higher abundances of *M. undulatus* during fall and higher abundances of *T. similis*, *Stenotomus caprinus* and *P. burti* during summer.

## DISCUSSION

Significant spatial and temporal differences in community structure were detected within coastal waters off of Louisiana and Mississippi. Spatial differences were primarily related to bathymetry, and were similar during both summer and fall. There was also evidence of strong seasonal differences in community structure within most of the spatial zones, including nearshore zones, where similar seasonal patterns were evident in both central Louisiana and eastern Louisiana/Mississippi. We did not detect any long-term change in community structure in the northern Gulf of Mexico, although the possibility exists that hypoxia-induced changes in community structure occurred prior to the earliest data incorporated in these analyses. Alternately, the effects of hypoxia on demersal communities may be partially buffered by characteristics of the northern Gulf of Mexico ecosystem as well as the nekton themselves. Future analyses incorporating a wider spatial coverage as well as additional historical data appear warranted.

**Table 3.** Bray-Curtis dissimilarity values between summer (June – Aug) and fall (Sep – Nov) for nearshore zones (5 – 25 m depth) of central Louisiana (CLA) and eastern Louisiana and Mississippi (ELA/MS). Values reported include total dissimilarity (Tot.Dis), average abundance (Avg.Abund, in number 1000 $m^{-2}$), average dissimilarity (Avg.Dis), ratio of average dissimilarity to standard deviation of dissimilarity (Dis/SD) and the percent contribution to the total dissimilarity (%).

| Alongshore Zone Season | Tot.Dis | Taxon | Zone I Avg.Abund | Zone II Avg.Abund | Avg.Dis | Dis/SD | % |
|---|---|---|---|---|---|---|---|
| CLA | | | | | | | |
| Summer – Fall | 41.0 | *M. undulatus* | 4.8 | 17.2 | 4.0 | 1.7 | 9.8 |
| | | *T. similis* | 5.7 | 0.6 | 2.8 | 1.6 | 6.8 |
| | | *S. caprinus* | 8.4 | 3.0 | 2.1 | 1.2 | 5.1 |
| | | *P. burti* | 4.0 | 0.6 | 2.1 | 1.7 | 5.1 |
| | | *C. similis* | 2.1 | 6.2 | 2.0 | 0.8 | 4.8 |
| ELA/MS | | | | | | | |
| Summer – Fall | 45.3 | *S. caprinus* | 10.6 | 7.3 | 3.0 | 1.4 | 6.6 |
| | | *T. similis* | 4.6 | 1.1 | 2.6 | 1.5 | 5.7 |
| | | *P. burti* | 7.3 | 0.9 | 2.6 | 0.9 | 5.6 |
| | | *M. undulatus* | 2.7 | 4.1 | 2.4 | 1.5 | 5.4 |
| | | *C. chrysurus* | 0.4 | 3.0 | 2.4 | 1.5 | 5.2 |

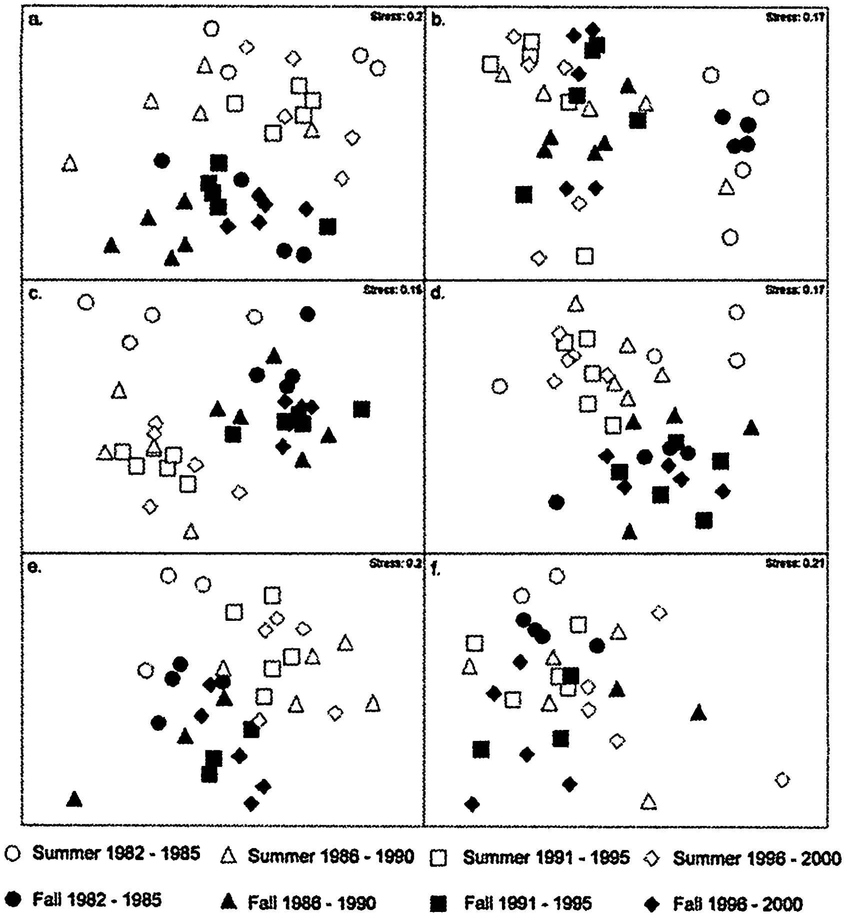


**Figure 3.** Temporal patterns of community structure based on non-metric multidimensional scaling for a) Inshore CLA, b) Inshore ELA/MS, c) Nearshore CLA, d) Nearshore ELA/MS, e) Offshore CLA, and f) Offshore ELA/MS, respectively.

Spatial differences in community structure were generally more pronounced than were temporal differences, and were primarily related to bathymetry and to a lesser extent alongshore position east and west of the Mississippi River. Higher abundances of anchovies (both *Anchoa mitchilli* and *A. hepsetus*) within inshore waters coupled with the virtual absence of anchovies in waters deeper than 5 m contributed to observed spatial patterns of community structure (Table 1), especially in eastern Louisiana/Mississippi (Table 2). While previous studies have also documented high abundances of anchovies within shallow, inshore waters of both Louisiana (Rakocinski et al. 1992; Baltz et al. 1993) and Mississippi (Ross et al. 1987), our results may be confounded by gear bias. Because anchovies are pelagic, observed density differences may be partially attributable to the fact that demersal trawls sample a greater proportion of the water column in shallow areas. Observed densities of *Trachypenaeus similis*, *Peprilis burti*, *Stenotomus caprinus* and *Serranus atrobranchus* also contributed to bathymetric differences in community structure, and agreed with previously-published reports regarding the distribution of these species along depth gradients (Moore et al. 1970, Brusher and Ogren 1976, Chittenden and McEachran 1976, Chittenden and Moore 1976, Geoghegan and Chittenden 1982, Murphy and Chittenden 1991). Despite clearly-defined bathymetric patterns of community structure, observed differences cannot be soley attributed to depth. We know that other factors covary with depth and may affect nekton; these include distance from shore, temperature, salinity, dissolved oxygen and chlorophyll *a* concentrations (Grimes and Finucane 1991, Rabalais et al. 1991). Future analyses need to address the relative importance of these other environmental factors on the community structure of nekton in the northern Gulf of Mexico.

Seasonal differences in community structure were evident for four of six spatial zones, including the nearshore zones of both central Louisiana and eastern Louisiana/Mississippi. Similar seasonal patterns were evident within both nearshore zones, and appear to be primarily related to ontogenetic movements of selected species. Within nearshore zones, *Micropogonias undulatus* were found in higher numbers during fall. *M. undulatus* spawn during late fall/early winter, and the fall peaks in abundance most likely represent an influx of new recruits from inshore nurseries (Gunter 1938, Moore et al. 1970). Three other species, *Trachypenaeus similis*, *Peprilus burti* and *Stenotomus caprinus*, occurred in higher numbers during summer. Summer peaks in *T. similis* abundances corresponded to those observed in coastal Florida (Brusher and Ogren 1976). Juvenile *P. burti* use nearshore waters as nurseries during summer, eventually dispersing into deeper waters as they approach 9 – 12 months of age (Murphy and Chittenden 1991). Summer peaks of *S. caprinus* most likely represent age-I individuals, since mature adults primarily spawn from January through April, with young gradually dispersing into deeper waters as they mature (Geoghegan and Chittenden 1982). Based upon these analyses, we did not detect any seasonal differences in community structure that may be directly related to the occurrence of hypoxia during summer months within nearshore waters of the northern Gulf of Mexico.

While we did not detect any significant long-term changes in community structure in the northern Gulf of Mexico, the temporal coverage of these data may be inadequate to detect such changes. Although continental shelf hypoxia was first reported in the early 1970s (Hanifen et al. 1997), evidence suggests that the concentration of nutrients within the Mississippi River discharge began to rise some years earlier (Turner and Rabalais 1991, Turner and Rabalais 1994). Additionally, other long-prevalent anthropogenic influences, including alterations to watershed hydrology and the impacts of fishing, may have resulted in previous alterations to community structure (Gunter 1952, Chesney et al. 2000). The potential exists that any significant changes to community structure occurred well before the earliest data included in the current analyses (1982). It is also possible that the effects of hypoxia on demersal communities have been buffered to date by characteristics of the basin, the nekton and/or the ecosystem (Chesney and Baltz 2001). Nevertheless, these analyses represent an important first step in understanding the potential effects of hypoxia as well as other anthropogenic factors on the demersal community as a whole in the northern Gulf of Mexico. Future analyses are recommended that build upon these efforts by expanding spatial coverage to include the remainder of Louisiana and Texas and by expanding temporal coverage by incorporating historical data. It will be especially important to incorporate measures of environmental variability to identify the relative effects of various environmental parameters, including dissolved oxygen, on observed patterns of community structure.

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# Metamorphic Response of Queen Conch (*Strombus gigas*) Larvae Exposed to Sediment and Water from Nearshore and Offshore Sites in the Florida Keys

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ABSTRACT

Queen conch, *Strombus gigas*, is an important fisheries species that has been over-harvested in many locations throughout the Caribbean including Florida. The conch population in the Florida Keys has been slow to recover due, in part, to diminished recruitment and declining environmental conditions. Therefore, it is crucial to evaluate the efficacy of management strategies aimed at conserving and restoring queen conch populations. As such, this study examined the effects of juvenile conch habitat quality on metamorphosis. Competent conch larvae were exposed to sediment and water collected from two nearshore sites adjacent to the land and two offshore sites along the reef tract in the Florida Keys. Juvenile conch aggregations were present at all sites. Metamorphic response to nearshore and offshore treatments were similar ($p < 0.05$), and the average number of larvae that metamorphosed ranged from 62% to 85%. In addition, there was no significant difference in metamorphic response for larvae exposed to site sediment with site water or to those larvae exposed to site water only ($p < 0.05$). However, larvae that metamorphosed when exposed to nearshore treatments were not as robust (defined as crawling on the substrate and searching for food with proboscis) as those exposed to offshore treatments. These findings indicate that both nearshore and offshore habitats are favorable settlement locations for competent larvae; however, nearshore sites may not have the same quality as offshore sites. Resource managers can apply these results to assist in defining critical juvenile nursery grounds for conservation and stock enhancement.

KEY WORDS: Queen conch, metamorphosis, *Strombus gigas*

# La Respuesta Metamórfica de las Larvas del Caracol (*Strombus gigas*) Expusieron a Sedimento y Agua de Sitios Cercanos a la Costa y Arrecifales de los Cayos de la Florida

El caracol, *Strombus gigas*, es una especie importante de pesquerías que ha sido sobre-explotado a través del Caribe inclusive en la Florida. La población del caracol en los Cayos de la Florida se ha recuperado lentamente debido, en parte, a un reclutamiento mínimo y ha condiciones ambientales en deterioro. Es importante evaluar la eficacia de estrategias de manejo que proponen a conservar y restaurar poblaciones del caracol. Por lo tanto, este estudio examinó los efectos de la calidad del habitat juvenil sobre la metamorfosis de las larvas del caracol. Larvas competentes fueron expuestas a sedimento y agua colectado de dos sitios cerca de la costa y dos sitios arrecifales en los Cayos de la Florida. Agregaciones de juveniles existen en todos sitios. La respuesta metamórfica en los tratamientos cercanos a la costa y arrecifales fueron similares ($p < 0.05$), y el porcentaje de larvas que metamorfosearon fue de 62% a 85%. Además, no había diferencia significativa en la respuesta metamórfica de larvas expuestas al sedimento del sitio con agua del sitio ni a esas larvas expuestas al agua del sitio sólo ($p < 0.05$). Sin embargo, las larvas que metamorfosearon cuando expuesto a tratamientos cerca de la costa no fueron tan robustas (definido como arrastrándose en el sustrato y buscando alimento) como esos expuesto a tratamientos arrecifales. Estos resultados indican que los habitates cercanos a la costa y arreciflaes son areas favorables de reclutamiento para larvas competentes; sin embargo, parece que los sitios cerca de la costa no tienen la misma calidad que los sitios arrecifales. Estos resultados se pueden aplicar para definir el habitat crítica de los juveniles.

PALABRAS CLAVES: Caracol, metamorfosis, *Strombus gigas*

## INTRODUCTION

Queen conch (*Strombus gigas*), a marine gastropod, is found throughout the Caribbean and southern Florida (Randall 1964). The conch industry is a valuable commercial fishery for the Caribbean exceeded only by the harvest of spiny lobster (Appeldoorn 1994). Due to intense pressure from fishing, queen conch was listed in the Convention on International Trade of Endangered Species (CITES) in the 1980s and in 1992 was listed in Appendix II of CITES. In Florida, the decline of the queen conch population resulted in the government enacting legislation (Florida Administrative Code 1985) that made the collection of queen conch illegal (Glazer and Berg 1994). Though pressure from fishing has decreased, recovery of the queen conch population in the Florida Keys has been slow (Glazer and Berg 1994). In 1992, belt-transects estimated that 5,800 adult conch were present in the Florida Keys. In 2003, approximately 37,000 adult were present in the Keys with estimates of another 25,000 juveniles (Delgado Pers. comm.). Even with the increase in abundance, the current population would not be sustained if fishing were allowed again.

In the Florida Keys, two distinct conch populations exist in nearshore and offshore waters (Glazer and Quintero 1998). The two populations do not exchange genetic information, which has been attributed to the Hawk Channel (Delgado et al. 2004). The channel acts as a physical barrier due to its composition of soft sediment, which the conch do not inhabit (Glazer and Berg 1994). The slow recovery of the conch has been attributed to smaller spawning aggregations and decreased recruitment between populations as a result of the channel (Delgado et al. 2004). Adding to problems of low abundance, nearshore aggregations have not reproduced since the early 1990s (Glazer and Berg 1994). Nearshore aggregations lack gonadal development required for reproduction, while offshore aggregations have normal gonadal development (Delgado et al. 2004). Translocation has been an effective way to improve reproductive success.

Possible cues that induce larvae to settle include the presence of adults, a food source, or an appropriate habitat (Walters et al. 1996). The quality of water at habitats may also affect the development of larvae (Glazer and Quintero 1998). It is known that larvae will go through metamorphosis when exposed to the red algae *Laurencia*, but only in high concentrations (Davis 1994, Boettcher and Targett 1996). When exposed to different substratum and sediment samples found in conch nurseries, larvae showed a high rate of metamorphosis (Stoner et al. 1996b). To better understand the quality of the two habitats, larvae were exposed to sediment from nearshore and offshore sites where conch were present. Sediment was also taken from directly beneath juveniles at an offshore site to determine if there was a response to conspecifics.

## MATERIALS AND METHODS

### Culture

Queen conch egg masses were collected from the Florida Keys on June 16, 2004 and cultured at Harbor Branch Oceanographic Institution from June 17-July 7, 2004 following procedures described by Davis (1994). The egg masses were incubated until they were ready for hatch. Larvae were raised in 700 L larval tanks under static conditions. A complete water change occurred every 48 hours, and larvae were fed daily with Tahitian *Isochrysis*. Larvae were raised until competent for metamorphosis, which was at twenty-one days, when pigment on the foot changed from orange to dark green (Davis 1994).

A test set was performed prior to the experiment to determine if larvae were competent for metamorphosis and to determine which concentration of *Laurencia* to be used during the experiment. The *Laurencia* treatment was prepared as described in Davis and Shawl (In press). Twelve larvae were exposed to *Laurencia* extract at a concentration of 7ml/L of seawater. Ten larvae were placed in 100 ml glass dishes and exposed to Laurencia concentrations of 10, and 15ml/L of seawater. Larvae were exposed to the *Laurencia* treatments for 4 hours and then percent metamorphosis was determined. The larvae had complete metamorphosis when their velar lobes were lost, they were crawling around with the propodium, and they were searching for food with the proboscis (Davis 1994). Dosage was determined to be effective when 60% or greater of the larvae have gone through metamorphosis. It was found that 15ml/L had the best rate of metamorphosis.

**Experiment**

On July 7, 2004, competent larvae were transported in gallon plastic bags placed in coolers. Approximately 160 conch were placed in each bag, with a total of twelve bags. Temperature within the bags was 28.6°C. Larvae were in the bags for five and a half hours prior to their arrival in the Keys.

On arrival, the larvae were exposed to a 16 different treatments to induce metamorphosis: a positive control of Laurencia extract (15ml/L seawater), a negative control of Harbor Branch seawater (27.5 °C), which was filtered and UV treated were used. Queen conch larvae were exposed to sediment samples from two offshore sites and two nearshore sites (Table 1). All sediment samples were taken from areas where conch were present (Figure 1). Each treatment used 75 ml of water, site water or HBOI water. There was a slight variation in water temperature between nearshore and offshore sites (Table 1). Each treatment and control had four replicates with 10 larvae per replicate (Table 2). Each treatment sat overnight in dark conditions (19 hours), in a water bath of 28 °C. Ending water temperature for the treatments was 26 °C. Larvae from the *Laurencia* treatment were removed after four hours and placed in negative control water and fed. They were analyzed when the other treatments were viewed.

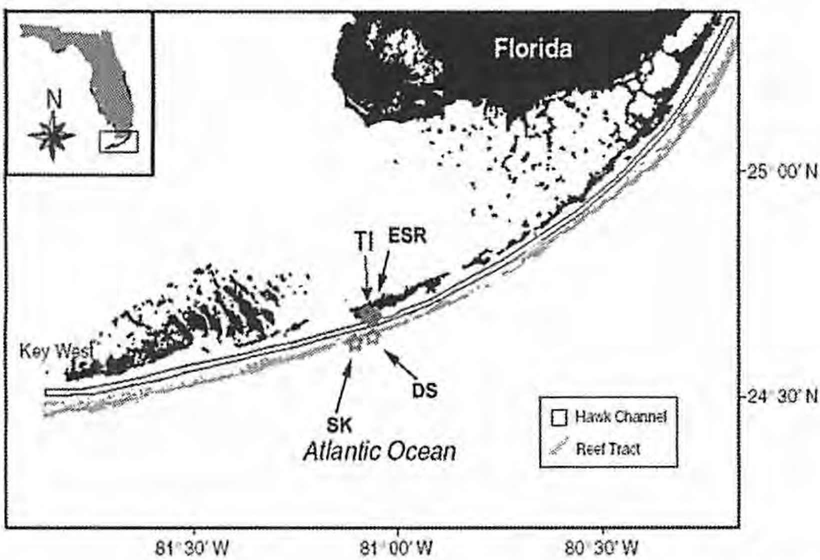


**Figure 1.** Location of sediment sampling sites in the Florida Keys. Arrows point to the general location of sampling sites. (TI) Tingler Island, (ESR) East Sister Rock, (SK) Sombrero Key, (DS) Delta Shoal

**Table 1.** Description of sediment samples from nearshore and offshore sites in the Florida Keys, July 8, 2004

| Site | Location | Depth (ft) | Tide | Water Temp (°C) | Vegetation | Sediment Description |
|---|---|---|---|---|---|---|
| Tingler Island (TI) | Nearshore | 6 | Slack low | 30.7 | Calcareous red algae, possible *Dictyota* sp. | Hard bottom, mix of rubble and coarse sand, has pieces of algae (*Halimeda*, calc. red algae), snail shells, color: dark tan and brown |
| East Sister's Rock (ESR) | Nearshore | 6 | Slack low | 30.7 | A little *Bataphora*, many sponges, Bivalve pieces encrusted with red algae | Little rubble, mostly fine sand, color: dark tan |
| Sombrero Key (SK) | Offshore | 10 | Ebb | 30.1 | *Thalassia* green and detrital blades, *Halimeda* live and dead, possible *Hypnea* | Few rubble pieces (*Halimeda*), majority of course sand with some fine sand, color: light tan |
| Delta Shoal (DS) | Offshore | 6 | Ebb | 30.1 | *Halimeda incrussata*, *Thalassia*, green and detrital blades, *Halimeda opuntia* | Few rubble pieces (*Halimeda*), mostly course sand, with some fine sand, color: light tan |
| Delta Shoal (DS) | Offshore under conch | 6 | Ebb | 30.1 | *Thalassia*, Seagrass live and detrital | Mostly fine sand with some coarse sand, pieces of coral rubble, live *Halimeda*, color: light tan |

**Table 2.** List of treatments in metamorphosis experiments on *Strombus gigas* conducted at Florida Fish and Wildlife Center in the Florida Keys. HBOI: Harbor Branch Oceanographic Institution; TI: Tingler Island; ESR: East Sister Rock; SK: Sombrero Key; DS: Delta Shoal

| Treatment | Source | Quantity Sediment | Quantity water |
|---|---|---|---|
| ***Control*** | | | |
| *Positive: Laurencia* | *Laurencia* | | 75mL |
| Negative: HBOI seawater | HBOI seawater | | 75mL |
| ***Nearshore*** | | | |
| TI sediment w/ TI water | Tingler Island | 2mL | 75mL |
| TI sediment with HBOI water | Tingler Island | 2mL | 75mL |
| TI water only | Tingler Island | | 75mL |
| ESR sediment w/ ESR water | East Sister's Rock | 2mL | 75mL |
| ESR sediment with HBOI water | East Sister's Rock | 2mL | 75mL |
| ESR water only | East Sister's Rock | | 75mL |
| ***Offshore*** | | | |
| SK sediment w/ SK water | Sombrero | 2mL | 75mL |
| SK sediment with HBOI water | Sombrero | 2mL | 75mL |
| SK water only | Sombrero | | 75mL |
| DS sediment w/ DS water | Delta | 2mL | 75mL |
| DS sediment with HBOI water | Delta | 2mL | 75mL |
| DS water only | Delta | | 75mL |
| DS sediment under juvenile with DS water | Delta | 2mL | 75mL |
| DS sediment under juvenile with HBOI water | Delta | 2mL | 75mL |

Percent metamorphosis was determined after larvae sat overnight (19 hours) in the treatments. Larvae were visually analyzed using dissecting microscopes and placed in clean seawater. Three classifications were used to describe the larvae: lobes remaining, metamorphosed, or dead. Larvae that had undergone metamorphosis were described as lethargic, weak, or robust: lethargic larvae had undergone metamorphosis, but were not moving around; weak larvae were moving, but not actively searching for food; and larvae that were moving around and actively searching for food were classified as robust.

**Statistical Analysis**

The Shapiro-Wilk test was used to test the data for normality. Data conformed to a normal distribution. Bartlett's Test was used to determine homogeneity of variance. Mean percent metamorphosis among treatments was compared using a two-way ANOVA and Tukey's Method for mean separation.

## RESULTS

Larvae metamorphosed when they were exposed to all treatments including HBOI seawater negative control. There was no observed difference between nearshore and offshore treatments. A significant difference was found between the HBOI seawater control and most of the treatments (Figure 2). The control was not significantly different from Tingler Island with water from HBOI, East Sister Rock sediment with HBOI water, Delta Shoal sediment with HBOI water and Sombrero Key water only. The lowest metamorphic response (50%) was to sediment from nearshore site Tingler Island with water from HBOI. The highest response (82.5%) was from larvae exposed to sediment directly beneath a juvenile from offshore site Delta Shoal with water from Delta Shoal.

Larvae appeared to have a higher metamorphic response when exposed to site sediment and site water (Figure 3). When exposed to site sediment and Harbor Branch water, a decrease in metamorphic response was found. Larvae did metamorphose when exposed only to site water. Site water was found to have a significant effect on metamorphic response ($p < 0.05$), while sediment did not have a significant effect. Sediment and site water, and site water only were found to have a significantly better response than the HBOI control ($p < 0.05$). Mortality occurred in fifty percent of the treatments, with the highest mortality (22.5%) occurring with larvae exposed to the offshore site, Sombrero Key, water only (Figure 4). There were no consistent trends between treatments that did have mortalities.

Of the larvae that had a metamorphic response, the majority were either robust or lethargic (Figure 5). All larvae exposed to the seawater control were lethargic. The offshore site Sombrero Key had the greatest percentage of larvae that were robust, while the nearshore site East Sister's Rock had the least robust larvae. The only treatments without lethargic larvae were the *Laurencia* control and larvae that had been exposed to sediment from directly beneath a juvenile at the offshore site, Delta Shoals. The larvae exposed to the *Laurencia* control had been fed after their exposure time, which would account for why they were robust.

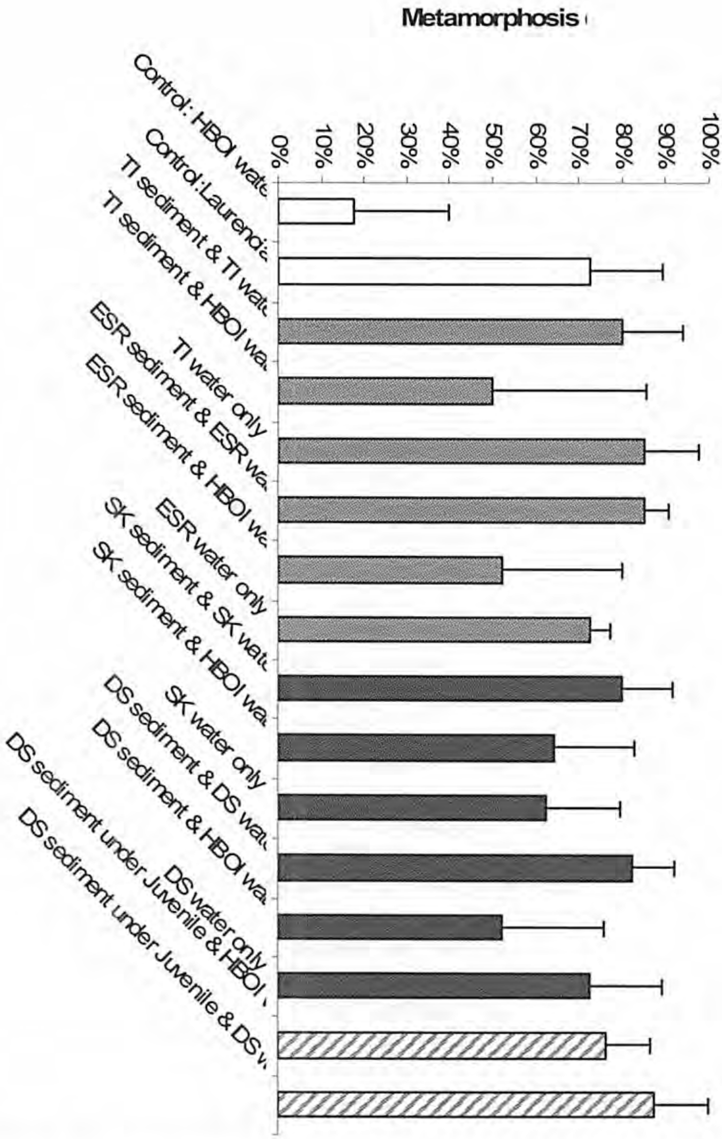


**Figure 2.** Percent metamorphosis treatments grouped by nearshore and offshore sites. White: controls; Light Gray: nearshore; Black: offshore; Striped: Offshore underneath Juvenile. TI: Tingler Island, ESR: East Sister Rock, SK: Sombrero Key, DS: Delta Shoal

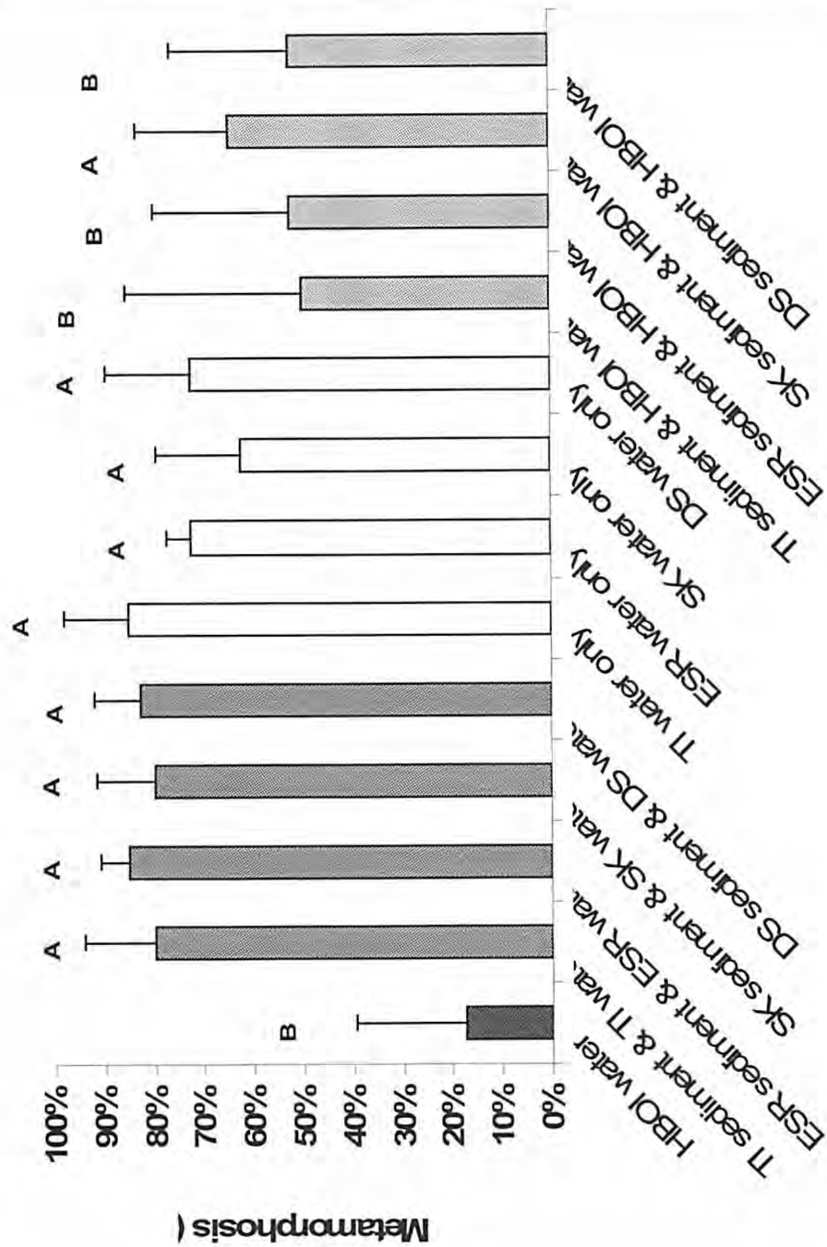


**Figure 3.** Percent metamorphosis grouped as site sediment to site water, site sediment to HBOI water and site water only. Black: Negative HBOI control; Dark Gray: Site sediment with site water; White: Site water only; Light Gray: Site sediment with HBOI water. TI: Tingler Island, ESR: East Sister Rock, SK: Sombrero Key, DS: Delta Shoal

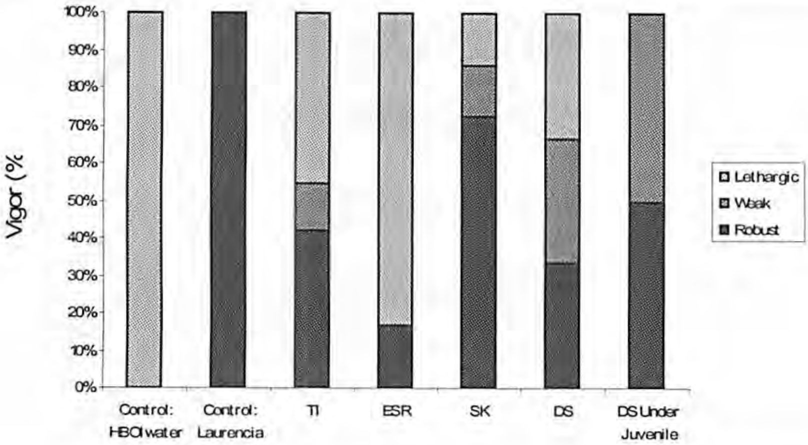


**Figure 5.** Condition of larvae from each treatment site. TI: Tingler Island, ESR: East Sister Rock, SK: Sombrero Key, DS: Delta Shoal

## DISCUSSION

Spontaneous metamorphosis is when larvae have a metamorphic response to environments where metamorphic cues would not normally occur, such as sterile seawater. While spontaneous metamorphosis does not usually occur, Harbor Branch water did elicit a metamorphic response. Though the seawater used had been filtered and UV sterilized prior to use, nutrients or algae may have been present. It has been found that some vessels carrying seawater develop a microflora film that could induce metamorphosis (Davis and Stoner 1994).

A high response was seen when larvae were exposed to just site water. Boettcher and Targett (1996) found that certain foods that conch consume, such as Laurencia and Thalassia are water soluble. While the cues do not extend far from the substrata, the solutes may have been present in the water causing the high metamorphic response to site water only. It has been found that water soluble cues do exist less than 4mm from the substrata to in the water column for oyster larvae (Boettcher and Targett 1996). Temperature is also a known inducer of metamorphosis. When water temperatures are above culture levels, metamorphosis may be induced (Boettcher In review). Water that had been collected from the sites did have a high water temperature (> 30.1 °C).

Queen conch larvae are known to metamorphose in response to substrata and sediment collected from juvenile conch nursery grounds (Davis and Stoner 1994, Boettcher and Targett 1996, Stoner et al. 1996b). Larvae had a high metamorphic response to sediment treatments from all sites. This may be explained by the presence of red algae at each site, many of which are known inducers of metamorphosis (Boettcher and Targett 1996). *Bataphora* sp. and *Thalassia* sp., which were present at the nearshore and offshore sites, are also known to induce metamorphosis. They are some of the most abundant macrophytes in juvenile conch habitats (Davis and Stoner 1994). Sediment is also known to contain micro-organisms, such as diatoms, and organics that have been found to be cues for conch metamorphosis. The findings agree with Davis and Stoner (1994) which indicates that metamorphosis is a trophic cue. Habitat texture may also contribute to metamorphic success. Coarse sand versus fine sand may also accumulate organics and inorganics in higher concentrations (Stoner et al. 1996b). There was some variation between sediment between nearshore and offshore sites. Nearshore sites had coarser sand with rubble pieces while offshore sites had finer sand.

Larvae that metamorphosed in nearshore treatments were not as robust as those that metamorphosed when exposed to offshore treatments. Greater percentages were lethargic after being exposed to nearshore treatments than the offshore treatments. This may be a consequence of eutrophication nearshore. Nearshore waters are subjected to a higher concentration of sewage discharge and pesticides (Glazer and Quintero 1998). Shackleton et al (2002) found that *Haliotis midae*, South African abalone, larval development was negatively affected by water with poor quality. When studying development, larvae were grown in conditions similar to offshore and nearshore conditions. Larvae raised in offshore conditions grew better than those raised in nearshore conditions (Glazer and Quintero 1998). When ready to settle and go through metamorphosis, conch appear to seek out habitats that are of good quality and appear to be areas for high survivorship (Davis and Stoner 1994). Davis (1994) hypothezied that the swim crawl stage (where lobes are still present, but they are using their foot to move around) may be an adaptation to test substrates out, but they still have the ability to swim away if the habitat is not suitable.

Larvae exhibited a metamorphic response to both nearshore and offshore habitat cues. This indicates both nearshore habitats and offshore habitats are good areas for settlement for queen conch larvae. While larvae will settle in both habitats, it does not indicate that both areas are good for post-settlement survival or reproductive activities. It is already known that nearshore habitats do not favor reproductive output due to habitat quality (Delgado et al. 2004). Resource managers can apply these results to assist in defining critical juvenile nursery grounds for conservation and stock enhancement.

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# The Effects of the Pesticides Biomist 30/30® and Dibrom® on Queen Conch (*Strombus gigas*) Embryos and Larvae: A Pilot Study

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ABSTRACT

Pesticides targeting mosquitoes are increasing in use as the mosquito population continually poses a threat and a nuisance to residents and animals. However, as the use of pesticides increases there is a need to investigate the effects that these pesticides have on the marine environment. Four bioassays were conducted to determine if the pesticides used for mosquito control in the Florida Keys, Biomist 30/30® and Dibrom®, are affecting the recovery of *Strombus gigas*. The bioassays tested the effects of each pesticide on embryogenesis and veliger survival. Three concentration levels were tested: the target spray concentration used by mosquito control, half the target concentration, and twice the target concentration. Embryonic development was determined by measuring the perivitellin space of developing embryos. Larval survival was determined by counting the number of veligers swimming in the water column after 48 hours of exposure to the pesticides. Embryos exposed to the pesticides exhibited delayed or abnormal development while embryos in the controls showed normal development. Larvae exposed to Biomist 30/30® had 100% mortality after 48 hours. Unfortunately, all the larvae (including those in the control) in our Dibrom® bioassay crashed after 24 hours. These results may have implications for continued coastal development in the Florida Keys, as the pesticides used in mosquito control may be negatively affecting the recovery of nearshore queen conch populations.

KEY WORDS: Queen conch, larvae, pesticides, Florida Keys

# Los Efectos de los Pesticiads Biomist 30/30® y Dibrom® en los Embriones y Larvas del Caracol Rosado (*Strombus gigas*): Un Estudio Piloto

Pesticidas contra mosquitos estan aumentando en uso, como la población de mosquitos es una amenaza y un fastidio a residentes y animales. Sin embargo, como el uso de pesticidas aumenta hay una necesidad de investigar los efectos que estos pesticidas tienen en el ambiente marino. Cuatro experiomentos se realizaron para determinar si los pesticidas utilizadas para el control de mosquitos en los Cayos de la Florida, Biomist 30/30® y Dibrom®, afectan la recuperación de *Strombus gigas*. Los experimentos pruebaron los efectos de cada pesticida sobre la sobrevivencia de embriones y larvas. Tres concentraciones de pesticidas se probaron: la concentración que se aplica por el control del mosquito, la mitad de esa concentración, y el doble de esa concentración. El desarrollo embrionario fue determinado midiendo el espacio de perivitellin. Sobrevivencia de larvas fue determinada contando el número de larvas nadando en la columna de agua después de 48 horas de la exposición a los pesticidas. Los embriones expusieron a los pesticidas mostraron desarrollo retrasado o abnormal mientras embriones en los controles mostraron desarrollo normal. Las larvas expusieron a Biomist 30/30® tuvo 100% de mortalidad después de 48 horas. Desgraciadamente, todas las larvas (inclusive ésos en el control) en nuestro experimento con Dibrom® se murieron después de 24 horas. Estos resultados pueden tener implicaciones para el desarrollo costero en los Cayos de la Florida como los pesticidas utilizaron en el control de los mosquitos pueden estar afectando negativamente la recuperación de poblaciones de *Strombus gigas* en aguas costeras.

PALABRAS CLAVES: *Strombus gigas*, larvas, pesticidas, Cayos de la Florida

## INTRODUCTION

Queen conch (*Strombus gigas*) once supported a significant commercial fishery in the Florida Keys, but overfishing and habitat degradation caused a vast decline in the number of queen conch in the area. Due to the large reduction in the Florida Keys conch population, the commercial fishery was closed in 1976 and the recreational fishery was closed in 1986 (Glazer and Berg 1994, Glazer et al. 2003). Despite protection for more than 17 years in the state of Florida, there has been very little recovery of the population since the fishery closure (Glazer and Berg 1994, Stoner et al. 1997, Glazer et al. 2003). The queen conch is not currently threatened with extinction, but it is listed by the Convention of International Trade in Endangered Species (Ray-Culp and Stoner 2000).

The Florida Keys population of queen conch resides on the backside of the Florida Keys reef tract. Conch reproduce during the summer months by laying an encapsulated egg strand that may contain up to 500,000 embryos (Davis 1994). The strand is wrapped around itself and covered with sand for protection. After four days of development the larvae emerge from the egg mass. Larvae can be found in water up to 100 m deep, but most are found in the upper 5 m (Stoner 1997). Veligers spend 3-4 weeks in the water column before settling to the ocean floor. During this time larvae may travel large distances from where they hatched. Past surveys have shown an infrequent and irregular supply of larvae in the Florida Keys area (Stoner 1997). The irregular supply of larvae may partially account for the lack of recovery among the queen conch population (Stoner et al. 1997).

It is possible that locally sprayed pesticides may cause damage to the developing embryos and larvae, thereby, causing mortality and a reduction in the larval supply. Dibrom® and Biomist 30/30® are sprayed throughout Monroe County to control the mosquito population. Dibrom® is 85% Naled (Dimethyl 1,2-dibromo- 2,2- dichloroethyl phosphate), the remaining 15% is a petroleum distillate solvent (Valent USA Corporation). Dibrom®is applied by aerial application to 289,531.96 acres in the Florida Keys (Monroe County Mosquito Control). It is applied at a rate of ½ oz per acre (Monroe County Mosquito Control). Naled has a half-life of 16 hours under a pH of 7, degradation decreases as the pH rises (Pierce 1998). The primary by-product is dichlorvos, DDVP (2,2- Dichlorovinyl dimethyl phosphate) is highly toxic and insoluble in water (Snedaker and Rumbold 1997). Dichlorvos does not bind to sediments and has a half-life of four days in aquatic environments (Extension Toxicology Network).

Biomist 30/30®, (active ingredient permethrin), is sprayed in an ultra-low volume form from a sprayer mounted on the back of a truck (Monroe County Mosquito Control). Permethrin ((3- Phenoxyphenyl) methyl (+) cis, trans- 3-(2,2- dichloroethenyl)- 2,2- dimethyl cyclopropanecarboxylate) is a synthetic pyrethroid with a mixture of both cis and trans isomers. It is ephemeral with a half-life of 14 days in seawater exposed to sunlight (Schimmel et al. 1983 and Gonzalez-Doncel et al. 2003). Synthetic pyrethroids are toxic to fish and other aquatic organisms, including aquatic invertebrates (Lee et al. 2002). Biomist 30/30® is combined with the synergist piperonly butoxide (Butylcarbityl- 6-propyliperonyl ether. Piperonly butxide is considered toxic to fish and aquatic invertebrates (National Pesticide Telecommunications Network).

Dibrom® and Biomist 30/30® enter the water by drift, runoff, and leaching. Tests indicate that DDVP appears to enter the water by tidal flushing of pesticide residue from residential canal systems where Dibrom® is sprayed (Pierce 1998). Sea surface microlayers frequently become enriched with contaminants, including pesticides. Embryos and larvae have displayed developmental toxicity when exposed to contaminated microlayers (Snedaker and Rumbold 1997). Snedaker and Rumbold (1999) demonstrated that sea surface microlayers collected off the Florida Keys adversely affect the embryogenesis of invertebrates and fish. The present study will test the effects of the two pesticides used in mosquito control in the Florida Keys on queen conch embryos and larvae to determine if they play any role in limiting recruitment and, thus, the recovery of the conch population in the Florida Keys.

## METHODS

Conch egg masses were collected from breeding aggregations located on the back-reef of the Florida Keys reef tract. The egg masses were brought to the lab and disinfected using a 0.5% Clorox® solution. The 0.5% Clorox® solution was prepared by placing 10 milliliters of 5% household strength Clorox® per 2 liters of filtered seawater. Each egg mass was placed in the solution for 30 seconds, removed, and dipped in 3 beakers of clean seawater for 10 seconds per dip as per the method of Davis (1994). There were four bioassays conducted, Biomist 30/30® (Clark Mosquito Control) was tested using embryos and larvae; Dibrom® (Amvac Chemical Corporation) was also tested using embryos and larvae. There were five treatments (with three replicates of each treatment) for each run of the experiments. Treatments consisted of a control using Instant Ocean® made with deionized water, filtered nearshore seawater, and three concentrations of Dibrom® and Biomist 30/30®. The three concentrations of Biomist 30/30® were 5.05051E-08 ml, 2.52525E-08 ml (target concentration), and 1.26382E-08 ml per 1 ml of artificial seawater. The three concentrations of Dibrom® were 4.45931E-08 ml, 2.22965E-08 ml (target concentration) and 1.11483E-08 ml per 1 ml of artificial seawater. The salinity of the artificial seawater was adjusted to 35‰ and was vacuum filtered through 50 micron filter pads to remove any particles prior to use. The nearshore water was collected from Florida Bay and filtered through a 0.45 micron Millipore filter prior to use. The effects of nearshore water on embryos and larvae were tested in conjunction with the Biomist 30/30® assays.

Biomist 30/30® was tested on queen conch embryos to determine its effects on embryonic development. The disinfected egg mass was broken into small sections and placed in 1,000 ml beakers containing 500 ml of one of the five treatment solutions. All beakers were covered with a watch glass to minimize contamination and evaporation. Beakers were placed in a water bath maintained at a constant temperature of 28 $\pm$ 1°C. The temperature was maintained using an aquarium heater and thermostat and was recorded at three locations in the water bath every 24 hours. The experiment ran for four days (96 hours). On days 2 and 4, cultures were taken of all five treatments to test for *Vibrio* contamination. The pH and oxidation/reduction potential were also measured for each treatment and recorded. The egg mass sections were examined using a dissecting microscope. The scope was equipped with a camera, and five pictures were taken of each section. Within each picture, two eggs were used to determine average perivitellin space (i.e. the space in-between the egg capsule and the developing embryo). We used perivitellin space as our performance measure because as the embryo develops normally within the egg capsule, the perivitellin space will decrease over time. The vertical and horizontal distance in millimeters of each egg and each embryo within the egg was measured (Figure 1). Perivitellin space was determined by taking the mean of the vertical and horizontal measurements of the egg and then subtracting the mean of the vertical and horizontal measurements of the embryo. A nested ANOVA was used to calculate differences in perivitellin space among the different treatments for each day.

In the second bioassay, Biomist 30/30® was used to test the effects on queen conch larvae mortality and growth. Larvae were hatched from egg masses collected in the wild. The egg masses were disinfected as described above. The larval experiment consisted of five treatments (with three replicates in each treatment). The same concentrations as the previous bioassay were used. Upon hatching, 10 larvae were placed in each replicate and covered with a watch glass to prevent contamination and evaporation. They were placed in a water bath maintained at a temperature of 28 $\pm$ 1°C. The experiment ran for 48 hours. On days 1 and 2 cultures were taken of all five treatments to test for *Vibrio* contamination. Every 24 hours the temperature, pH, and oxidation/reduction potential was measured and recorded. The larvae were examined and mortality rates were determined for each treatment by counting the number of dead larvae versus the number of living larvae. Mortality was determined by position in the water column. Veligers that were able to maintain position in the water column by rotation or retraction of the velum were considered alive. Veligers that were resting on the bottom, with or without beating of a larval heart, were considered dead (Rumbold and Snedaker 1997). A chi-square test was used to analyze the data for each day.

Dibrom® was tested on queen conch embryos and larvae as described in the embryo and larval tests conducted with Biomist 30/30®. The experiment consisted of four treatments (an artificial seawater control and three pesticide concentrations) with three replicates of each treatment. The concentrations used were 4.45931E-08 ml, 2.22965E-08 ml (target concentration) and 1.11483E-08 ml per 1 ml of artificial seawater.

## RESULTS

Temperature was constant throughout the study. We were unable to analyze pH and ORP because of faulty equipment. On day 2 of the first experiment the pH and ORP probes were no longer taking accurate readings.

### Experiment 1: Queen Conch Embryogenesis and Biomist 30/30®

The first day of this experiment showed no significant difference ($F_{(4, 10)}$ = 0.944, p = 0.478) among any of the treatments (Figure 1). However, Day 2 showed a significant difference between the control and the treatments ($F_{(4, 10)}$ = 13.054, p = 0.001) as the embryos in the synthetic seawater control began to develop normally (Figure 2). Day 3 continued to show a significant difference between the control and the three pesticide concentrations; the nearshore treatment also began to show a slight difference compared with the three pesticide treatments ($F_{(4, 10)}$ = 6.234, p = 0.009) (Figure 1). However, on Day 4, there was no difference among the treatments ($F_{(4, 10)}$ = 3.20, p = 0.062) even though the embryos exposed to the pesticide concentrations were not as far along in their development as the conch in the synthetic seawater control or those in the nearshore water treatment (Figure 2).

### Experiment 2: Queen Conch Embryogenesis and Dibrom®

Day 1 did not show a significant difference among the treatments ($F_{(3, 8)}$ = 3.13, p = 0.088) (Figure 3). Day 2 continued to show no difference among the treatments ($F_{(3, 8)}$ = 2.12, p = 0.176) (Figure 3). However, Day 3 showed a significant difference among the treatments ($F_{(3, 8)}$ = 14.482, p = 0.001) as the control animals began to develop normally and the embryos exposed to the pesticide concentrations were either developing abnormally or not developing at all (Figure 3). Day 4 showed an even greater disparity in perivitellin space between the control and the three pesticide concentrations with the control showing normal development and the pesticide treatments exhibiting no change in perivitellin space over time (Figure 3). However, the ANOVA for Day 4 was not significant ($F_{(3, 8)}$ = 2.19, p = 0.167); this was probably due to the large deviations about the mean found in the pesticide concentrations.

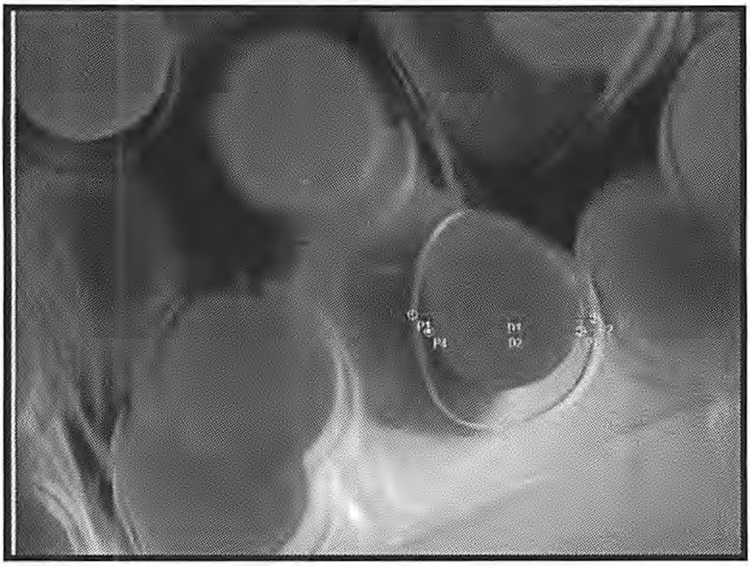


**Figure 1.** Picture of perivitellin space measurements being taken using the computer program Image Pro Plus. Horizontal and vertical measurements of the eggs and embryos were used to determine perivitellin space for each embryo.

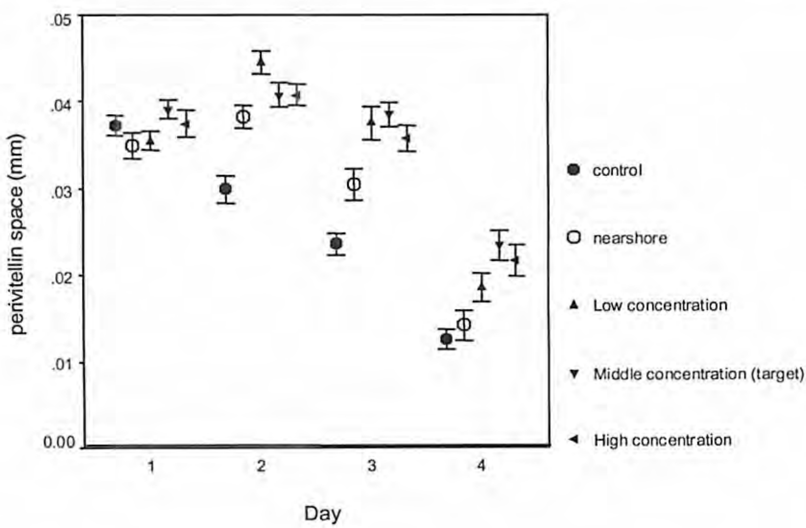


**Figure 2.** Graph of perivitellin space measurements for all five treatments of the Biomist30/30® bioassay (experiment 1). The graph shows the mean perivitellin space for each treatment on all four days of the bioassay. The error bars represent ± one standard error.

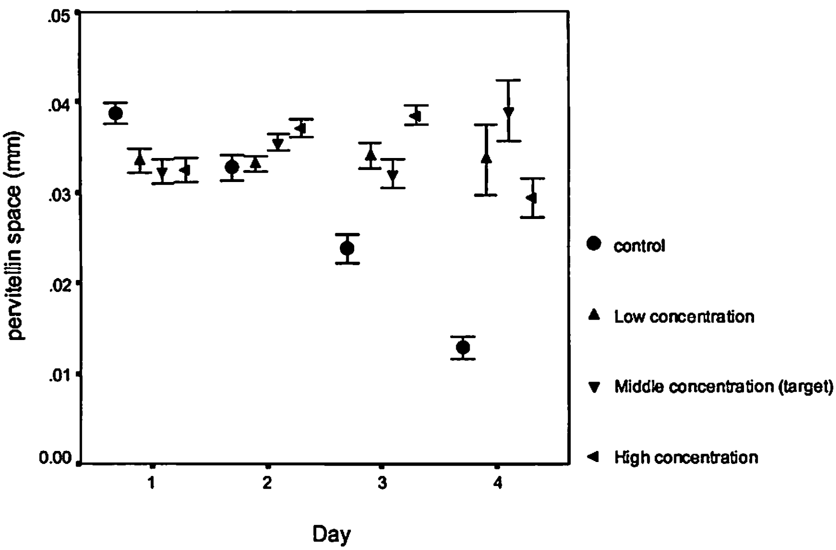


**Figure 3.** Graph of perivitellin space measurements for all five treatments of the Dibrom® bioassay (experiment 1). The graph shows the mean perivitellin space for each treatment on all four days of the bioassay. The error bars represent ± one standard error

**Experiment 3: Queen Conch Larvae and Biomist 30/30®**

Queen conch larvae exposed to Biomist 30/30® experienced a high degree of mortality in all three treatment concentrations after 48 hours (Figure 4). The chi-square test for Day 1 showed a significant difference in mortality ($X^2$ = 57.32, $p < 0.001$) with mortality in the control and the nearshore water treatment hovering around 20% while the mortality in the pesticide treatments ranged from about 50% to 95% (Figure 4). On Day 2, mortality in the pesticide treatments jumped to almost 100%, whereas mortality was much lower in the control and nearshore water treatment (Figure 4). The chi-square test results for Day 2 were significant ($X^2 = 48.33$, $p < 0.001$).

**Experiment 4: Queen Conch Larvae and Dibrom®**

Due to 100% mortality among all of the treatments and the control after the first 24 hours, no statistical analyses were run for this experiment.

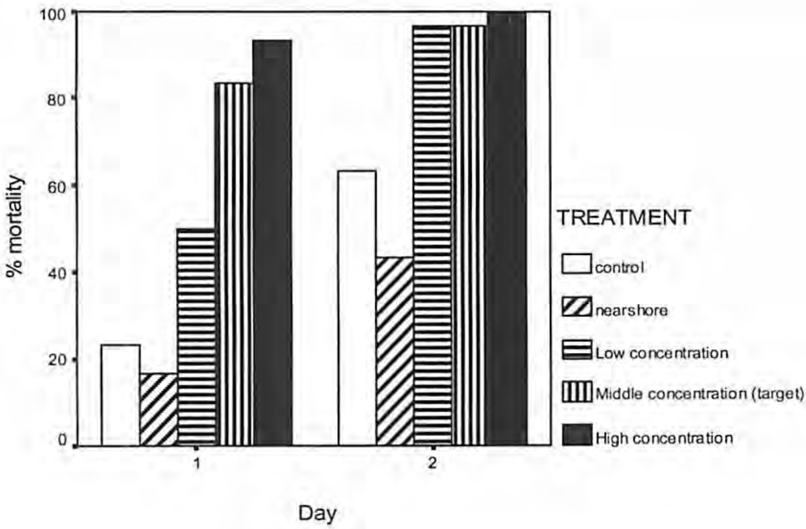


**Figure 4.** The percentage of mean larval mortality in all five treatments of Biomist 30/30® within 48 hours.

## DISCUSSION

Our results showed that Biomist 30/30® and Dibrom® have significant toxicological effects on the development and survival of queen conch embryos and larvae. Biomist 30/30® proved to be toxic to embryos at all three concentrations. The greatest number of effects was seen at the target concentration and higher. Abnormalities were noted during embryogenesis, with slow development seen in all the pesticide treatments (Figure 2). It was also noted that several embryos appeared to be shedding cells. A great number of larvae died during the first 24 hours of the Biomist 30/30® larval bioassay (Figure 4). All of the pesticide treatments had 100% mortality within 48 hours. There were also deaths among the control and nearshore treatments. These deaths may be attributed to the fact that it is difficult to keep larvae alive in the lab without large tanks, water exchanges, or aeration (Davis 1994). Death may have also occurred due to the extraction method used on the veligers from the initial beaker. A 10 ml pipette was used to transfer each veliger out of the beaker and into one of the treatments.

The effects caused by Biomist 30/30® may only be a portion of the effects permethrin has on queen conch embryogenesis. Permethrin does not dissolve in water and therefore binds to other sources such as glass and plastic (Lee et al. 2002). The bioassays were static, as such this would allow for the permethrin to bind readily to the glass and may have reduced the amount of pesticide effecting the embryos and larvae. Unfortunately, there were not enough funds to run chemical analyses to test the actual concentration at the end of the bioassays; therefore, the amount of pesticide that remained in the water could not be determined. Degradation could be estimated by the half-life of either pesticide; degradation can fluctuate with the pH level, and it would be necessary to determine the pH to estimate the amount of pesticide remaining in the water. Unfortunately, as stated in the Results, the pH meter malfunctioned and pH levels could not be determined at the end of the experiment.

With Dibrom® having such a high toxicity, it was not surprising to get such a vast difference in perivitellin space between the control and the pesticide treatments (Figure 3). All three treatment concentrations seemed to have the same effect. Many of the embryos exhibited major deformities during development, and many did not undergo embryogenesis, but instead began shedding cells until an embryo was no longer visible (Figure 5). Unfortunately, this affected the accurate measurement of the perivitellin space since the ultimate goal was to measure the growth of the embryo as it developed. Many of the embryos that shed cells took up a large portion of the egg capsule even though the embryos were not developing and were not viable, thus, explaining our non-significant result on Day 4 of the experiment.

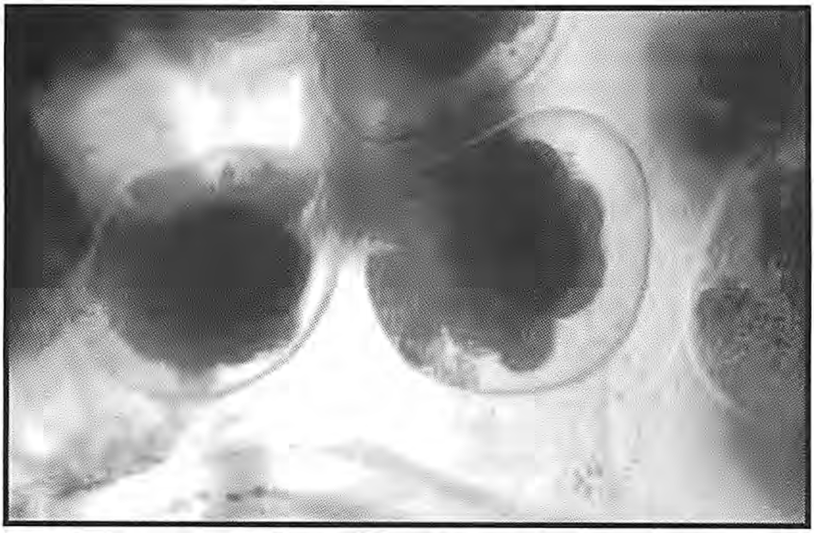

**Figure 5.** Image of embryos in Dibrom® concentration 2.22965E-08 ml (target concentration). Embryos are displaying the observed shedding of cells.

Many factors may have influenced the failure of the final bioassay testing larval survival after exposure to Dibrom®. As stated previously, it is difficult to raise veligers in the lab. Nevertheless, cross contamination is the likely culprit. Another possible mode of contamination is based on the structure of the pesticide. Naled is mixed with petroleum products making Dibrom® an aromatic hydrocarbon; therefore, it is possible that the control beakers were contaminated in this way.

It is unknown if Biomist 30/30® and Dibrom® reach breeding aggregations offshore; although, larvae undoubtedly drift into nearshore areas where they could encounter either of these pesticides. Pierce (1998) reported that only a small percentage of DDVP and permethrin sprayed in the Florida Keys can be found in surface and subsurface water. Further studies are needed to determine the amount of pesticide remaining in the water column after spraying. Benthic substrates should also be tested to determine if permethrin or Dibrom® bind to them since they are insoluble in water. In addition, studies have shown that outflow from Florida Bay and Biscayne Bay transport pollutants from the Florida mainland (Rumbold and Snedaker 1999). Therefore, other pesticides or pollutants might interfere with queen conch development and growth.

This pilot study has provided evidence that the pesticides used for mosquito control in the Florida Keys may be negatively affecting the queen conch population. However, further testing of Biomist 30/30® and Dibrom® would be beneficial. For example, using flow-through chambers (instead of static chambers) to better mimic what the embryos and larvae are exposed to in the natural environment and testing more environmentally relevant pesticide concentrations (along with chemical analyses to confirm actual test concentrations) would provide a more accurate picture of how these mosquito control agents affect queen conch embryos and larvae and in-turn how they may affect the recovery of the queen conch population in the Florida Keys.

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# Estructura Genética del Pulpo *Octopus maya* en los Estados de Campeche y Yucatán en la Península de Yucatán

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RESUMEN

Se determinó la estructura genética poblacional del pulpo rojo *Octopus maya* en los estados de Campeche y Yucatán en la Península de Yucatán, México, mediante la expresión de isoenzimas en geles de poliacrilamida. Muestras de manto de 25 organismos, capturados en cinco sitios de la Península de Yucatán, se utilizaron para caracterizar la expresión genotípica revelada por la expresión de 23 loci en treinta sistemas enzimáticos. Se utilizó el programa TFPGA versión 1.3 ( Tools for population genetic analyses), para procesar los datos de frecuencias génicas de aloenzimas de las poblaciones en estudio.

Los parámetros determinados fueron: Estadística descriptiva, Estadística F, Distancias genéticas, Equilibrio de Hardy - Weinberg, UPGMA y el número de migrantes como indicador del flujo de genes.

Los valores de heterocigosis en un rango de 0.2335 para la ME y de 0.4293 para la PGM 1, con un valor de heterocigosis promedio de 0.1238, los de **Fis** con un valor promedio de 0.4100 y los de **Fst** de 0.0111 indican una deficiencia de heterocigotos pero que se encuentran dentro de los rangos reportados para especies de invertebrados marinos. El número de migrantes derivado de la ecuación de Slatkin resultó de 2.1 por generación, lo que en forma global indica un cierto grado de variabilidad entre las poblaciones y es consistente con los bajos valores de distancia genética de Nei encontrados, particularmente el nodo que sugiere la separación de la población de Rio Lagartos y de Dzilam Bravo de las otras poblaciones estudiadas, con un valor obtenido de 0.0004. Por los resultados de este estudio, se concluye que las poblaciones de *Octopus maya* presentan un cierto grado variabilidad genética interpoblacional que no refleja fragilidad en la subsistencia de estas poblaciones.

PALABRAS CLAVES: Estructura genética, isoenzimas, *Octopus maya*

# Genetic Structure of *Octopus maya* in the Campeche and Yucatan States in the Yucatan Peninsula

Genetic population structure of the red squid Mayan Octopus in the Campeche and Yucatan States of the Yucatan, Peninsula, Mexico was determined, by means of the expression of iso-enzymes in poliacrylamide gels. Samples of mantle of twenty five organisms, captured in five sites of the Yucatan Peninsula, were used to characterize the genotipic expression revealed by the expression of 23 loci in thirty enzymatic systems. The TFPGA Program, version 1,3 (for Tools population genetic analyses), was used to process the data of gene frequencies of isozymes of the populations in study. The parameters used were: Descriptive statistic, Statistical F, genetic Distances, equilibrium of Hardy - Weinberg, UPGMA and the number of migrantes like indicator of the flow of genes. The heterozygosity values, in a range of 0,2335 for ME and 0,4293 for PGM 1, with a value of heterozygosis average of 0,1238, those of Fis with a range of 0,4100 and those of Fst of 0,0110 indicate us a heterozigosity deficiency, but they are within the ranks reported for species of marine invertebrates. The derived number of migrantes of the equation of Slatkin was from 2,1 by generation, which in global form indicates a certain degree of variability between the populations and is consistent with the low values of genetic distance of Nei found, particularly the node that suggests the separation of the population of Rio Lagartos and Dzilam Bravo with the others studied populations, with an obtained value of 0.0004. In function of the results of this study, we can conclude that the populations of Mayan octopus present a certain degree of interpopulation genetic variability that does not reflect fragility in the subsistence of these populations.

KEY WORDS: Genetic structure, isozymes, *Octopus maya*

## INTRODUCCIÓN

La caracterización de la estructura genética poblacional constituye un criterio de gran utilidad para la preservación de especies de importancia comercial y ecológica ya que ésta es indicadora de la heterogeneidad u homogeneidad de las poblaciones sobre grandes regiones geográficas (Bates y Innes 1995). El pulpo *Octopus maya* Voss y Solís, (1966) cefalópodo marino del Phylum mollusca, es una especie litoral propia de la Península de Yucatán, que viven en resquicios de rocas y oquedades del fondo y en algunas ocasiones ocupando conchas de gasterópodos y diversos objetos sumergidos que le sirven de madriguera. La pesquería de *Octopus maya*, comúnmente llamado pulpo rojo, es de gran importancia en las costas del Estado del Yucatán en donde compite por su gran volumen de captura con la pesquería de mero (*Epinephelus morio*) y en Campeche con la pesquería de camarón (*Penaeus sp.*) (Solís y Chávez 1986, SEPESCA 1994).

La gran presión de pesca ha la que ha estado sometido el recurso, ha propiciado una caída drástica en los volúmenes de extracción de biomasa en los últimos años, lo cual dio pauta para la implementación de un periodo de veda que abarca del 16 de diciembre al 31de julio, periodo en el que supuestamente se le da oportunidad a las hembras de poner sus huevos y a los juveniles de crecer.

En el caso de *O. maya*, punto importante lo representa el hecho de que cuando eclosiona del huevo ya es un pulpo con todas las características de sus congéneres adultos, lo cual a final de cuentas incide en su poca dispersión ya que desde pequeño tiende a guarecerse y a no moverse mucho (SEMARNAP 1998). Lo anterior conlleva a establecer si las poblaciones de *O. maya* en los estados en los que se le captura son aisladas o bien pertenecen a una sola población ampliamente distribuida.

En vista del desconocimiento de la información fundamental sobre la genética de las poblaciones de *Octopus maya* en la Península de Yucatán, que sirva como criterio para la mejor explotación y complemente las normas de la pesquería de este recurso, es objetivo del presente trabajo determinar la estructura genética de las poblaciones mas importantes de *O. maya* en esta área con el fin de coadyuvar al establecimiento de los mecanismos y estrategias adecuadas para el mejor manejo de la pesquería de esta especie.

## MATERIALES Y MÉTODOS

La obtención de los organismos se realizó en cinco sitios en los estados de Campeche y Yucatán en las costas de la Península de Yucatán. Veinticinco organismos de todas las tallas de cada sitio fueron colectados con la ayuda de pescadores de cada lugar.

Muestras de manto se homogeneizaron en un volumen igual de buffer de extracción consistente de Tris HCl 12.1 g, EDTA 336 mg, NAD+ 20 mg y ajustado a un pH de 7 (Shaklee y Keenan 1986), se centrifugaron a 10 000 rpm por 10 min. a 7 °C en una centrífuga refrigerada. Geles de poliacrilamida al 7.7 %, preparados para ser utilizados con el sistema nativo (Brewer 1970) se utilizaron para efectuar el corrido electroforético, el revelado histoquímico y la determinación fenotípica de las muestras. La presencia fenotípica se determinó siguiendo los procedimientos de Shaw y Prasad (1970), Brewer (1970) y Shaal y Anderson (1974). Loci presumidos y alelos fueron designados por medio del sistema de nomenclatura utilizado por Shaklee y Keenan (1986). Múltiples loci de una enzima en particular se designaron numéricamente (1, 2, 3, etc.) considerando el de más rápida a más baja movilidad anodal. Alelos de un locus en particular fueron designados por su movilidad anódica relativa y nombrando al alelo mas frecuente como 100 y los demás por arriba y por debajo de éste con los valores respectivos. Loci y alelos fueron designados de acuerdo al sistema de nomenclatura propuesto por Shaklee y Keenan (1986). Un locus se consideró polimórfico si el alelo más frecuente tiene una probabilidad menor que 95 %. Towsend y Shing (1984) y el nivel de heterocigosis se determinó con relación a la ley del Equilibrio de Hardy-Weinberg. Se utilizó el programa denominado TFPGA versión 1.3 (Tools for population genetic analyses), para efectuar el análisis de datos genéticos de aloenzimas de poblaciones (Miller 2000). Los diversos parámetros determinados fueron: Estadística descriptiva, Estadística F, Distancia Genética, Pruebas de robustez para Hardy - Weinberg y UPGMA.

## RESULTADOS

Se utilizaron únicamente los loci que no fueron monomórficos para determinar el nivel de polimorfismo. En la Tabla 1, se presentan los resultados promedio de los valores de heterocigosis, así como los de polimorfismo en dos formas diferentes para todos los sitios y los valores globales. El valor de 0.1238 de heterocigosis global, se puede considerar bajo. Asimismo, se presentan los valores de polimorfismo, 34.782 % para Isla Arenas, 34.7826 % para Celestún, de 27.2727 para Champotón, de 27.2727 para Dzilam de Bravo y de 28.5714 % para Río Lagartos con un valor global del 34.7826 % en todas las poblaciones. Estos valores indicaron diversidad intrapoblacional con poca heterogeneidad interpoblacional.

**Tabla 1.** Resultados de estadística descriptiva para las poblaciones y el total en manto de *Octopus maya*

| Parámetro | Arenas | Celestún | Champotón | Dzilam Bravo | Río Lagartos | Global |
|---|---|---|---|---|---|---|
| Tamaño promedio de muestra | 25 | 25 | 25 | 25 | 25 | 125 |
| Heterocigósis promedio | 0.1360 | 0.1446 | 0.1000 | 0.0952 | 0.0885 | 0.1238 |
| Heterocigósis promedio directa | 0.1096 | 0.0974 | 0.0436 | 0.0418 | 0.0457 | 0.0738 |
| % Loci polimorficos sin criterio | 34.782 | 34.7826 | 27.2727 | 27.2727 | 28.5714 | 34.7826 |
| % Loci polimorficos al 95 % | 34.782 | 34.7826 | 27.2727 | 27.2727 | 28.5714 | 34.7826 |

La Tabla 2, presenta los valores globales obtenidos con las pruebas de Chi Cuadrada. Se aprecia que solo el locus de la FBP presento significancia para esta prueba estableciéndose que de los 8 loci que presentaron variación en el tejido de manto en las tres poblaciones analizadas, el 12.5 % se apartan de la condición de equilibrio. El análisis de remuestreo utilizando el método de Monte Carlo para cada uno de los sitios confirmó que solamente la FBP es el locus que presenta alguna variabilidad.

**Tabla 2.** Pruebas de Bondad de ajuste para el equilibrio de Hardy – Weinberg, Chi Cuadrada, en manto de *Octopus maya* para todas las poblaciones.

| Locus | Genotipo | Observados | Esperados | $X^2$ |
|---|---|---|---|---|
| | 11 | 89 | 76.0500 | |
| ARGK | 12 | 17 | 42.9000 | |
| | 22 | 19 | 6.0500 | 0.0000 |
| | 11 | 77 | 69.1920 | |
| EST1 | 12 | 32 | 47.6160 | |
| | 22 | 16 | 8.1920 | 0.0002 |
| | 11 | 32 | 29.6450 | |
| FBP | 12 | 13 | 17.7100 | |
| | 22 | 5 | 2.6450 | 0.0600*** |
| | 11 | 76 | 69.1920 | |
| G6PDH1 | 12 | 34 | 47.6160 | |
| | 22 | 15 | 8.1920 | 0.0014 |
| | 11 | 85 | 74.4980 | |
| MDH | 12 | 23 | 44.0040 | |
| | 22 | 17 | 6.4980 | 0.0000 |
| | 11 | 81 | 74.8225 | |
| ME | 12 | 11 | 23.3550 | |
| | 22 | 8 | 1.8225 | 0.0000 |
| | 11 | 79 | 70.6880 | |
| OCTDH | 12 | 30 | 46.6240 | |
| | 22 | 16 | 7.6880 | 0.0001 |
| | 11 | 71 | 59.1680 | |
| PGM1 | 12 | 30 | 53.6640 | |
| | 22 | 24 | 12.1680 | 0.0000 |

Los valores de **Fis** y los del índice de fijación **Fst**, de la Tabla 3, van desde 0.2857 para la FBP hasta 0.6057 para la ARGK con un valor promedio de 0.4100, para el primer parámetro y los segundos presentan un valor promedio de 0.0110 con un rango de - 0.0209 para la OCTDH hasta 0.0293 para la FBP.

Los valores de Distancia e Identidad Genética, se determinaron por medio del concepto de Nei 1972, se presentan en forma de matriz en la Tabla 4, todas las poblaciones son comparadas de manera pareada.

En el caso de la Identidad, la relación Isla Arenas – Dzilam de Bravo tuvo el valor menor de 0.9927 y la relación Champotón – Dzilam de Bravo fue la de mayor valor, en el caso de la Distancia genética la relación se mantuvo siendo el menor valor con 0.0004 y la de 0.0073 fue la mayor. Independientemente de cual haya sido el modelo que se utilizara los valores de relación menores y mayores siempre se mantuvieron entre los pares de poblaciones.

**Tabla 3.** Resultados de estadístico F en manto de *Octopus maya*

| Loci | Alelo | F | θ | f |
|---|---|---|---|---|
| | 1 | 0.6057 | -0.0081 | 0.6088 |
| ARGK | 2 | 0.6057 | -0.0081 | 0.6088 |
| | totales | 0.6057 | -0.0081 | 0.6088 |
| | 1 | 0.3290 | -0.0196 | 0.3419 |
| EST 1 | 2 | 0.3290 | -0.0196 | 0.3419 |
| | totales | 0.3290 | -0.0196 | 0.3419 |
| | 1 | 0.2857 | 0.0293 | 0.2642 |
| FBP | 2 | 0.2857 | 0.0293 | 0.2642 |
| | totales | 0.2857 | 0.0293 | 0.2642 |
| | 1 | 0.2906 | 0.0072 | 0.2855 |
| G6PDH1 | 2 | 0.2906 | 0.0072 | 0.2855 |
| | totales | 0.2906 | 0.0072 | 0.2855 |
| | 1 | 0.4793 | -0.0112 | 0.4851 |
| MDH | 2 | 0.4793 | -0.0112 | 0.4851 |
| | totales | 0.4793 | -0.0112 | 0.4851 |
| | 1 | 0.5538 | 0.1871 | 0.4511 |
| ME | 2 | 0.5538 | 0.1871 | 0.4511 |
| | totales | 0.5538 | 0.1871 | 0.4511 |
| | 1 | 0.3575 | -0.0209 | 0.3706 |
| OCTDH | 2 | 0.3575 | -0.0209 | 0.3706 |
| | totales | 0.3575 | -0.0209 | 0.3706 |
| | 1 | 0.4428 | -0.0130 | 0.4500 |
| PGM1 | 2 | 0.4428 | -0.0130 | 0.4500 |
| | totales | 0.4428 | -0.0130 | 0.4500 |
| Promedio | | 0.4100 | 0.011 | 0.4034 |

**Tabla. 4.** Matriz con los valores de distancia e identidad según Nei 1972 para todas las poblaciones de *Octopus maya.* Los datos de arriba de la diagonal son valores de distancia y los de debajo de identidad.

| Población | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | ***** | 0.0020 | 0.0066 | 0.0073 | 0.0034 |
| 2 | 0.9980 | ***** | 0.0042 | 0.0055 | 0.0049 |
| 3 | 0.9934 | 0.9958 | **** | 0.0004 | 0.0013 |
| 4 | 0.9927 | 0.9945 | 0.9996 | **** | 0.0013 |
| 5 | 0.9967 | 0.9951 | 0.9987 | 0.9987 | **** |

## DISCUSIÓN

Las cinco poblaciones de *Octopus maya* analizadas en las costas de la Península de Yucatán presentan una baja variabilidad y una poca diferenciación geográfica entre ellas, los valores de heterocigosis son relativamente bajos e indican una cierta deficiencia de heterocigotos, el valor de polimorfismo encontrado es relativamente bajo 34.7826%, si se compara con el 58% en promedio para invertebrados marinos (Saavedra et al. 1993). Estos bajos niveles de variabilidad pueden tener diversos orígenes desde una circunstancia propia de la especie, el nivel de explotación de las poblaciones en el área o el tamaño de muestra utilizado ( Heist et al. 1995). El valor de heterocigosis media global de 0.1238, aunque se puede considerar bajo cae dentro de los típicamente esperados para especies de invertebrados marinos en general ya que la deficiencia de heterocigotos es una característica común encontrada en estudios en invertebrados marinos (Mamuris et al. 1998, Boisselier et al. 1999) aunque las características reproductoras de muchas de esas especies reflejen el clásico modelo panmítico de las poblaciones genéticas (Bierley et al. 1996). No obstante, existe la posibilidad de que otros factores influyan para que se presenten niveles bajos de heterocigotos tales como el resultado de la mezcla de poblaciones (Efecto Wahalund), los diversos tipos de selección, la presencia de alelos nulos o la perdida de cromosomas que podrían causar estimaciones incorrectas de las fracciones fenotípicas ( Creasey et al. 1996). En el caso de *O. maya* los bajos valores de Fst 0.0110 y de Fis 0.4100 determinados entre las poblaciones nos indican que no se puede considerar al efecto Wahalund como la causa de este fenómeno, aunque se mantiene la idea de que existe la entrada de migrantes (2.1) en las poblaciones. Como no se consideró la presencia de alelos nulos, es menester pensar que la alternativa que esta ocurriendo en las poblaciones se deba al efecto de algún tipo de selección.

No obstante se ha sugerido y en algunos casos demostrado el flujo de genes, los resultados obtenidos mediante el análisis por Chi – Cuadrada nos indican que solo un mínimo de loci son significativamente diferentes.

Las pruebas de randomización efectuadas en los loci que mostraron significancia también sugieren la idea de que algún factor desconocido pueda ser el responsable de los resultados del análisis estadístico. Aunque el fenómeno de baja heterocigosis observada puede causar problemas con el uso de datos electroforéticos en la discriminación de las poblaciones de *Octopus maya*, al utilizar parámetros como lo son la identidad y la distancia genética estos trabajan bien cuando los valores de heterocigosis encontrados en especies bajo investigación son bajos y se tiene un número suficiente de loci, 23 para este trabajo, con los cuales se subsana el problema de contar con un tamaño pequeño de muestra ( Bierley et al. 1996).

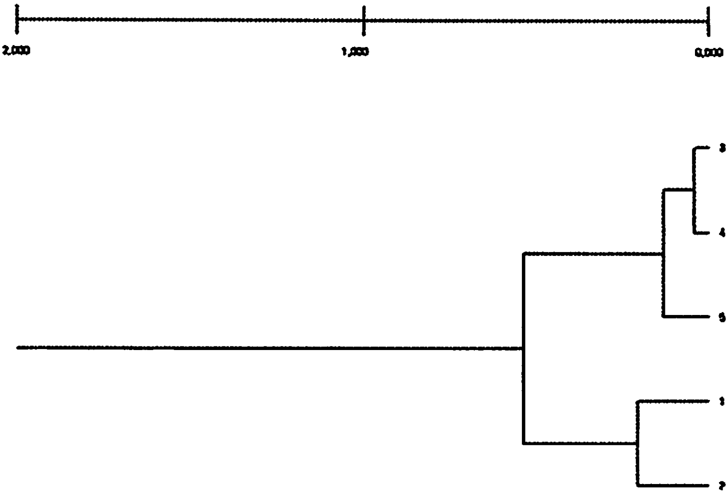


**Figura 1.** Dendográma con los valores de distancias según Nei 1072. 1.- Isla Arenas 2.- Celeste 3.- Champotón 4.- Dzilam de Bravo 5.- Río Lagartos

Los valores de distancia e identidad obtenidos para *Octopus maya* indican que son valores típicos para especies o poblaciones que se encuentran bien mezcladas.

Los dendogramas generados por las medidas de distancia de Nei y el análisis UPGMA Cluster fueron similares pero no idénticos al agrupar las poblaciones. Los valores de distancias fueron diferentes en todos los casos, sin embargo, en ninguno se cambio la distribución de las poblaciones en el análisis Cluster siendo la población de Río Lagartos la que presento la mayor distancia respecto a las otras. Este resultado es congruente con el patrón de corrientes que se dan en el Golfo de México y que propicia que la estructura y variación genética de esta población comparada con las otras cuatro, sea la que manifieste las mayores diferencias.

No obstante, variaciones estocásticas en la corriente de agua, los vientos de superficie, eventos meteorológicos y aun remolinos localizados, podrían afectar la dispersión de los organismos y modificar el reclutamiento de estos en localidades particulares corroborando y concluyendo que tales eventos pueden mantener el estado de discreción de las poblaciones en forma espacial o temporalmente, lo que a final de cuentas evitan la homogenización de estas y propician la diferenciación y valores de distancia genética característicos de esta población.

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# Evaluación Histórica y Bio-Ecológica de la Pesquería del Botuto (*Strombus gigas*) en el Parque Nacional Archipiélago de Los Roques (Venezuela), a través del Estudio de sus Concheros

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RESUMEN

El alto contenido proteico de su carne y la facilidad con la que puede ser recolectado, han hecho del botuto (*Strombus gigas*) uno de los recursos marinos más apreciados en todo el Caribe, después de la langosta. Grandes acumulaciones de conchas (o *concheros*) distribuidas a lo largo y ancho del Parque Nacional Archipiélago de Los Roques revelan la importancia que este recurso a tenido para la región. Con la finalidad de realizar la caracterización de la pesquería de botuto en el Archipiélago a través del tiempo, y el impacto que esta pesca ha tenido sobre las poblaciones naturales de este molusco, se analizaron los concheros ubicados en el cayo La Pelona y sus alrededores. Los análisis radiocarbónicos y el levantamiento detallado de la composición de diversos concheros tanto prehispánicos (1270 a 1450 D.C.) como contemporáneos (1980 a 1995 D.C.), reveló que los indígenas recolectaban principalmente individuos adultos (entre 80 y 90 %), mientras que el pescador contemporáneo extendía su rango de recolección a todas las clases de edad. Estas diferencias observadas en cuanto a los criterios de selección que caracterizaron a los diversos regímenes de pesca (precolombino vs. contemporáneo), seguramente tuvieron influencia en la talla de madurez sexual de los individuos de *Strombus gigas* que habitaron la localidad estudiada. Se evidenció una disminución significativa de la longitud promedio de la concha de subadultos entre los concheros contemporáneos (de 22.5 a 20.8 cm de LT)($p < 0.001$), a medida que transcurrió la actividad pesquera, mientras que para los concheros precolombinos, estas diferencias no fueron significativas (entre 22.7 y 22.1 cm de LT)($p = 0.683$).

PALABRAS CLAVES: Concheros, *Strombus gigas*, pesquería, talla de madurez sexual

# Historical and Bio-Ecological Evaluation of the Queen Conch (*Strombus gigas*) Fishery in the Archipiélago de Los Roques National Park (Venezuela), through the Study of its Shell Middens

Because of the high protein value of its meat and the low catch per unit effort required, the queen conch (*Strombus gigas*) has been situated among one of the most important fishery resources of the Caribbean, after the spiny lobster. Shell middens distributed throughout the Archipiélago de Los Roques National Park reveal the importance of this marine resource for the region. In order to establish the characterization of the fishery of queen conch through time, and the impact this activity had in the natural populations of the mollusk, surveys of seven shell middens situated in the cayo La Pelona and its surroundings were made. The radiocarbon analysis and the detailed composition of the each of the studied shell middens, pre-hispanic (1270 to 1450 A.C.) and contemporary (1980 to 1995 A.C.), demonstrated how pre-colombian indians fished mostly adults conchs (80 to 90 %), while contemporary fishermen broadened their range of catch through all age classes. These observed differences between the two fisheries regimes (pre-hispanic vs. contemporary) probably had influences on the size at maturity of the individuals in natural populations of *Strombus gigas*. A significant decrease in the mean shell length of subadults was measured between the contemporary middens through time (from 22.5 to 20.8 cm)($p < 0.001$), while between the pre-hispanic middens these differences were not observed (22.7 to 22.1 cm)($p = 0.683$).

KEY WORDS: Shell middens, *Strombus gigas*, fishery, size at maturity

## INTRODUCCION

Debido a su comportamiento gregario, y su distribución en zonas de baja profundidad, el botuto, *Strombus gigas*, ha constituido un recurso natural de gran rentabilidad para el ser humano. El alto contenido proteico de su carne y la facilidad con la que puede ser recolectado, han hecho de este molusco uno de los recursos marinos más apreciados en todo el Caribe, después de la langosta (Appeldoorn 1997). La presencia de grandes acumulaciones de conchas (o concheros) de *S. gigas* ubicados a lo largo de todo el Parque Nacional Archipiélago de Los Roques, revela la importancia que dicha empresa ha tenido para las diversas comunidades de humanos que han habitado el archipiélago, a lo largo de los años.

Numerosas evidencias arqueológicas testimonian que esta actividad pesquera se remonta a épocas precolombinas. De acuerdo con los análisis estilísticos y la datación radocarbónica de los artefactos cerámicos hallados en distintas localidades del archipiélago (Cayo Sal, Dos Mosquises Norte, Dos Mosquises)(1430 y 1480 ± 80 D.C.) (1330 ± 80 D.C.)(Antczak y Atnczak 1991), se identificó la presencia de poblaciones indígenas provenientes de la costa centro-occidental del país. Estos indígenas, además de explotar una amplia gama de recursos (e.j., peces, tortugas, aves marinas), centralizaron su empresa en la explotación masiva del botuto. La carne de este caracol era extraída para el consumo, no sólo por parte de los navegantes que frecuentaban el archipiélago, sino también para proveer de alimento a las poblaciones continentales de donde provenían estos navegantes prehispánicos (Antczak y Antczak 1988). Luego de la llegada de los colonizadores europeos al continente, el botuto fue explotado principalmente por holandeses y curazoleños que habitaron el archipiélago entre 1850 y 1910. Sin embargo, la explotación fue menos intensa debido a que estos colonizadores centralizaron su industria en la extracción de sal, cal y carbón (Laughlin et al. 1985).

Posteriormente, el archipiélago sufrió una fuerte inmigración de pescadores provenientes de la isla de Margarita, quienes comenzaron a desarrollar una importante actividad pesquera en torno al botuto y a la langosta. A partir del año setenta, comienzan a registrarse importantes tasas de extracción de botuto. Para el período 1980-1983, Laughlin y col. (1985) reportan tasas de extracción anuales comprendidas entre 160.000 y 245.000 kg de carne.

En Venezuela, el único control de pesca que existía hasta 1985 se llevaba a cabo por medio de permisos de pesca, que el Ministerio de Agricultura y Cría (MAC) entregaba mensualmente, en los cuales se establecía una cuota máxima de pesca de 500 kg/mes/permiso, que los pescadores debían reportar. Sin embargo, estudios realizados por Laughlin y Weil (1985), revelaron una gran discrepancia entre la cantidad de botuto que era declarada oficialmente por los pescadores y la que se extraía. En base a estos resultados, se propuso un plan de manejo para regular la pesca del botuto, sin embargo esta propuesta no fue tomada en cuenta por las autoridades competentes, y se decidió establecer una veda total en todo el área del Parque desde el año 1985 hasta 1989, lo que paradójicamente causó un alza en los precios del botuto. Este fenómeno ocasionó a su vez un alza en la explotación ilegal del recurso, producto de la poca coordinación y falta de interés de los cuerpos de supervisión (Posada y Álvarez 1988). Ante esta realidad, en octubre de 1989 se decide implementar un plan de manejo a nivel nacional, y se vuelven a otorgar permisos, lo cual contribuyó con la devastación del recurso incluso en aquellas zonas de protección (Rodriguez y Posada 1994). No fue sino hasta enero del año 1991, cuando se vuelve a decretar veda total en el Parque, y posteriormente, en agosto de ese mismo año, a nivel nacional (Rodríguez y Posada 1994).

Hoy en día, la veda total continua, a falta de un acuerdo preciso entre todos los entes involucrados en la implementación de un posible plan de manejo. Sin embargo, los esfuerzos invertidos en la supervisión por parte de INPARQUES han incrementado, lo que ha ocasionado una reducción importante en la pesca ilegal de botuto, aunque ésta sigue ocurriendo de forma clandestina.

Mediante este estudio se pretende realizar una reconstrucción histórica de la pesquería del botuto en el Parque Nacional Archipiélago de Los Roques, a partir del análisis de los concheros ubicados en el cayo La Pelona y sus alrededores, depositados durante los diferentes regímenes de pesca que han ocurrido en la localidad de estudio. Al mismo tiempo, serán evaluadas las posibles presiones que estos regímenes han ejercido sobre las poblaciones naturales de Strombus gigas que han habitado la zona.

## METODO

### Área de Estudio

El presente trabajo se llevó a cabo en el cayo La Pelona (11° 47 latitud Norte y 66° 52′ longitud Oeste) y sus alrededores, ubicado en la región sur - suroeste del Parque Nacional Archipiélago de Los Roques. Este archipiélago se encuentra localizado a 160 km. al norte franco de La Guaira, entre los 11°48′ - 11°58′ de latitud Norte y los 66°32′ - 66°57′ de longitud Oeste.

### Diseño Muestral

Para la obtención de los resultado se realizaron tres salidas de campo a la localidad de estudio (Agosto y Noviembre 2002, Marzo 2003) con una duración aproximada de 10 días cada una. A continuación se describen las actividades realizadas a lo largo de dichas jornadas.

*Selección y datación de los concheros excavados* — Fueron elegidos para las excavaciones aquellos concheros prehispánicos cuya ubicación sugiriera, de manera indirecta, que fueron depositados durante épocas distintas. Esto se realizó mediante el estudio de los patrones de deposición apreciados en las fotografías aéreas. Para la datación de los concheros seleccionados, se extrajo la concha que se encontraba a mayor profundidad en cada uno de los pozos realizados. Las conchas extraídas fueron enviados a **Beta Analytic Inc.**, para la realización de las dataciones radiocarbónicas.

Los concheros contemporáneos fueron seleccionados y datados mediante la comparación de las fotografías aéreas tomadas durante el año 1971, por el Instituto Geográfico de Venezuela Simón Bolívar, y las fotografías aéreas tomadas durante el presente estudio. Adicionalmente se tomó en cuenta la información suministrada por pescadores, funcionarios de INPARQUES e investigadores que se encontraban familiarizados con la zona de estudio.

*Levantamiento de la composición de los concheros* — Para la excavación fueron seleccionados siete (7) concheros, tres (3) prehispánicos (P1, P2, P3) y cuatro (4) contemporáneos (C1, C2, C3, C4). Sobre cada conchero, se colocó una cuadrícula de PVC de 1m x 1m, con la cual se definió el área a ser muestreada. Se establecieron capas verticales de 25 cm de profundidad para la excavación, de tal manera que las conchas extraídas eran agrupadas en pilas correspondientes a los diferentes niveles preestablecidos (nivel 0 - 25, nivel 25 - 50, etc., siendo el valor 0 cm el punto más alto del conchero).

Las mediciones de las conchas se realizaron utilizando una cinta métrica y un vernier, y a cada concha seleccionada, se le midió: largo total (L) y grosor del labio (G), siempre y cuando la concha presentase un labio desarrollado, como se muestra en Figura 3. Además fueron tomadas en cuenta las siguientes apreciaciones cualitativas: tipo morfológico (juvenil, subadulto, adulto), presencia o ausencia, y forma de la perforación (circular o alargada).

Para realizar las comparaciones entre las medidas morfométricas de la concha para cada uno de los concheros, en primer lugar se realizaron pruebas mediante el método de Kolmogorov-Smirnov para comprobar la normalidad de la distribución de frecuencias de cada una de las variables (longitud y grosor del labio) para cada uno de los tratamientos (los concheros P1, P2, P3, C1, C2, C3, C4), y se realizó el test de Barlett's para comprobar la homogeneidad de las varianzas. En los casos donde se cumplieron ambas suposiciones (normalidad y homoscedasticidad), se utilizó un análisis de varianza paramétrico (ANOVA de una vía), para realizar las comparaciones entre cada una de las distribuciones. En los casos donde la hipótesis de normalidad fue rechazada, se utilizó el test no paramétrico de Kruskal-Wallis (Apéndice 3). En ambos casos se utilizó un $\alpha = 0.05$ (Sokal y Rohlf 1995) .

Todos los análisis se realizaron en el programa MiniTab® v.13.

## RESULTADOS

En la Tabla 1, se muestran las dataciones realizadas para cada uno de los concheros estudiados. Las dataciones realizadas con carbono 14 de las conchas extraídas en estos pozos, confirmaron que efectivamente la actividad pesquera en la isla se remonta a épocas prehispánicas (P1: 1270 D.C.; P2: 1310 D.C.; P3: 1450 D.C.), abarcando un período aproximado de 200 años.

**Tabla 1.** Datación de los diferentes concheros estudiados en el cayo La Pelona y sus alrededores.

| Conchero | Fecha radiocarbónica convencional | Fechas calibradas 2 Sigma (95% IC) | Fecha estimada de formación |
|---|---|---|---|
| P1 | 1150 ± 60 | 1160 – 1330 | 1270 |
| P2 | 1070 ± 60 | 1230 - 1420 | 1310 |
| P3 | 870 ± 60 | 1390 - 1540 | 1450 |
| C1 | - | - | 1980 - 1985 |
| C2 | - | - | 1980 - 1985 |
| C3 | - | - | 1984 - 1985 |
| C4 | - | - | 1990 - 1995 |

En la Figura 1 se muestra la proporción de los diferentes tipos morfológicos (juvenil, subadulto y adulto) encontrados en cada uno de los estratos, para cada conchero. A la izquierda de esta figura se encuentran representados los concheros precolombinos (P1, P2 y P3), y a la derecha se encuentran representados los concheros contemporáneos (C1, C4, C3 y C4), ordenados en función de la fecha de su formación. A pesar de que no se observan variaciones en cuanto a la proporción de los diferentes tipos morfológicos a medida que se desciende en el gradiente de profundidad en ninguno de los concheros precolombinos, se aprecia una importante proporción de conchas pertenecientes a la clase adulto (entre 80 y 90%). En el caso de los concheros contemporáneos se puede observar entre los concheros contemporáneos que el porcentaje de conchas de juveniles y subadultos aumenta mientras más reciente es el conchero. En el conchero C2, el porcentaje de juveniles/subadultos es de 26.47 %, mientras que en el conchero C4, este porcentaje es de 72.66 %. Estos resultados contrastan con lo hallado por Torres (2003) en República Dominicana, dado que en este estudio, fueron aquellos concheros precolombinos los que presentaron menor proporción de conchas de individuos adultos (1 a 4 %), mientras que en los concheros contemporáneos se encontró una mayor proporción de conchas de adultos (15 %, aproximadamente).

En la Figura 2 se muestran los valores promedio de la longitud de la concha para los individuos subadultos donde se aprecia la magnitud de la variación del tamaño promedio de las conchas durante los regímenes de pesca precolombino y contemporáneo. No se observaron diferencias significativas entre las distribuciones de los diferentes concheros precolombinos ($p = 0.693$), sin embargo las distribuciones de los concheros contemporáneos mostraron una tendencia significativa hacia la disminución de la longitud de la concha en los concheros más recientes ($p < 0.001$). En el caso de los concheros precolombinos, la longitud promedio osciló entre 22.1 y 22.7 cm (P3 y P1, respectivamente), mientras que para los concheros contemporáneos, la variación fue de 22.5 a 20.8 cm (entre C1 y C4, respectivamente).

## DISCUSIÓN

Como se observó observar en la Figura 1, durante el régimen de pesca precolombino, la mayor presión de depredación se hallaba concentrada entre las clases de edad de adultos. Sin embargo, las diferencias de tamaño observadas entre los diferentes concheros precolombinos no fueron significativas, por lo que no se podría afirmar que el régimen de pesca realizado por los indígenas tuvo repercusiones importantes sobre el tamaño de madurez sexual de la especie (Figura 2).

Durante el régimen de pesca contemporáneo, la presión de depredación se extendió prácticamente a todas las clases de edad, particularmente hacia las clases juvenil y subadulto (ver Figura 1), con tasas de extracción elevadas (Laughlin et al. 1985). Esta alta presión de depredación aplicada a todas las clases de edad seguramente tuvo un efecto mucho más pronunciado sobre las poblaciones naturales, dado que en el lapso de aproximadamente 15 años (desde C1 hasta C4), se evidenció una disminución significativa del tamaño de las conchas de los subadultos. En este caso, la presión de depredación es aplicada a toda la población, por lo tanto, aquellos individuos que se reproduzcan lo más temprano posible, tendrán igualmente mayor probabilidad de dejar descendencia.

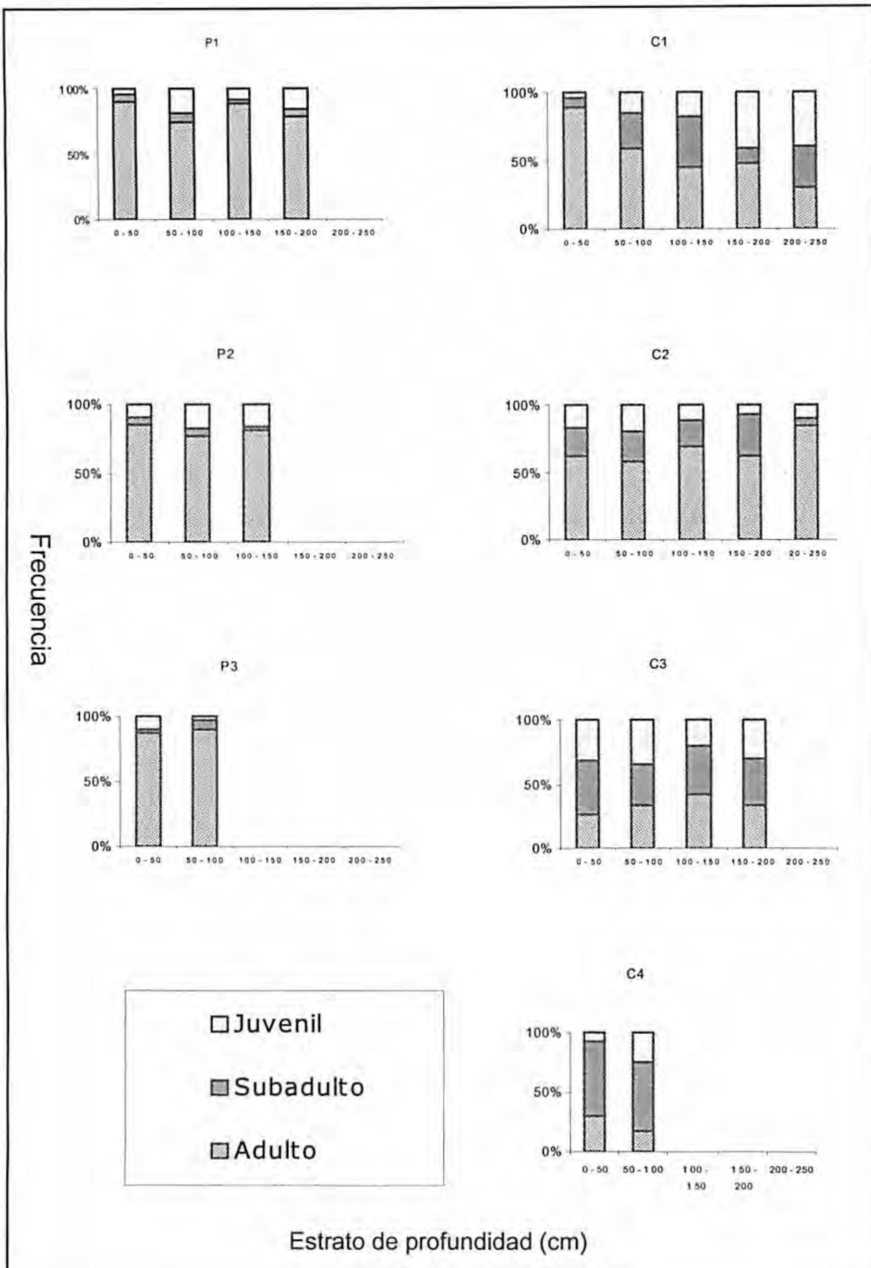


**Figura 1.** Proporción de los tipos morfológicos encontrados en los diferentes estratos de profundidad excavados, para cada uno de los concheros.

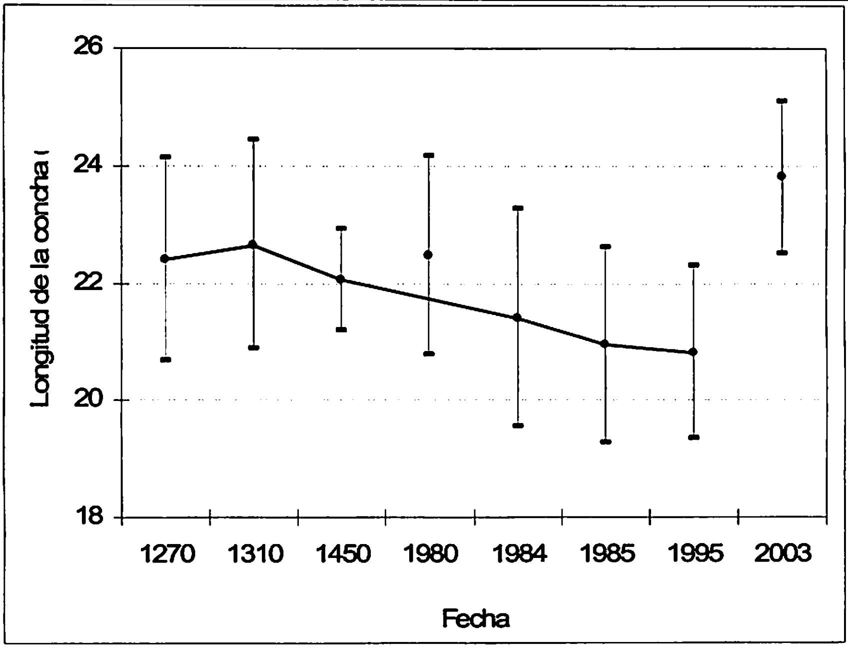


**Figura 2.** Variación de la longitud promedio de la concha de subadultos a lo largo del tiempo, para los diferentes concheros estudiados.

En la evaluación de la estructura poblacional de *Stormbus gigas* realizada más recientemente en el archipiélago de Los Roques en el año 1999 (Schweizer 2000), se registró una longitud promedio de la concha de los subadultos de 23.11 cm, lo cual representa una aumento con respecto a los valores medidos en los concheros excavados. Durante el presente estudio, se midieron conchas de subadultos vivos que se encontraban a los alrededores de la isla de Dos Mosquises, e igualmente mostraron tamaños de concha superiores (23.81 cm LT). Estas observaciones sugieren que el establecimiento de la veda total en el año 1991 contribuyó a la recuperación de las tallas promedio de los individuos que se distribuyen en la región sur-suroriental del archipiélago. Posiblemente el incremento de la actividad turística en el Parque para la década de los noventa influyó igualmente en la disminución de la presión pesquera. Frente a la medida de veda total, muchos *botuteros* comenzaron a dedicarse al transporte de turistas, dejando de lado la pesca clandestina (Posada Comunicación personal).

Los resultados presentados en este estudio, evidencian los efectos que pueden tener diversos regímenes de pesca sobre las poblaciones depredadas. En particular, los efectos de la presión de depredación a la que fue sometida la población de botuto en el Parque Nacional Archipiélago de los Roques durante aproximadamente 30 años, reflejan la vulnerabilidad del recurso a corto plazo. La pesca indiscriminada de botuto no sólo afecta a la densidad de las poblaciones (como se ha comprobado en diferentes localidades en todo el Caribe), sino que también afecta al tamaño promedio de los individuos que la componen.

Una reducción significativa en el tamaño de los individuos, ocasiona una disminución en su fecundidad, lo cual disminuye el éxito reproductivo de la especie (Stearns 1992). No sólo los individuos tendrán menor probabilidad de encuentro debido a la disminución de las densidades poblacionales, sino que a su vez cada individuo dispondrá de menor presupuesto energético para reproducirse, por lo tanto su adecuación será menor. En términos económicos, la productividad será cada vez menor, debido a que la biomasa total de la población tenderá a decrecer a lo largo del tiempo, como se demostró anteriormente.

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# Recent Developments in CITES Concerning the International Trade in Queen Conch (*Strombus gigas*)

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ABSTRACT

Despite years of regional discussions and trade regulation under the Convention on International Trade in Endangered Species (CITES), most queen conch fisheries suffer from uncoordinated management and unsustainable harvest. Queen conch is listed in Appendix II of the treaty and, as such, each shipment of the species must be accompanied by a permit for which the exporting country has made findings that the specimens have been legally acquired and that the trade is sustainable. The Appendix-II listing for Queen conch has proven to be a useful complement to national management programs. In April 2003, the CITES Secretariat released a lengthy analysis of the Caribbean conch fisheries and associated international trade. Subsequently, the International Queen Conch Initiative (IQCI) convened its members to discuss this report and renew calls for regional cooperation on law enforcement, management measures, and capacity building. A list of regional commitments resulted from this meeting, and will be formally transmitted to the CITES process as the trade analysis unfolds. These commitments will be considered as CITES considers how member countries should act to reduce poaching, coordinate management, and ensure sustainable international trade in the species. This entire process, known as the CITES "review of significant trade" will require governments in the Wider Caribbean to bring about sustainable use of this resource, via binding management advice from an international technical committee. Specific CITES actions and timelines for their completion will be available by autumn 2003. This report discusses the reasons for a second CITES trade analysis, presents fundamentals of the CITES significant trade review process, highlights the outcomes of a 2003 technical committee meeting, and makes some conclusions about the future of regional conch management in the wider Caribbean.

KEY WORDS: CITES, Queen conch, *Strombus gigas*

# Sucesos Recientes en la Convención sobre el Comercio Internacional de Especies Amenazadas de Fauna y Flora Silvestres (CITES) Relacionados con el Comercio Internacional del Carrucho o Cobo (*Strombus gigas*)

A pesar de varios años de discusiones regionales y regulación de comercio bajo la Convención sobre el Comercio Internacional de Especies Amenazadas de Fauna y Flora Silvestres (CITES), la mayoría de las pesquerías del carrucho sufren de manejo no coordinado y la extracción no sustentable. El carrucho está incluido en el Apéndice II de CITES y, por consiguiente, para su exportación se requiere un permiso para el cual el país exportador ha determinado que los especímenes han sido adquiridos legalmente y que el comercio es sustentable. La inclusión en el Apéndice II del carrucho ha comprobado ser un complemento muy útil para los programas de manejo nacionales. En abril de 2003, la Secretaría de la CITES hizo público un análisis de las pesquerías de carrucho en el Caribe y el comercio internacional asociado con ellas. Posteriormente, la Iniciativa Internacional sobre el Carrucho (IQCI por sus siglas en inglés) convocó a sus miembros para discutir este reporte y reanudar las llamadas para la colaboración regional en la aplicación de la ley, medidas de manejo y capacitación. Una lista de compromisos regionales fue producida durante esta reunión, la cual será transmitida oficialmente al proceso CITES mientras el análisis del comercio continúa. Estos compromisos serán considerados mientras CITES considera como los paises miembros deben actuar para reducir la caza furtiva, coordinar manejo, y asegurar el comercio internacional sustentable en la especie. Este proceso, conocido como el "examen de comercio significativo de CITES," requerirá que los gobiernos de los países de distribución de la especie realicen el uso sustentable de este recurso a través de recomendaciones de manejo de un comité técnico internacional. Las acciones específicas de la CITES y fechas para realizarlas estarán disponibles para el otoño de 2003.

PALABRAS CLAVES: CITES, Carrucho, lambí, carocol reina, strombe géant *Strombus gigas*

## EFFORTS TOWARD QUEEN CONCH CONSERVATION IN FISHERIES ORGANIZATIONS

The need for coordinated management of queen conch (*Strombus gigas*) has long been recognized by fisheries scientists and managers in the wider Caribbean region. At the "Workshop on Biology, Fisheries, Mariculture and Management of the Queen Conch *Strombus gigas*", convened in Caracas, Venezuela, in 1991, many scientific and management officers expressed their concern about the status of the resource in the Caribbean region and the need to implement a common regional management strategy for the fishery. In 1996, the First International Queen Conch Conference was convened, supported by the Caribbean Fisheries Management Council, the National Marine Fisheries

Service Office of Protected Resources, the Government of the Commonwealth of Puerto Rico, and the Food and Agriculture Organization of the United Nations (FAO).

The Conference was held in San Juan, Puerto Rico, on July 29-31, 1996. It convened fishery managers and scientists from the Caribbean Region to discuss the latest information on research, stock assessment and management alternatives for the queen conch fishery. The participants adopted the Declaration of San Juan, which called for a common international management strategy for the queen conch resource in the Caribbean region, as the initial step of the Initiative. From 1996 to 2001, seven meetings and workshops of the wider Caribbean Initiative and numerous sub-regional meetings were convened.

In addition to fisheries bodies, other organizations were concerned about the status of the species. In 1990, the Parties to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (Cartagena Convention) included queen conch in Annex II of its Protocol Concerning Specially Protected Areas and Wildlife (SPAW Protocol) as a species that may be utilized on a rational and sustainable basis and that require protective measures. Because of this recognition, the United States proposed queen conch for listing in Appendix II at the 8th Meeting of the Conference of the Parties to CITES (COP8, Kyoto (Japan), 2-13 March 1992), where the proposal was adopted.

## INTRODUCTION TO CITES

The CITES treaty was agreed in 1973 in Washington, and entered into force in 1975. The treaty now has over 160 member countries or "Parties", and aims to ensure that international trade in specimens of wild animals and plants does not threaten their survival. Meetings of the Conference of the Parties (COPs) are convened meet every two to three years to review how the treaty is working, resolve policy issues, amend lists of protected species and work together to ensure wildlife trade is carried out in accordance with the treaty.

The CITES Animals and Plants Committees, which includes technical experts from each of six global regions, meet annually between COPs to provide technical support to decision-making about species in international trade.

These committees of experts were established to fill gaps in biological and other specialized knowledge regarding species of animals and plants that are (or might become) subject to CITES trade controls. The Standing Committee also meets annually to provide policy guidance to the Secretariat and oversees the management of the Secretariat's budget. Beyond these key roles, it coordinates and oversees, where required, the work of other committees and working groups and to carry out tasks given to it by the Conference of the Parties.

## CITES BASICS

CITES regulates international trade, not only in endangered species of animals and plants, but also in those that might become endangered if trade is not subject to strict controls. Following are the definitions and requirements for the various levels of regulation in CITES:

i) *Appendix I* — species in danger of extinction. All commercial trade in wild specimens is prohibited. Other international movement of Appendix-I specimens (e.g., scientific collections) occurs if the exporting and importing country concur and issue appropriate permits. Appendix I includes hundreds of species, including a number of marine taxa such as the great whales, all marine turtles, and several finfish.

ii) *Appendix II* — species vulnerable to overexploitation for which commercial trade should be regulated so that they will not become further threatened with extinction. Commercial trade and other international movement of Appendix-II specimens is allowed if the exporting country has issued a permit and determined that the specimens were legally obtained and their export does not constitute a threat to the species' survival. Appendix II contains over 30,000 taxa (more than 90% of all CITES-listed species), including such marine species as seahorses, all dolphin species not included in Appendix I, queen conch, all stony corals, and giant clams.

iii) *Appendix III* — species for which a country needs the cooperation of other countries in order to control international trade to complement domestic regulation. International trade requires an export permit from the listing country and a certificate of origin from all other countries. Appendix III contains a modest number of species, including marine taxa such as walrus and an Ecuadoran sea cucumber.

Countries may unilaterally list species for which they have domestic regulation in Appendix III at any time. Decisions concerning Appendix I and II species listings and resolutions are made at meetings of the Conference of the Parties that are convened approximately every two years.

The benefits of CITES are many and varied. It establishes a legal framework to regulate international trade, monitor trade volumes, and prevent overexploitation or extinction. It generates the most thorough database of information on global wildlife and plant trade available. In the CITES system, importing and exporting countries share responsibility to ensure trade is sustainable and legal. CITES listings (or the potential for listing) also promote research to assess population status of species in trade and the effects of international trade on those taxa.

## SUMMARY OF MODERN QUEEN CONCH TRADE

Queen conch has been listed in Appendix II since 1992. Despite several years of CITES regulation, the international trade in queen conch dramatically escalated in volume between 1992 and 2001. Exports of *S. gigas* meat tripled from 1.1 million kg in 1994 to 3.1 million kg in 2001 (Theile 2003). The increase in exports was most notable in countries such as Honduras, the Dominican Republic, and Haiti that lacked significant programs for monitoring landings, effort, or stock status (Theile 2003). The shell trade, which is incidental to the meat fishery, also escalated from a minimum of 59,000 specimens in 1994 to 370,000 minimum in 2001 (Theile 2003). Although some countries have large domestic markets for conch meat (e.g., Bahamas, United States), most of the global landings in *S. gigas* are destined for international trade (Theile 2003). The resource has attained significant socio-economic importance, since it is commercially harvested in 26 of the 36 range countries and has a landings value second only to spiny lobster (*Panulirus argus*) (CRFM 2003). There is currently no regional fishery management organization (RFMO) responsible for cooperative management of the queen conch resource. Therefore, the CITES Parties have attempted to address unsustainable trade through a process of data review, international dialogue, and the threat of trade sanctions.

## QUEEN CONCH AND CITES: THE REVIEW OF SIGNIFICANT TRADE

In 1992, the CITES Parties codified a process in which their technical committees could analyze voluminous commercial trade in Appendix-II species. The Plants Committee and Animals Committee select species for this review based on recent trade trends, recommendations of the Parties, and independent reports. Most importantly, this process could make binding recommendations to countries that the committees determined were trading selected species unsustainably. These recommendations are binding since noncompliant countries face the threat of trade suspension from all the other CITES Parties. This process, known as the "review of significant trade" first appeared as CITES Resolution Conf. 8.9 and then revised in 2002 as CITES Resolution Conf. 12.8.

After the technical committees select a species for review, Resolution Conf. 12.8 permits the CITES Secretariat to contract with outside experts and authors to draft a report on the species' status in the wild, its global trade volumes, and its status in national management programs.

Queen conch was the subject of a significant trade review in 1995-96, which resulted in a number of trade suspensions in minor exporting (CITES 1999). Most of these trade suspensions, with the exception of that for St. Lucia, remain in effect. At the 2nd International Queen Conch Initiative Convention in 2001, the countries at the meeting took a decision to request CITES to reopen its Significant Trade review. In the face of continued stock declines and poor CITES implementation, the 17th meeting of the CITES Animals Committee (Hanoi, Vietnam; August 2001) decided to begin another review of significant trade for Queen conch. This is the first time in CITES history that a species has undergone this analysis twice. The draft report on the second significant trade review was written by TRAFFIC Europe and released by the CITES Secretariat on April 30, 2003 for a 60-day comment period among the Parties (Theile 2003). During the comment period, the International Queen Conch Initiative convened a workshop as an opportunity for fisheries and CITES authorities in queen conch range countries to review the report and provide their input to it. The workshop generated a number of recommendations related to the CITES significant trade process, the biological and trade status of the species, in addition to needs for law enforcement, regional cooperation and public outreach.

In August 2003, the Animals Committee convened in Geneva, Switzerland and reviewed the final report on queen conch trade, which incorporated many of the comments provided by CITES Parties. At this meeting, the Committee formed a working group made up of representatives from the United States, France, Mexico, the United Kingdom, the World Bank, and the CITES Secretariat to formulate recommendations for the conch exporting countries. A single Animals Committee representative from Latin America and the Caribbean attended the working group as well. As per the mandates of Resolution Conf. 12.8, the working group categorized each of the 36 range countries in one of three categories: "urgent concern" (when it is clear that CITES export permits are issued by the government without regard to detriment on wild populations); "possible concern" (when it is not clear whether current export levels are detrimental to the species); and "least concern" (when it is clear the CITES treaty is properly applied and exports appear non-detrimental). The CITES Animals Committee then reviewed the working group's conclusions, approved the categorization of countries, and endorsed a set of recommendations for transmission to the trading countries as per Resolution Conf. 12.8.

## RESULTS

Theile (2003) provided an exhaustive analysis of trade in queen conch since the species was placed in CITES Appendix II in 1992. The report also discussed national management programs, recent research findings, and stock status in each range country.

According to Theile (2003), the Unites States imports 78% of the queen conch meat in trade each year. Approximately 99% of the exports are supplied by Jamaica (39%), Honduras (27%), Turks and Caicos (10%), the Dominican Republic (7%), Bahamas (7%), Colombia (4%), Belize (4%), and Haiti (< 1%).

At their August 2003 meeting, the Animals Committee placed Honduras, the Dominican Republic, and Haiti in the category of "urgent concern." The Committee determined these countries did not have adequate information to justify their current levels of trade, and recommended a set of short-term and long-term actions to remedy the situation. Within four weeks of receiving the Committee's recommendations, these countries had to impose unilateral moratoria on the commercial harvest (excluding legal harvest in territorial waters) and international trade of queen conch. Within six months, these countries were to designate specific areas for commercial conch fisheries in their waters, undertake density studies in these areas, analyze trends in landings data, establish a standardized minimum weight of unprocessed and processed meat that corresponds to adult specimens, and establish cautious export quotas based on these data. Within 18 months, these Parties are to design and implement fishery-dependent and – independent data collection programs, and give consideration to the recommendations from the IQCI workshop held in June 2003 (see above).

The Animals Committee placed several countries in the category of "possible concern", including Antigua and Barbuda, Barbados, Bahamas, Belize, Colombia, Cuba, Dominica, Grenada, Nicaragua, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago. Within 12 months of receiving the Committee's recommendations, these countries are to establish cautious catch and export quotas (with justification), establish a standardized minimum weight of unprocessed and processed meat that corresponds to adult specimens, and implement fishery-dependent and – independent data collection programs. Within 24 months, these countries shall apply adaptive management procedures to ensure that future harvesting regimes will be based on newly collected data, and implement the recommendations from the June 2003 IQCI workshop (see above). Antigua and Barbuda, Barbados, Dominica, and Trinidad and Tobago are still under trade suspension for queen conch from the 1995 - 1997 CITES trade review.

Finally, the Animals Committee placed the remaining range countries in the category of "least concern", which included Bermuda, Brazil, Costa Rica, France (including Guadeloupe and Martinique), Guatemala, Jamaica, Mexico, the Netherlands (including Aruba and the Netherlands Antilles), Panama, United Kingdom of Great Britain and Northern Ireland (including Anguilla, British Virgin Islands, Cayman Islands, Montserrat and Turks and Caicos Islands), United States of America (including Puerto Rico and the US Virgin Islands), and Venezuela. These countries were asked to implement the recommendations from the June 2003 IQCI workshop (see above).

The deadline for the countries of "urgent concern" to implement their first recommendation (moratoria on most commercial harvest and trade) passed on September 29, 2003. Honduras and the Dominican Republic complied with the Committee's recommendation, whereas Haiti apparently did not. The CITES Secretariat recommended that other Parties suspend trade in queen conch with all three of these countries effective September 29, 2003. The other deadlines in the Committee's recommendations had not passed when this report was written. The United States implemented this suspension immediately, and continued existing suspensions with Antigua and Barbuda, Barbados, Dominica, and Trinidad and Tobago.

## CONCLUSIONS

The current suspension in queen conch trade with Honduras, Haiti, and the Dominican Republic represents a stoppage in more than half of the United States' supply of queen conch meat. This will ostensibly result in changing market patterns, emerging source countries, and potential price restructuring. In addition, law enforcement agencies will almost certainly have to readjust or heighten their investigations as traders may try to illegally import conch originating from these countries.

In addition, the authors expect that the severe trade measures recently imposed by CITES will encourage the countries in the wider Caribbean to form an RFMO for the sustainable harvest and trade in queen conch. Existing organizations such as the Caribbean Regional Fisheries Mechanism (CRFM) and the Western Central Atlantic Fishery Commission (WECAFC) have already expressed a desire to initiate such work, with the support of the United Nations Food and Agriculture Organization (FAO) and the United States.

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# Overview del Patrón Reproductivo del Caracol *Strombus gigas* para Diferentes Localidades del Caribe

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RESUMEN

*Strombus gigas* es una especie de importancia económica en el Caribe, que proviene de la demanda de los mercados locales, turística y de exportación. Dada la facilidad que representa la captura de este organismo y la demanda de los mercados se ha traducido en una disminución severa de las poblaciones en todas las localidades del Caribe. Por lo cual diferentes medidas de manejo se han implementado para regular la explotación que van de la talla mínima basada en la longitud de la heliconcha, cuotas de captura, y vedas temporales y permanentes. Sin embargo, las temporadas de veda no forzosamente corresponden a la época reproductiva de esta especie, por lo que en este trabajo se analizan datos del ciclo reproductor obtenido por observaciones histológicas y observaciones en el campo de su comportamiento reproductivo (masas de huevos, desoves) y se sobrepone a las épocas de temporada de veda para ver el ajuste que presentan y que tanto protegen al stock reproductor de esta especie. Ya que el nivel de protección de una especie va a depender del ajuste entre la época de veda y su temporada reproductiva y la vigilancia que se pueda tener sobre las poblaciones para evitar la pesca ilegal.

PALABRAS CLAVES: *Strombus gigas*, reproducción, vedas

# Overview of Reproductive Patterns of the Queen Conch *Strombus gigas* from Different Reef Systems in the Caribbean

*Strombus gigas* is a species of primary economic importance in the Caribbean region. Its importance comes from the demand for local consumption and the tourist market. Due to its accessibility in low energy grass and algal beds, its populations have been depleted in many areas and seriously diminished in others. Therefore, different measures have been taken to regulate exploitation, which include minimum size limit based on shell length; catch quotas, and temporal and permanent fishing bans. However, some of these temporall bans do not always correspond to the reproductive period. In this work, data of the reproductive cycle and field reproductive observation were used in order to analyze the reproductive pattern for *Strombus gigas* to determine the variability and similarities of their reproductive cycle under

diverse environmental conditions in the Caribbean. Finally, it analyzes the temporal bans fishing periods *versus* the reproductive cycle of *Strombus gigas*. The success of protection to *S. gigas* resulting from a temporal fishing ban will be dependent upon its coincidence with the reproductive, adequate enforcement, and controlled exploitation.

KEYS WORDS: *Strombus gigas,* reproduction, temporal bans

## INTRODUCCIÓN

La pesquería comercial de *Strombus gigas* se desarrolló a partir de los años 1980s en respuesta al aumento en la demanda internacional de su carne. En algunos países caribeños es la segunda pesquería en importancia económica. En países como Jamaica la pesquería de *S. gigas* se ha convertido en el producto pesquero más importante tanto en captura como de ingreso económico. En 1998 sus desembarcos representaron 15 a 20 millones de dólares americanos, empleando 3 000 personas, sobre todo en el procesado y empaquetado (Miller 2000). Entre 1992 y 1998, los desembarcos anuales de carne de *S. gigas* en todo el Caribe fueron de 6 520 y 7 369 toneladas (T). En 1999 la captura fue de 5 554 T, en 2000 de 4 598 T y en 2001 de solo 3 132 T. La mayor parte de estos desembarcos se destina a la exportación a Estados Unidos de América; pero en Bahamas y República Dominicana el consumo local excede las exportaciones. De 1992 a 2001, se registraron un total de 21 649 T de carne de *S. gigas* proveniente de todo el Caribe, 2 345 868 conchas, 143 T de conchas, 407 140 especimenes vivos y 342 T de especimenes vivos, todo para exportación (CITES 2003). Dada su importancia económica y social y su situación de sobrepesca, se requieren medidas de regulación para su captura que protejan el stock existente en el Caribe que le permitan renovarse, siendo una de estas mediadas las vedas que protegen la época reproductiva de la especie.

## ANTECEDENTES

En el Caribe, el Caracol *Stombus gigas* ha sustentado las pesquerías de subsistencia, artesanal e industrial en todos los países (CFMC y CFRAMP 1999, CITES 2003), pero la sobrepesca es la principal amenaza a sus poblaciones. *S. gigas* ha sido una fuente de proteína en muchas de las dietas nativas de los países del Caribe (Randall 1964b), iniciándose en los años 80 su explotación comercial, convirtiéndose en una fuente importante de ingresos para unos 25 países del Caribe (Theile 2001). Entre 1992 y 2001 el comercio internacional de este molusco involucró más de 90 países y en los años 90 su valor se estimó en 60 millones de dólares americanos; cantidad subestimada dado que no toma en cuenta el empleo que genera (CITES 2003, Chakalall y Cochrane 1997).

**Medidas de Conservación para *S. gigas* en el Caribe**

*S. gigas* está incluido en el Anexo III del Protocolo de SPAW (Specially Protected Áreas and Wildlife in the wider Caribbean region) de la Convención de Cartagena de Indias, Colombia; como especie que puede ser utilizada bajo la base del uso racional y sostenible requiriendo medidas adecuadas para asegurar su protección y recuperación. El Protocolo de SPAW se adoptó en 1990, pero sólo entró en vigor en abril de 2002 (CEP 2002). A partir de 1992, *S. gigas* se encuentra incluida en el Apéndice II de la Convención sobre el Comercio Internacional de Especies Amenazadas de Flora y Fauna Silvestre (CITES) como una especie comercialmente amenazada, que debe ser sometida a reglamentación y en 1994 se le incluyó en la lista roja de la Unión Internacional para la Conservación de la Naturaleza (IUCN), como un animal vulnerable que enfrenta riesgo de extinción. Por lo anterior, la Organización de Estados Caribeños Orientales (OECS) recomendó a principios de 1990 que sus países miembros implementaran medidas de manejo para su captura. Las medidas que se han implementado son: Longitud mínima de la talla de la concha y peso mínimo de carne, captura de especimenes con un labio grueso y el establecimiento de temporadas o áreas de veda. Siete de los nueve países miembros de la OECS han llevado a cabo todas o alguna de estas medidas, con excepción de Anguila y Montserrat. Se han implementado estrategias regionales para el manejo de *S. gigas*. En julio de 2001 se efectuó la Segunda Conferencia Internacional del Queen conch en República Dominicana, que reunió a 22 estados, concluyéndose la necesidad de conocer la reproducción de esta especie a nivel del Caribe (Anónimo 2001, CFMC 2003).

En la Tabla 1 se resumen diversas medidas de regulación para el manejo de *S. gigas* como: cierre de pesquerías por áreas, cierre de pesquerías por estación, exportación prohibida, limite de talla mínima de extracción, colecta prohibida de juveniles, prohibición de equipo autónomo para colecta, cuotas de pesca, cuota de exportación, permisos de captura (Theile 2001). Desafortunadamente la falta de vigilancia hace ineficaces estas medidas, debido a la captura ilícita y al limitado conocimiento de algunos aspectos de la biología básica de esta especie; poniendo en riesgo la sustentabilidad de su pesquería.

**Tabla 1.** Algunas medidas utilizadas para regular la pesca del Caracol *Strombus gigas, y* países que las aplican (Theile, 2001).

| Medida de regulación | Países |
|---|---|
| Veda temporal | Aruba, Bermuda, Belice, Bonaire, Colombia, Costa Rica, Cuba, Guadalupe, Honduras, Islas Vírgenes U.S., Islas Caimán, Jamaica, México, San Martín, Turks y Caicos, Venezuela. |
| Cierre de pesquerías en algunas áreas | Bahamas, Belice, Barbados, Colombia, Cuba, Honduras, Islas Caimán, Islas Vírgenes Británicas, Islas Vírgenes U.S., México, Turks y Caicos, Venezuela. |
| Talla mínima de captura | Antillas Neerlandesas, Antigua y Barbuda, Belice, Granada, Haití, Honduras, Islas Vírgenes U.S., Martinica, Santa Lucia, Turks y Caicos. |

**Época de Desove de *S. gigas* en el Caribe**

La época de desove reportada para *S. gigas* en todo el Caribe ha sido obtenida en su mayoría a través de las observaciones de masas de huevos en el campo. Stoner et al. (1992) definen la época de desove de *S. gigas* como el periodo en la cual este molusco manifiesta comportamiento reproductivo: Apareamiento, cópula, desove y presencia de masas de huevos. En la tabla 2 se resumen los periodos de desove para *S. gigas* en varias localidades del Caribe, observándose diferencias espaciales, pero los autores han utilizado diferentes métodos, número de observaciones y frecuencia de observación. Para una misma localidad, existen diferencias del numero de meses del desove de *S. gigas*. Wiklund reporta para Bahamas un período de desove de mediados de abril a septiembre; mientras Stoner observa un periodo más amplio de abril a octubre. Pese a lo anterior, el desove es común en todas las localidades en Junio, Julio y Agosto.

**Biología Reproductiva de *S. gigas***

Los primeros estudios sobre *S. gigas* son de la década de los 60, existiendo unas 600 publicaciones, de las cuales sólo el 1% son sobre reproducción y de ellas sólo Egan (1985), Aldana Aranda (2003) y Avila (2004) han sido sobre el ciclo de madurez de la gónada por histología. Egan (1985) estableció el desarrollo gonádico para *S. gigas* de Belice. Aldana-Aranda et al. (2003a) comparó el ciclo reproductivo de *S. gigas* en dos arrecifes de México y Avila estudio lo hizo para el archipiélago de San Andrés en Colombia. Buckland (1989) evaluó la cantidad de tejido gametogénico de *S. gigas* en St. Christopher Nevis. Estos trabajos difieren en el número de organismos analizados, periodos de estudio, frecuencia de muestreo, y la propia clasificación de los estadios gonádicos utilizados por cada autor.

Otros trabajos de reproducción por métodos histológicos sin estudiar el ciclo de madurez gonádico son el de Reed (1998) quien estudió la anatomía reproductiva de *S. gigas* y *S. pugilis* con énfasis en hembras masculinizadas. Glazer y Quintero (1998) que compararon el tejido gonádico de caracoles adultos de aguas abiertas con el desarrollo gonadal de *S. gigas* en zonas costeras y Delgado et al. (2004) que examinaron el desarrollo gonádico en *S. gigas* transplantado para rehabilitación de sitios.

En las tablas 3 y 4 se reportan los estadios de madurez y desove establecidos por análisis histológico de la gónada de *S. gigas* en varias localidades del Caribe, respectivamente. La madurez es común de junio a septiembre independientemente de la localidad, con excepción de Egan, que observa organismos maduros casi todo el año y Avila que observa dos picos en abril y en agosto, sin embargo de marzo a noviembre al menos 10% de la población esta maduro. El desove es común en junio, julio y agosto, excepto para *S. gigas* de Belice donde Egan observó desove todo el año en porcentajes inferiores o iguales al 10% y Avila (2004) que observa dos picos de marzo a junio y en septiembre.

Tabla 2. Época de desove de *Strombus gigas en* el Caribe, a través de observaciones de cópula, ovoposición y masas de huevos. ☼ No hay observaciones posteriores (modificada de Stoner, 1992 y Avila, 2004).

| Época de desove | | | | | | | | | | | | Localización | Sitio | Referencia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E | F | M | A | M | J | J | A | S | O | N | D | | | |
| | | | | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼ | | | | 32°20′ N, 64°45′ W | Bermudas | Berg *et al.*, 1992 |
| | | | | ☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | | | 24°40′ N, 82°00′ W | Florida | Davis *et al.*, 1984 |
| | | | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | | 23°35′ N, 76°05′ W | Bahamas | Stoner *et al.*, 1992 |
| | | | ☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | | | 23°35′ N, 76°05′ W | Bahamas | Wicklund *et al.*, 1991 |
| | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | | 22°30′ N, 89°40′ W | Alacranes, México | Pérez-Pérez y Aldana-Aranda, 2002 |
| | ☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | | 22°30′ N, 89°40′ W | Alacranes, México | Pérez-Pérez y Aldana-Aranda, 2003 |
| | | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | | | 21°30′ N, 72°15′ W | Turks y Caicos | Davis *et al.*, 1987 |
| | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | | 18°15′ N, 65°00′ W | Islas vírgenes | Randall, 1964 |
| | | | | ☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼ | | 18°15′ N, 66°30′ W | Puerto Rico | Appeldoorn, 1988 |
| | | | ☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | | | 17°05′ N, 62°30′ W | St kitts/Nevis | Wilkins *et al.*, 1987 |
| | | | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | | | 13°00′ N, 81°00′ W | San Andrés, Colombia | Márquez-Pretel *et al.*, 1994. |
| | | | | | ☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | | 13°00′ N, 81°00′ W | San Andrés, Colombia | García-Escobar *et al.*, 1992 |
| | | | | | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | 11°40′ N, 66°30′ W | Venezuela | Brownell, 1977 |
| | | | | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | | 11°40′ N, 66°30′ W | Venezuela | Weil, y Laughlin, 1984 |
| | | | ☼☼ | ☼☼ | ☼☼ | ☼☼ | L | | | | | 11°30′ N, 74°05′ W | Santa Marta, Colombia | Botero, 1984 |
| ☼<br>☼ | | | | | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | ☼☼ | 9°45′ N, 75°50′ W | San Bernardo, Colombia | Lagos-Bayona *et al.*, 1996 |

**Tabla 3.** Periodo de madurez de *Strombus gigas* establecido por métodos histológicos en diferentes áreas geográficas. Las referencias están citadas de acuerdo a la latitud del área geográfica. Se señala el período de muestreo, el numero de muestras mensuales analizadas , se tomo como criterio que al menos 20 % de la población se encuentra en ese estadio,

| Localización | Periodo de muestreo | Numero de muestras mensuales | Época de madurez (ambos sexos) E | F | M | A | M | J | J | A | S | O | N | D | Referencia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| México (Arrecife Alacranes) 22°30′ N, 89°40′ W | marzo- noviembre | 20 | | | | | | ☼ | ☼ | ☼ | ☼ | | | | Aldana-Aranda *et al.*, 2003a, b |
| México (Banco Chinchorro) 18°46′ N, 87°20′ W | junio-septiembre | 20 | | | | | | ☼ | ☼ | ☼ | ☼ | | | | Aldana-Aranda *et al.*, 2003a, b, c |
| Belice (Boca Chica) 17°45′ N, 86°56′ W | enero-diciembre | 34 | | ☼ | ☼ | ☼ | ☼ | ☼ | ☼ | ☼ | ☼ | ☼ | ☼ | ☼ | Egan, 1985 |
| St kitts/Nevis 17°05′ N, 62°30′ W | junio- diciembre abril-junio | – | | | | ☼ | ☼ | ☼ | ☼ | ☼ | ☼ | | | | Buckland, 1989 |
| Colombia (San Andrés) 12°32′ - 81°28′ W | enero-diciembre | 31 | | | | ☼ | | | | ☼ | | | | | Avila Poveda, 2004 |

**Tabla 4.** Periodo de desove de Strombus gigas establecido por métodos histológicos en diferentes áreas geográficas. Las referencias están citadas de acuerdo a la latitud del área geográfica. Se señala el período de muestreo, el numero de muestras mensuales analizadas , se tomo como criterio que al menos 20 % de la población se encuentra en ese estadio.

| Localización | Periodo de muestreo | Numero de muestras mensuales | Época de desove (ambos sexos) | | | | | | | | | | | | Referencia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | E | F | M | A | M | J | J | A | S | O | N | D | |
| México (Arrecife Alacranes) 22°30´ N, 89°40´ W | marzo- noviembre | 20 | | | | | | ☼ | ☼ | ☼ | ☼ | | | | Aldana-Aranda *et al.*, 2003a, b |
| México (Banco Chinchorro) 18°46´ N, 87°20´ W | junio-septiembre | 20 | | | | | | ☼ | ☼ | ☼ | ☼ | | | | Aldana-Aranda *et al.*, 2003a, b, c |
| Belice (Boca Chica) 17°45´ N, 86°56´ W | Enero-diciembre | 34 | + | | | | | ☼ | ☼ | ☼ | ☼ | | | | Egan, 1985 |
| Colombia (San Andrés) 12°32´ - 81°28´ W | Enero-diciembre | 31 | | | ☼ | ☼ | ☼ | ☼ | | | ☼ | | | | Avila Poveda, 2004 |

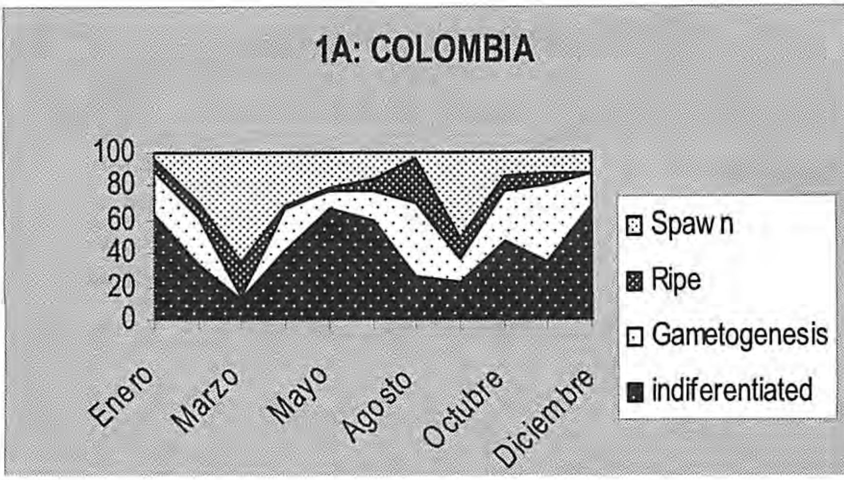
**Ciclo Gonádico de *Strombus gigas* en el Caribe**

*Colombia* — Avila (2004) observa reposo todo el año, con un mínimo de 3% en marzo y porcentajes de 67% en mayo y 60% en junio y en diciembre y enero (68% y 63%, respectivamente). La gametogénesis se presenta todo el año, con su mínimo en marzo (3%) y máximo en noviembre (45%) y agosto (43%). La *Madurez,* esta presente todo el año excepto en diciembre; con valores máximos de 26% en agosto y 20% en marzo. El resto del año se mantiene entre 3% y 13%. El desove se presenta en dos picos de 23% en septiembre y 57% marzo (Figura 1a).

*Belice* — La población de *S. gigas* de Belice presenta un porcentaje bajo en estadio de indiferenciado, solo de septiembre a diciembre fue superior a 20% con un pico en septiembre. La gametogenesis (beginning and developing) fue constante en el año, con valores entre 20-70%. La fase de Madurez fue observada a lo largo del año, con un pico de junio a julio del 50 % y otro en octubre del 40%. El desove se presento todo el año, en porcentaje bajo (Figura 1b).

*Banco Chichorro, Mexico* — En el período de indiferenciado fueron detectados dos periodos de baja intensidad: Mayo 13% y septiembre con 33 %. La gametogenesis se observó a través de todo el periodo de muestreo, con dos picos; uno en mayo (54%) y en agosto (44%). La madurez fue contante durante el periodo de studio con una media de 37%, alcanzando un maximo de 50% en septiembre. El desove fue de junio a agosto con un maximo de 40%. Post desove se observó sólo de mayo a junio (Figura 1c). La presencia de un alto porcentaje de organismos maduros en septiembre sugiere un posible desove tardio o la acumulación de gametos maduros para un desove temprano durante la primavera. Acción que es soportada por la presencia de post desovantes y organismos en reposo durante mayo y junio.

*Arrecife Alacranes, Mexico* — Se observó un periodo discontinuo de reposo en mas del 30% de la población, donde solo un pico esta correlacionado con el desove. La gametogenesis es continua en el periodo de muestreo, con un mínimo de 30% en julio y un máximo en mayo, previo a una fase de acumulación de gametos maduros de junio a septiembre. El desove, fue observado en un porcentaje bajo de la población y post desove está claramente definido, abarcando de junio a octubre (Figura 1d).



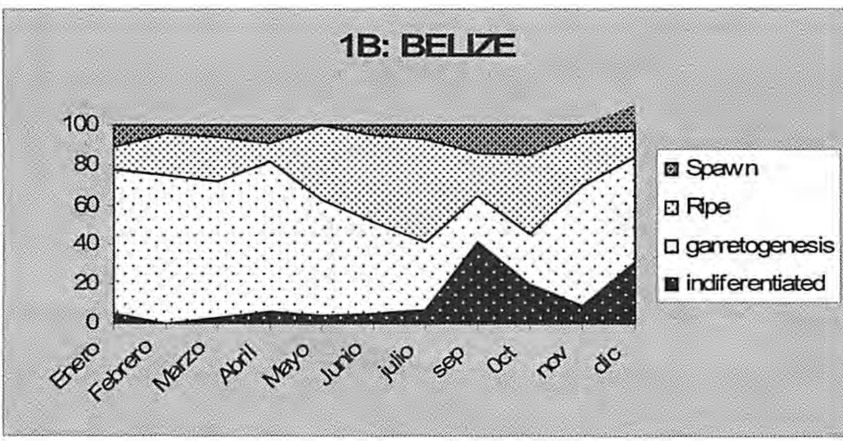




**Figura 1.** Ciclo gonádico de *Strombus gigas* en el Caribe: 1A = Colombia, 1B = Belize

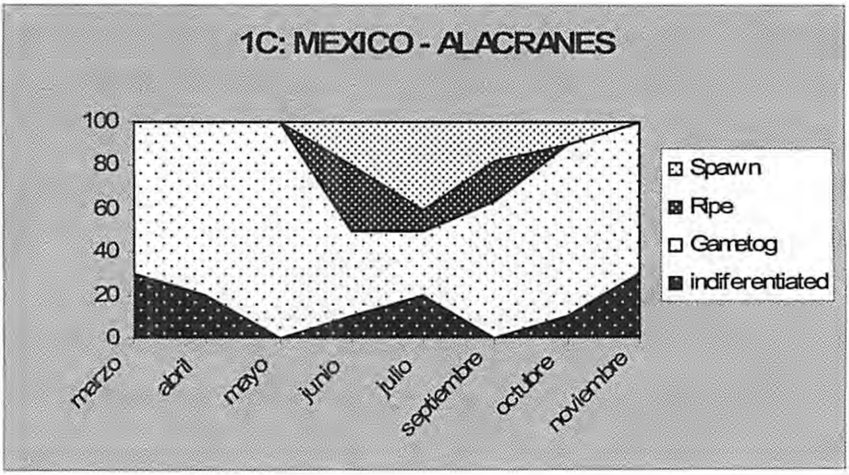




**Figura 1.** Ciclo gonádico de *Strombus gigas* en el Caribe: 1C = México - Alacranes, 1D = México - Chinchorro

## DISCUSIÓN

### Estadios de Desarrollo Gonádico

Egan (1985) observa cinco estadios de desarrollo gonádico (undifferentiated, beginning, developing, ripe y spent. Gordillo-Morales (1996) observa cinco estadios: indiferenciado, ovogénesis o espermatogénesis inicial, ovogénesis o espermatogénesis intermedia, ovogénesis o espermatogenesis final y postdesove. Aldana-Aranda et al. (2003a, b, c) observaron cinco estadios: Rest, gametogenesis, mature, spawn y post-spawn. Delgado et al. (2004) no estudian el ciclo de madurez sexual, pero definen ocho estadios de madurez: no tissue, early development, mid development, ripe, spent, atresia, regresed y no tissue. Avila (2004) observo y utiliza los cinco estadios de Aldana Aranda (2003). Se observa que no existe una terminología común para los estadios de madurez gonádica de *S. gigas*, existiendo 17 términos para designar los diferentes estadios de madurez, sin considerar las diferencias propias del idioma (Tablas 5).

Los estadios undifferentiated, rest y no tissue; tienen en común que el sexo es histológicamente indeterminable, se propone llamarlo **Indiferenciado (Undifferentiated)**. Los estadios beginning, developing, early ovogenesis o espermatogensis, early development and regressed, tienen en común la presencia de ovogonias de primer orden. Los estadios mid ovogenesis o mid espermatogenesis, gametogenesis, mid development tienen en común la presencia de folículos bien definidos. Este conjunto de diferentes niveles de genésis de gametos, se propone denominarlo **Gametogenesis** cualquiera que sea el nivel de desarrollo.

Los estadios ripe, mature, end ovogenesis y development; tienen en común folículos muy unidos y ovocitos con gránulos de vitelo, proponiendose el nombre de **Madurez (Mature).**

Spent, spawn, desove y eyaculación se caracterizan por presentar folículos parcialmente vacíos y gametos en los conductos y Postspawn, postdesove y atresia; tiene en común la presencia de fagotitos, tejido reticular y folículos atrésicos. Para los diferentes niveles del la evacuación de la gónada se proponen los nombres **Desove o Eyaculación (Spawn).**

Con base en la descripción de los estadios de madurez de la gónada de los autores anteriores se propone una clasificación de 4 estadios para *S. gigas*, para poder comparar su desarrollo para las poblaciones del Caribe, y establecer las bases de una veda común para el Caribe (Tabla 6).

**Tabla 5.** Terminología para los estadios de madurez gonádicos de *Strombus gigas* (modificado de Avila Poveda, 2004)

| Terminología Estadios gonádicos | Egan (1985) | Gordillo Morales (1996) | Aldana Aranda *et al.* (2003a,b,c) | Delgado *et al.* (2004) | Avila Poveda (2004) |
|---|---|---|---|---|---|
| undifferentiated – indiferenciado | ♦ | ♦ | | | |
| rest – reposo | | | ♦ | | ♦ |
| no tissue | | | | ♦ | |
| beginning | ♦ | | | | |
| developing | ♦ | | | | |
| ovogénesis o | | ♦ | | | |
| ovogénesis o | | ♦ | | | |
| ovogénesis o | | | | | |
| gametogenesis – | | | ♦ | | ♦ |
| early development | | | | ♦ | |
| regressed | | | | ♦ | |
| mid development | | | | ♦ | |
| late development | | | | ♦ | |
| ripe - mature – madurez | ♦ | | ♦ | ♦ | ♦ |
| spent, spawn, desove, | ♦ | | ♦ | ♦ | ♦ |
| post-spawn, post desove, | | ♦ | ♦ | | ♦ |
| atresia | | | | ♦ | |

**Tabla 6.** Estadios para el desarrollo de madurez de la gónada de *Strombus gigas*, con base en las características observadas por los autores que han estudiado el ciclo gametogénico de esta especie.

| Estadio gonádico | Características |
|---|---|
| Indiferentiated (indiferenciado) | Abundante tejido conectivo<br>Escaso tejido folicular<br>No presencia de células germinales<br>Sexo histológicamente indeterminable |
| Gametogenesis | Presencia de tejido folicular<br>Folículos bien definidos<br>Ovogonias o espermatogonias de 1er orden y 2° orden |
| Mature (madurez) | Tejido folicular abundante, ocupa la mayoría del área de la gónada<br>Folículos unidos<br>Gametos maduros<br>Ovocitos con gránulos de vitelo |
| Spawn (desove y eyaculación) | Folículos separados, parcial o totalmente vacíos, atrésicos y rotos<br>Lumen del folículo vacío o con gametos<br>Gametos en los conductos<br>Tejido folicular<br>Fagocitos |

## Estrategias Reproductivas de *S. gigas* en el Caribe

El ciclo gonádico de una especie va a variar en duración e intensidad de los estadios de madurez gonádica. Aldana-Aranda *et al.* (2003b) identifican dos estrategias de gametogenesis como respuesta al medio ambiente:

i) oblaciones con una corta gametogenesis o un porcentaje bajo de organismos en esta fase; son de gametogenesis rápida (**S. gigas** de Chinchorro y San Andrés Colombia ) y
ii) Poblaciones con una gametogenesis continua en un porcentaje alto de la población (*S. gigas* de Alacranes, y de Boca chica, Belice)

Para el desove, Aldana-Aranda et al. (2003b) plantean tres variantes:

i) Poblaciones con un periodo extendido de desove, con o sin pico dominante (*S. gigas* de Boca Chica, Belice);
ii) Poblaciones con dos o más picos (*S. gigas* de San Andrés, Colombia);
iii) Poblaciones con un desove corto pero bien definido (*S. gigas* de Alacranes).

Por lo que respecta a la capacidad de regeneración de la gónada es otro factor importante en la duración e intensidad de los periodos de indiferenciación y post desove, así como en los períodos de gametogenesis y madurez. Tres variantes plantean estos autores:

i) Poblaciones con o sin un corto periodo de post desove o indiferenciación o de baja intensidad (*S. gigas* de Chinchorro y de Boca Chica, Belice);

ii) Poblaciones con una recuperación de gónada rápida, en la cual solamente un pequeño porcentaje de organismos pueden ser detectados en gametogenesis, con constante presencia de gametos maduros (*S. gigas*, de Colombia) y

iii) Poblaciones con un periodo de madurez limitado o sin él, soportado por un desove constante o intenso (*S. gigas* de Alacranes).

De acuerdo con Baqueiro-Cárdenas y Aldana-Aranda (2000) y Aldana-Aranda et al. (2003b), *S. gigas* que es una especie con amplia distribución geográfica, presentando de acuerdo a este análisis una variedad de estrategias gametogénicas dependiendo de las condiciones ambientales, reflejándose en la intensidad y duración de cada uno de los estadios gonádicos (Tabla 7).

**Tabla 7.** Patrón reproductivo de *Strombus gigas* para diferentes localidades del Caribe.

| Patrón reproductivo | Localidad |
|---|---|
| **Gametogenesis** | |
| 1. Gametogenesis intensa | Banco Chinchorro, México<br>San Andrés Colombia<br>Boca Chica, Belice |
| 2. Gametogenesis de baja intensidad | Arrecife Alacranes |
| **Desove** | |
| 1. Desove constante | Boca Chica, Belice |
| 2. Dos o mas pulsos | San Andrés, Colombia |
| 3. Un pulso corto | Alacranes, México<br>Chinchorro, México |
| **Recuperación de la gónada** | |
| 1. Mínimo o no presencia de fases de post-desove e indiferenciado | Chinchorro, México<br>Boca Chica, Belice |
| 2. Recuperación rápida de la gónada | San Andrés, Colombia |
| 3. Estado de madurez limitado o no presente | Alacranes, México |

## Medida de Regulación Periodo de Veda versus Ciclo de Madurez para *S. gigas*

En la tabla 8 se presentan los períodos de veda para diferentes países del Caribe. De donde se puede observar que solo 16 de 30 países aplican una veda temporal como medida para proteger el recurso Caracol. Por otra parte el rango de veda va desde tres hasta seis meses, siendo variable el período que cubre. Con base en la información de los estudios de madurez sexual para *S. gigas* por métodos histológicos (tablas 3 y 4) y por observaciones de masas de huevo en el fondo marino (tabla 2), se puede ver que el grado de protección que presentan las poblaciones de *S. gigas* con las vedas actuales es sólo parcial. En todos los casos la veda actual de cada país protege sólo una parte del período de desove reportado para cada país Tabla 9.

Dado que se requiere que la veda evite la captura tanto de organismos en desove como de los maduros, y con base en los resultados de este trabajo de overview sobre la reproducción de *S. gigas* se propone:

> *" una veda del 1° de mayo al 31 de octubre para el conjunto de países del Caribe, y que durante estos meses quede prohibido la venta o compra de carne de S. gigas en el mercado que es vigilado por CITES",*

es decir una veda 6 meses y 6 meses de captura del 1° de noviembre al 30 de abril. Es una propuesta que a corto término puede tener un impacto social pero a corto mediano y largo plazo será de beneficio social y económico, permitiendo la recuperación de poblaciones de *S. gigas* y su uso sustentable en el Caribe.

**Tabla 8.** Períodos de veda para Strombus gigas en diferentes países del Caribe

| País | Enero | Febrero | Marzo | Abril | Mayo | Junio | Julio | Agosto | Septiembre | Octubre | Noviembre | Diciembre |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Belice | | | | | | | xxx | xxx | xxx | | | |
| British | xxx | xxx | xxx | xxx | xxx | | | | | | | xxx |
| Caimán | | | | | xxx | xxx | xxx | xxx | xxx | xxx | | |
| Colombia | | | | | | | xxx | xxx | xxx | | | |
| Cuba | | | | | xxx | xxx | xxx | xxx | xxx | | | |
| Guadalupe | | | | xxx | xxx | xxx | xxx | xxx | | | | |
| Honduras | | | | | xxx | xxx | xxx | xxx | | | | |
| Jamaica | | | | | | | | xxx | xxx | xxx | xxx | |
| Martinica | | | | xxx | xxx | xxx | xxx | xxx | | | | |
| México | | | | | xxx | xxx | xxx | xxx | | | | |
| P. Rico | | | | | | | xxx | xxx | xxx | | | |
| R. Dom | | | | | | | xxx | xxx | xxx | | | |
| T. Caicos | | | | | | | xxx | xxx | xxx | xxx | | |
| I.Vírgenes | | | | | | | xxx | xxx | xxx | | | |
| Venezuela | | | | | | | xxx | xxx | xxx | | | |

**Tabla 9.** Época de desove de *Strombus gigas en* el Caribe, a través de observaciones de cópula, y masas de huevos y por observación histológica de la gonada. En </☼ los meses de madurez o desove . En < la época de desove y en ☼ la época de desove y madures que

| Época de desove | | | | | | | | | | | | Localización | Sitio | Referencia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E | F | M | A | M | J | J | A | S | O | N | D | | | |
| | ☼ | ☼ | ☼ | << | << | << | << | << | << | | | 22°30′ N, 89°40′ W | Alacranes, México | Pérez-Pérez y Aldana-Aranda, 2002 |
| | ☼ | ☼ | ☼ | << | << | << | << | << | << | | | 22°30′ N, 89°40′ W | Alacranes, México | Pérez-Pérez y Aldana-Aranda, 2003 |
| | | ☼ | ☼ | ☼ | << | << | << | << | | | | 21°30′ N, 72°15′ W | Turks y Caicos | Davis et al., 1987 |
| | ☼ | ☼ | ☼ | ☼ | << | << | << | << | ☼ | | | 18°15′ N, 65°00′ W | Islas virgenes | Randall, 1964 |
| | | | | ☼ | ☼ | << | << | << | ☼ | ☼ | | 18°15′ N, 66°30′ W | Puerto Rico | Appeldoorn, 1988 |
| | | | ☼ | ☼ | ☼ | << | << | << | | | | 17°05′ N, 62°30′ W | St kitts/Nevis | Wilkins et al., 1987 |
| | | | ☼ | ☼ | ☼ | << | << | << | | | | 13°00′ N, 81°00′ W | San Andrés, Colombia | Márquez-Pretel et al., 1994. |
| | | | | | ☼ | << | << | << | ☼ | | | 13°00′ N, 81°00′ W | San Andrés, Colombia | García-Escobar et al., 1992 |
| | | | | | ☼ | << | << | << | ☼ | ☼☼ | | 11°40′ N, 66°30′ W | Venezuela | Brownell, 1977 |
| | | | | ☼ | ☼ | << | << | ☼ | ☼ | ☼☼ | | 11°40′ N, 66°30′ W | Venezuela | Weil, y Laughlin, 1984 |
| | | | ☼ | ☼ | ☼ | << | < | | | | | 11°30′ N, 74°05′ W | Santa Marta, Colombia | Botero, 1984 |
| ☼☼ | | | | | ☼ | << | << | << | ☼ | ☼☼ | ☼☼ | 9°45′ N, 75°50′ W | San Bernardo, Colombia | Lagos-Bayona et al., 1996 |

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# Consumption of Local Conch by Residents of the TCI

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ABSTRACT

*Strombus gigas* (Queen Conch) is an economically important fishery species managed by an export quota system in the Turks and Caicos Islands (TCI). The quota is based on the maximum sustainable yield (MSY) less an allowance for domestic consumption. A lack of data on domestic consumption however, raises the concern that if underestimated, stocks managed using MSY will diminish from over harvest. In 1999-2000, 5% of the MSY was allocated for domestic consumption, however, there is anecdotal evidence that domestic consumption of conch is much higher. In 2003, of the Total Landed Conch (1,657,876 lbs), 99% was exported, suggesting most domestic consumption does not pass through this system. To provide an accurate estimate of conch consumption by TCI residents, an intercept survey was administered to the adult population between July and September 2004. Information collected included individual consumption of conch and other seafood as well as limited demographic information (age, gender, island of residence, nationality). The majority of respondents ate conch (72%). The majority of conch consumed does not go through the market, with 15% claiming personal capture, while 36% receive the conch as a gift from fishermen. Median serving size differed by island (Krushal-Wallis test: $H$ (3, n = 258) = 23.760, p = 0.0000) and gender ($H$ (1, n = 339) = 6.651, p = 0.010). The median serving size was 0.114 kg for all respondents. Frequency of consumption did not vary significantly by island or age, but differed by nationality (Krushal-Wallis test: $H$ (3, n = 337) = 10.240, p = 0.017), source ($H$ (3, n = 250) = 22.087, p = 0.0001) and gender ($H$ (1, n = 339) = 7.781, p = 0.005). The median frequency of consumption was 4.333 times/month. Concerns with potential biases in the results will be addressed through the use of a supplemental survey to be administered in conjunction with the larger survey to an additional sample of residents. With more conclusive figures, local consumption can be included in the calculations for MSY and utilized to determine the landings quota.

KEY WORDS: Conch, local Consumption, Turks and Caicos Islands

# El Consumo de Caracola Local por Residentes del TCI

En las islas Turkos y Caicos (TCI) la especie *Strombus gigas* (Caracola de Reina) es económicamente importante en las pesquerías manejada por un

sistema de la cuota de la exportación. La cuota se basa en el rendimiento sostenible máximo (MSY) menos una concesión para el consumo doméstico. La falta de datos en el consumo doméstico levanta el peligro que la pesqueria es subestimado, y el uso de MSY solamente, podria resultar en sobre cosecha. En 1999-2000 5% del MSY fue asignado para el consumo doméstico, sin embargo, evidencia anecdótica indica que el consumo doméstico de caracola es mucho más alto. En 2003, del total de Caracola pesquado (lbs de 1,657,876), 99% fue exportado, sugiriendo que la mayoría de los consumos domésticos no pasan por este sistema. Para proporcionar una estimación exacta del consumo de caracola por residentes de TCI, administramos un estudio de 201 adultos entre los meses de Junio y Agosto en 2004. La información incluyó tres temas: el consumo individual de caracola; el consumo individual de otros tipos de mariscos; información demográfica limitada (edad, género, isla de residencia, nacionalidad). La mayoría (72%)de participantes comen caracola. La gran proporcionde caracola consumida no pasa por el mercado, sino 26% reclaman atravez de la captura personal, mientras 37% adquieren caracola en forma de regalo de un pescador. El consumo medio de caracola era 42 lbs/persona/año (± 6, el error uniforme). El análisis de ANOVA que no hay diferencias significativas en niveles de consumo entre las cuatros islas representadas (df = 3, p = 0,90), o las nacionalidades (df = 3, p = 0,83). Los datos resultados del censo de población 2001, indican que el consumo anual medio de caracola limpiada se estima ser más alto que el 5% asignado. Para mejorar la administración de Caracola de Reina en el TCI, un porcentaje exacto (basado en las inspecciones) debe ser incluido en los cálculos para MSY y utilizado para determinar la cuota.

PALABRAS CLAVES: Caracol de reina, *Strombus gigas,* consumo doméstico, las islas Turkos y Caicos

## INTRODUCTION

People throughout the world, including the Caribbean region, have relied on marine resources as an important source of food. Marine resources such as fish stocks are not infinate and require a responsible management and development to contribute to the nutritional, economic, and social prosperity of the people in the Caribbean region (Haughton 1999).

The management of marine fisheries to ensure the best use of the resources of the ocean has become the major problem over the years facing fishery scientist and managers (Gulland 1974) in the region. Haughton (1999) argues that the traditional approaches to fisheries development and management will not transform Caribbean fisheries into sustainable dynamic systems capable of meeting future demands for food and employment. He proposes that a combination of traditional and new, innovative approaches are needed in the region for sustainable fisheries development. It is now widely accepted by many that the effective management of fisheries resources, requires a holistic approach, that is, the incorporation of interrelated disciplines taking into account all components which may impact on the fishery, including biological and socio-economic aspects. It is also important to consider all available information concerning exploitation levels, such as commercial catch destined for export as well as for local consumption.

The Caribbean queen conch (*Strombus gigas)* is one of the most important marine fisheries in the region, being surpassed in economic value only by the spiny lobster (*Panulirus argus*) and by fin-fish as a dietary supplement (Brownell and Stevely 1981). Queen conch exploitation as a source of protein in the region has a long tradition dating back to pre-Columbian times (Sadler 1997, Clerveaux and Danylchuk 2001, Theile 2001).

With the introduction of freezing technology coupled with the growing demand and the expansion of export markets, queen conch stocks have been fished to such low levels in many countries that a viable fishery no longer exists in many of these locations (Clerveaux 2003). In an attempt to manage the queen conch resources, an assortment of mathematical models are being utilised by many range States to predict the productivity of the resource, the effect of fishing pressure, as well as the impact of management measures on the resource (Gulland 1983). On the other hand, Sparre and Venema (1992) pointed out that a model is only as good as its inherent assumptions and input parameters.

The importance of local consumption information is exemplified in the use of mathematical models such as surplus production models (e.g. Schaefer Model) which utilise catch and effort data to assess the status of the stock. Incomplete catch information may underestimate production and/or overestimate the stock size thereby masking gradual overexploitation of the resources.

Many countries in the region are faced with a similar challenge, that is, the lack of complete time series data sets. Most fisheries data in the region only represent catch which are destined for export, generally landed at centralized locations. In contrast, catch utilised for local consumptions is often more difficult to track because of the numerous possible landing sites which may exist in any one country.

Many countries, for example Belize, have reported that the catch obtained from the co-operatives or fish processing plants are not a true representation, as it does not include what is sold on the local market. Hence, the estimates based on the catch and effort data are considered unreliable. Similarly, the Bahamas have reported that the biomass dynamic (Schaefer) model, which is currently utilized to assess the status of the queen conch stock, did not produce a good fitted to the observed catch and effort data because of inadequate data (Anonymous 1999).

Likewise, in countries with a high tourist population, such as Grenada and the U.S. Virgin Islands, conch is used extensively by the local people. The fishery is artisanal in nature, and therefore, conch are marketed by fishermen along the roadside or sold directly to hotels and restaurants. The respective management authorities have reported that this arrangement has created a problem in determining total production (Anonymous 1999).

The challenges facing the Turks and Caicos Islands are similar to that of many countries in the region. Conch has been fished in the TCI for many years and used as a local food or for trade with Haiti. Catch and effort data are collected from the five processing facilities located on the islands of Providenciales and South Caicos. To date product diverted from the processing plants is not documented. In 2003, of the Total Landed Conch (1,657,876 lbs), 99% was exported, with the remaining 1% sold locally to restaurants and individuals. Since 1992, the TCI has utilized a biomass dynamic (Schaefer) model to determine stock biomass which forms the basis of the yearly queen conch Total Allowable Catch (TAC).

Medley and Ninnes (1998) reported that the model did not fit the observed CPUE time series well. While overall the fit seems reasonable, the model has consistently underestimated the CPUE in recent years, forecasting a decline which has never materialized. It is proposed that the model is inherently faulty because not all catches are accounted for owing to fluctuations in local consumption and/or illegal catches (Anonymous 1999, Clerveaux and Danylchuk 2001).

Ninnes (1994) proposed that since local consumption is not taken into account in the catch data, then the data only represents a minimum estimation of total catch. Few previous estimates of local conch consumption have been made for the TCI. In 1984, Olsen estimated local seafood consumption index of 25.9 kgs/person/year for the Eastern Caribbean, including the Turks and Caicos Islands. He further estimated local consumption of queen conch at 312 mt (Olsen 1985). In 1985, Olsen estimated local consumption of queen conch for all residents and visitors in the Turks and Caicos Islands to be at 35.4 kgs/person/year, which Medley and Ninnes (1998) suggest is referring to unclean meat. In 2001, a social and economic impact census was conducted to validate the quantify the estimates from Olsen in (1985). Clerveaux (2003) estimated a conch consumption rate of 4.93 kgs/resident. However, unlike Olsen a separate tourist consumption rate of 0.28 kgs/person was determined. However, the estimation of consumption is assumed to be underestimated, because of the small number of surveyed respondants.

It was customary for the TCI to set the TAC at the MSY. However, from the 1999 - 2000 fishing season to the 2002 - 2003 fishing season, 5% of the MSY has been allocated for local consumption. In 2003 - 2004 fishing season, the allocation for local consumption was raised to 10% of the MSY, because of the increased concern of growing local consumption. The particular study reports the initial results of TCI residents' local conch consumption.

## MATERIALS AND METHODS

### Survey Design

Consumption surveys are generally conducted at the household level (Myrland et al. 200, Olsen 2001, 2003), with individual consumption calculated as the total prepared for the household divided by the number of individuals in the household (Anderson et al. 1994). In the TCI there are a large number of island commuters who live on multiple islands, which precludes household level data collection. By surveying random individuals, the potential for double counting was eliminated.

The survey was designed and pretest in March 2004. The six pre-tested individuals illustrated some of the difficulties with the standard format. Participants requested that they be allowed to determine their own time frame for frequency of consumption on either a weekly, monthly or yearly basis. Some individuals had difficult in determining quantity of conch contained in a meal. This lead to the development of visual aids. Additionally, some respondents showed a preference for reporting consumption in terms of number of conch, rather than in weight. Conversion calculation were developed allowing for reporting in both formats. Finally, several participants indicated difficulties determining individual consumption as they prepared meals for the household. To assist these people, a section was added which allowed for reporting of household data, however respondents were still asked to determine his/her individual share of that consumption.

The intercept survey was administered by trained DECR conservation officers July – September 2004 on Grand Turk, Providenciales and South Caicos. The stratified design by island population and nationality was based on the adult resident population (> 15 years of age) as determined by 2001 Population Census for the Turks and Caicos Islands.

### Weigh Calculations and Visual Aids

To allow for the conversion of alternate formats of a "serving of conch", a variety of calculations were conducted and visual aids created. Conch cleaning tests determined that a conch fully cleaned of all skin, visera (eyes, mouth, snout, anus, rectum, kidney and stomach) and operculum weighed an average of 0.11 kgs. Local restaurants indicated a serving size of conch was consistant with the 0.11 kgs. Additionally, tests determined that 20 conch fritters also utilized 0.11 kg of cleaned conch.

Alternatively, to weight calculations, a visual aid was created to allow respondents to visualize a one conch serving. A single serving of cracked conch (0.11 kg) was place on a dinner plate with traditional side dishes and photographed. Respondents were able to base serving sizes relative to the pictured portion.

### Data Analysis

The data were analyzed using a non-parametric Krushal-Wallis ANOVA by Ranks test (StatSoft 1998), as the data failed tests for homogenity and normality.

## RESULTS

A total of 434 surveys were conducted with 359 useable for the conch component of this analysis. The demographic profile of respondents closely matched that of the general population (Table 1), except for an over-representation of South Caicos residents and an under-representation of the Haitian community. This was the result of logistical and linguistic difficulties in Providenciales, limiting the number of surveys that could be completed within the allocated time. This issue will be addressed under recommendations.

**Table 1.** Demographic comparison of survey respondents and Turks and Caicos Island 2001 Population Census.

| | 2001 Census | | Respondents | |
|---|---|---|---|---|
| | # | % | # | % |
| **Island population >15 yrs old** | | | | |
| Providenciales | 9,247 | 65.2 | 151 | 42.1 |
| Grand Turk | 2,830 | 19.9 | 87 | 24.2 |
| South Caicos | 777 | 5.5 | 101 | 28.1 |
| Other islands | 1,338 | 9.4 | 20 | 5.6 |
| **Nationality by total population** | | | | |
| TCI Belonger | 10,335 | 52.0 | 217 | 64.4 |
| Haitian | 5,027 | 25.3 | 53 | 15.7 |
| Dominican | 693 | 3.5 | 28 | 8.3 |
| Other | 3,83 | 19.3 | 39 | 11.6 |
| **Gender for those > 15 yrs old** | | | | |
| Female | 7,033 | 49.6 | 170 | 50.2 |
| Male | 7,160 | 50.4 | 169 | 49.9 |
| **Age** | | | | |
| 15-24 yrs | 2,663 | 18.8 | 79 | 22.8 |
| 25-49 yrs | 9,168 | 64.6 | 231 | 66.6 |
| 50-64 yrs | 1,605 | 11.3 | 30 | 8.7 |
| 65+ | 775 | 5.3 | 7 | 2.0 |

## Source of Conch Consumed

The source of conch for personal consumption appears to differ by island (Figure 1) and nationality (Figure 2). Approximately 51% of TCI conch consumers obtained their conch from non-market sources, including personal capture (15%) and as gifts from fishermen (36%). The proportions differ by island with South Caicos having the highest share obtained as gifts from fishermen (65%) and Grand Turk having the lowest (13%). Grand Turk however, has the highest proportion of conch obtained by personal capture (25%).

There appears to be differences between nationalities in the source for conch consumed (Figure 3), with TCI Belongers (native born residents) and Haitians obtaining a larger share from personal capture and gifts from fishermen compared to other nationalities. A higher proportion of individuals from the Dominican Republic and countries other than Haiti or the TCI obtain their conch by buying it or eating at restaurants.

## Frequency of Consumption and Serving Size

Total consumption is a combination of the frequency with which people eat conch and the average serving size. Overall 28% of the population indicated they do not consume conch (Figure 4). The mean frequency of consumption for those that consumed conch was 6.723 times/month (± 0.427 SE), with a median value of 4.333 times/month. Frequency of consumption did not vary significantly by island (Krushal-Wallis test: $H$ (3, n = 359) = 4.487, p = 0.216), or age ($H$ (1, n = 339) = 7.781, p = 0741), but did differ by nationality ($H$ (3, n = 337) = 10.240, p = 0.017), source ($H$ (3, n = 250) = 22.087, p = 0.0001) and gender ($H$ (1, n = 339) = 7.781, p = 0.005). Median frequency of consumption values by nationality were: TCI Belonger 2.2 times/

month, Haitian 3.5 times/month, Dominican Republican 4.3 times/month and other nationalities 0.25 times/month. By source, the median values were personal capture 8.7 times/month and for all other sources 4.3 times/month. The median consumption frequency gender was 4.0 times/month for males and 1.0 times/month for females.

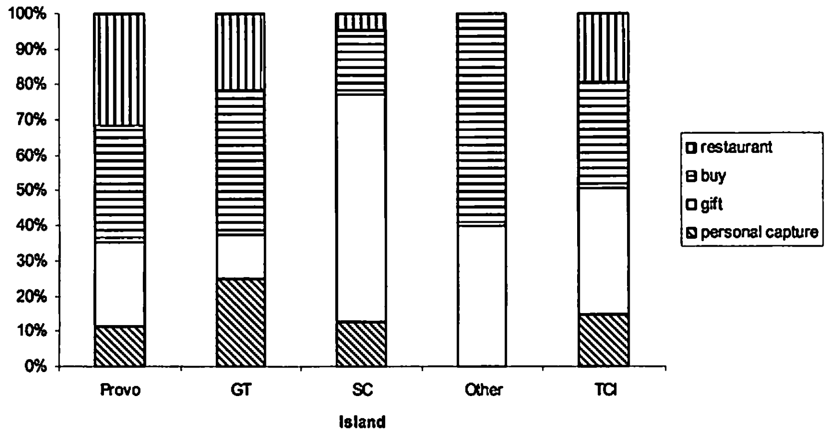


**Figure 1.** Distribution of conch for personal consumption by source for Providenciales (Provo, n = 104), Grand Turk (GT, n = 56), South Caicos (SC, n = 88), other islands (Other, n = 10) and the Turks and Cacios Islands overall (TCI, n = 258). Sources include personal capture, gift from fishermen (gift), (TCI, n = 169), Haitians (n = 43), Dominican Republican (Dominican, n = 21), purchases from fishermen (buy) and consumed at restaurants (restaurant).

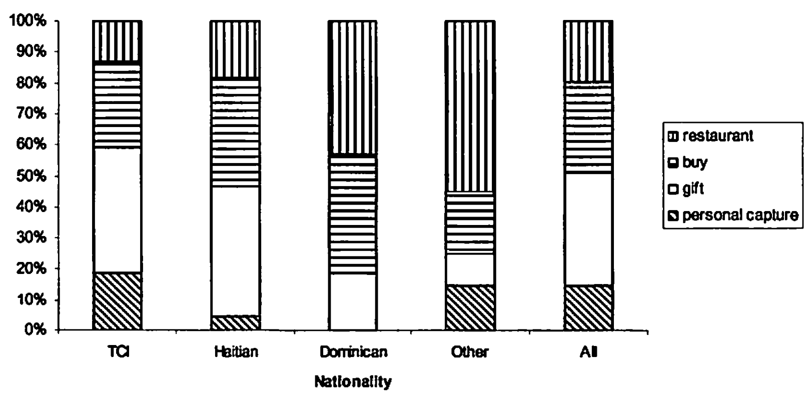


**Figure 2.** Distribution of conch for personal consumption by source for TCI Belongers other nationalities (Other, n = 20) and all nationalities (All, n = 253). Sources include personal capture, gift from fishermen (gift), purchases from fishermen (buy) and consumed at restaurants (restaurants).

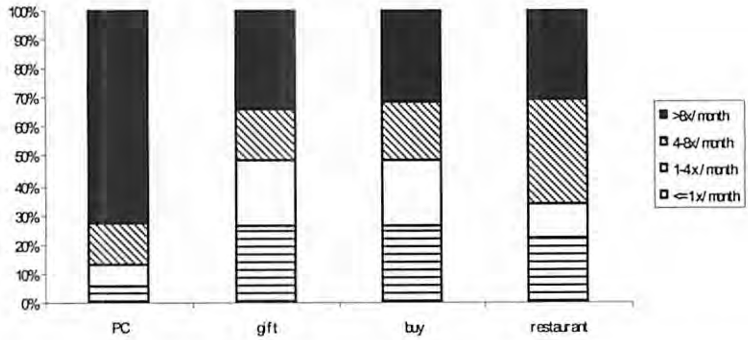


**Figure 3.** The distribution of the frequency of conch consumption by Sources (PC or Personal Capture, n = 37), (Gift from fishermen, n = 92), (Buy from fishermen or plants, n = 76). (Resturants, n = 53).

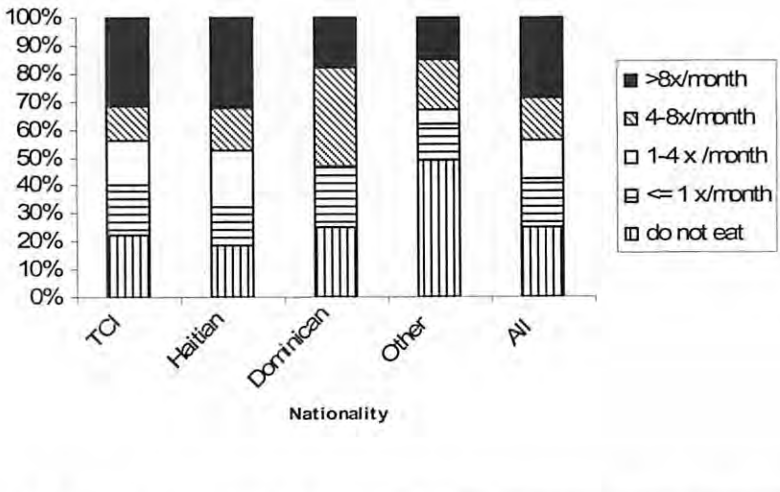


**Figure 4.** The distribution of the frequency of conch consumption by nationality (TCI) TCI residents, n = 217), (Haitian, n = 53), (Dominican, n = 28). (Other, n = 39) and the TCI (All, n = 337) overall.

Serving size differed between islands with the median value smaller for Grand Turk (0.113 kg/meal) than for Providenciales or South Caicos (both 0.227 kg/meal) and the other islands (0.454 kg/meal) ($H$ (3, n = 258) = 23.760, p = 0.000). Additionally, serving size differed between male and female respondents ($H$ (1, n = 339) = 6.651, p = 0.010) with females having a smaller median serving size (0.170 kg/meal) than males (0.227 kg/meal). Serving size did not differ by nationality ($H$ (3, n = 253) = 2.333, p = 0.506), source of the conch ($H$ (3, n = 258) = 1.465, p = 0.690) or age ($H$ (5, n = 347) = 2.734, p = 0.741).

## DISCUSSION

The Turks and Caicos Islands has actively tried to protect its queen conch stocks. However, often when protecting the stocks we are only considering commercial catch for export in this management. It is time to also consider the local community and its own consumption. Often conch for local consumption does not even pass through landing sites for documentation. As we can see, a significant portion of conch is retrieved by personal capture and/or directly from local fishermen. Currently, local consumption is not utilized in the determination of the Maximum Sustainable Yield (MSY). Instead, the TCI sets a quota below MSY to accommodate for local consumption. The fact remains, that if the local consumption rate is higher than the "buffer" between the quota and MSY, the stocks will be overfished.

The initial results of the TCI local conch consumption survey suggested an annual consumption level well above the levels indicated in previous studies (Olsen 1985, Clerveaux 2003). The higher estimate could be due to a larger estimated serving size or higher frequency of consumption.

Clerveaux (2003) found 40% of survey participants in Grand Turk were frequent consumers, consuming conch at least once per week. Our results indicate that for the TCI as a whole, approximately 43% of survey respondents consume conch one or more times per week (4+ times per month). However, this group contains some very frequent consumers, including some individuals with daily consumption. This results in a highly skewed distribution with a mean value of almost seven times per month, while the median value is only four times per month. This suggests the use of the median value for national level calculations. However, there are significant differences in the frequency of consumption between some user groups, which suggests further analysis.

The frequency of consumption appears to be similar between islands, which suggests that any potential bias is most likely to reside with respondents. About half of the consumers appear to be heavy consumers, eating conch once a week or more. Such a heavy level of dependence on conch for protein may be reasonable for a location with a long history of utilization of conch, such as the TCI. However, such high utilization levels also call for further investigation to determine if it is indeed true or whether people are over estimating their frequency of consumption.

The serving size does show differences between genders, as might be expected, although other seafood consumption studies show no differences between men and women (Myrland et al. 2000). Explaining differences in the median serving size between islands is more difficult. One would expect that where an individual lives would not play a role in serving size. The most obvious sources of the difference are bias and leading questions by interviewers. Training was conducted with all officers, however it is possible that it was not sufficient or that interviewers may have ignored instructions. Each island was surveyed by a small number of officers, ranging from two (Grand Turk and South Caicos) to four (Providenciales). While this might lead to consistent results for an individual location, it could introduce consistent bias for inter-island comparisons.

## RECOMMENDATIONS

After reviewing the initial results of the survey, it has been determined that a supplemental survey will be administered to a smaller sample of TCI residents. The objective of the supplemental survey will be to further probe areas of potential respondent bias, such as frequency of consumption and quantity consumed. To address the potential problem of interview bias, a single officer will conduct all surveys on all three islands.

The survey, which explored local consumption by residents, is just the first step in further identifying consumption within the TCI. Currently, the DECR is collecting information on the volume of conch purchased by restaurants, including source information. Additionally, an airport survey of departing tourists will be used to estimate the visiting population's consumption. Together this information will provide a clearer picture of the amount of conch that is being harvested, but not recorded at the processing plants.

In order to manage marine fisheries in the Caribbean region, countries need to examine a holistic approach. Not only are basic catch and effort information necessary for stock assessment and management, but other parameters such as local consumption may play a larger role than first thought.

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# Portrait of the Fishery of Spiny Lobster, *Panulirus argus*, in Puerto Rico during 1988-2001

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ABSTRACT

The Puerto Rico Department of Natural and Environmental Resources (DNER) is responsible for the conservation and management of the Island's natural resources, including the fishery resources. The DNER's Commercial Fisheries Statistics Program (CFSP) collects and analyzes the dependent fisheries data. The CFSP has been collecting data since 1971. During the 1980s, Puerto Rico's commercial fishery resources had shown overfishing symptoms (e.g. decrease in landings pounds, change in catch composition, decrease in the size of some important species).

Spiny lobster, *Panulirus argus*, is a very valuable exploited marine crustacean in the shallow water of the Caribbean Islands. During the 1950s, the fishery and economic of the spiny lobster started to increase. Spiny lobster has been the most important shellfish by landed weight and price per pound in Puerto Rico's fishery since the 1970s to 2001. Spiny lobster showed symptoms of overfishing during the 1980s. Since 1985, then the Caribbean Fishery Management Council (CFMC) and the DNER have regulations to protect the spiny lobster. These include a minimum legal size (MLS) of 89 mm carapace length (CL), forbidden to take egg-bearing females, forbidden the use of gaff to catch lobsters, and all spiny lobster must be landed whole. Despite these fishing regulations, CFSP personnel observed that very little or no enforcement occurred until 1995. During 1989 - 1991, more than 50% of the spiny lobsters were caught before reaching the MLS. Since 1995, the DNER's rangers started to enforce the spiny lobster regulations, with the result that during 1998, only 24% were caught before MLS.

The objective of this study is to describe the fishery of the spiny lobster thru the data collected by the CFSP (landings and biostatistics data) during 1988 - 2001. Length frequency distributions (LFD) of this species by years, fish traps and SCUBA diving have been analyzed.

KEY WORDS: Biostatistics data, commercial landings, Puerto Rico, spiny lobster

# Un Retrato de la Pesquería de Langosta, *Panulirus argus*, en Puerto Rico durante 1988-2001

El Departamento de Recursos Naturales y Ambientales de Puerto Rico (DRNA) es el responsable de conservar y administrar todos los recursos naturales de la Isla, incluyendo los recursos pesqueros. El Programa de Estadísticas Pesqueras (PEP) del DRNA se encarga de recolectar y analizar los datos dependientes de la pesca. El PEP ha estado recolectando datos desde 1971. Estos datos muestran que durante la década de 1980, la pesca comercial en Puerto Rico mostraba indicios de sobre pesca (Ej. disminución en las libras desembarcadas, cambios en la composición de la captura, disminución en el tamaño de especies importantes).

La langosta espinosa, *Panulirus argus* es un crustáceo marino explotado en las aguas someras de las islas caribeñas. Durante los años 50 la pesquería y la economía de la langosta espinosa aumentaron. La langosta espinosa ha sido el marisco más importante por libras desembarcadas y por precio por libra en la pesquería de Puerto Rico desde 1970 hasta 2001. La langosta espinosa mostró indicios de sobre pesca durante los años 1980. Desde 1985, el Consejo de Pesca del Caribe (CFMC) y el DRNA tienen reglamentaciones para proteger a la langosta espinosa. Estas reglamentaciones incluyen un tamaño mínimo legal de 89mm del largo del carapacho, la prohibición de capturar hembras con huevos, el uso de bichero para capturarlas, y todas las langostas espinosas deben estar completas al momento del desembarco. A pesar de estas reglamentaciones el personal del PEP observó que no se hicieron cumplir las mismas hasta el 1995. En el periodo de 1989-91, más del 50% de las langostas espinosas eran capturadas antes de alcanzar el tamaño mínimo legal. A partir de 1995, los vigilantes del DRNA comenzaron a hacer cumplir las reglamentaciones de la langosta espinosa, dando como resultado para el año 1998, sólo el 24% fue capturado antes de alcanzar el tamaño mínimo legal.

El objetivo de este estudio es describir la pesquería de la langosta espinosa utilizando los datos recolectados por el PEP (desembarcos y datos bioestadísticas) durante 1988-2001. Se analizó la frecuencia de tallas (LFD) de esta especie por año, nasas y buceo.

PALABRAS CLAVES: Datos de bioestadísticas, desembarcos comerciales, Puerto Rico, langosta espinosa

## INTRODUCTION

The Puerto Rico Department of Natural and Environmental Resources (DNER) is responsible to conserve and manage all the Island's natural resources, including the fishery resources. The DNER's Commercial Fisheries Statistics Program (CFSP) collects and analyzes the dependent fisheries data. The CFSP has been collecting data since 1971. Matos-Caraballo (2005, 2004) mentioned that during the 1980s Puerto Rico's commercial fishery resources had shown over fishing symptoms (e.g. decrease in landings pounds, change in catch composition, decrease in the size of some important species). Species considered in the market as trash during the 1970s, today have been considered a second class market species (Matos-Caraballo 2005, 2004).

Spiny Lobster *Panulirus argus* it is a very valuable marine crustacean in the shallow water of the Caribbean Islands (Mateo and Die 2004). Jarvis (1932) mentioned that in early 1930s fishermen frequently caught spiny lobsters, although they did not have a good market. Old commercial fishers report to CFSP that until early 1950s most lobsters were used as fish trap baits (Matos-Caraballo 2001). Mattox (1952) and Feliciano (1958) described how the fishery and economy of the spiny lobster started to increase during the 1950s. Spiny lobster has been the most important shellfish by landed weight and price per pound in the Puerto Rico's fishery since the 1970s to 2001 (Suárez-Caabro 1979, Matos-Caraballo 2005, 2004, 2001). Spiny lobster showed symptoms of overfishing during the 1980s, and since that time the Caribbean Fishery Management Council (CFMC) and the DNER have enacted regulations to protect the spiny lobster. The mentioned regulations includes a minimum legal size (MLS) of 89 mm carapace length (CL), forbidden to take egg-bearing females, forbidden the use of gaff to catch lobsters, and all spiny lobster must be landed whole. Although the mentioned fishing regulations CFSP personnel observed that very little or none enforcement occurred until 1995 (Matos-Caraballo 2001). During 1989 - 1991,more than 50% of the spiny lobster were caught before reaching the MLS. Since 1995, the DNER's rangers started to enforce the spiny lobster regulations, with the result that during 1998, only 24% were caught before MLS.

The objective of this study is to describe the fishery of spiny lobster thru the data collected by the CFSP (landings and biostatistics data) during 1988-2001. Length frequency distributions (LFD) of this species by year, fish traps, and SCUBA divers have been analyzed.

## METHODS

This report will discuss the spiny lobster fishery using two types of dependent data collected by CFSP through 1988 - 2001. First, the landings data were collected by CFSP's port samplers. The commercial fishers and/or fish houses reported their catch in a ticket.

The second type of data used in this study was biostatistics. This data were also collected by CFSP's port samplers. They visited the fishing centers and randomly selected commercial landings. Then they proceeded to identify by species all the catch to obtain data about composition. Then port samplers measured CL in mm. If it was possible, the whole catch was individually measured and sexed. CFSP's port samplers collect catch per unit effort data (CPUE) *in situ* when they do the biostatistics sampling. The total landings by trip and by gear, number of traps hauled, and net lengths in fathoms were recorded.

Port samplers delivered the landings and biostatistics data to CFSP and statistical clerks edited and entered it in computers using Microsoft FoxPro and NMFS Trip Interview Program (TIP). The data were analyzed using length frequency distribution (LFD) of this species by years, fish traps, SCUBA divers, and lobster traps. LFD for both species by years and by gears were analyzed. Kolmogorov-Smirnov Two Sample Test, $p \leq 0.05$ (Sokal and Rohlf

1981) was used to know if there is any significant difference among the comparisons.

## RESULTS

Landings data indicate that a total of 3,238,755 pounds of spiny lobster were reported to the CFSP during 1988 - 2001 (Figure 1). An increase is observed in the spiny lobster reported during the period of 1988 - 1994 (1,228,856 pounds), compared to 1995 - 2001 (2,009,899). The spiny lobster landings increase coincides with the higher participation in the number of commercial fishers (Matos-Caraballo 2004). During 1988 - 2001, spiny lobster reported represented approximately 8% of the total pounds reported for fish and shellfish. The spiny lobster continues to be the most important shellfish in pounds and traps in Puerto Rico's fishery. Also, spiny lobster is one of the top five species of fish and shellfish in Puerto Rico's landings.

Figure 2 shows the trend of landings reported by fish trap, lobster trap, gill net, trammel net, and SCUBA divers during 1988 - 2001. Landings reported by these gears show that fish traps caught 42% of the 3,238,755 spiny lobster pounds during 1988 - 2001. For the same period, lobster traps caught 9.4%, gill nets caught 1.0%, trammel nets caught 5.1%, and SCUBA divers caught 42.4% of the total landed pounds reported. Figure 2 shows that SCUBA divers and fish traps were the most productive gears in this fishery.

Biostatistics data from 1988-2001, shows that a total of 13,418 spiny lobsters were measured by CFSP (Figure 3). The spiny lobster caught during 1988 - 94, had an average of 93 mm CL (Figure 4). On the other hand, the spiny lobster caught during 1995 - 2001 had an average of 99 mm CL (Figure 5). Kolmogorov-Smirnov test shows that the LFD for 1995 - 2001 were significantly larger than the LFD 1988 - 1994 (Dmax = 0.1799).

Spiny lobster males caught during 1988-94 had an average of 96 mm CL (Figure 6). During 1995 - 2001 the average was 101 mm CL (Figure 7). The trend observed in males was observed also in the females LFD for the same periods of time. Spiny lobster females caught during 1988 - 1994 had an average of 90 mm CL (Figure 8) and during 1995 - 2001 the average was 96 mm CL (Figure 9). The females caught during 1988 - 1994 were significantly smaller than the females caught during 1995 - 2001 (Dmax = 0.1859).

A total of 1,492 individuals of spiny lobsters caught by fish traps were measured by CFSP's port samplers during 1988 - 2001 (Figure 10). Length frequency distribution shows that 471 (31%) individuals were caught before reaching the MLS of 89 mm CL. On the other hand, 9,766 spiny lobster caught by SCUBA divers were sampled by CFSP. From this total 2,434 (25%) were caught before reaching the MLS (Figure 11). The lobster trap caught only 18% of the individuals before reaching the MLS (Figure 12).

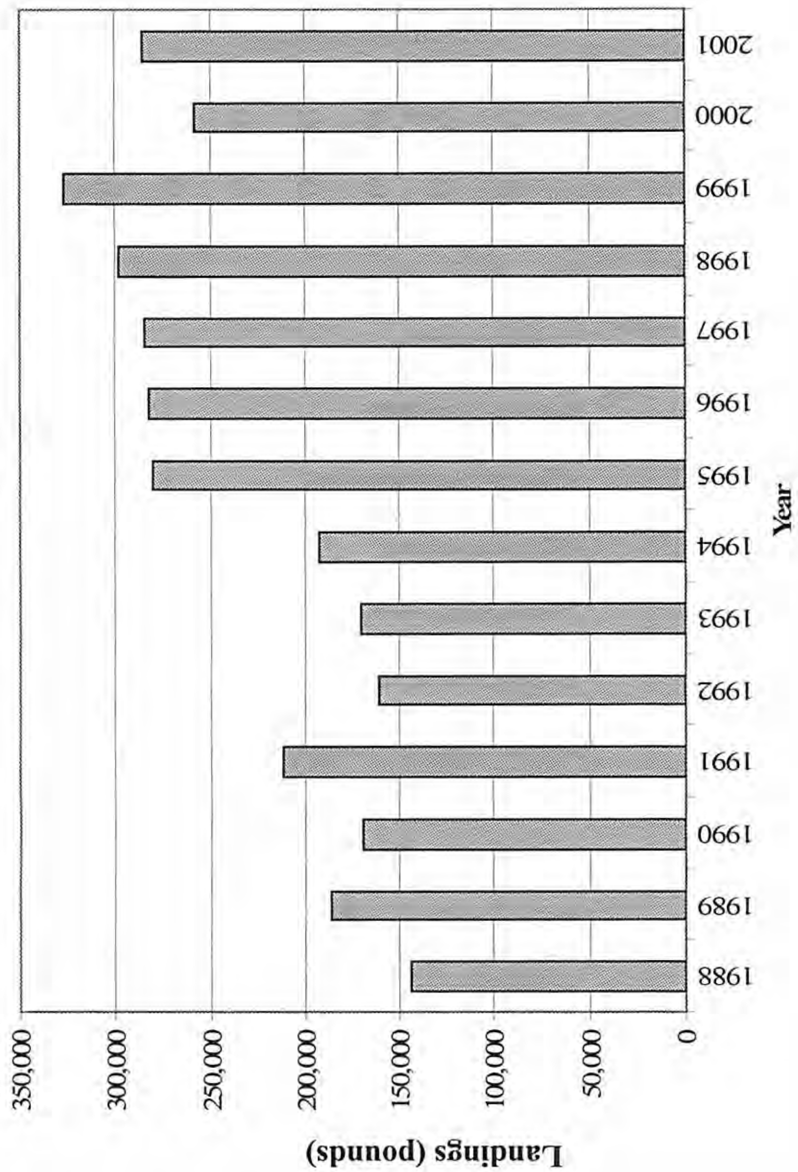


**Figure 1.** Landings reported of spiny lobster in Puerto Rico during 1988 - 2001.

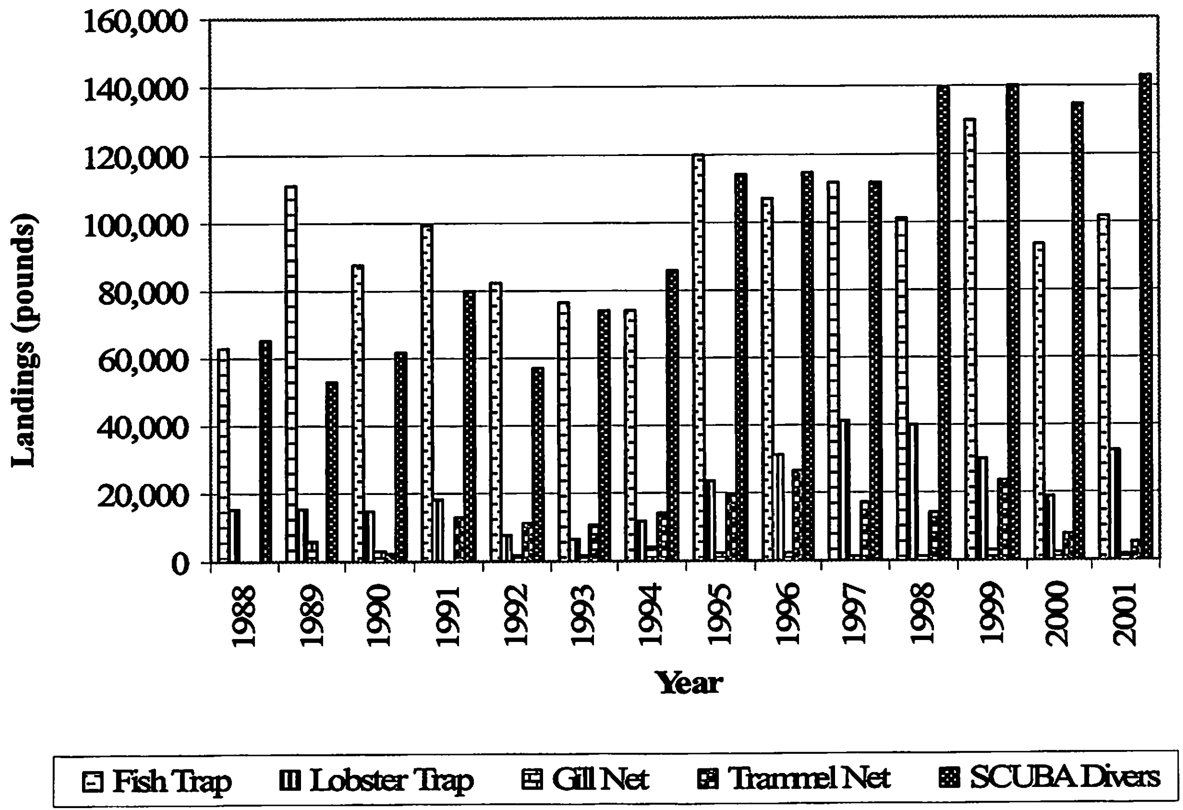


**Figure 2.** Landings reported for spiny lobster by fish trap, lobster trap, gill net, trammel net, and SCUBA divers in Puerto Rico during 1988 - 2001.

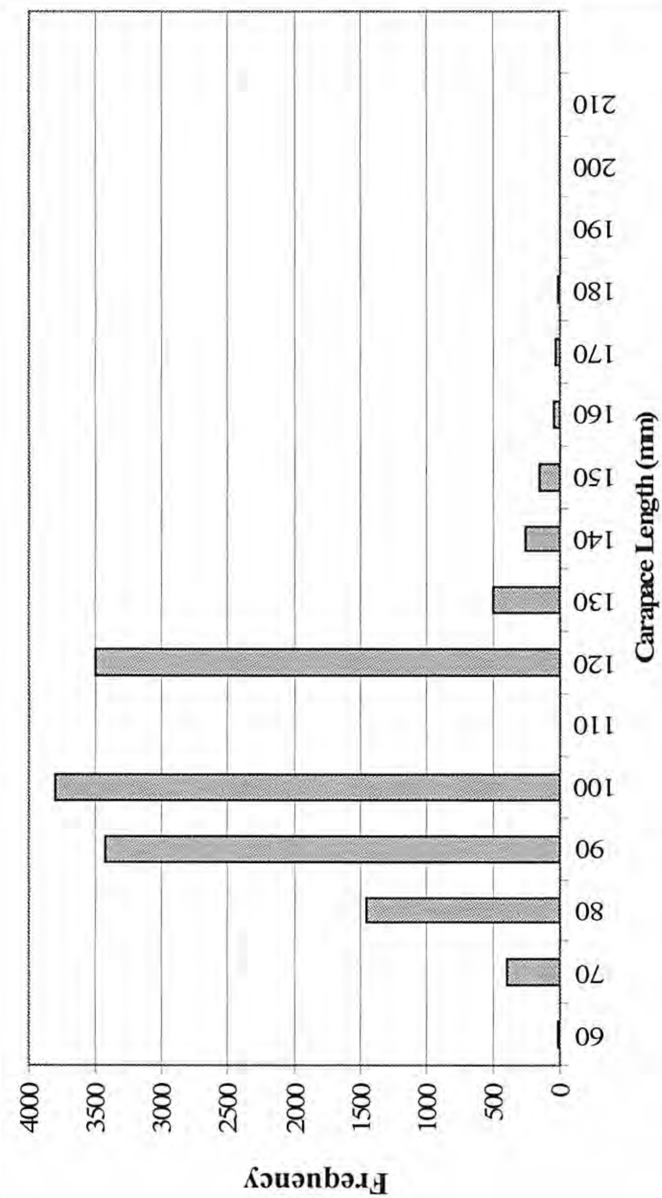


**Figure 3.** Length frequency distribution for spiny lobster caught in Puerto Rico during 1988 - 2001.

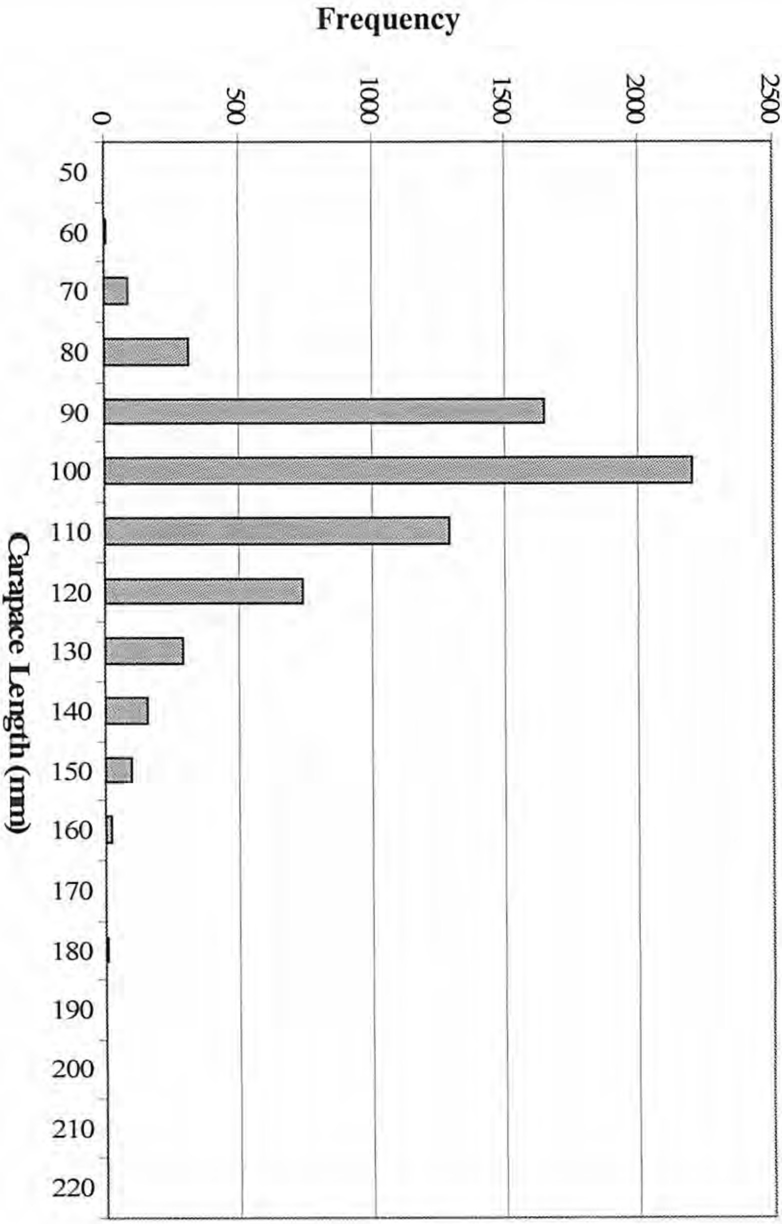


**Figure 4.** Length frequency distribution for spiny lobster caught in Puerto Rico during 1988 - 1994.

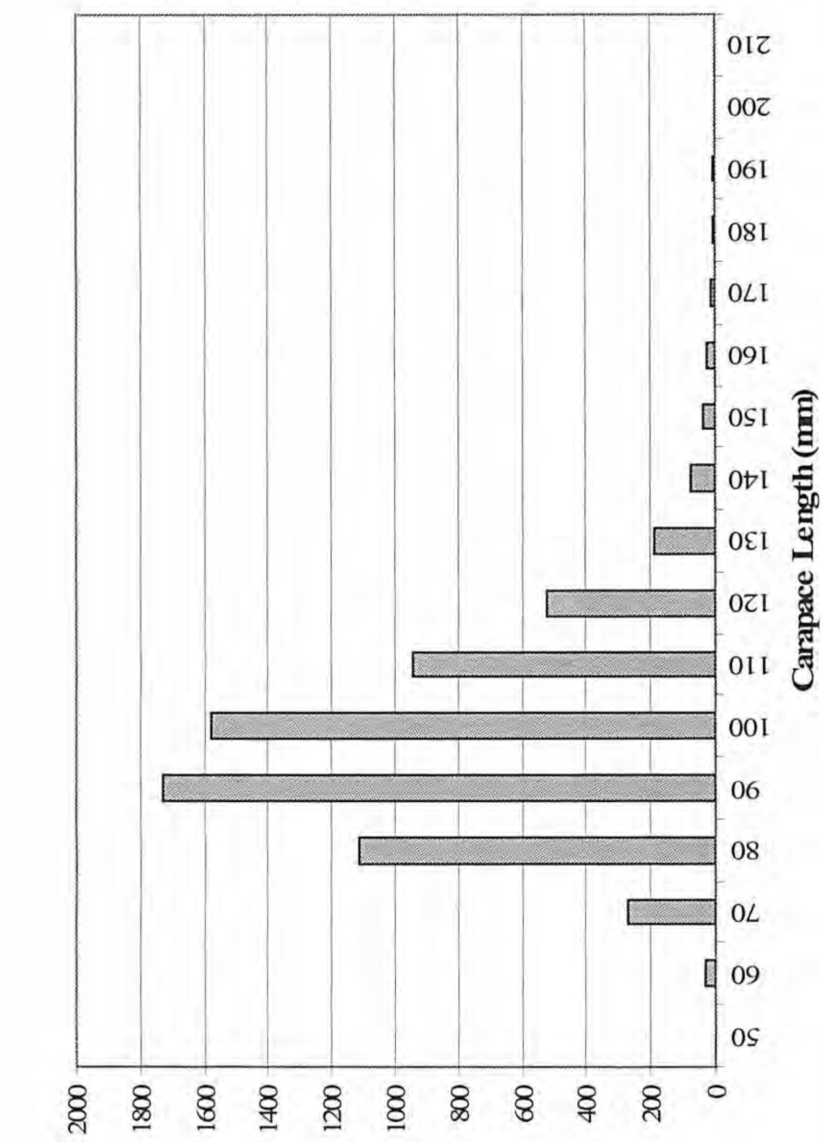


**Figure 5.** Length frequency distribution for spiny lobster caught in Puerto Rico during 1995 - 2001.

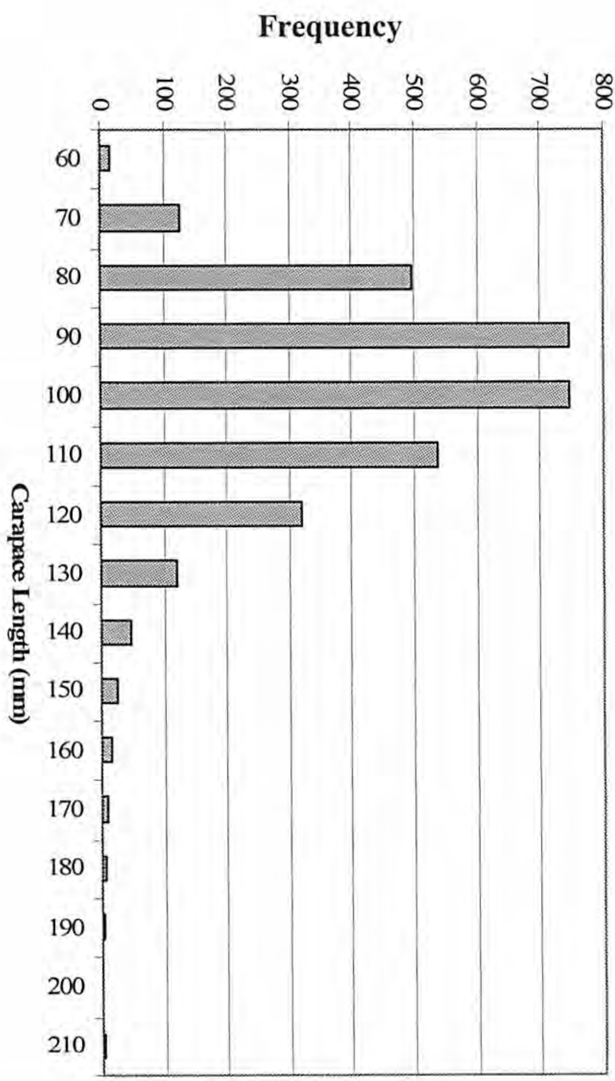


**Figure 6.** Length frequency distribution for spiny lobster males caught in Puerto Rico during 1988 - 1994.

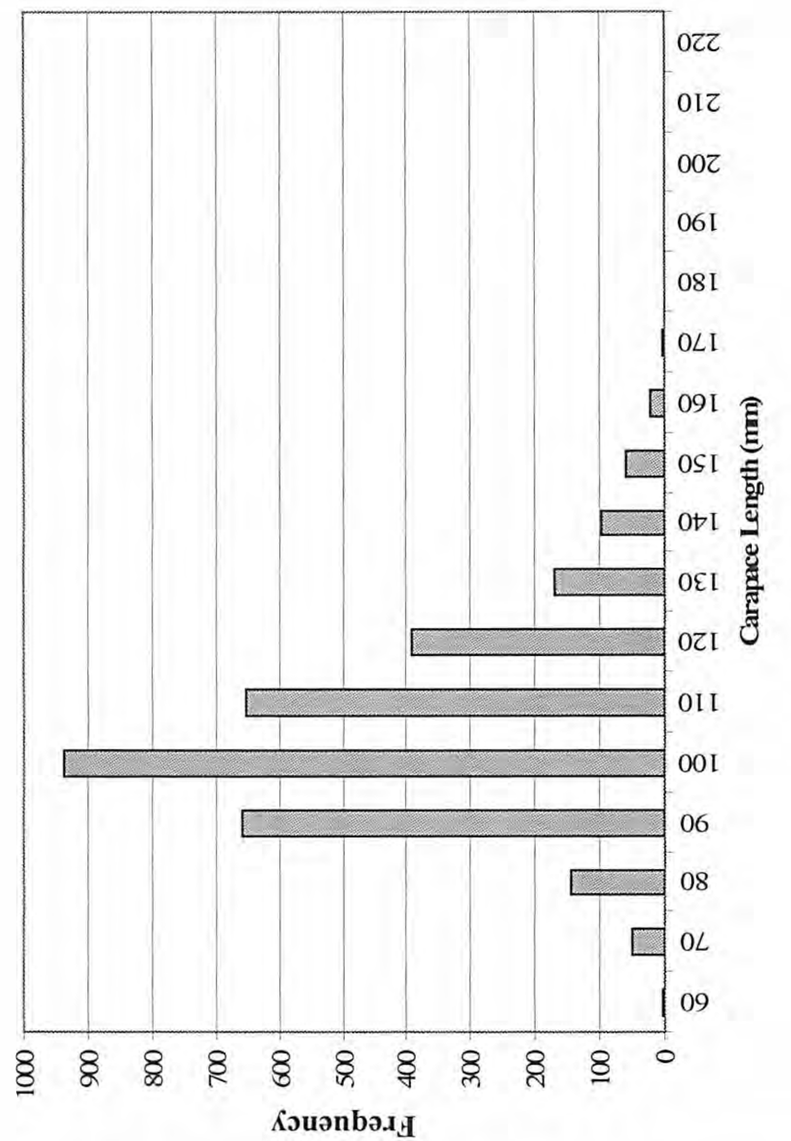


**Figure 7.** Length frequency distribution for spiny lobster males caught in Puerto Rico during 1995 - 2001.

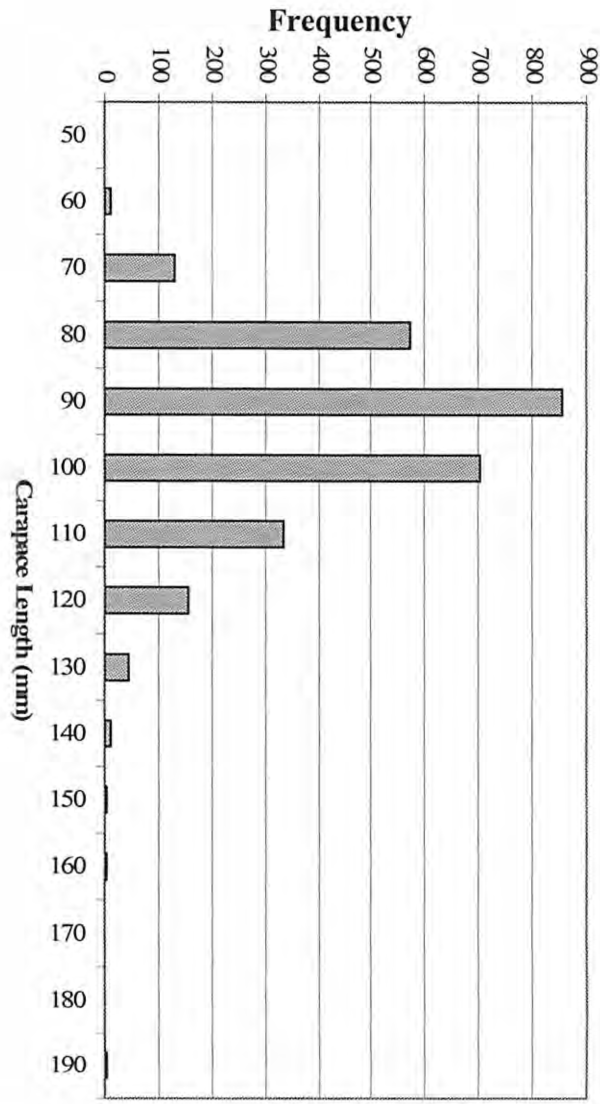


**Figure 8.** Length frequency distribution for spiny lobster females caught in Puerto Rico during 1988 - 1994.

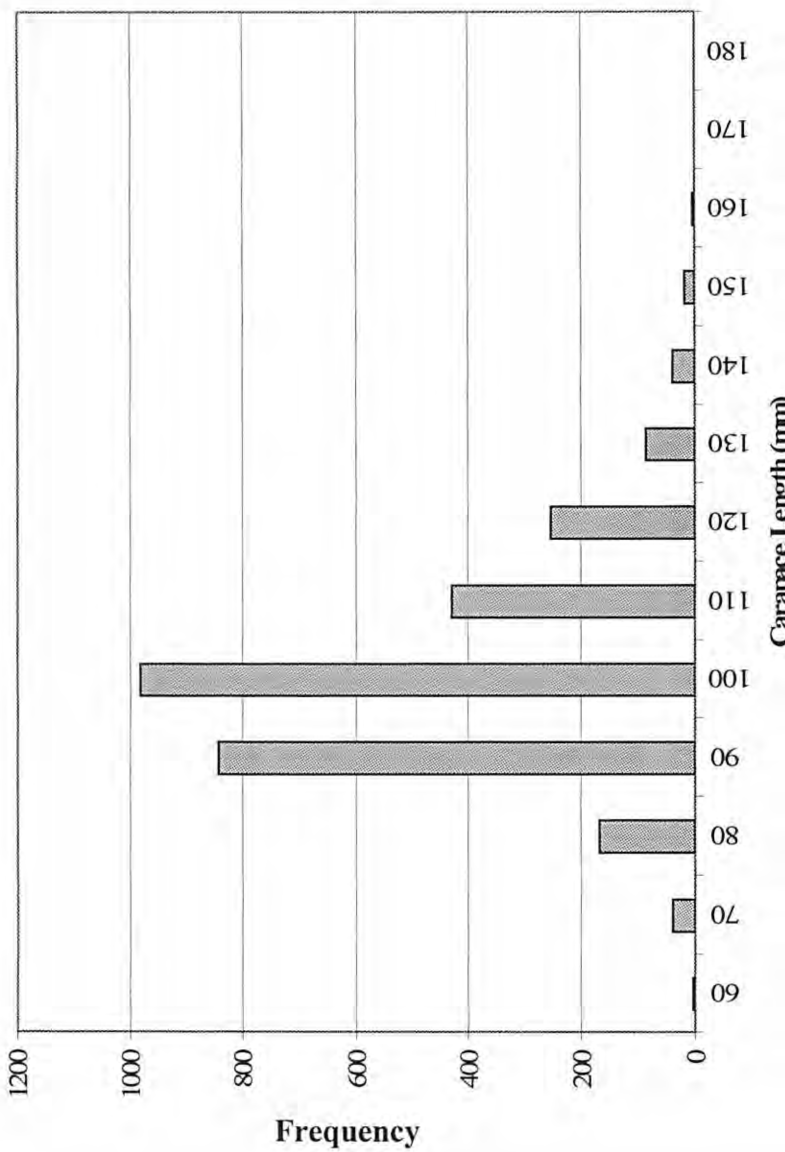


**Figure 9.** Length frequency distribution for spiny lobster females caught in Puerto Rico during 1995 - 2001.

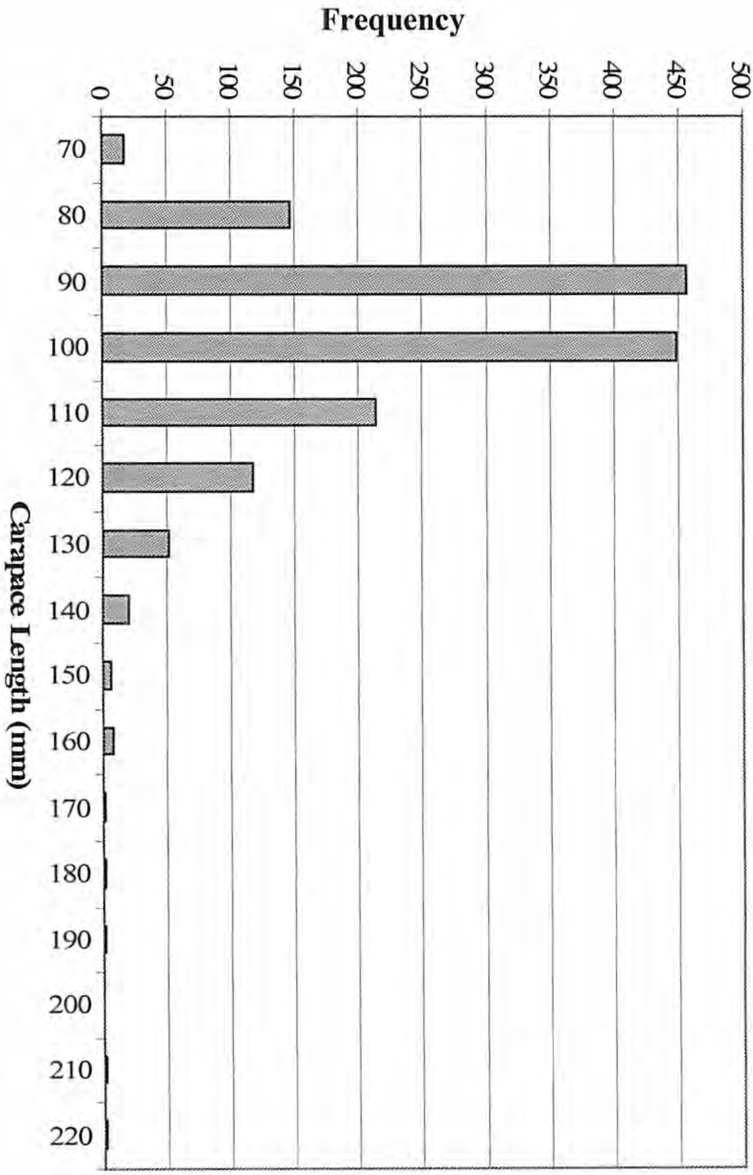


**Figure 10.** Length frequency distribution for spiny lobster caught in Puerto Rico by fish traps during 1988 - 2001.

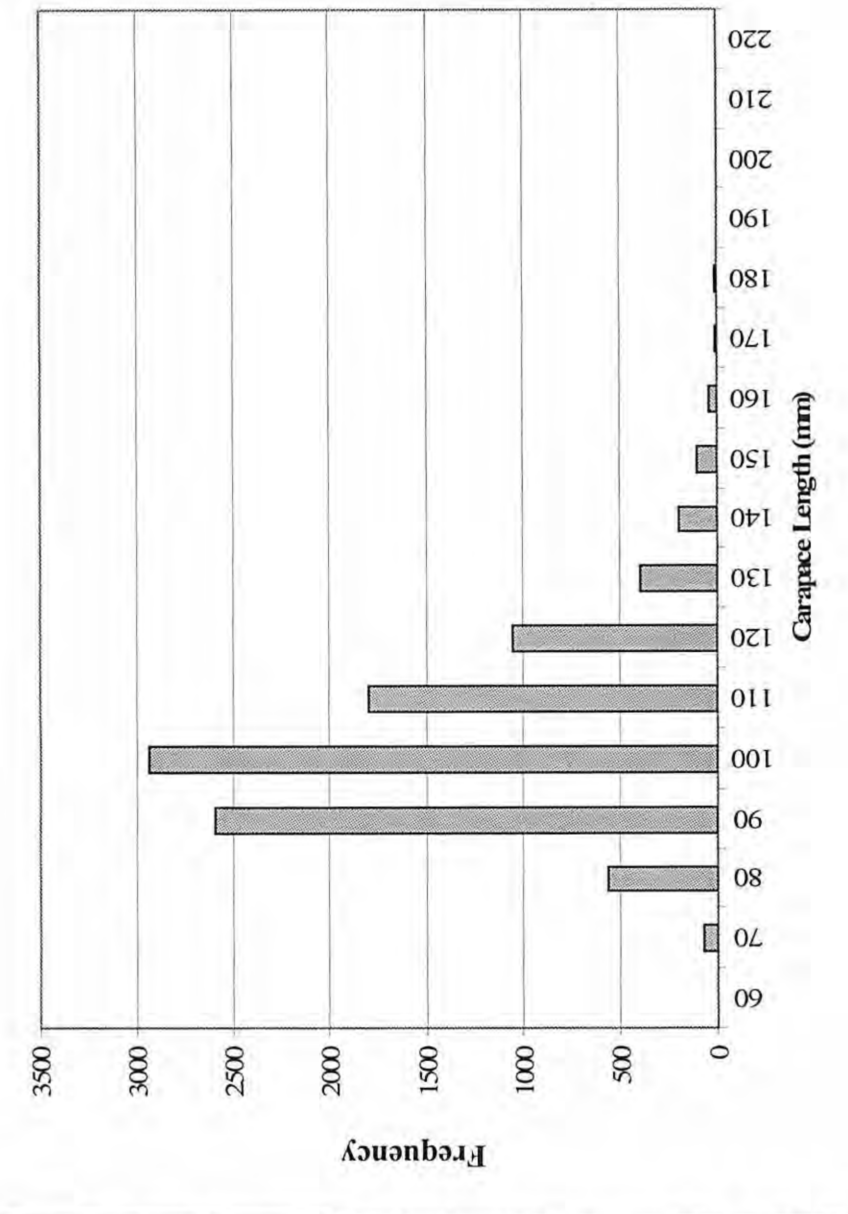


**Figure 11.** Length frequency distribution for spiny lobster caught in Puerto Rico by SCUBA divers during 1988 - 2001.

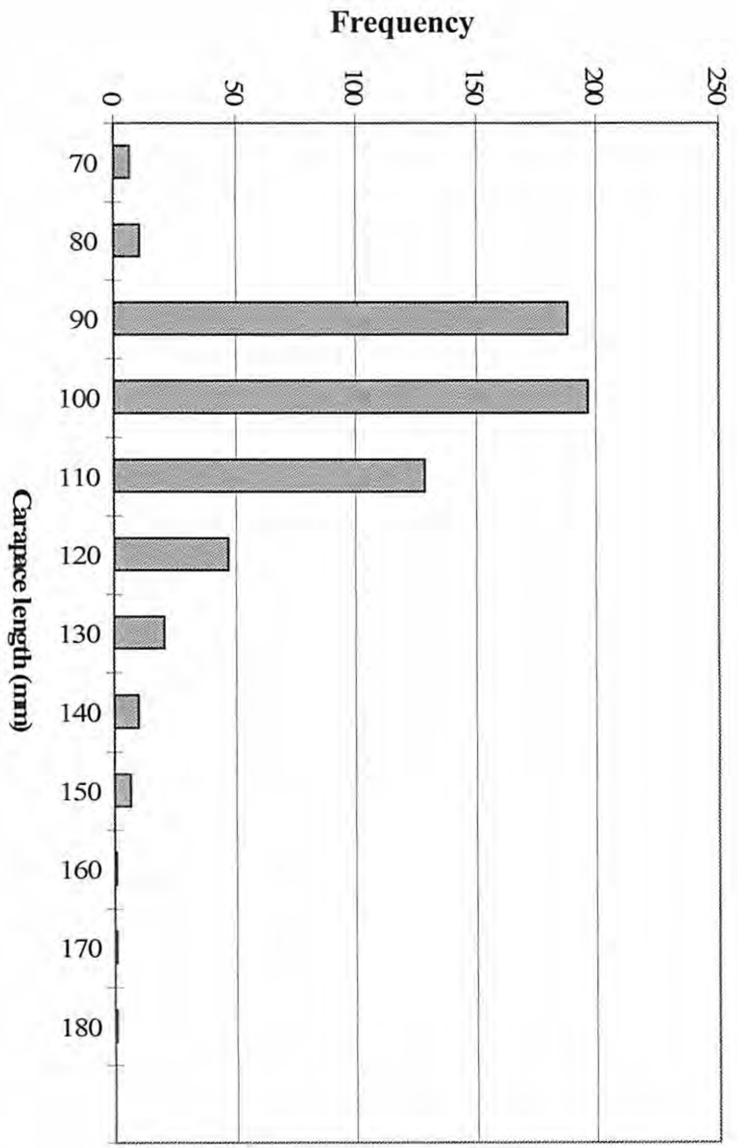


**Figure 12.** Length frequency distribution for spiny lobster caught in Puerto Rico by lobster traps during 1988 - 2001.

A total of one-hundred biostatistics interviews were randomly selected to obtain spiny lobster CPUE estimates data analysis. Most of the interviews included reports of spiny lobsters, conch, and other reef fishes. However, the spiny lobster was significant in number of individuals and weight in the landings interviews. CFSP data showed that during 1988 - 1994, the fish traps had an average catch of 48 pounds/trip. During this period, fishing trips had an average of hauling 27.5 fish traps, and the average soak time was 4.6 days. It was estimated that every fish trap caught 0.39 pounds/trap/day. On the other hand, for the period of 1995 - 2001, fish traps showed a landings increase, obtaining an average of 57 pounds/trip. Fishing trips showed an increase in the average of fish traps hauled to 32.0, and the average soak time increased to 5.3 days. For this period, it was estimated that every fish trap caught 0.33 pounds/trap/day. During 1988 - 1994, SCUBA divers' fishing trips had an average of 44 pounds/trip. During this period, fishing trips had an average of 1.7 divers, and the average diving time was 3.6 hours. It was estimated that SCUBA divers caught 7.23 pounds/diver/hour. On the other hand, for the period of 1995 - 2001, SCUBA divers showed a landings increase, obtaining an average of 47 pounds/trip. During this period, reef fishes fishing trips had an average of 1.33 divers per trip, and the average diving time was 4.3 hours. It was estimated that SCUBA divers caught 8.18 pounds/diver/hour.

## DISCUSSION

Puerto Rico's commercial fishery of spiny lobster has shown that market demand for this species continues to make it one of the most important resources during the last 15 years. The data analyzed in this report showed that a high fishing pressure occurred on spiny lobster during 1988 - 2001. The landings data showed increasing landings in spiny lobster during 1995 - 2001. Two facts would explain this increase. First, starting in 1995, more fishers participated in the CFSP (Matos-Caraballo 2002). Second, many fish traps users mentioned to CFSP's principal investigator that due to the profit, they targeted mostly their gear to catch spiny lobster. This fact is supported by the CPUE landings by trip data analysis that shows an increase in the fishing pressure on the spiny lobster for SCUBA divers. Also, fish traps increased the average number of fish traps hauled per trip and the average number of soak days.

SCUBA divers and fish traps were more efficient gears to catch spiny lobster. Due to regional tradition, the lobster trap is used only in three or four south coast municipalities and in the east coast. The trammel net is used to catch spiny lobster during the season of strong wave surges in November-February along the western coast. Fishers mentioned that spiny lobsters migrate together, and trammel nets are able to catch hundreds of pounds of this species in a single day. Unfortunately, a significant part of these catch were not reported to CFSP.

This study shows that the spiny lobsters caught during 1995 - 2001 were significantly larger than during 1988 - 1994, for all individuals, males and females. These results indicate that the spiny lobster fishing regulation enforcement has been working to conserve the resource (Matos-Caraballo, 2001).

LFD data shows that fish traps caught a higher percent of spiny lobster before reach LMS, follow by SCUBA divers and lobster trap. However, after 1995, the catch of individuals before reaching the MLS, decreased for all gears.

Effort by gear data shows an increase in the effort to catch spiny lobster by fish traps and SCUBA divers. Again, these facts reflect an increasing fishing pressure on this resource. The landings, biostatistics, and CPUE data showed that spiny lobsters were subject to high fishing pressure. Although spiny lobster landings decreased occurred from the 1970s to the 1980s, during 1988 - 2001 the landings have been steady (Mateo and Die 2004). Spiny lobsters were caught significantly larger during 1995 - 2001, probably due to the enforcement of the fishing regulations. Due to the high fishing pressure on this resource, it is necessary to continue the enforcement action in order to diminish or eliminate from the landings those individuals that are below the MLS. Also, it is essential to continue the monitoring of the landings, biostatistics, and CPUE data by the CFSP.

## ACKNOWLEDGEMENT

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# Spatial and Temporal Variations in Postlarval Settlement of the Spiny Lobster, *Panulirus argus*, between 1992 and 2003 within the Cas Cay/Mangrove Lagoon and Great St. James Marine Reserves, St. Thomas USVI

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ABSTRACT

Postlarval settlement of the commercially important Caribbean spiny lobster, *Panulirus argus*, was monitored at five sites within the Cas Cay/ Mangrove Lagoon and Great St. James Marine Reserves on the southeast side of St. Thomas, United States Virgin Islands. Over a period of one year, a total of 202 postlarvae (pueruli = 57; juveniles = 145) were collected from 270 samples for a combined mean annual CPUE of 0.07 (± 0.19) pueruli/collector/ day for all sites. Overall CPUE was low despite location within the protected waters of the marine reserves. The highest settlement occurred at Nazareth Bay, which had a mean annual CPUE of 0.18 (± 0.35). Month to month variability was low, although there appears to be a seasonal peak occurring in late spring (May). The highest recruitment levels occurred between new moon and first quarter moon phases. Postlarval settlement declined among common sites between 1992 - 1993 (combined mean annual CPUE = 0.20 ± 0.29), 1997 - 1998 (combined mean annual CPUE = 0.15 ± 0.30) and 2002 - 2003 (combined mean annual CPUE = 0.07 ± 0.19). Spatial differences in settlement over time indicated that pre-settlement pueruli were most likely influenced by changes in habitat, and water movement.

KEY WORDS: Recruitment, catch per unit effort, pueruli

# Variaciones Espaciales y Temporales en el Establecimiento de las Etapas Post Larvales de la Langosta Espinosa, *Panulirus argus*, entre 1992 y 2003 dentro de la Laguna de Cas Cay/ Mangrove y de la Reserva Marina de St. James, St. Thomas, USVI

El asentamiento postlarval de la comercialmente importante langosta espinosa, *Panulirus argus*, fue monitoreada en 5 sitios en Cas Cay/Mangrove Lagoon y en la reserva marina Great St James en el lado sureste de St Thomas, Islas Virgenes Estadoudinenses. Un total de 202 postlarvas (pueruli = 57;juveniles = 145) fueron colectadas de 270 muestras para un promedio de captura por unidad de esfuerzo (PCPUE) de 0.07 para todos los sitios. En general, los promedios del CPUE para todos los sitios fueron bajos a pesar de localizarse dentro de las aguas protegidas de la reserva marina. La mayor parte del asentamiento ocurrio en Nazareth Bay, cual obtuvo un promedio de CPUE de 0.17 (SD = 0.35). La variabilidad entre mes fue baja con un valor maximo tarde en la primavera (Mayo). Los maximos valores del reclutamiento ocurrieron en luna nueva y en el primer cuarto creciente de la luna. Se registro una disminucion en los promedios anuales del asentamiento postlarval en los sitios estudiados entre 1992 - 1993 (PCPUE = 2.65 pueruli), 1997 - 1998 (PCPUE 0.16 pueruli) y 2002 - 2003 (PCPUE = 0.07 pueruli). Las diferencias entre las localidades de asentamiento atraves del tiempo indicaron que la abundancia del pueruli de la etapa de preasentamieneto pueden estar influenciada por cambios en el habitat, y el movimiento y la calidad del agua.

PALABRAS CLAVES: Langosta, asentamiento postlarval, USVI

## INTRODUCTION

Spiny lobsters (Palinuridae) are among the most economically important crustaceans in the world (Olsen et al. 1975). The Caribbean spiny lobster, *Panulirus argus*, supports an important commercial and recreational fishery in the U.S. Virgin Islands (USVI). Effective management of such a fishery not only requires adult stock assessment but also identifying trends in settlement and recruitment. Spatial and temporal variability in recruitment is characteristic of many invertebrate fisheries (Butler and Herrnkind 1997). Therefore, settlement and early post-settlement processes that influence recruitment demand great attention. The influx of postlarval lobsters can be monitored using modified Witham collectors (Witham et al. 1968). These collectors are useful in determining the relative abundance of pueruli in an area and have been used to make general comparisons across areas (Witham et al. 1968).

Over the last decade, spatial and temporal trends in pueruli settlement and abundance has been studied using modified Witham collectors around St. Thomas (both inside and outside the Inner Mangrove Lagoon, Cas Cay/ Mangrove Lagoon, and St. James Marine Reserves). Studies were previously conducted in 1992 - 1993 (Quinn and Kojis 1997), and 1997 - 1998 (Kojis et al. 2003).

The objectives of this study were to examine current spatial and temporal variations in *P. argus* pueruli settlement and relative abundance at previously studied sites within marine reserve habitats and compare trends in relative abundance and settlement of pueruli between 1992 - 1993, 1997 - 1998, and 2002 - 2003.

## MATERIAL AND METHODS

Pueruli collectors were modified from the original design used by Witham et al. (1968). Collector frames were made from 1.90 cm closed PVC pipes that measured 40.5 cm x 40.5 cm, and comprised of four crossbars connected by 90° elbows. For each collector, four "hogs hair" air-conditioning filters were cut into 40.5 cm x 61 cm pieces, folded lengthwise with the webbed backing material to the inside, slipped over each crossbar on the PVC ladder frame, and secured. Each collector was moored with two concrete cinder blocks and suspended in the water column by a sub-surface buoy. At each site the collectors were spaced approximately 10 m apart.

On 4 June 2002, two pueruli collectors each were deployed at five sites within the Cas Cay/Mangrove Lagoon and Great St. James Marine Reserves on the southeast side of St. Thomas (Figure 1). Study sites in 2002 - 2003 were similar to previous studies by Quinn and Kojis (1997) and Kojis et al. (2003). Of the sites sampled in 2002 - 2003, all were identical to the sites sampled by Kojis et al. (2003) in 1997-98, however, only the Mangrove Lagoon and Great St. James Island sites were sampled in 1992 - 1993. Two collectors were used at each site in 1992 - 1993, while three collectors were used in 1997-1998.

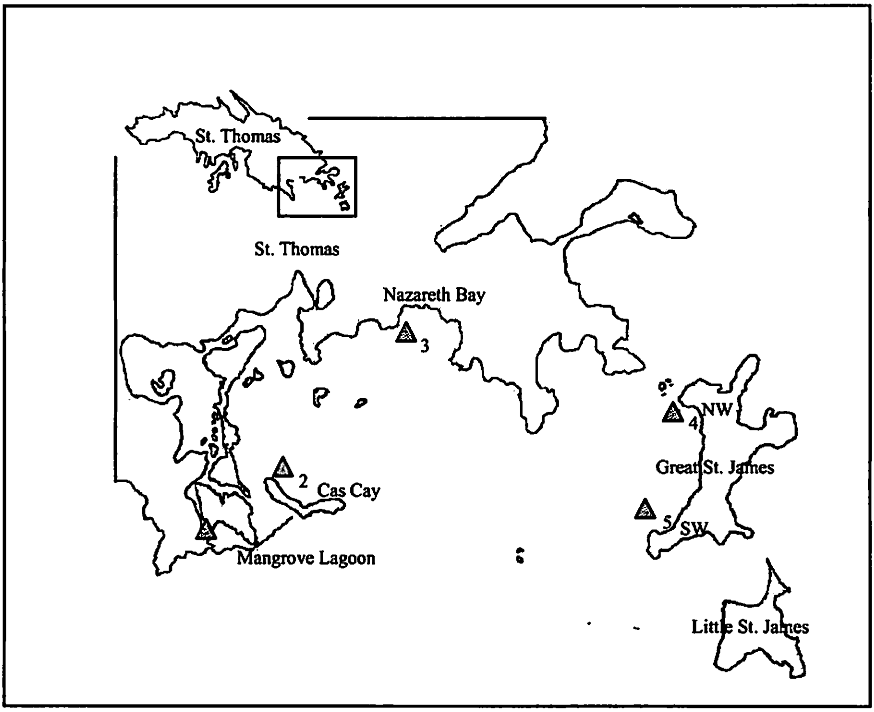


**Figure 1.** Map of the east end of St. Thomas showing the locations of the five pueruli collection sites.

The Mangrove Lagoon site (18°18.3' N, 64°52.5' W) was located in a shallow protected channel in the inner lagoon of the Mangrove Lagoon Marine Reserve. Due to its enclosure, the inner lagoon experiences limited flushing and current. Conversely, the Cas Cay site (18°18.5' N, 64° 52.1' W) was located in the outer Mangrove Lagoon Marine Reserve and experienced heavy wind and moderate wave action. Although both sites were essentially mangrove habitats the substrate at the first was a dense macroalgal plain while the latter a dense seagrass bed. The collectors at both sites were positioned approximately one meter below the surface in 1.5 - 2 m of water.

The Nazareth Bay (18° 19.1'N, 64° 51.4'W) and southwest Great St. James (18°18.4'N, 64° 50.1'W) sites were positioned over sparse seagrass beds approximately 100 m from the rocky shoreline. The collectors at both sites were suspended 3 m below the sea surface in approximately 6 - 11 m of water.

Finally, the northwest side of Great St. James (18°18.8'N, 64°49.9'W) was the only site that was characterized by a patch reef. This site was adjacent to (~20 m away) the rocky shoreline and Current Cut Passage, which experiences moderate to strong bidirectional tidal currents. The collectors at this site were suspended three meters below the surface in water that was approximately eight meters deep.

## SAMPLING AND ANALYSIS

Collectors were sampled every two weeks over a 12 month period. Each collector was enclosed in a one millimeter mesh bag prior to being brought to the surface for inspection. All lobster pueruli and juveniles were counted and staged as follows: transparent, semi-pigmented, pigmented, and algal-phase juvenile, based on descriptions by Bannerot et al. (1992), CARICOM (1996), and Butler and Herrnkind (1997). Damaged, lost, or heavily encrusted collectors were replaced. Each sample represented a 14 to 16 day settlement period.

Catch per unit effort (CPUE) for each collector was calculated using:

*CPUE = (total catch/number of days between sample periods).*

CPUE calculations included first stage juveniles (dark pigmented body; ~5-15 mm CL) as well as pueruli. Samples that had missing or unattached collectors were not included in the data analysis. There was no difference in abundance between collectors at each site on each sample date (Paired-t: $p > 0.05$) in all cases except Cas Cay. Collectors at each site, except Cas Cay, were therefore combined in subsequent analysis. Collectors at Cas Cay often broke and were lost, leaving either single sample or no sample for this site over eight sample periods. Data were therefore log (x +1) transformed to conform to the assumptions of parametric testing. Following transformation, collectors tended to differ in total catch (ANOVA: $F_{1,52} = 3.825$, $p = 0.056$). Therefore, comparisons between sites were made using a mean CPUE calculated for each site.

Timing in settlement was examined graphically by month and site. Spatial patterns in settlement were also investigated graphically and using standard one-way ANOVAs to test for differences in catch per unit effort between sites. Additionally, each sample date was classified into one of four lunar phases: new moon, first quarter, full moon and last quarter. Sample dates without a distinct/obvious lunar phase were assigned to the nearest lunar phase.

Comparison of CPUE between years was made graphically and using ANOVA to test for differences between years. CPUE in the previous studies by Quinn and Kojis (1997) and Kojis et al. (2003) were derived using a different method and were recalculated from the original data to allow direct comparison across years. Additionally, the NW Great St. James and SW Great

St. James sites in 2003 were combined to compare to the 1992 - 1993 and 1997 - 1998 data sets.

## RESULTS

Five sites, with two Witham collectors each, were sampled from 18 June 2002 to 17 June 2003. A total of 202 postlarvae were observed (Table 1). Of the total catch, ten (5%) of the pueruli collected were transparent, 19 (9%) were semi-pigmented, 28 (14%) were pigmented, and 145 (72%) were early algal-phase juveniles (Table 1).

**Table 1.** Number of *Panulirus argus* postlarvae on Witham collectors of different stages settling at each site, 2002-2003. Numbers in brackets indicate the total number of samples per site.

| Site | Transparent | Semi-pigmented | Pigmented | Juvenile | Total |
|---|---|---|---|---|---|
| Mangrove Lagoon (27) | 0 | 1 | 0 | 18 | 19 |
| Cas Cay (24) | 0 | 4 | 0 | 14 | 18 |
| Nazareth Bay (27) | 8 | 10 | 25 | 84 | 127 |
| NW, Great St. James (27) | 1 | 3 | 0 | 6 | 10 |
| SW, Great St. James (27) | 1 | 1 | 3 | 23 | 28 |
| **Total** (132) | 10 | 19 | 28 | 145 | 202 |

Pueruli abundance was consistently low across most sites (Figure 2). However, overall pueruli abundance in Nazareth Bay was considerably higher than the other four sites (Figure 2) with 127 postlarvae counted during the study. The overall catch between the Mangrove Lagoon and Cas Cay sites was similar with 19 and 18 postlarval juveniles, respectively. NW Great St. James exhibited the lowest total catch with 10 postlarvae while SW Great St. James had a total catch of 28 (Table 1, Figure 2).

Catch per unit effort (CPUE) varied greatly across sample dates (Figure 3). Similarly, differences existed in the CPUE between sites (Mean $\pm$ S.D: Mangrove Lagoon: 0.03 $\pm$ .04, Cas Cay: 0.03 $\pm$ 0.05, Nazareth: 0.18 $\pm$ 0.35, NW St James: 0.01 $\pm$ 0.03, SW St James: 0.04 $\pm$ 0.07; One-way ANOVA: $F_{4, 127} = 4.355$, $p = 0.002$). Nazareth Bay consistently yielded a higher CPUE in 2002 - 2003 than the other four sites (Figure 3).

Peaks in settlement occurred primarily in the spring and early summer (Figure 4). The Mangrove Lagoon, Cas Cay, and NW Great St. James sites all had low settlement not exceeding 0.15 CPUE for any sample period. Seasonal peaks for these sites were in the spring (Figure 3). The SW Great St. James site had highest settlement during the summer months, with a peak CPUE of 0.32 (Figure 3). The greatest settlement occurred in May 2003 at the Nazareth Bay site, with a CPUE of 1.54 (Figure 3).

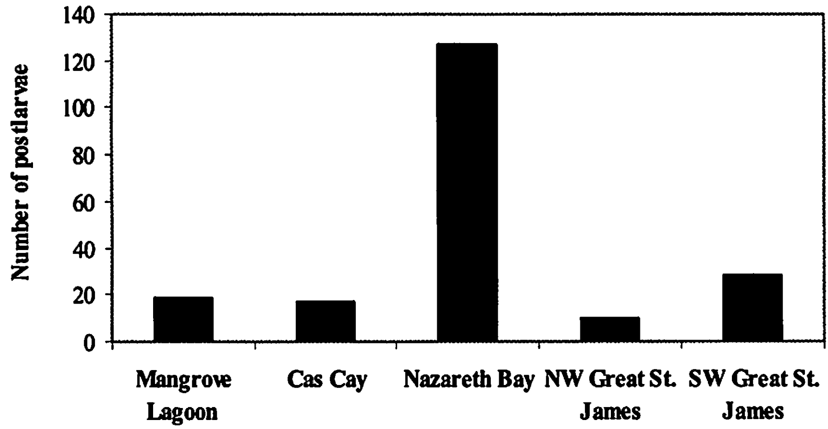


**Figure 2.** Total catch of *Panulirus argus* postlarvae on Witham collectors at each site in 2002 - 2003.

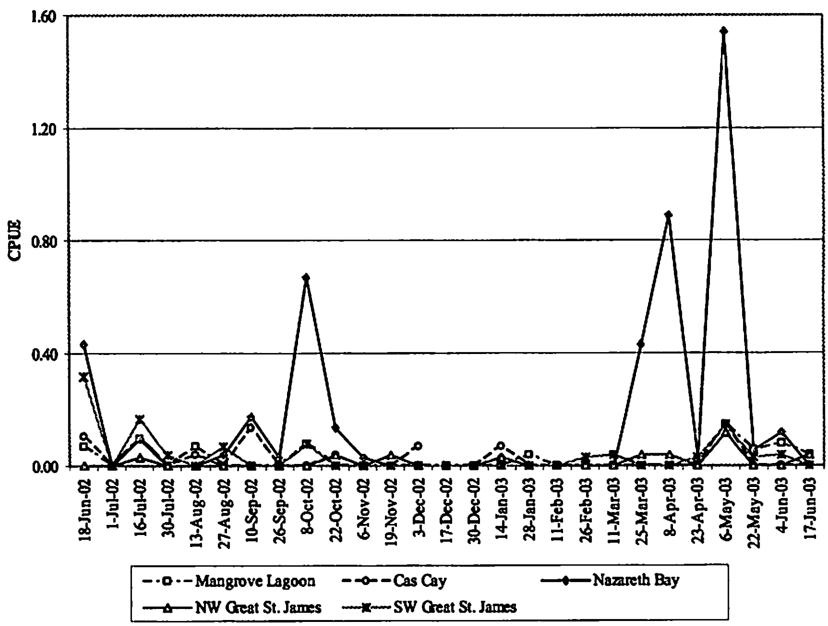


**Figure 3.** Mean catch per unit effort (pueruli/day) of postlarval *P. argus* for each sample date at all sites, 2002 - 2003.

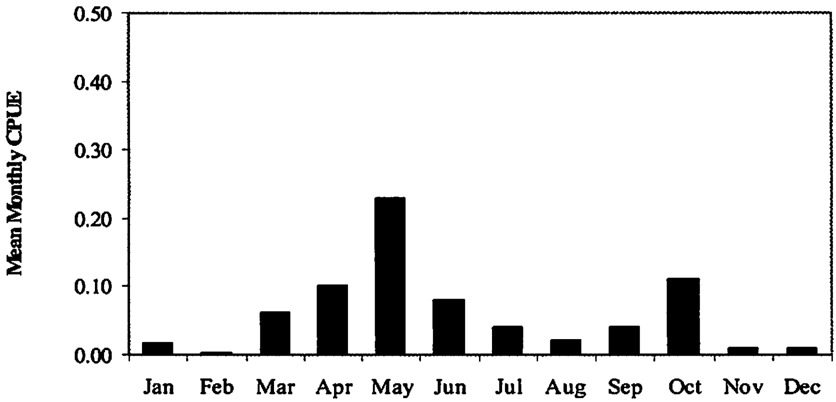


**Figure 4.** Seasonal variation in the mean monthly CPUE, all sites combined, 2002 - 2003.

Pueruli settlement was greatest for all sites during first quarter moon phases
(Table 2). The total number of pueruli collected during the first quarter phase accounted for 73% of all settlement. CPUE was combined according to lunar phase for all sites. The greatest CPUE was during samples that were most closely associated with first quarter and new moon phases (0.09 and 0.10 respectively; Table 2).

**Table 2.** Number of postlarval spiny lobster collected on Witham collectors, 2002-2003, in relation to lunar phase (n = number of samples) and the combined mean CPUE ± SD for each lunar phase.

| | Number of postlarvae | | | |
|---|---|---|---|---|
| **Site** | new moon (n = 2) | first quarter (n = 11) | full moon (n = 5) | last quarter (n = 9) |
| Mangrove Lagoon | 2 | 15 | 1 | 1 |
| Cas Cay | 2 | 15 | 1 | 0 |
| Nazareth Bay | 16 | 91 | 5 | 15 |
| NW, Great St. James | 0 | 6 | 3 | 1 |
| SW, Great St. James | 2 | 21 | 0 | 5 |
| **Total** | 22 | 148 | 10 | 22 |
| **Combined CPUE** | 0.09± 0.21 | 0.10± 0.24 | 0.02± 0.03 | 0.02± 0.07 |

CPUE was generally greater in 1992 - 1993 than in either 1997 - 1998 or 2002 - 2003 (Two-way ANOVA: $F_{2,280}$= 10.88, $p < 0.001$, Table 3). Similarly, across all years, the average CPUE differed between sites ($F_{3,280}$= 8.798, $p < 0.001$) CPUE has steadily declined from 1992 to the present at both the Mangrove Lagoon site and the St. James site. From 1997 - 1998 to 2002 - 2003 CPUE declined at all sites except the St. James sites where the mean annual CPUE increased slightly from 0.02 to 0.03, respectively.

**Table 3.** Comparison of mean annual CPUE (Mean ± SD) by site and between years. *indicates data were not collected.

| | Mean annual CPUE ± SD | | | | |
|---|---|---|---|---|---|
| Year | Mangrove Lagoon | Cas Cay | Nazareth Bay | Great St. James | Combined Mean Annual CPUE ± SD |
| 1992-1993 | 0.23 ± 0.30 | * | * | 0.16 ± 0.30 | 0.20 ± 0.29 |
| 1997-1998 | 0.09 ± 0.10 | 0.21 ± 0.31 | 0.30 ± 0.46 | 0.02 ± 0.04 | 0.15 ± 0.30 |
| 2002-2003 | 0.03 ± 0.04 | 0.03 ± 0.05 | 0.18 ± 0.35 | 0.03 ± 0.04 | 0.07 ± 0.19 |

## DISCUSSION

Many factors may have contributed to the temporal and spatial variability in recruitment of *Panulirus argus*. For example, low CPUE values at the Mangrove Lagoon site in 2003 may be reflective of water quality issues (as discussed in Quinn and Kojis, 1997 and Kojis et al. 2003) and/or lack of suitable juvenile habitat. Acosta and Butler (1997) suggest that although mangrove habitats may be important nursery habitats the use of such is dependant on sheltering characteristics. Kojis et al. (2003) suggested that high CPUE values in the mangrove lagoon may have been a function of the site's proximity to pueruli settlement habitat. However, in 1999 hurricane Lenny disrupted the natural tidal flow at this site by piling coral rubble at the lagoon/ seaward interface. The resultant berm limited water flow into the lagoon and may have resulted in a reduction of suitable juvenile habitat as well as a reduction of larval supply to the site. A *Porites porites* bed used to lie near the Mangrove Lagoon site. However, hurricane Lenny devastated the *P. porites* bed (discussions with Division of Fish and Wildlife staff) and reduced water flow such that *P. porites* growth was probably limited. The *P. porites* bed, which at one time would have provided adequate juvenile habitat, has since been covered with sediment and algae. Postalgal spiny lobsters have been demonstrated to prefer silt-free environments with adequate amounts of stony corals, but make use of mangrove prop roots whenever coral cover is sparse (Herrnkind et al. 1988 in Acosta and Butler 1997). The decrease in CPUE in the mangrove lagoon before and after hurricane Lenny, suggests that although mangrove habitats may be important nursery areas, as implied by Little (1997), the absence of nearby coral for the postalgal juvenile stage may have a greater influence on postlarval settlement than merely the presence of mangroves.

Furthermore, Nazareth Bay which is close to a rock shoreline, consistently demonstrated high settlement rates over the years (see Table 3) despite the absence of mangroves. As discussed in Kojis et al. (2003) the current flow to this site may increase the supply of pueruli. Similarly, lower CPUE values at the St. James sites may be due to their orientation to the mass water flow; these sites appear to be oriented in the lee of an easterly current. Additionally, the NW St. James site is situated near an area that experiences heavy tidal currents which may flush pueruli past the collectors. Current flows may, therefore, act in tandem with water quality and juvenile habitat availability to create complex spatial patterns in pueruli settlement.

In this study, the timing of greatest settlement was in the spring/summer (April- June). These findings are consistent with Quinn and Kojis (1997) in which they report highest settlement during the summer months (April - October). It is suggested that the larval phase of lobster can exceed nine months (Butler et al. 1997; Acosta and Butler 1999), therefore it is likely that pueruli settlement in the U.S. Virgin Islands is dependant on an upstream supply.

In the Florida Keys, weekly collection of *P. argus* indicated that peak supply occurred during new moon and first quarter lunar phases (Acosta *et al.*, 1997). In the U.S. Virgin Islands, Quinn and Kojis (1997) report higher CPUE during new moons than full moons. The findings from this study are similar, however, in this study lunar cycles were broken into four lunar phases rather than two. The results of this study indicate that higher CPUE values occurred during first quarter new moon phases (Table 2). Pueruli typically travel and arrive at near-shore settlement areas during new moon and first quarter lunar phases to avoid predation (Heatwole et al. 1992). Therefore, settlement may be triggered by the dark periods of a new moon and carry through the first quarter phase, resulting in higher catches of pueruli during the first quarter as observed in this study.

Settlement has steadily declined from 1992 - 1993 at similar sites. Unfortunately, there are no clear reasons for the decline in pueruli settlement over the years. However, because of such a lengthy larval phase (Butler et al. 1997, Acosta and Butler 1999), pueruli supply is probably not local; therefore, it is unlikely that the decline in CPUE shown in this study is related to mortality or catch of adult *P. argus* in the U.S. Virgin Islands, but may be due in part to habitat degradation or water quality parameters.

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# 'Connecting the Dots' in the Caribbean: An Overview and Directed Approach for Long-term Spiny Lobster Puerulus Settlement Studies

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ABSTRACT

The puerulus (postlarval) stage of spiny lobsters represents a critical and pivotal life-history link between the long-lived oceanic phyllosoma and the benthic dwelling adult-phase juvenile. Although great strides continue to within this realm of lobster research, there remain major gaps with respect to quantifying potential "connectivity" among populations as well as the ecological requirements and attributes for species that reside in remote habitats or are of non-commercial fishery interest. Through cooperative monitoring programs, The Puerulus Identification Project (PIP) seeks to gather, collate and disseminate current and additional data on the ecological requirements, natural settlement zones and early habitat shifts of pueruli throughout the Caribbean where lobster remains actively and intensely fished. Although not limited to any one species, the Caribbean spiny lobster, *Panulirus argus*, is the focal animal for this survey based on its immense economic and social significance throughout its range. Monitoring and collating electronically-linked data on the magnitude of puerulus recruitment to coastal areas around the Caribbean region could help elucidate more detailed patterns of postlarval influx, provide specimens for research, and help to model correlations of settlement to habitat and predictive patterns of recruitment leading to potential forecasting of good or bad years of fishery catch.

KEY WORDS: Caribbean spiny lobster, collectors, connectivity, puerulus

## El Proyecto de Identificación de Puerulus (PROYECTO PIP): "Conectando los puntos" a través del Caribe

La etapa de puerulus (postlarval) de langosta espinosas representa una conexión crítica y esencial de su vida entre el phyllosoma oceánico y el fase bentonico juvenil-adulto. Aunque gran pasos hayan sido y continúan ser hecho dentro de este reino de investigación de langosta, todavía queda areas de investigación, especialmente con respecto a requisitos y atributos ecológicos para las especies que residen en habitates remotos y en que no hay interéses comerciales. A través de programas cooperativos, Proyecto PIP reunirá, cotejará y difundirá datos adicionales sobre los requisitos ecológicos, las zonas de reclutamiento, y cambios de habitat de pueruli en el Caribe. Información de este tipo sería especialmente importante para directores de pesquerias importantes y proporcionaría predicciones valiosas de períodos buenos o malos en el futuro. Específicamente, los objetivos de Proyecto PIP incluye: (1) una evaluación y descripcion de los requisitos ecológicos de pueruli para definir las zonas de reclutamiento; (2) calcular el número de etapas de puerulus y la longevidad de cada etapa; (3) comparar los tamaño proporciones de pueruli a adultos; (4) evalúar las tendencias evolutivas en la ecología y el comportamiento de puerulus que ha resultado debido a cambios en el ambiente; (5) asistir en el diseño de colectores artificiales para especies que requiere programas de monitoreo así como nuevas empresas comerciales que piensan colectar pueruli para aquicultura. El enfoque de este proyecto será triple e incluye un estudio a traves del Caribe sobre puerulus, la compilación de una base de datos emparejada con una biblioteca de fotos digital, y la conservación de archivos de puerulus para investigaciones en el futuro.

PALABRAS CLAVES: Langosta espinosas, puerulus, colectores, atributos ecológicos

## INTRODUCTION

Spiny lobsters comprise one of the most economically valuable and ecologically significant marine fishery resources in the Caribbean. The Caribbean spiny lobster (*Panulirus argus*, Latrielle 1804) fishery in the Western Central Atlantic for example is one of the largest in the world and constitutes the biggest single-species fishery in Cuba, contributing 60 - 65% of the country's gross income in fisheries products (Baisre 2000). Throughout the Mesoamerican coast, spiny lobster sustains the economy and social fabric of many important regional fisheries. The FAO Year Book of Fishery Statistics reports that along the Central American coast, between 1975 - 1997, more than 20% of Caribbean spiny lobster landings originated from this region (FAO 2000, Ehrhardt 2000). In the US state of Florida *P. argus* is at the apex of a commercial fishing history that spans over 100 years and includes a popularized and highly intense recreational fishery (Hunt 2000, Sharp et al. In press). Additionally, Florida spiny lobster catches consistently remain the State's second most valuable commercial fishery after pink shrimp (Muller et al. 1997).

Like all spiny lobsters worldwide, the Caribbean spiny lobster possesses a complex, and protracted larval stage (phyllosoma) that can remain especially elusive, easily exceeding six months (Lewis 1952, Kittaka 1994). During this long-term oceanic existence, phllyosomata are subjected to an assortment of physical oceanographic elements (e.g. currents, fronts, eddies, gyres) coupled to a suite of active and innate behavioral traits (e.g. swimming ability, vertical migration) that allows a wide dispersal resulting in larval transport to near-shore environments, later supporting coastal fisheries in a new home. Following these 11 or so distinct phyllosomal stages, a postlarval (puerulus) stage develops that represents a critical and pivotal life-history link between the long-lived, phyllosoma and the benthic dwelling adult-phase juvenile. The puerulus stage ($\approx$ 6.5 - 7.0 mm CL) is characterized as a clear, non-feeding, fusiform-shaped, strong swimming lobster that, at an undetermined distance from shore, actively seeks appropriate settlement habitat, primarily in near-shore environments (Acosta and Butler 1999). The constant interchanges of biotic and abiotic factors operating at various temporal and spatial scales (i.e. recruitment variability) acts to influence the distributions of these ongoing recruitment episodes and thus shapes the population dynamics and stability of marine ecosystems (Gaines and Roughgarden 1985, Cowen 2000, Sale and Kritzer 2003). Consequently, there is a directed effort at understanding how both physical and bio-mechanistic processes harmonize in influencing these critical life history phases, eventually linking them to adult (fished) populations. (Katz et al. 1994, Cobb et al. 1997, Moksnes et al. 2003).

Although great research strides have been and continue to be made within the realm of spiny lobster early life history, there are still major gaps, particularly with respect to ecological requirements and habitat attributes for species that reside in remote habitats or are of non-commercial fishery interest (Butler and Herrnkind 2000). For example, the reclusive and obligate reef dwelling spotted spiny lobster, *Panulirus guttatus,* although presently not of significant commercial value, does warrant more investigation as a species whose pueruli utilize and occupy a very different suite of benthic habitat types as does its counterpart, *P. argus*. Recent ecological studies and surveys of *P. guttatus* population dynamics have documented various and important aspects of puerulus and juvenile spiny lobster ecology, although more is needed (Briones-Fourzan and McWilliam 1997, Lyons and Hunt 1997, Sharp et al. 1997, Robertson and Butler 2003). There also lacks a centralized source for general puerulus information from which to access, both from the historical literature and from ongoing projects. Recent research of the 50 or so palinurid species provides reasonably detailed morphological descriptions of these phases for identification (McWilliam 1995) and should be expanded upon and correlated with both coastal habitat and ecological dynamics among regions.

In light of what information exists and what we can further gather, PIP seeks five main aims that include:

i) Assessing the comparative ecological requirements of pueruli, helping to define a range of natural settlement zones (Figure 1),
ii) Assessing the number of puerulus stages and the longevity of each stage,
iii) Comparing size ratios of pueruli to adults,
iv) valuating past evolutionary trends in puerulus behavior and ecology that have resulted from ecological and environmental changes, and
v) Assisting in the design of specialty artificial collectors for species and regions that still require effective monitoring programs as well to potential commercial enterprises that intend to perhaps harvest pueruli for future aquaculture ventures.

Although not limited to any one species, the Caribbean spiny lobster, *Panulirus argus*, is the focal animal for this survey based on its immense economic and social significance throughout its range.

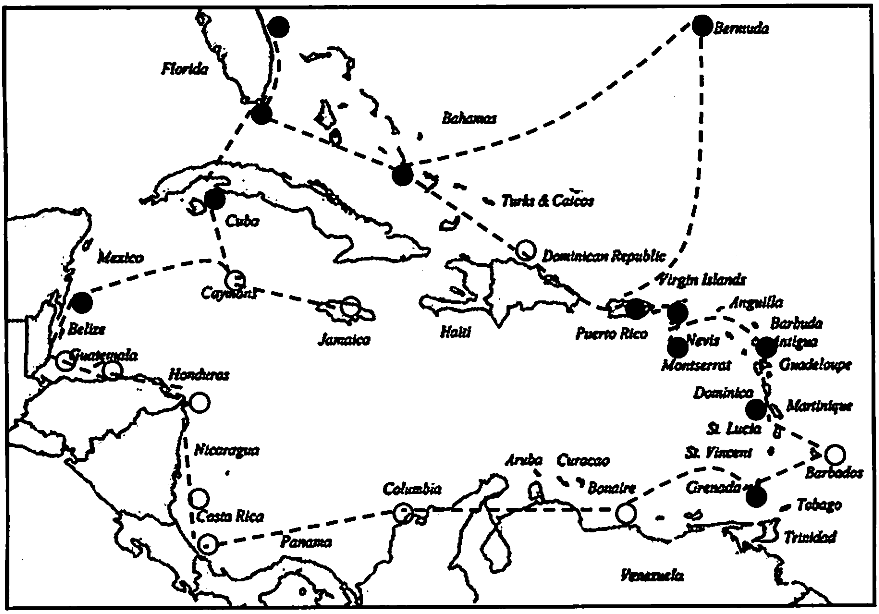


**Figure 1.** "Connecting the Dots": A graphic summary of historical and mostly published puerulus recruitment and monitoring study areas (•) and potentially new coastal regions (o) that could provide new data and ecological links to other areas throughout the Caribbean.

## METHODOLOGY AND APPROACH

The approach in carrying out this long-term project will be threefold:

i) A comprehensive Caribbean-wide puerulus field survey conducted via institutional and individual participation,
ii) The compilation of a relational database coupled with an interactive digital photo library, and
iii) The preservation of archival puerulus material via museum cataloging for future research.

### Survey and Field Collections

For decades, field-collector studies based on the fundamental designs of Witham and Phillips have served as templates and experimental units for the collection, quantification, monitoring, and research of spiny lobster pueruli worldwide (see Phillips 1994, 1995 for reviews, also Witham 1968, Figure 2). Subsequently, both large and small-scale monitoring programs in the Caribbean have documented puerulus recruitment trends along with seasonal variability for particular locations (summarized in Table 1). Although there has been tremendous and in some instances, multi-national cooperative efforts, with respect to puerulus monitoring, with the exception of Mexico, there still remains a paucity of monitoring studies throughout the Mesoamerican region

(Figure 1). Based on their rudimentary design and inexpensive cost, the use of Witham or modified Witham collector units for future planning and design of monitoring studies particularly in Central America, where fishing effort is high, is encouraged.

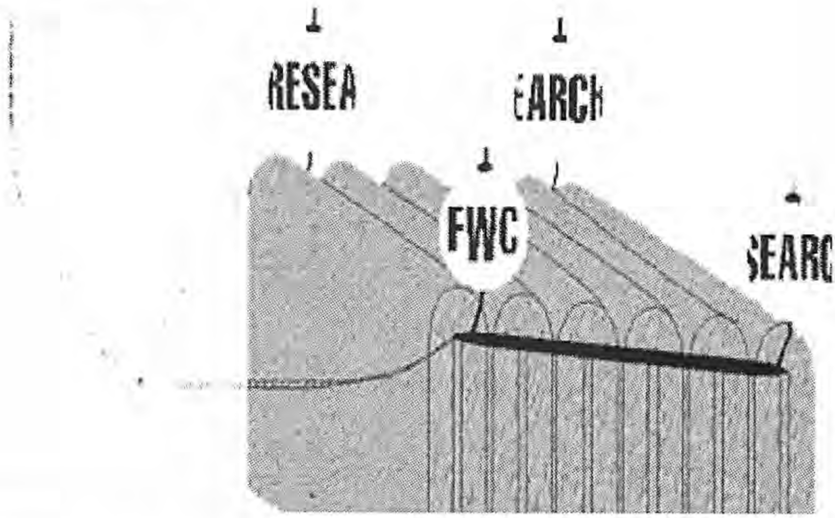


**Figure 2.** 'Witham-style' puerulus (postlarval) lobster collector using PVC, airfilter material, rope, and buoys. (redrawn with permission from FWRI)

**Relational Database and Digital Library**

Relational databases (RDs) provide an efficient and cost-effective mechanism for archiving and retrieving linked data. RD operations are constructed from linked data tables and subsequent queries are performed on that data (i.e. tables themselves), producing output tables (Sigler and Flis 1998). As a result, RDs serve managers and scientists alike who want to rapidly access critical information and query multiple links in this case, between factors such as habitat, region, and puerulus characteristics. PIP will develop a RD using Microsoft Access. One such model is the RD LarvalBase® (http://www.larvalbase.org 2005), a global and comprehensive information system of data on fish larvae that is relevant to the field of finfish aquaculture. LarvalBase is an excellent MS-Access-designed RD, although it will eventually be converted to the more efficient SQL (structured query language)(B. Ueberschaer Pers. comm.). From this RD will evolve an online digital library of graphics consisting of digitized puerulus pictures linked with habitat areas from around the region. A potential user would be able access pueruli online for identification, as well as descriptive links (e.g. lat/long, collectors used, habitat types,) to the locations from where they are being monitored.

**Table 1.** A summary of historical and mostly published puerulus recruitment and monitoring studies for *P. argus* and *P. guttatus* throughout the Caribbean region

| Species | Collector Method | Region / Country | Reference |
|---|---|---|---|
| *P. argus* | Witham | Florida, USA | Acosta and Butler 1999, Heatwole et al. 1991, Herrnkind and Butler 1986, Herrnkind and Butler 1994, Little 1977, Little and Milano 1980, Witham 1968, Matthews et al. (unpub data) |
| | Channel Nets | Florida Keys, USA | Yeung et al. 2001, Butler and Goldstein (unpub data) |
| | Witham (modified) | Bahamas | Eggleston et al. 1998 |
| | Witham | Bermuda | Ward 1992 |
| | Witham | Antigua | Bannerot et al. 1991 and 1992, Ryther et al. 1988 |
| | Witham | St. Thomas, USVI | Quinn and Kojis 1997, Quinn et al. 1998, Kojis et al. 2003 |
| | Witham | St. Croix, USVI | Cox et al. (unpub data) |
| | Witham (modified) | Puerto Rico | Monterrosa 1991 |
| | Witham | Martinique | Ricelet 1998 |
| | Witham | Grenada | Calinski 1995 (unpub data) |
| | Phillips | Cuba | Cruz et al. 1991, Phillips et al. 1994 |
| | GuSi | Mexico | Briones-Fourzan and D. Gutierrez-Carbonell 1992, D. Gutierrez-Carbonell et al. 1992 |
| *P. guttatus* | GuSi and plankton tows | Mexico | Briones-Fourzan and McWilliam 1997 |
| | SCUBA | Florida, USA | Sharp et al. 1997 |

**Archival Information**

The Museum of Comparative Zoology (MCZ) at Harvard University was founded in 1859 through the efforts of zoologist and scholar Louis Agassiz (1807-1873). The Department of Invertebrate Zoology houses some of the most extensive and historically important collections available to researchers today. There are an estimated 307,100 lots of approximately one million specimens in the collections; the crustacean collection (> 215,000 specimens) is one of the largest in the U.S. (Johnston Pers. Comm.). Through their generosity and cooperation, MCZ will serve as a repository for this lobster material. Prospective sub-samples will be digitally archived and kept within the RD for future queries and research applications. Specimens that are deposited will be catalogued and preserved in accordance to museum protocols and would be available for future research projects to visiting scientists, graduate students, and others.

**Participation**

Co-operative participatory relationships will continue with active and potential fishery managers, scientists, and fishermen throughout the region. These individuals will be contacted via email and from FAO stock assessment meetings in providing *P. argus* and other pueruli specimens from the following key locations, but not limited to: Florida Keys, Cuba, Bahamas, Bermuda, Mexico, Belize, Puerto Rico, St. Croix, Barbados, Honduras, and Venezuela.

## DISCUSSION

One of the most significant challenges within this fishery remains the lack of basic data in terms of quantifying the influx of new postlarval lobster recruits to some regional areas. Gathering more of this kind of data lends itself to further understanding aspects of local and regional population structure and stability, health, and habitat quality of known juvenile nursery grounds. Gaining insight into these areas will allow for better, more informed decisions of the fishery in the future. Attaining such a level of knowledge, however, requires small steps and well designed science coupled with persistent funding and consistent regional participation. Successful campaigns and long-term programs for postlarval lobster surveys and monitoring programs are documented in such places as Western Australia, Cuba, and the Florida Keys. Understanding some of the early life history aspects through monitoring and exploratory science has allowed fisheries managers in these regions the benefit of affording local fishermen of the fragility and sometimes cyclical nature of marine stocks. Getting to a level of being able to make predictions of recruitment to the fishery (as is the general case for Western Australia) requires, as a prerequisite, a significant correlation between postlarval supply and juvenile abundance.

**Applications and Benefits**

Along with other scientists and fishery managers, the potential "connectivity" among lobster populations is a reality throughout the Caribbean, linked intimately by physical oceanographic elements and biological characteristics intrinsic to these animals. PIP strives to gather better information starting at the pre-juvenile (puerulus) level in order to ascertain, explore, and apply our understanding to fisheries and ecological disciplines. Applications for such data would include but not be limited to:

i) Obtaining a broad and descriptive assessment of comparative ecological requirements of pueruli through survey information, helping to define a range of natural settlement zones,
ii) Assessing the number and type of puerulus stage(s) among species caught and the longevity of each stage and comparing the size ratio of the puerulus to adult,
iii) Acquiring additional data on the genetic stock structure and sources of recruitment in the Caribbean using microsatellite and other DNA sequencing technologies (see Silberman et al. 1994),
iv) Investigating the physiological differences of pueruli (e.g. nutritional condition) over spatial and temporal time scales and their implications on settlement success (Jeffs et al. 2005) (Figure 3),
v) Identifying settlement indices and their consequences on recruitment to specific habitat areas, and
vi) Assisting in the design of specialty artificial collectors for many species that still require effective monitoring programs as well as assistance to new commercial enterprises (Mills and Creer 2004) that intend to harvest pueruli and grow them to marketable sizes.

Additionally, understanding aspects of climatic variability and oscillation may, over time, explain some of the variation in puerulus settlement. The El Nino Southern Oscillation (ENSO) for example is the most famous and well studied of all the decadal scale climate variations. Caputi and Brown (1993) show a clear correlation between ENSO and the strength of puerulus settlement in conjunction with the Leeuwin Current in Western Australia. Booth (1989) documents onshore wind frequencies and the seasonal effect it has on the puerulus settlement index of *Jasus edwardsii* in New Zealand. The expansion of a more widely spread and methodologically connected Caribbean-wide study will help us two-fold in understanding the mechanisms of environmental variation and its effects on both annual and seasonal puerulus settlement across locations as well how spawning stock biomass is being influenced concomitantly.

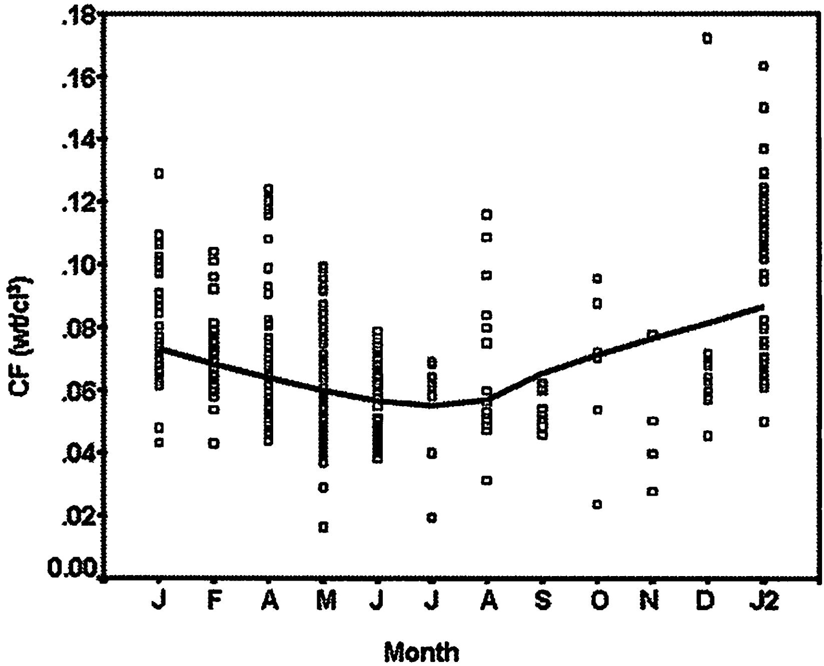


**Figure 3.** Condition factor (CF) as a proxy for nutritional condition over time (2002-2004, duplicate months pooled) for pueruli (n = 683) of *P. argus* monitored and collected at three sites in the Florida Keys (n = 683) (regression model constructed from the Loess deterministic function, modified from Goldstein 2005).

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# An Example of a Sustainable and Well-managed Community-based Lobster (*Panulirus argus*) Fishery Within the UNESCO Bioreserve of Sian Ka'an, Mexico

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ABSTRACT

The community based artisanal spiny lobster (*Panulirus argus*) fishery has been in operation within the Ascension Bay region of The UNESCO Sian Ka'an Biosphere Reserve, Yucatan, Mexico, for approximately 50 years. Fishermen are organized in a community-based cooperative, Cooperativa de Pescadores Vigía Chico. The cooperative shows exemplary management techniques, obtaining sustainable and constant landings within the shallow lagoonal patch reef environment, compared with many lobster fisheries within the Caribbean that have experienced a sharp decrease or collapsed in recent years. Sustainability of this fishery has been achieved by establishing a sense of stewardship in all fishermen, dividing the lagoon into individually owned 'fishing-fields'. The use of concrete lobster aggregating devices ('shades' or 'sombras') was developed from techniques used by Cuban fishermen who fished in the area in the 1950s. Fishermen check their individual shades every couple of days with the use of snorkel equipment. These aggregation devices, in combination with the shallow nature of the reef, allow fishermen to be selective and to land full body lobsters, permitting fishermen to comply with national and park regulations on minimum carapace size and no landing of berried females. Seasonal restrictions also apply, allowing for the natural re-stocking of populations. Local fishermen have been developing alternative livelihood strategies, such as eco-tourism, in order to maintain the long-term sustainability of the lobster fishery. Future plans include the introduction of an eco-labelling programme in order to promote sustainable practices and to be able to target specific market niches.

KEY WORDS: *Panulirus argus*, reef fishery, lobster aggregation devices

# Un Ejemplo de Pesquería Local de Langosta (*Panulirus argus*) Sostenible y Bien Manejada en la Reserva de la Biosfera UNESCO de Sian Ka'an, México

La pesquería local artesanal de langosta espinosa (Panulirus argus) en la Bahía de la Ascensión, Reserva UNESCO de la Biosfera de Sian Ka'an, Yucatán, México, ha estado en funcionamiento durante aproximadamente 50 años. Los pescadores están organizados en una cooperativa en la comunidad, Cooperativa de Pescadores Vigía Chico. La Cooperativa demuestra tener técnicas de manejo ejemplares, obteniendo capturas constantes y sostenibles en el arrecife lagunal parcheado de la Bahía, contrastando con muchas pesqueras de langostas del Caribe que han experimentado bruscos descensos o colapsos en recientes años. La sostenibilidad de esta pesquería a sido conseguida mediante el establecimiento de un sentimiento de propiedad en todos los pescadores, dividiendo la laguna en 'campos de pesca' individualmente poseídos por pescadores. El uso de mecanismos de agregación de langosta en hormigón ('sombras') fue desarrollado a partir de técnicas utilizadas por pescadores Cubanos que pescaban en el área en los '50. Los pescadores revisan sus sombras cada par de días usando equipo de esnórquel. Estos mecanismos de agregación, junto con la naturaleza poco profunda del arrecife, permiten a los pescadores ser selectivos y pescar langostas enteras, ayudando así al cumplimiento de regulaciones nacionales y del parque en talla mínima del caparazón y en la prohibición de pesca de hembras con bayas. Vedas temporales también están emplazadas para asegurar el abastecimiento natural de las poblaciones. Para asegurar la sostenibilidad a largo plazo de esta industria, la comunidad local ha desarrollado estrategias alternativas de sustento, como por ejemplo ecoturismo. Entre otros, se pretende introducir en el futuro un programa de etiquetado ecológico para promover prácticas sostenibles y poder competir en posiciones concretas del mercado de venta de langosta.

PALABRAS CLAVES: *Panulirus argus*, Cooperativa Pescadores Vigía Chico, Sian Ka'an, pesca en arrecife, pesca sostenible, mecanismos de agregación de langostas

## INTRODUCTION

Fisheries are an important resource on coral reefs, particularly in the developing world. Grinding poverty characterizes most fishing villages in Latin America. The fisher's poverty is normally directly caused by the widespread degradation of marine and coastal resources (Roberts 2000), an all too common fate of shared or open access resources. If open-access conditions are allowed, resources will often become depleted with the inevitable fall of economical return (Harding 1968). The importance of putting in place bottom-up approaches when managing community based fisheries has been stressed by Roberts (2000). It is now accepted that if effective resource management is to be achieved, government and community must share authority on decision making. This concept is now known as community-based fishery management (Hotta 1997). This paper describes in detail how one community-based fishery in southern Mexico has organised itself into a cooperative, and has successfully and sustainably managed its resources for approximately 50 years.

Cooperativa Pescadores Vigía Chico (PVC) is a community run lobster (*Panulirus argus*) fishing cooperative based in the village of Punta Allen within the The Sian Ka'an UNESCO Biosphere Reserve (Figure 1). The reserve is located between 19°05'20-20°06'N and 87°30'-87°58'W, on the east coast of the Yucatan Peninsula, Quintana Roo, and was declared a Biosphere Reserve in 1986 and inscribed as a World Heritage Site in 1987 (Salvat et al. 2002). The reserve covers approximately 6,808 $km^2$ and is Mexico's third largest protected area. Sian Ka'an is described as the largest effective nature reserve in Mexico and protects one of the most pristine expanses of wetland in Mesoamerica (Salvat et al. 2002).

Sian Ka'an follows the concept of a Biosphere Reserve, in which the goals of preserving the flora, fauna and ecosystems are integrated with the needs of the local inhabitants. Conservation is not conceived of as prohibiting use, but rather as the rational and long-term sustainable use of resources. Approximately 1,000 people live in the reserve, in either small family ranches along the coast or in the reserve's two fishing settlements, Punta Allen and Punta Herrero. At present, the main economic activities are fishing for lobster and finfish within the area of Ascensión Bay, and small-scale agriculture and ranching (CIQRO 1983).

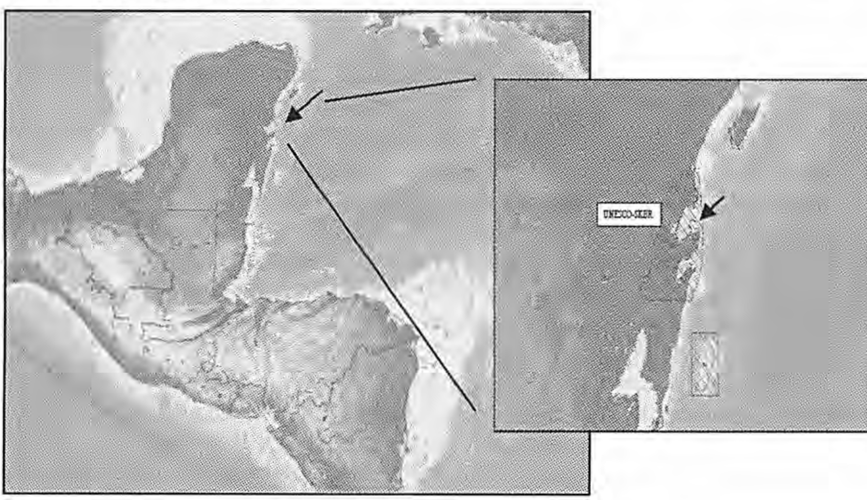

**Figure 1**. UNESCO Sain Ka'an Biosphere Resurve, Quintana Roo, Mexico

## THE HISTORY AND DEVELOPMENT OF THE FISHERY

Ascensión Bay is an open and shallow bay (Walker et al. 2004), of approximately 740 $km^2$ in area. The Bay supports a Caribbean spiny lobster (*P. argus*) fishery. This species is highly prized by fisheries throughout the Caribbean, and as a result, they are fished intensively wherever they are abundant (Lozano-Alvarez 1996). The *P.argus* fishery of Ascension Bay has attracted international interest due to the fishery's productivity and excellent sustainable management techniques (Sosa-Cordero 1995).

This community-based fishery has been in operation for approximately 50 years. Lobster fishing in this area originated as a result of Cuban fishers travelling to exploit the Bay (A. Pereira Pers. comm.). After realizing the potential, local inhabitants of Punta Allen began exploiting *P. argus* in a similar way. The fishers developed a community-based cooperative (PVC) founded in 1968 (A. Pereira Pers comm.) as a result of approximately 15 local fishers partitioning the bay into 'fields' or 'campos'. The fields were allocated on a first come - first served basis until PVC gained approximately 50 members. The limits of the fields were established by general agreement using underwater topography as natural markers (Sosa-Cordero and Ramírez-Gonzalez 1993). PVC employs aggregating devices ('shades' or 'sombras') to attract lobsters to certain areas within the fields. The use of concrete lobster aggregating devices was developed from techniques used by the pioneering Cuban fishermen in the 1950s. Originally, Florida Thatch Palm or 'chit' palm (*Trinax radiata*) trunks were used to build very simple square shaped aggregating devices or 'sombra de chit' (Figure 2). However, after the Representative Council banned the harvest of the palm due to the decrease on their population and the lack of knowledge on the sustainability of this practice in 1966, the design and materials used to construct the aggregating devices was altered (Bezaury et al. 1998) to the new concrete design. In order to avoid confusion and potential problems, a 25 meter wide band from the edge of the field's limit is not used when deploying lobster aggregating devices. Thus the 50 meter wide strip avoids ownership problems, and each aggregating device is uniquely inscribed, displaying ownership. This division of the bay permits even distribution of the fishing effort, making every member aware of the fishing geographical limits of their fishing activities.

The Bay, a predominantly shallow lagoonal and patch reef environment, is currently divided into 85 fields (Table 1 and Figure 3). Each field is for the exclusive use of its owner, although fishers that do not have their own fields can work for those who do, with benefits divided using the following the formula: Total captures /number of fishers +1, with the owner receiving the extra fishers catch to account for maintenance and other expenses. Poaching outside of a field is considered a serious offence (Actas y Bases 1995). If a boat is found to be fishing in some else's field, the fisher/s are expelled from the PVC and their engine confiscated (A. Pereira, Per. comms). Fishers are allowed to inquire as to the intentions of any boat entering their field (Sosa-Cordero and Ramírez-Gonzalez 1993).

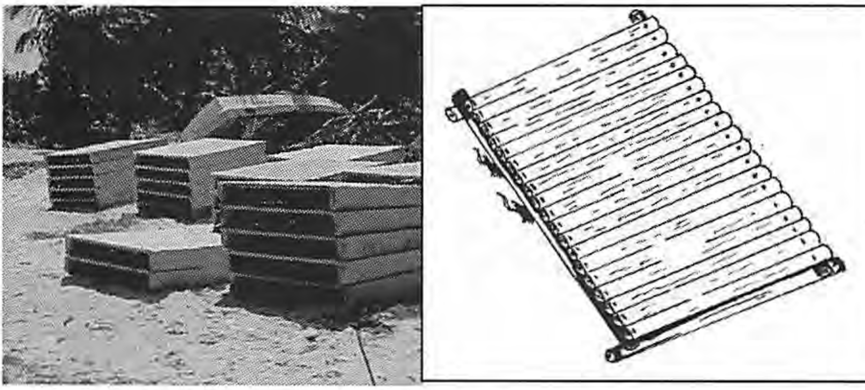

**Figure 2.** Traditional palm tree aggregating device or 'sombra de chit' (right) and present concrete lobster aggregating devices (right) (from Borges-Arceo 1999)

**Table 1.** Coop Vigía Chico general statistics adapted from Borges-Arceo, 1999

| | |
|---|---|
| Number of Fishers/Members | 78 |
| Number of fishers owning fields | 52 |
| Number of fields | 85 |
| Number of boats | 35 |

## FISHING TECHNIQUES

The new design and materials used in the construction of aggregating devices was developed by a series of 'trial-and-error' experiments (A. Pereira Pers. comm., Borges-Arceo 2001). The first designs used concrete as the main component, although at present most fishers use a combination of concrete and steel reinforcement (Figure 2). The decision on what material to use will depend on the targeted substratum, whether that might be sandy bottom or harder substratum closer to the reef. A typical aggregating device will be 1.5 x 1.5 m (Sosa-Cordero and Ramírez-Gonzalez 1993). The cost of building these devices is covered by the fishers, with national government help distributed by PVC. To date, PVC have been able to re-pay these 'loans' within the stipulated dates, and thus not incurring in any extra charges that would diminish the member's confidence in the organisation. This change reflects the willingness of PVC to collaborate and agree with the reserve managers — La Comisión Nacional de Áreas Naturales Protegidas.

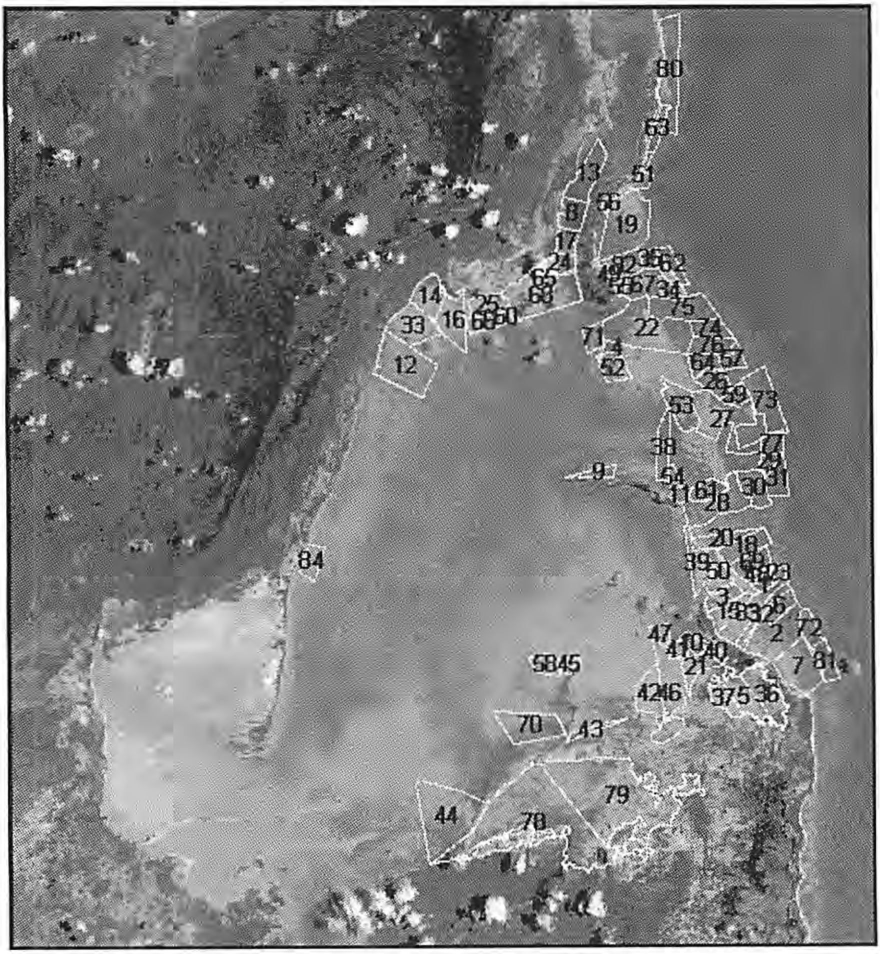


**Figure 3.** GIS of Ascension Bay with PVC's 85 fishing fields marked.

Fishers check their individual aggregating devices every 7 to 10 days with snorkel gear, although in certain periods, for example the beginning of the season and during high winds, the aggregating devices are checked more regularly. Fishers use a small net to extract lobster from the aggregating devices. This technique was developed after the original 'hook' was proved to be economically and ecologically non-viable. The hook technique used to damage, sometimes lethally, a high number of juvenile lobsters. By using a small net, fishers can be selective, both in size and reproductive stage of the females, thus complying with the reserve regulations. Typically, aggregating devices are deployed within areas of 3 to 7 m depth, although a small fraction are located at depths of 8 to 12 metres. Aggregation devices and the use of nets, in combination with the shallow nature of the reef, allow fishers to be selective and to land live lobsters, permitting fishers to comply with national and reserve regulations on minimum carapace size and no landing of berried females.

The effectiveness of the aggregating devices has been the subject of many studies (Sosa-Cordero and Ramírez-Gonzâlez 1993, Borges-Arceo 1999, Eggleston et al. 1990). It is obvious that aggregating devices will concentrate lobsters and thus make harvesting more effective. However, this can have a negative effect on the regional lobster population. PVC has identified areas of high productivity within the bay, targeting them by locating aggregating devices. The density of these devices within one field depends entirely on the owner, although experience has shown that even in the most device-populated fields the minimum distance between aggregating devices is 25 m (Sosa-Cordero and Ramírez-Gonzalez 1993). Conversely, to avoid overexploitation, fishers are also targeting areas of less productivity, in order to dissipate the fishing pressure (Sosa-Cordero and Ramírez-Gonzalez 1993).

The use of aggregating devices allows a better organization and scheduling of fishing activity. Checking each individual aggregating devices for lobsters and maintenance work can both be planned depending on weather conditions and past landings, thus maximizing time, fishing efficiency, and costs. Studies have reported this fishing technique is one of the most efficient and lucrative for small-scale fisheries (Sosa-Cordero and Ramírez-Gonzalez 1993).

## MANAGEMENT TECHNIQUES

PVC has adopted very strict fishing restrictions following national and reserve regulations, in some cases even stressing restrictions that go beyond those legally required. Decisions such as those show the deep commitment of the PVC members and directors to sustainable development of the industry and to eradicating activities and fishing methods that could harm the local marine ecosystem and stocks. Despite lobster aggregating devices located within the shallow lagoonal patch reefs, only approximately 5% of the annual landings come directly from reef-dwelling lobsters (Borges-Arceo 2001). The strategic location of the aggregating devices allows for reef dwelling individuals to restock regional populations.

Fishing by SCUBA gear is not allowed under PVC rules and reserve regulations. The shallow nature of the bay means that the use of SCUBA has gear never really been considered, with many fishers stating that the use of SCUBA gear would not be cost effective, thus making it much easier to regulate its use (A. Pereira Pers. comm.). Seasonal restrictions apply, allowing for the natural restocking of populations. The fishery is active from the 1st of July to the last day of February. The fishery only harvests individuals with a minimum carapace length (MCL) of 13.5 cm. PVC will not accept any lobster smaller than this, discouraging fishers to harvest them and allowing juvenile lobsters to reach reproductive age. It has been observed that 30 - 40% of the lobsters found within these devices are smaller than the MCL (Sosa-Cordero and Ramírez-Gonzalez 1993), so the non-destructive harvesting techniques ensure there is no bycatch of undersized individuals.

Berried females are not to be landed by fishers and are not accepted by PVC. This measure, not widely followed in the rest of the Caribbean, together with the MCL allows natural re-stocking of lobster populations. Fishers are very aware of the damage caused by poor and non-sustainable practices (A. Pereira Pers. comm.), thus becoming very protective of their resource.

## YIELD OF THE FISHERY

Responsible management has ensured local fishers have maintained landings in the region 80,000 - 125,000 kg per annum (Figure 4) between 1989 and 2003. Landings have increased every year with only the most ruthless hurricanes effecting catch levels (Gonzalez-Cano Publication date unknown) Presently, the fishery provides enough financial resource for the local population to overcome the closed season (A. Pereira Pers. comm.).

## DISCUSSION

In 2000, almost 36,000 metric tonnes of lobster species were exported from the Caribbean and west central Pacific (FAO 2002) indicating the valuable resource potential of the species. A biodiversity survey of Ascensi6n Bay goes some way to demonstrating the sustainability of the fishery. Twelve sites within the bay were surveyed with results showing that abundance of *P. argus* were higher than the regional mean for the wider Caribbean (Hodgon and Lebeler 2002) across eight of the 12 sites (Walker et al 2004). Hodgon and Lebeler (2002) state that 49% of surveyed reefs in the Caribbean are completely devoid of records for *P. argus*. Indeed, the study collected data that allowed the comparison of key species assemblages within the bay with other comparable sites within the same biogeographic region. Analysis of these data has shown that the status of the ecosystem within the Acensi6n Bay can be considered to be superior to many other comparable sites in terms of species richness and diversity (Hodgson and Liebler 2002). This suggests the fishery is having a minimal impact on the local environment.

The well managed structure and sustainable ideals that drive the PVC are well documented (Borges-Arceo 1999, Borges-Arceo 2001, Álvarez 2003). However, the effectiveness of this fishery has not been as well researched, although there is a belief amongst the fishers that there fishery is far more effective than similar fisheries exploiting the same species elsewhere in the region. It is clear that if it were to be concluded that the PVC is of higher effectiveness that other similar fisheries, the well managed structure and conservation vision would have played major roles. Small-scale community based fisheries management has become very critical during the past decade, and poses an extraordinary challenge both for local communities and governments. Small-scale fisheries are highly difficult to manage, and if open-access conditions are allowed, resources will become depleted with the inevitable fall of economical return (Harding 1996). The focus has moved to the opposite end of the spectrum; instead of the dated approach of 'protecting ecosystems from people', many successes have been achieved through 'protecting ecosystems by people and for people.'

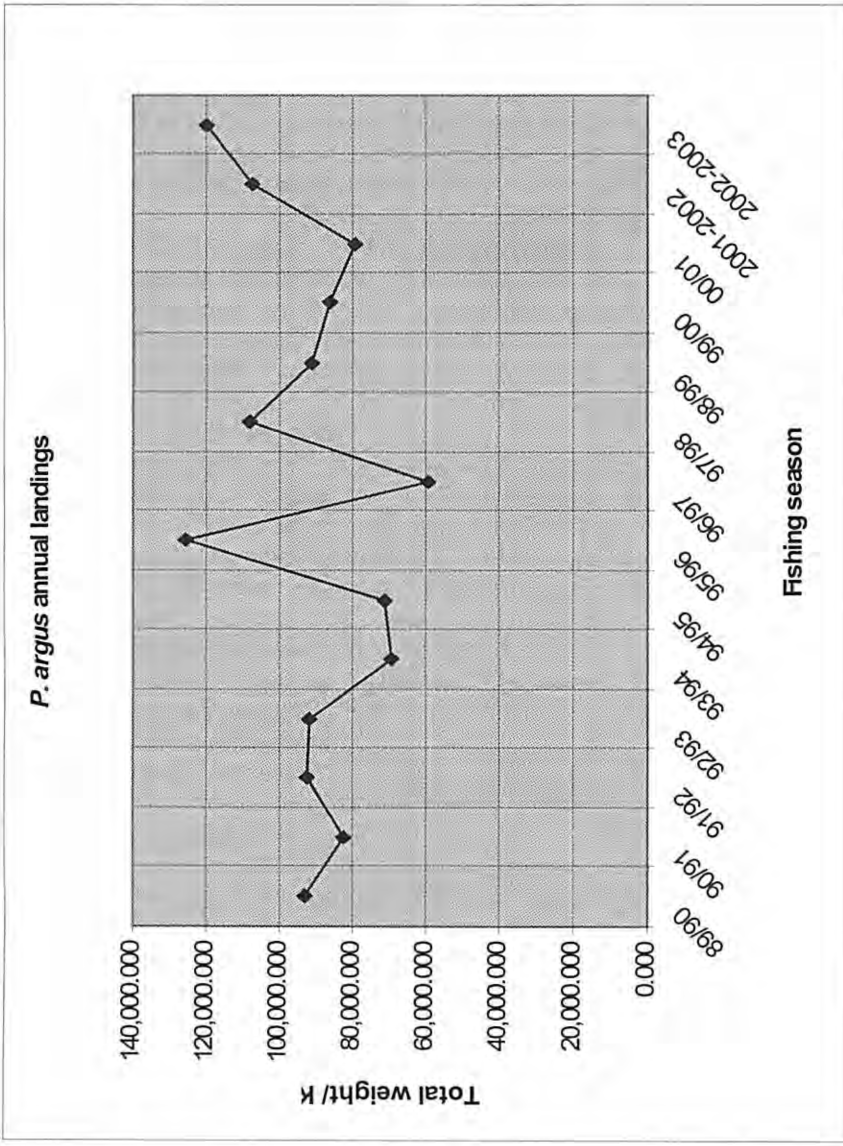


**Figure 4**. Annual landings of spiny lobster, *Panulirus argus*, from the Cooperativa Pescadores Vigía Chico. (adapted from Borges-Arceo 1999).

The custodial empowerment of the very stakeholders who were once seen as being the problem has lead to an increasing number of self-regulating community-based programmes being implemented. Projects such as the Apo Island Marine Sanctuary in Negros Oriental, Philippines (Russ and Alcada 1996), have proven that communities that are active stakeholders and decision-makers in the management of their own resources can succeed in finding ways to sustainably exploit those resources for their own benefit. This kind of stewardship system creates 'ownership' of the resource, tackling the 'tragedy of the commons' at the heart of the issue (Hardin 1968).

What makes the community-managed lobster fishery of PVC of particular interest is that it was the community itself which instigated such a 'stewardship' approach to their fishery, without the external influence of conservation ecologists. What is of further note is that the cooperative was set up half a century ago, when ecology was a fledgling science and had yet to learn the lessons that would ultimately lead it to endorse the self-imposed strategy of these fishers. The cooperative shows exemplary management techniques, obtaining sustainable and constant landings, compared with many lobster fisheries within the Caribbean that have experienced a sharp decrease or collapsed in recent years (FAO 2002). The members of PVC have recently had the foresight to try and establish alternitive livelihoods within the bay in the form of catch and release flyfishing and snorkel tours. This is to releave their sole dependency on the fishery as a sourse of income. Sustainability of this fishery has been achieved by establishing a sense of stewardship in all fishers, dividing the lagoon into individually managed 'fishing-fields' for which each steward is individually responsible. Plans are being implimented for the introduction of an eco-labelling program in order to promote sustainable practices and to be able to target specific market niches. Furthermore, the development of a 'cooperative' approach to the exploitation of the resource encourages 'good practice' amongst the fishers of the community, and stigmatizes misuse of the resource as being socially unacceptable.

The lesson to be learned from the interpretation of the data presented herein is that even vulnerable and exploited marine ecosystems can be sustainably managed by the communities who exploit them if the community is empowered to make the decisions which will affect their continued livelihood. It is, of course, a prerequisite that the community must be educated enough to make appropriate decisions in this regard, whether this 'education' is academic or learned through experience. It is hoped that other communities may be able to learn from the experience of the fishers Ascenión Bay.

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# A Preliminary Assessment of the Efficacy of a Chlorine Bleach Detection Method for use in Spiny Lobster (*Panulirus argus*) Fisheries

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ABSTRACT

The destructive and illegal practice of using chemicals (bleach, dishwashing liquid, gasoline) to catch spiny lobster (*Panulirus argus*) is thought to be common throughout much of the Bahamian Archipelago. Injection of a chemical irritant into a lobster den will result in either a rapid escape response or a subduing effect, both of which make it easier to capture spiny lobster. We used laboratory trials to determine the efficacy of a Starch-Iodide swab technique, previously developed for the detection of bleach usage in the American lobster (*Homarus americanus*) fishery, on *P. argus*. Tests were conducted on male and female spiny lobsters of varying sizes (juvenile, sub adult and adult), each of which were swabbed for the presence of test chemicals on their exoskeleton at varying intervals before and after exposure. All lobsters exposed to bleach tested positive immediately following exposure and for varying periods thereafter. No false positives were detected on control lobsters. The length of time that the chemical remained detectable on the exoskeleton varied, some individuals testing positive 12 hours after exposure. This swab technique will provide fisheries enforcement officers with a powerful tool to reduce or eliminate the illegal use of bleach for harvesting lobster throughout the Turks and Caicos Islands, Bahamas, and wider Caribbean.

KEY WORDS: Chlorine bleach, illegal fishing techniques, *Panulirus argus*

# La Validación de una Técnica de Algodón de Almidón-Yoduro para Discernir el uso de Sustancias Químicas Ilegales en los Turcos e Islas de Caicos Langosta con Púas (*Panulirus argus*) Pesquería

La práctica destructiva y a menudo ilegal de utilizar sustancias químicas (decolorante, dishwashing líquido, la gasolina) agarrar langosta con púas (*Panulirus argus*) es considerado común a través de mucho del Caribe. La inyección de una substancia irritante química en una guarida de langosta tendrá como resultado o una respuesta rápida del escape o un efecto que druegan, ambos de que lo hacen más fácil de capturar langosta con púas. Utilizamos tanto los ensayos del laboratorio como el campo para determinar la eficacia de una técnica de algodón de almidón-yoduro, previamente desarrollado para el descubrimiento del uso de decolorante en la langosta Americana (*Homarus americanus*) pesquería, en *P. argus*. Las pruebas se realizaron en el joven, sub el adulto y el adulto, langostas masculinas y femeninas con púas, cada uno de que fueron limpiados para la presencia de sustancias químicas de prueba en su dermatoesqueleto en variar intervalos antes de y después de la exposición. Toda langosta expuso de blanquear probado positivo siguiendo inmediatamente la exposición, mientras no falso positivo siendo discernidos en langostas de control. El plazo de tiempo que la sustancia química se quedó perceptible en el dermatoesqueleto variado, algunos individuos que prueban positivas muchas horas después de la exposición. Esta técnica de algodón proporcionará pesquerías oficiales de aplicación con un instrumento poderoso reducir o eliminar el uso ilegal de sustancias químicas para cosechar langosta a través del Caribe.

PALABRES CLAVES: Langosta, *Panulirus argus*, decolorante, técnica de algodón de almidón-yoduro, Islas de Turks & Caicos

## INTRODUCTION

In April 2002, the School for Field Studies (SFS) and the Turks and Caicos Islands (TCI) Government, Department of Environment and Coastal Resources (DECR), who are the regulatory and enforcement authority for the environment, entered into a Memorandum of Understanding concerning cooperation in the conduct of research and data sharing on topics including, but not limited to spiny lobsters (*Panulirus argus*). The spiny lobster fishery in the TCI is the most valuable marine export product to the economy each year. Locally at South Caicos, where SFS operates a teaching and research center (Center for Marine Resource Studies – CMRS), marine resource harvesting (e.g. conch, lobster) is the principle component of the economy and employment, and in combination with fisheries from the other islands of the TCI, contributes approximately 2.4% of the TCIs GDP (2000 estimate).

Lobster fishing is only permitted from August 1$^{st}$ to March 31$^{st}$. During the closed season, no lobster can be exported or served in local restaurants. Minimum carapace length for harvested lobster is 3¼" (83 mm) (Fishery

Protection Ordinance 1998). In 1992, 1,312,795 lbs of lobster were landed in the TCI, however, this was soon followed by a dramatic decline in catches to a low of just 398,909 lbs in 1996. Since then, catches have remained relatively stable at around 550,000 lbs per year (Figure 1) with Catch Per Unit Effort (CPUE) also remaining relatively stable (DECR Unpublished data).

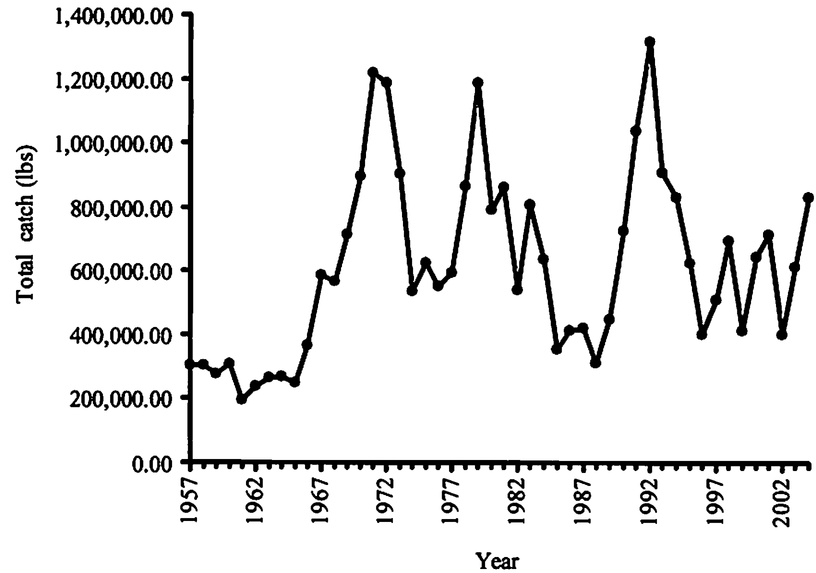


**Figure 1.** Spiny Lobster catches in the TCI from 1957 to 2004 (source: DECR landing data).

There is no harvest quota for spiny lobster, thus local stocks are subject to intensive fishing pressure during the open season. Spiny lobsters are harvested predominantly by "free diving" (i.e. without underwater breathing support - the use of SCUBA for fishing purposes is illegal) with the remainder being caught with traps. Free diving is in itself a form of effort limitation on the rate and quantity of harvesting, due to the depths that the divers can achieve. Free divers fishing for lobsters currently utilize several illegal fishing methods, most notably "the hook" (a large fishing hook fixed to the end of a 3 - 5 ft fiberglass rod) and household bleach, or liquid detergent sometimes mixed with gasoline, to force spiny lobsters from their dens (Clerveaux and Vaughan 2001, Rudd 2003). Chlorine bleach injected into lobster dens has a 'subduing' effect, making them easier to catch. As a side-effect of this form of fishing, the surrounding habitat is quickly destroyed and algal blooms follow (Campbell 1977). Specifically, corals and other organisms are killed by the bleach, with fleshy and turf algae rapidly recolonizing the area, thereby making the recolonization by corals and other organisms difficult and slow. This process, known as a coral-algal phase shift (Hughes 1994), can be accelerated when noxious chemicals or other pollutants are discharged into coral reef environments (McManus et al. 2000). The DECR is currently looking to eliminate the use of the hook, implement a harvest quota, and develop additional/further techniques to detect the use of illegal chemicals in the fishery.

The use of noxious substances to capture marine fishery products is prevalent in many fisheries around the world. Cyanide is the most common, with fisherman in the aquarium trade using cyanide to stun ornamental fish for collection (Barber and Pratt 1998, Halim 2002, Mak et al. 2005). Chlorine bleach has also been employed widely, with uses ranging from the stripping of eggs from berried (egg-bearing) females in the Maine rock lobster (*Homarus americanus*) fishery (Austin 1995, Cogger and Bayer 1996, Lobster Institute 1997, Heckmann et al. 2000), to its use as a subduing agent in both reef fish and crustacean (spiny lobster) fisheries in the Bahamas (Campbell 1977) and the TCI (Lang et al. 1998, Clerveaux and Vaughan 2001, Rudd 2003, Tewfik and Bene 2004). The deleterious effects of chlorine bleach on marine organisms are well documented (Carpenter et al. 1972, Campbell 1977, Lehtinen et al. 1988, Rosemarin 1994), with effects ranging from decreased productivity to partial or total community mortality (Campbell 1977).

In the Maine lobster fishery, ovigerous (berried) lobsters are taken by fisherman, and the eggs are subsequently removed by dipping the tails into a seawater and bleach solution. Bleach solutions frequently exceed 20% concentrations and result in the complete removal of eggs in less than two minutes (Cogger and Bayer 1996), quicker at higher concentrations. To combat this illegal technique, researchers developed two techniques to detect the use of bleach. Firstly, Cogger and Bayer (1996) developed a microscopic examination technique, where chemical scrubbing of berried lobster using bleach was detectable from the damaged caused to the plumose setal hairs on the lobster tail. However, this technique required the removal of the swimmerets for microscopic evaluation, thereby causing physical damage to the lobster (Lobster Institute 1997). An alternative and less invasive technique developed by Heckman et al. (2000), involved the use of a simple swab test, that combined two chemicals (Potassium Iodide and a Starch Indicator Solution) to detect the use of concentrated (20% or greater solutions) chlorine bleach (5.25% NaOCL) on lobster.

The Turks and Caicos Islands spiny lobster fishery is plagued with similar problems as those in the Bahamas and other areas throughout the world where chlorine bleach is readily available. In recognition of this fact, in March 2004, the DECR requested that the SFS-CMRS carry out a research program designed to develop a portable test kit for the detection of noxious chemicals such as household bleach (e.g. Clorox$^{TM}$) in the TCI fishery, thereby providing the DECR with an effective enforcement tool. Following the request from the DECR, we embarked upon a series of laboratory experiments to develop such a kit. Specifically, we aimed to determine the efficacy of the Starch-Iodide swab technique developed by Heckman et al. (2000), to detect bleach use on *P. argus* in a controlled laboratory environment.

# METHODS

## Study Site

The efficacy of a Starch-Iodide swab technique was tested in a laboratory environment at South Caicos, T.C.I. (Figure 2), from August through November 2004.

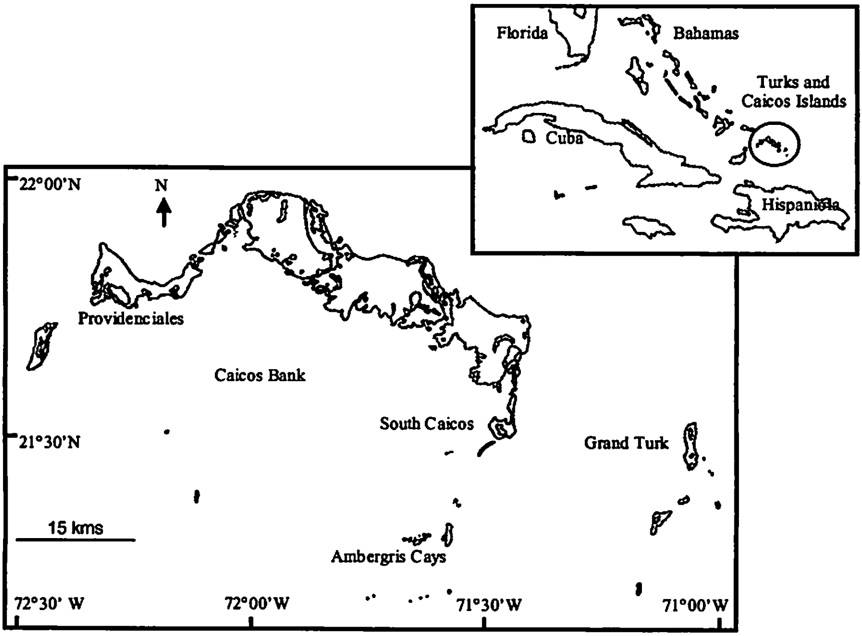


**Figure 2.** Location of the Turks and Caicos Islands at the southern end of the Bahamian Archipelago.

## Starch-Iodide Swab Technique

Rather than starting from scratch, we chose to use a Starch-Iodide based, chlorine bleach detection method developed for the Maine rock lobster (*Homarus americanus*) fishery by Heckman et al. (2000), on spiny lobster (*Panulirus argus*) from the T.C.I. fishery. The swab test consisted of two primary chemicals (Potassium Iodide and a Starch-Indicator). The Potassium Iodide crystal (Spectrum Chemical® code #P1335-10) was prepared as a 0.1% solution prepared in distilled water. The Starch-Indicator solution (Fisher Scientific® code #SS408) was used in its manufactured concentration.

## The Efficacy of the Starch-Iodide Swab Technique in a Controlled Laboratory Environment

Using the aquarium facilities located at the Department of Environment and Coastal Resources (DECR) South Caicos base, five raceways measuring 3 x 0.5 x 0.5 m (length x width x depth) were used in the experimental manipulations. Four of the raceways were used as replicate treatments with the fifth raceway as the control (Figure 3).

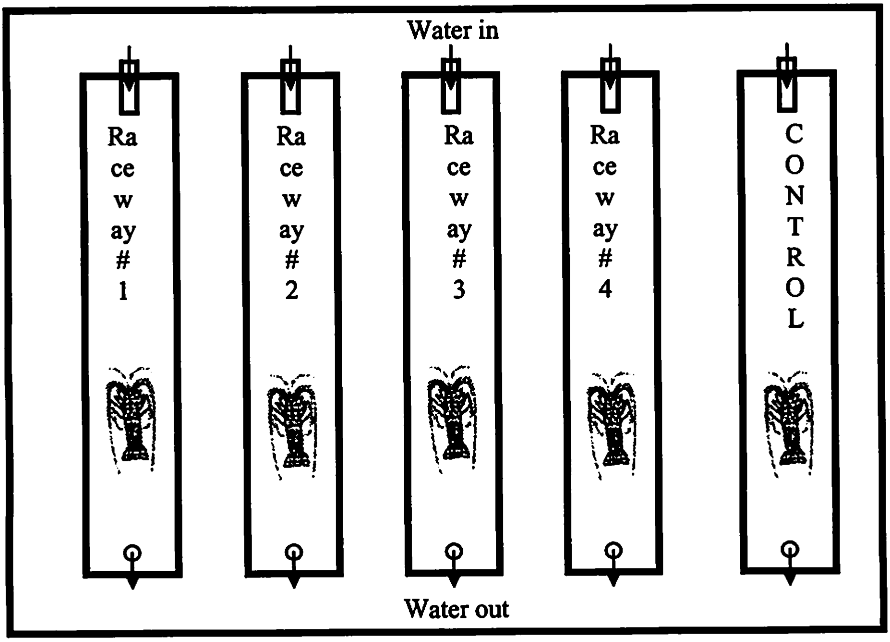


**Figure 3.** Experimental aquaria and layout for the bleach detection experiments in the laboratory. Each raceway had a single lobster of known size and sex for each trial.

The laboratory trials were repeated five times for female lobsters (n = 25) and five times for male lobsters (n = 25). Lobsters for experimental trials were collected using industry standard lobster traps to minimize potential injury to, and ensure no previous exposure to bleach. Prior to each trial the water in each raceway was tested for the presence of bleach using a standard chlorine test kit. In all cases the test produced a negative result. Five lobsters were then taken from a main holding tank and were swab tested for the presence of bleach. If negative (all were negative), each lobster was measured to the nearest mm carapace length, sexed, then placed into a separate raceway. This gave four treatment raceways and one control for each trial (n = 5). Water flow was then turned off and 40 ml of household bleach was added to each experimental tank using two 20 ml syringes (40 ml) (not the control) and left *in situ* for a period of approximately 60 seconds. Lobsters were then removed from all raceways and placed in separate holding baskets. The lobsters were then swab tested using the Starch-Iodide solution (including the control) to test for the presence of bleach and the result recorded as either a "+" or "-". A positive result occurred when the white swabs turned purple after being rubbed on the bleach exposed exoskeleton of a lobster. Lobsters were placed back into their separate holding baskets for further swab tests to be carried out at 2, 4, 6, 8, 10, 12 and 14 hrs after initial testing. At the end of each trial, the raceways were drained, flushed with fresh seawater, and left to dry until the next morning. Prior to the next trial, the raceway was flushed again and filled with seawater. The experiment was repeated using the protocol described above.

Analysis of bleach detectability between male and female spiny lobsters was conducted using a t-test. A logistic curve (Non-linear regression) was then used to determine the predictability of lobster testing positive to bleach at intervals post-exposure.

## RESULTS

Trials produced clear results with all lobster that were exposed to bleach testing positive using the swab technique immediately after exposure with no false positives. The percentage of male and female lobster that remained positive (two hourly swabs) slowly declined with time (Table 1). The comparison of test efficacy between male and female lobsters showed no significant difference between sexes ($p = 0.92$). Both results for male and female lobsters were then combined as a total percentage testing positive post-exposure to bleach (Table 1). The logistic curve analysis of the combined data shows that the detectability of bleach on lobster slowly decreases over time (Figure 4).

**Table 1.** Laboratory swab test results on male and female spiny lobsters over time, from exposure to bleach (0 to 14 hrs). Expressed as a percentage that test positive. T-test indicated that there were no differences between male and female lobsters ($p = 0.92$. $n = 40$).

| Sex | Time (hours) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 |
| Male % | 100 | 100 | 95 | 64 | 41 | 14 | 5 | 0 |
| Female % | 100 | 95 | 82 | 64 | 45 | 14 | 0 | 0 |
| Total % | 100 | 98 | 89 | 64 | 43 | 14 | 2 | 0 |

### Independent Validation

To further validate the swab technique using a semi-independent technique, three officers from the Department of Environment and Coastal Resources (DECR) were given a blind test using the swab technique. For the validation, lobsters went through the same exposure and non-exposure regime as described previously. The DECR officers then tested ten experimental lobsters for the presence or absence of bleach four hours after the initial treatment. The swab tests by the DECR officers correctly identified all bleached and unbleached lobsters ($n = 10$) (Table 2).

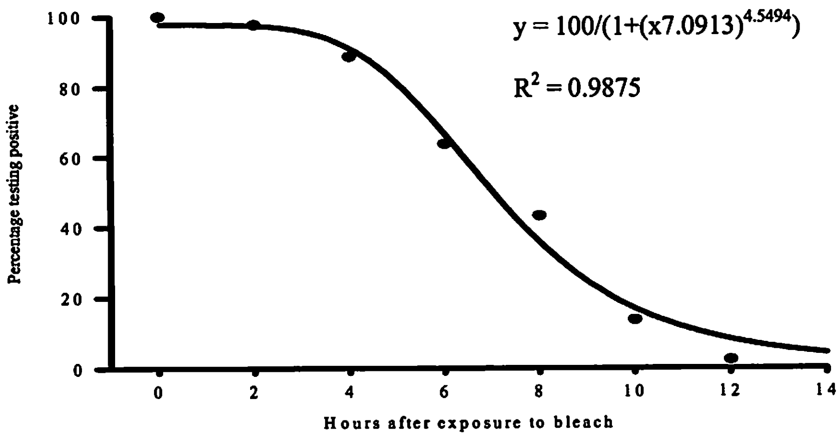


**Figure 4.** Predictive logistic curve applied to the total percentage data from Table 1.

## DISCUSSION

The Starch-Iodide swab test described in this study proved to be an effective tool for detecting the presence of chlorine bleach in laboratory treated spiny lobster. The most important aspect of the swab test, is that it is consistent and easily interpreted (white swabs turn purple when rubbed on the bleach exposed exoskeleton), and is 100% accurate with no false positive results. In addition, the test does not cause any physical damage to the lobster (e.g. removal of pleopods for laboratory analysis), is fast and extremely accurate. The chemicals that form the test are also non-toxic (Potassium Iodide and Starch Indicator) and have been approved for food and drug use by the U.S. Food and Drug Administration (F.D.A. 2005). As such, the swab test poses no threat to the integrity of the fishery product for human consumption (Heckman et al. 2000).

A typical days fishing for spiny lobster in the TCI is less than eight hours (Pers. obs.). This involves departing the docks around 7:00 am, followed by a 30-60 minute boat ride to the desired fishing grounds. The days fishing usually lasts approximately eight hours, with fisherman returning to the landing docks from 3 - 5 pm. Thus, from the time fisherman arrive at the fishing ground and begin fishing (around 8:00 am) until they land their catch back in port, is approximately 7 - 9 hours. As shown in the laboratory trials for the bleach detection kits, ~50% of bleach exposed lobster tested positive up until eight hours after exposure. After this time, bleach detectability declined rapidly until 14 hours after exposure when no lobsters tested positive. Therefore, given that the average days fishing is less than eight hours, the likelihood of detecting bleach use by swabbing lobster at the landing docks is extremely high. However, before the bleach detection swab test can be used as a fishery management tool, it will need to be tested thoroughly in field validations.

If successful in field trials, we would recommend the bleach test kits be used not only at the landing docks, but also in the field (at lobster capture/ fishing grounds). Enforcement and conservation officers could board fishing vessels and swab test the most active lobsters in the vessel, as well as several which appear to have been caught early in the day (dead or in poor condition). This would circumvent any issues associated with fisherman only using bleach early in the day to catch spiny lobsters.

Previously, it was extremely difficult for enforcement and conservation officers to prove that a certain fisherman was using bleach to catch lobster, as there were no obvious external signs on the lobster. Typically, when fisheries patrol boats would approach a fishing vessel in the field, the fisherman could simply dispose of the bleach bottle under a coral ledge or just throw it overboard (in water discard), thereby removing any physical evidence. However, with the development of the bleach detection swab test, the fisherman would have to throw away their entire catch overboard when a fishery patrol boat approaches in order to avoid detection. Obviously, this is not an economically viable option for the fisherman. The largest benefit of the bleach detection kits therefore, will be that they will act as a deterrent to fisherman who currently use bleach as a fishing tool.

Once the bleach detection kits have been validated in the field, they will be ready for use in the TCI spiny lobster fishery and will be an effective fisheries management tool if used correctly and frequently. The swab test will provide fisheries enforcement and conservation officers with a powerful tool to reduce or eliminate the illegal use of chlorine bleach for harvesting lobsters throughout the Bahamas and wider Caribbean.

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The authors gratefully acknowledge the key financial and field logistical support provided by The School for Field Studies (SFS), Center for Marine Resource Studies, South Caicos, T.C.I. Also, the DECR provided invaluable logistical support by procuring lobster for the trials, use of their aquarium facility and additional staff support during trials. Lobster traps were loaned to us by Caicos Fisheries. The production of the kits for use by the DECR was supported by a grant from the Turks and Caicos Islands Conservation Fund, Community Conservation Project Programme (CFCCPP). The manuscript was improved by comments from W. Clerveaux and others at the DECR.

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# Specialization Differences in Anglers' Preferences for Red Drum (*Sciaenops ocellatus*) Harvest Regulations

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ABSTRACT

While constraints on anglers' harvest behavior have become increasingly necessary, there is little understanding of angler diversity in preferences for particular management restrictions. This study's objectives were to understand anglers' opinions and preferences for management harvest restrictions using a stated preference choice approach (SPCA), to view the diversity of anglers' opinions and management preferences using the recreation specialization concept, and to suggest feasible management options for fisheries managers. Using a fractional factorial design with seven regulation and expectation attributes required 10 different versions of the mail questionnaire with 8 choice sets each. With an effective response rate of 60%, the final data set included the total responses of 522 red drum anglers with 261, 206, and 55 casual, intermediate, and advanced anglers, respectively. We used conditional logit models to estimate four different preference models including a pooled model for all anglers. As expected, we found that increases in bag limit and maximum size as well as catch probability will lead to considerable increases in the choice of one fishing trip over another. Likewise, anglers preferred a lower minimum size and favored the current two fish over 28" maximum size per year regulation over other options presented. Each specified model of a heterogeneous specialization segment, however, showed different patterns of significant variables. While most variables were statistically significant with the same expected signs, distinctions were noticed. For example, minimum size limit, maximum size limit, average fish size, and expected catch probability were not significant for advanced anglers. Overall, advanced anglers were less interested in relaxing current red drum regulations, while casual anglers showed a strong preference for catching more red drum by relaxing regulations. Results are discussed to help fishery managers take angler diversity into account in future decision-making. Analysis of various scenarios will help optimize the selection of the best combination of regulation attributes.

KEY WORDS: Red drum, *Sciaenops ocellatus*, anglers

# Diferencias de Especialización en las Preferencias de los Pescadores por las Normas de Regulación de las Capturas de 'Red Drum' (*Sciaenops ocellatus*)

Mientras que las restricciones en las actividades pesqueras se han hecho cada vez más necesarias, se sabe poco sobre la diversidad de preferencias de los pescadores por regulaciones particulares. Los objetivos del estudio fueron comprender las opiniones y preferencias de los pescadores por restricciones de captura, utilizando una aproximación establecida de selección preferente ('stated preference choice approach', SPCA); examinar la diversidad de opiniones y preferencias de manejo de los pescadores utilizando el concepto de especialización recreativa; y sugerir opciones de manejo viables a los gestores de pesquerías. El uso de un diseño factorial fraccional con siete atributos de regulación y de expectativa requirió 10 versiones diferentes del cuestionario enviado por correo, con 8 conjuntos de alternativas cada uno. Con una tasa de respuesta efectiva del 60%, el conjunto final de datos incluyó el total de respuestas de 522 pescadores de 'red drum', con 261, 206 y 55 pescadores ocasionales, intermedios y avanzados respectivamente. Utilizamos modelos logit condicionales para estimar cuatro modelos diferentes de preferencias, incluyendo un modelo conjunto para todos los pescadores. Como era de esperar, encontramos que el incremento en el número máximo y la talla máxima, así como la probabilidad de captura, conllevarían un incremento considerable en la participación en actividades de pesca. Del mismo modo, los pescadores prefirieron un tamaño mínimo más bajo y favorecieron la normativa actual de dos peces al año con tamaño máximo de 28'', por encima de otras opciones presentadas. En cambio, cada uno de los modelos especificados para cada segmento de especialización mostró un conjunto diferente de variables significativas. Mientras que la mayoría de las variables fue estadísticamente significativa con el signo esperado, se pueden hacer distinciones. Por ejemplo, el límite en el tamaño mínimo, en el tamaño máximo, en el tamaño medio del pez, y la probabilidad esperada de captura no fueron significativas para los pescadores avanzados. En conjunto los pescadores avanzados se mostraron menos interesados en relajar la normativa actual sobre el 'red drum', mientras que los pescadores ocasionales mostraron una fuerte preferencia por la captura de un mayor número de 'red drum' mediante una normativa menos estricta. La discusión de los resultados se hace con el fin de ayudar a los gestores de pesquerías a tener en cuenta la diversidad de pescadores de cara a futuras decisiones de manejo. El análisis de varios escenarios ayudará a optimizar la selección de la mejor combinación de atributos de regulación.

PALABRAS CLAVES: Red drum, *Sciaenops ocellatus*, pescadores

## INTRODUCTION

The fact that recreational fishing typically involves a direct consumption of fishery resources requires management agencies to enforce various management measures. As constraints on recreationists' behavior and resource uses become a common goal of management strategies, fisheries managers have increasingly shown an interest in understanding angler preferences for various management alternatives. Thus, fisheries managers should have a scientific knowledge of understanding, evaluating and predicting anglers' support for current and proposed management regulations to the most practicable extent (Wilde and Ditton 1994, Aas et al. 2000).

A typical research design such as public opinion measurement (Smith 1983) requires individuals to reveal their preference for each item of rule making and concern, one at a time. In contrast, a stated preference choice approach (SPCA) is advantageous in that anglers' preferences are exposed by making use of a set of hypothetical choice scenarios in combination with the most important attributes and consequent levels (Boxall et al. 1996, Louviere et al. 2000). Based on the rational assumption that anglers make their decisions on multiple attributes of fishing products viewed simultaneously (Schroeder and Louviere 1999), a SPCA is useful for understanding anglers' holistic preferences allowing for trade-offs among regulation attributes together with inserted expectation attributes.

Previous studies have shown that recreationists are not a homogeneous group and that sub-groups vary in terms of behavior, experience, skill and the importance of an activity (e.g., Bryan 1977, Ditton et al. 1992). As an effective market segmentation tool, recreation specialization has been used widely with robust theoretical and empirical support since its initiation by Bryan (1977). The main advantage for managers using specialization is that it can enhance an understanding of group differences (i.e., diversity) on a variety issues that enable them to improve services already provided (Driver 1985, Fedler and Ditton 1994). Using the recreation specialization framework (e.g., Bryan 1977, Ditton et al. 1992, Scott and Shafer 2001), it would be expected that various preferences for management interventions are preferred to a lesser or greater extent among participant sub-groups along a continuum.

There has been no managerially useful research on anglers' preferences for various rules and regulations using the recreation specialization framework. Therefore, the objectives of this paper were to:

i) Understand anglers' opinions and preferences for management harvest restrictions using stated preference choice modeling;
ii) Identify anglers' opinions and preferences by group segments using the recreation specialization framework; and,
iii) Suggest feasible options for management regulations that maximize angler satisfaction and conserve the limited fishery resources in a sustainable way.

## RECREATION SPECIALIZATION

As an alternative market segmentation approach, recreation specialization as proposed by Bryan (1977) has been gaining in popularity for understanding the diverse aspects of anglers' attitudes and behavior. According to the recreation specialization framework, as anglers become more involved in fishing, there is a focus shift from fish consumption to preservation and increased emphasis on the activity's generic nature and resource setting (Bryan 1977, Katz 1981, Ditton et al. 1992, Fisher 1997). Accordingly, high specialization anglers show greater appreciation of and support for resource management practices that reduce the adverse user impacts on natural resources. Overall, the understanding and support of management restrictions are also closely connected to their concerns for resource conservation.

Despite numerous studies, which have attempted to discover empirical support for management measures and conservation concerns separately, there has been less interest in an integrated understanding of the issues. Using the concept of recreation specialization, heterogeneous segments are expected to show different patterns of within-group preferences for management alternatives as an expression of their increasing commitment to their fishing activity. Given the need for constantly changing management harvest restrictions, it can be reasoned that anglers consider their preferences for restriction changes along with their concern for long-term sustainability of fisheries stocks (Gillis and Ditton 2002, Oh et al. In press). The study focus was to integrate the recreation specialization concept into an understanding of heterogeneous preferences for fishing management interventions.

## METHODS

### Instrumentation

Two mail surveys were conducted to identify and reach the target sample of red drum anglers in Texas. The initial survey questionnaire collected data on anglers' saltwater fishing participation, motivations, attitudes, and management preferences including eight variables that represent recreation specialization (e.g., total number of days in fishing for the behavioral dimension, self-evaluated fishing skill for the skill and knowledge dimension, and replacement cost for fishing equipment owned by angler for the commitment dimension). A follow-up mail questionnaire was sent to ask specifically about their red drum fishing trip preferences using a stated preference choice experimental design. To include the important attributes and levels for each attribute, discussions with fishery managers as well as the previous angler preference studies were used (e.g., Aas et al. 2000, Gillis and Ditton 2002, Hicks 2002). Finally, four types of restrictions (i.e., bag limit, minimum size limit, maximum size limit, and retention of big fish) were included as policy attributes. Furthermore, three expectation attributes were included in the study (i.e., average fish size sought, catch probability, and travel cost per day) so that anglers could predict simulated outcomes based on management changes affecting their future fishing trips (Aas et al. 2000, Gillis and Ditton 2002, Hicks 2002). Three levels including the current level for each attribute were selected to reduce burden as well as to secure sufficient variations in the policy options considered. A more detailed description of each attribute is presented in Table 1.

**Table 1.** Proposed attributes and levels

| | Attribute | Description | Level |
|---|---|---|---|
| Restrictions | Bag limit | The number of red drum that an angler can retain per day | 1. 3<br>2. 4<br>3. 5 |
| | Minimum size limit | The minimum size of red drum that an angler can legally retain | 1. 18"<br>2. 19"<br>3. 20" |
| | Maximum size limit | The maximum size of red drum that an angler can legally retain | 1. 28"<br>2. 29"<br>3. 30" |
| | Retain big fish | Each fishing year, an angler can retain one fish over the current maximum length (28"using a tag provided by TPWD) | 1. two fish over the maximum size per year<br>2. five fish over the maximum size per year<br>3. seven fish over the maximum size per year |
| Expectations | Average fish size | Anglers' expectations regarding size of red drum caught | 1. Smaller<br>2. Same as usual<br>3. Larger |
| | Catch Probability | The expected number of red drum that an angler catches on a typical fishing day | 1. about the same<br>2. one more fish caught<br>3. two more fish caught |
| | Travel cost / day | Travel cost that an angler spends for a fishing trip per day (including gas and other trip expenses) | 1. 25% less than your current total cost per day<br>2. Your current total cost per day<br>3. 25% more than your current total cost per day |

* The underlined levels reflect current state agency fishing regulations.

The use of fractional factorial designs with blocking generated 80 choice sets that were divided into 10 blocks of 8 paired trip comparisons. Figure 1 provides an example of one choice profile. To simulate the realistic decision making process for fishing trip participation, each choice set included the ability to not take either trip (Bennett and Adamowicz 2001).

| ATTRIBUTE | Trip A | Trip B | |
|---|---|---|---|
| BAG LIMIT | *5* | *4* | |
| MINIMUM SIZE | *20"* | *19"* | |
| MAXIMUM SIZE | *30"* | *30"* | |
| RETAIN BIG FISH | *Two fish over maximum size per year* | *Two fish over maximum size per year* | |
| AVERAGE FISH SIZE | *Same as usual* | *Same as usual* | |
| CATCH PROBABILITY | *One more fish caught* | *About the same* | |
| TRIP COST / DAY | *Your current trip cost / day* | *25% less than your current trip cost / day* | |
| Which trip do you prefer? (circle only one) | TRIP A | TRIP B | I would not take either trip |

Figure 1. An example of a choice set sent to respondents

**Models**

When it is reasonably assumed that individuals make choices to maximize utility (Manski 1977), random utility theory indicates that utility is estimated through an indirect utility function comprised of a deterministic component and a random error component (Louviere 1988, Louviere et al. 2000). Based on the assumption that the error terms are independently and identically distributed and Gumbel-distributed, this specification can result in the conditional logit model (McFadden 1974, Ben-Akiva and Lerman 1985).

Although there are several methods to take into account heterogeneous preferences of angler clientele, we used a segmentation approach that uncovers underlying latent classes or segments (i.e., cluster analysis approach). Because these segments, to which anglers belong, have different preference structures affected by attitudinal and behavioral information that correspond to their level of recreation specialization (Swait 1994), this method was seen as more advantageous than others.

## RESULTS

Of the 1,377 questionnaires mailed, 791 replies were received for a raw response rate of 57.4% using a modified Dillman Total Design Survey Method (Dillman 1978). When non-deliverables were deleted, the effective response rate was 59.8%. Compared to non-respondents, respondents were older, had higher household incomes, were more skilled and attributed more importance to fishing compared to other recreational activities. No significant differences were detected between respondents and non-respondents for other questions (e.g., total cost of fishing trip and level of fishing satisfaction). Caution is required in generalizing the study results to the population of anglers seeking red drum as these variables could be related to fishing avidity, which may influence responses to other questions.

Confirmatory factor analysis (CFA) was used to test the theoretical foundation of recreation specialization using the three dimensional model suggested by Scott and Shafer (2001). The CFA was implemented with eight variables to identify specialization levels: total days fished in the last 12 months (TDAYFISH) and total days fished in saltwater in the last 12 months (TDAYSW) for *the behavioral dimension*; self-perceived skill level in general fishing (ABILITY), self-perceived skill in saltwater fishing (ABILESW), and subjective constraint level of fishing skill (CSKILL) for *the skill and knowledge dimension*, and importance of fishing compared to other activities (COMPARE), member of a fishing club or organization (CLUB), and expenditure amount of fishing equipment (EQUIP) for *the commitment dimension*. The overall results for the CFA were satisfactory (e.g., Cronbach's alpha of 0.68, the Comparative Fit Index = 0.96, the Non-Normed Fit Index = 0.94 and the Standardized Root Mean Squared Residual = 0.03). Detailed results were not included here; for more details, contact the first author.

K-means cluster analysis based on three dimensions generated three groups, which we labeled as causal, intermediate and advanced anglers. A descriptive summary of the three clusters is provided in Table 2. Mean values of the three angler groups demonstrated the heterogeneity of the groups. Despite some slight inconsistency, intermediate and advanced anglers were more likely to spend more fishing days, rate their fishing ability higher and

**Table 2.** Mean value of variables by cluster level of recreation specialization

| | Level of Specialization | | |
|---|---|---|---|
| Variable | Casual (cluster 1) | Intermediate (Cluster 2) | Advanced (Cluster 3) |
| | n = 261 | n = 206 | n = 55 |
| TDAYFISH | 23 | 33 | 104 |
| TDAYSW | 11 | 20 | 74 |
| ABILESW | 1.48 | 2.33 | 2.25 |
| ABILITY | 3.24 | 4.43 | 4.07 |
| CSKILL | 3.75 | 4.58 | 4.36 |
| COMPARE | 2.70 | 3.25 | 3.58 |
| EQUIP | 6.12 | 13.50 | 21.59 |
| CLUB | 0.10 | 0.34 | 0.53 |

## The Results of the Stated Preference Choice Models

The conditional logit model was used to estimate four different preference models (including a pooled model for all anglers). Two interaction effects were added to improve the explained variance for the all-angler, casual-angler, and intermediate-angler models. However, the secondary effects were not included in the advanced-angler model because of no significant difference with the main effects only model. All effects of the primary attributes were statistically significant ($p < 0.05$) in the model. ASC was set to be an alternative specific constant and the negative value for ASC indicated that "no fishing trip" was less preferred to fishing trips conducted under the current management measures. Besides the attribute of RETAIN, which represents "to retain more fish larger than the maximum size limit", all other attributes had the expected signs. While an increase in bag limit and maximum size limit was likely to lead to considerable increases in fishing trip participation, a decrease in minimum size limit was preferred. Likewise, a strong preference was revealed for increasing catch probability and average fish size. However, contrary to expectations, the negative coefficients of RETAIN attribute indicated that anglers were likely to prefer the current "two fish over the 28" maximum size per year regulation" over the other options presented. Two interaction effects, which showed the modification effect of those two attributes on fishing trip participation, were likely to alleviate the strong positive effects of each attribute.

Each specified model of heterogeneous specialization segments, however, showed different patterns of explanatory powers and significant variables as expected. Although most variables were statistically significant with the same expected signs, some important distinctions were noticed. The following variables were not significant: MAXIMUM and the interaction effect between CATCH and BAGLIMIT for casual anglers, ASC and MINIMUM for intermediate anglers, and MINIMUM, MAXIMUM, AVERAGE3, and CATCH for advanced anglers. Overall, advanced anglers were less interested in relaxing current harvest restrictions, while casual anglers showed a strong preference for catching a greater number of red drum by relaxing current harvest restrictions (Table 3).

## DISCUSSION

Study results provided support for the proposition suggested by Bryan (1977) and stated by Ditton et al. (1992) that acceptance and support for the rules and procedures associated with fishing would depend on anglers' specialization level. High specialization anglers have more to lose from resource degradation and disturbance and hence have a more holistic view of natural resources and the need for management. As a result, they should show greater appreciation of and support for resource management practices such as harvest regulations than low specialization recreationists (Bryan 1977, Katz 1981, Ditton et al. 1992, Fisher 1997, Sutton and Ditton 2001). Thus, more specialized anglers were more likely to prefer current harvest regulations and be less willing to relax the rules and regulations to assure that the resources and the experiences they provide remain available. In contrast, less specialized anglers were likely more interested in catching more fish by relaxing harvest regulations.

**Table 3.** Results of Conditional Logit Model

| Variable | All Anglers | | Casual Angler | | Intermediate Angler | | Advanced Angler | |
|---|---|---|---|---|---|---|---|---|
| | | | Specialization Level | | | | | |
| | Estimated Coefficient | Z-value | Estimated Coefficient | Z-value | Estimated Coefficient | Z-value | Estimated Coefficient | Z-value |
| ASC | -0.7077 | -3.45** | -1.2757 | -4.35** | -0.1747 | -0.53 | -1.009 | -2.47** |
| BAGLIMIT | 0.4779 | 5.77** | 0.3891 | 3.30** | 0.5909 | 4.47** | 0.2724 | 2.84** |
| MINIMUM | -0.1077 | -3.40** | -0.1811 | -4.03** | -0.0115 | -0.23 | -0.1134 | -1.15 |
| MAXIMUM | 0.1591 | 2.10** | 0.0879 | 0.79 | 0.2359 | 1.92* | -0.0079 | -0.09 |
| RETAIN | -0.0939 | -8.05** | -0.0783 | -4.69** | -0.0887 | -4.79** | -0.2153 | -5.96** |
| AVERAGE2 | 0.3668 | 5.90** | 0.3396 | 3.88** | 0.3690 | 3.64** | 0.4413 | 2.33** |
| AVERAGE3 | 0.6444 | 9.49** | 0.5844 | 6.06** | 0.7749 | 7.12** | 0.3467 | 1.62 |
| CATCH | 0.4408 | 5.76** | 0.4582 | 4.19** | 0.4663 | 3.87** | 0.1475 | 1.56 |
| TRIPCOST | -0.0256 | -19.15** | -0.0262 | -13.86** | -0.0247 | -11.61** | -0.0264 | -6.11** |
| MAX*BAG | -0.0936 | -2.64** | -0.0658 | -1.30 | -0.1296 | -2.30** | N/A | |
| CATCH*BAG | -0.1277 | -3.60** | -0.1025 | -2.03** | -0.1774 | -3.16** | N/A | |

* indicates the statistical significance at 10% level

** indicates the statistical significance at 5% level.

Managers can expect angler groups with different levels of preferences to react differently to management options. Despite the ease of implementation and enforcement of uniform management restrictions, "a diverse management regime may increase public support for fisheries management and conservation, bringing a concomitant increase in regulatory compliance" (Fisher 1997, p. 8). Accordingly, management options that promote resource conservation and sustainability are likely to be more supported by high specialization anglers (accompanied with an expression of high economic value for the status quo option) than by low specialization anglers (Oh et al. Accepted). These results can help fishery managers take angler diversity into account and not disenfranchise certain angler segments by focusing on measures of central tendency.

There are some other points worth noting. First, we used three rather than the four segmented groups described previously by Bryan (1977). Although there is no way to know the true number of specialization groups, a more systematic approach for determining the number of groups will improve our understanding of angler diversity. S econd, because of the hypothetical nature of the SPCA, there have been concerns about the external validity of predictions (Hanley et al. 1998, Blamey and Bennett 2001). However, joint use of a revealed preference model and stated preference choice will improve predictive validity (Adamowicz et al. 1997, Louviere et al. 2000). Finally, this study was applied in the unique situation of an abundance of red drum fish stocks in Texas. In contrast with a scarcity situation, abundant stocks will be expected to have different influences on angler opinions and preferences for regulation changes considering future conservation.

In conclusion, an understanding of disparate group preferences and tradeoffs is essential to implementing harvest restrictions and other management rules. While managers' goals of maintaining or increasing angler satisfaction and preventing declines in angler numbers are all important from a service delivery standpoint, a balanced management approach is essential.

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# A Stated Preference Choice Approach to Understanding Angler Preferences for Tournament Policies and Characteristics

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ABSTRACT

Saltwater fishing tournaments have proliferated in number in recent years. Fishing tournaments in Texas are not regulated nor are there different fishing regulations for tournament and non-tournament anglers. As prize money and the number of events as well as their impacts have increased, some anglers have expressed the need for increased regulation of tournaments and their participants. The objectives of this study were to better understand the problems involved in saltwater fishing tournaments, to identify tournament and non-tournament angler preferences for possible fishing regulations, and to examine within group differences in attitudes, opinions, and preferences regarding salt water tournament issues. A stated preference choice approach, which uses hypothetical scenarios to derive individuals' preferences, provides an understanding of the relationships of multiple factors as they contribute to preferences or choice behavior. Using seven different management and expectation attributes (i.e., catch and release, bait restriction, tournament entrance fee, tournament type, trip cost, family event, and tournament size), we generated 56 choice sets. The mail survey was conducted with seven different versions of the questionnaire and each questionnaire had eight choice sets. From the conditional logit estimation, all primary attributes of angler preference were statistically significant. Not surprisingly, fishing participation was preferred to no participation in tournaments, but anglers strongly favored tournaments where catch and release behavior was promoted, where there were no bait restrictions, and tournaments were held by non-profit organizations rather than by other entities. Likewise, anglers showed a strong preference for tournaments with a greater variety of family events held, fewer numbers of tournament participants, and where a higher percentage of the tournament fee went to the management agency to support fishery management costs. We used scenario analysis to gain additional insights to angler behavior and preferences as a part of tournament management decision-making.

KEY WORDS: Angling tournaments, angler preferences

# Entendiendo las Preferencias de los Pescadores Deportivos de Aguas Marinas por los Campeonatos de Pesca

Los campeonatos de pesca en agua salada han proliferado en número en los últimos años. Las competiciones de pesca no están reguladas en Texas, ni existe una normativa de pesca pescadores de competición diferente de la del resto de pescadores. Ya que la cuantía de los premios y el número de eventos, así como sus impactos, se han incrementado, algunos pescadores han expresado la necesidad de incrementar la regulación de los campeonatos y sus participantes. Los objetivos del estudio fueron comprender mejor los problemas asociados a los campeonatos de pesca en agua marina, identificar las preferencias de los pescadores de competición y no competición por las posibles normas de pesca, y examinar las diferencias de actitud, opinión y preferencias dentro de cada grupo en lo relativo a los campeonatos en agua marina. Una aproximación establecida de selección preferente ('stated preference choice approach', SPA), que utiliza escenarios hipotéticos para derivar las preferencias individuales, permite comprender las relaciones entre múltiples factores según su contribución a las preferencias o los comportamientos de decisión. Utilizando siete atributos diferentes de manejo y de expectativa (es decir, captura y liberación, restricción de cebo, cuota de inscripción en el campeonato, tipo de competición, coste del viaje, actividades para la familia, y tamaño del campeonato), generamos 56 conjuntos de alternativas. El muestreo por correo se realizó con siete versiones diferentes del cuestionario con ocho conjuntos de alternativas cada uno. Según la estimación logit condicional todos los atributos primarios de las preferencias de los pescadores fueron estadísticamente significativas. Como era de esperar, la participación en los campeonatos de pesca se prefirió a la no participación, sin embargo los pescadores favorecieron fuertemente los campeonatos en los que se promoviera el comportamiento de captura y liberación, donde no hubiera restricciones de cebo, y aquellas competiciones organizadas por entidades sin ánimo de lucro más que por otro tipo de entidades. Del mismo modo, los pescadores mostraron fuertes preferencias por campeonatos con una mayor variedad de actividades para la familia, un menor número de participantes, y en los que un mayor porcentaje de la cuota de inscripción fuera destinada a la agencia de manejo para ayudar en los costes de manejo de la pesquería. Utilizamos análisis de escenarios para obtener una visión más profunda del comportamiento y las preferencias de los pescadores como una parte de toma de decisiones relativa al manejo de los campeonatos.

PALABRAS CLAVES: Campeonatos de pesca, las preferencias de los pescadores

## INTRODUCTION

Although the number of saltwater fishing tournaments has exploded in recent years, the number of saltwater fishing tournaments in the U.S. is currently unknown. Various sources indicate their numbers are increasing in Texas. For example, a recent inventory by Texas Parks and Wildlife Department (TPWD) staff in 2003 revealed 183 tournaments or a 227% increase compared to the number in 1983 (personal communication, Robin Riechers, 2004).

Fishing tournaments have been and continue to be a controversial use of saltwater fishery resources (Williams 1984, Schmied 1994) for the following reasons. First, only a small minority (14% in Texas) of the angler population participated one or more days per year in competitive fishing events (Anderson and Ditton 2003). Nevertheless, in contrast to tournament participants, most anglers do not view recreational fishing in competitive terms and hence don't share the values held by tournament anglers (Loomis and Ditton 1987). Second, many tournament events, run by profit-making businesses, make use of public fishery resources at no cost to event organizers. Currently, tournaments are not generally licensed or charged any fees, in addition to the fishing licensing requirements of participants, in support of fishery management activities. Third, with an increasing number of tournaments, there has been pressure for the state fisheries management agency to establish a permit system for better management of tournament events in state waters. Accordingly, fishery managers want to know to what extent various tournament characteristics and policies are preferred by tournament anglers as well as by those who are not tournament participants.

Much is known about those that participate in particular fishing tournaments in terms of their fishing motivations, attitudes, and socio-demographic characteristics (Falk et al. 1989, Antia et al. 2002). However, there have been no studies at the angler population level to understand their overall preferences for tournament opportunities that are currently provided or that could be provided. Such a study, if undertaken, would likely use a traditional approach, called opinion measurement or revealed preference methods. This would yield inconsequential insight to the relative importance of each of the options or the tradeoffs anglers were willing to make when viewing tournament options jointly. Alternatively, a *Stated Preference Discrete Choice Model* (SPDCM) makes use of hypothetical scenarios to simulate participation choices and understand preferences. Thus, SPDCMs enable an understanding of the relationship of multiple factors as they contribute to preference or choice behavior (Louviere and Timmermans 1990, Louviere et al. 2000). SPDCMs have been used previously in fishery management as well as in natural resource management broadly to understand consumer preferences for a variety of new multi-attribute products and services; this approach has not been used to understand consumer preferences for various aspects of fishing tournaments.

The fisheries management agency in Texas has previously left the matter of tournament formats to private sector providers. Management officials have discussed these issues recently in response to constituent questions and as a result, they wanted to know the extent to which various event characteristics and policies would be preferred by tournament participants as well as non-participants. The purpose of this paper was to understand the underlying rationale for anglers making trade-offs in tournament trips associated with various event characteristics and policies. We sought to help the state agency consider *pragmatic decisions* (Nielsen 1985) that maximize angler satisfaction consistent with more traditional fishery management responsibilities.

## METHODS

### Model

Originally developed in transportation choice research (McFadden 1974), the SPDCM is derived from a well-grounded random utility theory, which indicates that individuals make choices to maximize utility (Louviere 2000, 2001). Utilities, treated as random variables due to uncertainty factors, have two parts, a deterministic component and a random error component (Louviere 1988, Louviere et al. 2000). However, because utility cannot be observed directly, the probability of choice results should be used. Assuming the unobservable error component of utility is independently and identically distributed and Gumbel-distributed, the probability can result in the conditional (or multinomial) logit model (McFadden 1974, Ben-Akiva and Lerman 1985). However, the use of this model strictly requires the satisfaction of the independence of irrelevant alternatives (IIA) property (See Ben-Akiva and Lerman 1985 for more discussion of the IIA). One of the reasons for violations of the IIA property involves heterogeneous preferences among respondents (Morrison et al. 1999). Hence, one way to mitigate the IIA problem is to take into account the interaction effects of individual specific variables (e.g., socioeconomic characteristics, Hanley et al. 2001, Holmes and Adamowicz 2003).

Once the model has been estimated, willingness-to-pay values (WTP) can be used to evaluate the effectiveness of the proposals on the basis of diverse changes in attributes that reflect propose policies. WTP can be measured using

$$\frac{1}{\beta_{trip\,cost}}(V_0 - V_1)$$

where $V_0$ indicates the utility acquired from the initial condition of a fishing trip and $V_1$ is the utility from the new scenario with altered levels of attributes (Hanemann 1984).

### Identification of attributes and levels

The study began with identification of appropriate attributes and the subsequent levels or range that may surround each particular attribute. For example, the attribute would be how proceeds for a tournament are used and the range of levels would be profit and non-profit. Attributes and levels were identified and developed on the basis of discussions with fishery managers and a review of the fishing tournament literature. Four different tournament selection characteristics were identified as policy attributes:

i) Promotion of catch and release,
ii) Bait restrictions,
iii) Whether a percentage of the tournament entrance fee goes to support fishery management activities, and
iv) Whether a tournament is a non-profit or profit-making venture.

Three general expectation attributes were also inserted to help anglers' decision-making regarding their participation in fishing tournaments (Aas et al. 2000, Oh et al. In press). A detailed description for each attribute and consequent levels is presented in Table 1. Two or three levels were assigned to each attribute to describe the policy options involved.

**Table 1.** Proposed attributes and levels used for the choice experiments

| | Attribute | Description | Level and |
|---|---|---|---|
| Site Selection Factors | Catch and Release | Catch and release encouraged | 1. Catch and release behavior promoted<br>2. Catch and release behavior not promoted |
| | Bait Restriction | Nature of bait allowed | 1. No bait restriction<br>2. Artificial bait only |
| | Tournament entrance fee | Part of the angler entrance fee should go to TPWD to support costs of fishery management | 1. None of the tournament fee to go to TPWD<br>2. 10% of the tournament fee to go to TPWD<br>3. 20% of the tournament fee to go to TPWD |
| | Tournament Type | Type of tournament held by different organizations | 1. Tournament held as profit-making business<br>2. Tournament held by non-profit organization |
| General Expectations | Trip cost / day | Trip cost that an angler spends for a fishing trip per day (including gas and other trip expenses) | 1. $120<br>2. $150 (approximately current travel cost per day)<br>3. $180 |
| | Family Events | The number of events provided for spouse and children | 1. No family events<br>2. Some family events<br>3. Lots of family events |
| | Tournament Size | The approximate number of participants in a tournament | 1. 100<br>2. 200<br>3. 300 |

**Survey design**

A statewide survey was first conducted with a sample of 10,000 license holders (Anderson and Ditton 2003). After identifying anglers who have fished in saltwater in the previous 12 months, we conducted a follow-up survey using a choice experimental design (n = 1,633). A fractional factorial design was used to generate a manageable number of 56 choice sets. The choice sets were then divided into seven blocks of eight paired choice sets using blocking. An example of one choice profile is provided in Figure 1.

**Suppose that you could only choose from the two tournament trips below.**

**Which would you prefer?**

| TRIP A | ATTRIBUTES | TRIP B |
|---|---|---|
| *Catch and release not promoted* | CATCH & RELEASE | *Catch and release promoted* |
| *Artificial bait only* | BAIT RESTRICTIONS | *Artificial bait only* |
| *10% of tournament fee to go to TPWD* | ENTRANCE FEE | *None of tournament fee to go to TPWD* |
| *Tournament held by profit-making business* | TOURNAMENT TYPE | *Tournament held by profit-making business* |
| *$150* | TRIPCOST / DAY | *$150* |
| *No family events* | FAMILY EVENTS | *Some family events* |
| *100* | TOURNAMENT SIZE | *200* |

**I prefer...**(check one box below)

| | | |
|---|---|---|
| ❑ TRIP A | ❑ I WOULD NOT TAKE EITHER TRIP | ❑ TRIP B |

**Figure 1.** Example of a choice set for the tournament fishing participation .

## RESULTS

About 795 anglers responded for an effective response rate of 53% using a slightly-modified Dillman Total Design Survey Method (Dillman 1978). From non-response checks across socio-demographic and general fishing behavior variables, respondents were older, had higher incomes, and were more skilled than non-respondents. No significant differences were detected between these two groups for other important variables (e.g., total fishing days, total cost spent for a fishing trip). Nevertheless, caution should be exercised in generalizing study findings to the population of saltwater anglers.

**Conditional Logit Results**

To alleviate the IIA problem, a conditional logit model with eight interaction effects of individual specific variables was estimated. The parameter estimates of the conditional logit model are presented in Table 2. The positive value for ASC indicated that anglers were favorable toward tournament participation with current tournament characteristics. Regardless of whether they had participated in tournament fishing or not previously, it appeared that anglers were in favor of tournament fishing events. Effects codes were used for the qualitative attributes of catch and release, bait restriction, tournament type, and availability of family events.

**Table 2.** The results from conditional logit models.

| | Conditional Logit Model | |
|---|---|---|
| | Coefficient | Z-value |
| ASC | 1.298* | 5.35 |
| Catch and Release | | |
| *promoted* | 0.272* | 12.24 |
| *not promoted* | -0.272* | |
| Bait Restriction | | |
| *Artificial bait only* | -0.164* | -7.05 |
| *No bait restriction* | 0.164* | |
| Tournament Fee | 0.031* | 9.12 |
| Tournament Type | | |
| *profit-making business* | -0.351* | |
| *non-profit organization* | 0.351* | 12.58 |
| Trip Cost/ Day | -0.008* | -8.52 |
| Family Event | | |
| *no events* | -0.496* | |
| *some events* | 0.295* | 3.50 |
| *lots of event* | 0.201* | 2.25 |
| Tournament Size | -0.002* | -4.48 |
| age*ASC | -0.021* | -7.22 |
| income*ASC | 0.063* | 5.96 |
| gender*ASC | 0.255* | 2.87 |
| participate*ASC | 0.765* | 5.23 |
| gender*some events | -0.192* | -2.13 |
| gender*lots of events | 0.069 | 0.72 |
| participate*tournament size | -0.001 | -0.98 |
| participate*tournament fee | -0.312* | -5.68 |
| Log Likelihood | -5234.23 | |

* indicates statistical significant at the 5% significance level. The alternative specific constant is coded 1 for Trip A and Trip B in the choice sets and 0 for No Trip.

All effects of the primary attributes were statistically significant ($p < 0.05$). In general, most attributes had the expected signs except for promotion of catch and release and the one where part of the tournament entrance fee was to go to the agency to support fishery management costs (Tournament Fee). Contrary to initial expectations, anglers preferred the option of having catch and release promoted in tournaments. Similarly, the positive coefficient on Tournament Fee indicated that anglers were in favor of an increase in the percentage of tournament fee available to the agency for fishery management. The options of artificial bait only and of tournaments held as profit-making businesses were less preferred compared to the no bait restriction and tournaments held only by non-profit organizations, respectively. Likewise, while the number of family events held during tournaments was likely to increase choice probability for tournament fishing participation, there was a strong preference revealed for having fewer participants in tournaments. Finally, the negative coefficient of travel cost implies that anglers with higher expenditures were less likely to participate in tournament fishing, coinciding with consumer demand theory.

For interaction effects, male anglers and younger anglers were more likely to participate in fishing tournaments compared to female and older anglers. Additionally, anglers with higher household incomes were more likely to indicate that they participate in fishing tournaments. Likewise, anglers who have participated in tournament fishing previously were more likely to be enthusiastic about tournament fishing participation. The inserted interaction variables with selected attributes provided further insight such as that male anglers were likely to be less interested in the number of family events provided in tournaments (gender * some events).

**Assessing the Management Options**

The SPDCM permits researchers and decision-makers to determine whether anglers will be better or worse off depending on various changes in tournament options. A set of five tournament scenarios along with the changes in expectation variables for tournament fishing trips were developed in conjunction with fisheries managers. The results of the scenario analyses are presented with predicted probabilities and overall WTP values in Table 3. Scenario 1 was the base option (status quo) with no management interventions in the currently popular saltwater fishing tournaments, and Scenario 3 was an approach that included management options that are more conservation oriented. Scenario5 was proposed as a conservation plus option with the most restrictive (conservation oriented) management measures. Two additional scenarios were added to provide slightly different management insights to the three aforementioned scenarios. Results were somewhat surprising in that Scenario 1 with no management interventions (status quo), which was a priori expected to be most preferred, was not most preferred (a predicted probability of 8.4%). Anglers most preferred Scenario 3 (the conservation-oriented option) with a predicted probability of 31.3% and WTP of \$162. This scenario included some management interventions such as promotion of catch and release and 10% of the angler's tournament fee to go to the state agency to support fishery management. Furthermore, Scenario 5 (the conservation plus option) was also highly preferred with the predicted probability of 28.2% and WTP of $150 compared to Scenario 1. Overall, management scenarios with certain degrees of management intervention were generally more favored than the status quo situation with no management interventions.

## DISCUSSION

The aim of this paper was to enhance comprehensive understanding of anglers' preferences (regardless of their previous experience with tournament fishing) for various management attributes of tournament fishing trips and their willingness to make tradeoffs among attributes by using the SPDCM. Fortunately, we had a sufficient mix of tournament anglers (n = 235) and non-tournament anglers (n = 409) to reflect diverse preferences for tournament fishing management from these two groups. One of our major concerns at the start of the project was whether the mail survey would be salient enough to the latter group of anglers for them to respond.

Study results generally indicated a certain degree of support for management interventions (e.g., promotion of catch and release and an increase in the tournament fee available to the management agency) mainly due to concerns with possible tournament-induced negative impacts. Although respondents also showed their reluctance to adopt other management-related options (e.g., bait restriction and tournament type), these results confirmed that anglers were concerned with sustainability of fish stocks and potential conflicts between tournament and non-tournament users (Jacob and Schreyer 1980, Aas et al. 2000, Gillis and Ditton 2002). The high predicted probabilities and WTP for Scenarios 3 and 5 indicated their willingness to accept stricter management interventions (Gillis and Ditton 2002, Oh et al. In press). Support for the conservation option (Scenario 3) exceeded that for the status quo option (Scenario 1) which is likely a result of having both tournament and non-tournament anglers in the analysis. It can be argued that non-tournament anglers want more conservation-based tournament offerings whether they plan to participate in them or not. Some study limitations need to be kept in mind. First, this is a hypothetical contingent model and accordingly, it is not known whether or not people's stated behavior will match their actual or revealed behavior. Nevertheless, the model is useful for providing informed hypotheses for testing and application elsewhere. Second, there is a concern for strategic behavior on the part of some anglers who perhaps wanted to perpetuate the status quo and discourage *any* form of change. Other anglers may have provided socially desirable responses and even if positive changes are made in tournaments, may still choose not to participate. Third, compared to only 14% of tournament participants in the statewide angler survey (Anderson and Ditton 2003), a greater percentage of tournament participants (36%) in this study eagerly responded with their opinions and preferences. Thus, because of a concern with over-representation of tournament anglers, further adjustments will be needed will be needed to avoid developing policies based on an angler group that over represents tournament anglers or conversely under represents non-tournament anglers.

**Table 3.** The predicted probabilities and WTP of proposed scenarios with constraints on expectation attributes

| | | | | | | | | Conditional logit | |
|---|---|---|---|---|---|---|---|---|---|
| | Catch and Release | Bait Restriction | Fee | Type | Trip Cost | # of Events | Size | Prob. (%) | WTP ($) |
| S.1 | Not promoted | No restriction | 0% | Business | 120 | Some events | 200 | 8.4 | |
| S.2 | Not promoted | No restriction | 10% | Business | 120 | Some events | 200 | 11.5 | 38.7 |
| S.3 | Promoted | No restriction | 10% | Non-profit | 150 | Some events | 200 | 31.3 | 162.1 |
| S.4 | Promoted | Artificial only | 10% | Non-profit | 180 | Some events | 100 | 20.6 | 110.9 |
| S.5 | Promoted | Artificial only | 20% | Non-profit | 180 | Some events | 100 | 28.2 | 149.6 |

Finally, there is the matter of the extent to which natural resources agencies should get involved in matters beyond traditional natural resources management concerns. At a recent meeting of the Texas Parks and Wildlife Commission, a constituent accused the agency of engaging in *social engineering*, or in other words, promulgating rules and regulations that sought to produce particular recreational experiences for particular angler segments. It was argued that this was above and beyond resource conservation concerns. The mission of the TPWD is clear in its support for managing and conserving natural resources but also in providing "outdoor recreation opportunities for the use and enjoyment of present and future generations". In addition to the issue of over fishing in the recreational fishery, there would appear to be a clear rationale for the state agency to be involved in promulgating rules and regulations that create additional fishing "products" or experiences for anglers to maximize angler satisfaction. In this case, the task would be to reconfigure fishing tournaments to make them attractive to more anglers and conservation friendly.

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# Using a Stated Preference Choice Model to Understand Scuba Diver Preferences for Coral Reef Conservation

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ABSTRACT

Management of coral reefs is moving toward a new paradigm where the greatest challenges involve the management of people and resources. An understanding of the relationship between people and protected areas is essential for both protecting resources and providing recreational use opportunities. To protect coral reefs from negative impacts associated with scuba diving, managers need to understand the extent to which divers support management strategies. Traditional opinion measurement research designs do not provide insight on the relative importance of each alternative or the tradeoffs divers are willing to make. Stated preference choice models use hypothetical choice sets to derive individuals' preferences in a holistic manner. Our study objectives were to:

i) Identify realistic management measures for protecting coral resources,
ii) Estimate the relative importance of each management measure to divers, and
iii) Estimate the aggregate importance of various management measures using scenarios.

We used a fractional factorial design of six attributes (access, use levels, supervision levels, required education, access fee, and amount of flora/fauna observed) and generated 72 choice sets. Using nine versions of a mail questionnaire with eight choice sets in each, we mailed questionnaires to 639 scuba divers who were selected via purposive sampling in 2004. Based on the estimation of conditional logit model, divers did not prefer lower use levels, increased access with no additional access fee; they preferred some supervision in the water but not guided tours; and 30 minutes of coral reef education over no education. By identifying the tradeoffs divers are willing to make, the scenario analysis can help managers maximize constituent satisfaction and support while achieving biological management objectives.

KEY WORDS: SCUBA divers, coral reefs, preferences

# Uso de Modelos de Elección Discreta en la Comprensión de las Preferencias de los Buceadores por las Medidas de Conservación de los Arrecifes de Coral

En la actualidad el manejo de los arrecifes de coral se está orientando hacia un nuevo paradigma cuyo desafío es tratar de incluir el manejo de la gente y los recursos. Un buen conocimiento de las relaciones entre los usuarios y las áreas protegidas es esencial, tanto para proteger los recursos como para proveer oportunidades de uso recreativo. Para proteger los arrecifes de coral de los impactos negativos asociados con el buceo los gestores necesitan entender hasta dónde harán concesiones los buceadores en relación a las estrategias de manejo. Los diseños tradicionales de investigación para medir la opinión no permiten conocer la importancia relativa de cada alternativa o las concesiones que los buceadores están dispuestos a hacer. Los modelos de elección discreta ('stated preferente choice' models) utilizan conjuntos de alternativas hipotéticas para inferir las preferencias individuales en una forma holística. Los objetivos de nuestro estudio fueron:

i) Identificar medidas realistas de manejo para proteger los recursos coralinos;
ii) Estimar la importancia relativa para los buceadores de cada medida de manejo; y
iii) Estimar la importancia agregada de varias medidas de manejo usando escenarios.

Utilizamos un diseño factorial fraccional de 6 atributos (acceso, niveles de uso, niveles de supervisión, entrenamiento requerido, tarifa de acceso, y cantidad de flora / fauna observada) y generamos 72 conjuntos de alternativas. Se usaron nueve versiones de una encuesta con 8 conjuntos de alternativas cada uno, enviándose por correo a 639 buceadores, los cuales fueron seleccionados según un muestreo de conveniencia en 2004. Según la estimación del modelo logit condicional, los buceadores no prefirieron bajos niveles de uso, un incremento en el acceso sin aumento de la tarifa, alguna supervisión dentro del agua pero sin excursiones guiadas, y 30 minutos de entrenamiento frente a ningún tipo de entrenamiento. Mediante la identificación de las concesiones que los buceadores están dispuestos a hacer, el análisis de escenario puede ayudar a los gestores a maximizar el componente de satisfacción y de apoyo por parte de los buceadores, a la vez que se alcanzan los objetivos de manejo biológico.

PALABRAS CLAVES: Buceadores, arrecifes de coral, preferencias

## INTRODUCTION

While Marine Protected Areas (MPAs) were established for the primary purpose of conservation or preservation (Agardy et al. 2003), their multiple-use designation often incorporates a recreation and tourism component (e.g., Salm et al. 2000). This is, in part, because tourism revenue is one major benefit an

MPA can have on a local, state, or regional scale. Yet tourism and recreation participation can pose various threats to marine resources, especially with fragile ecosystems such as coral reefs (1998 Year of the Ocean 1998). This is the concern regarding recreational scuba diving on coral reefs.

Considerable attention has been paid to the negative impacts divers have on coral reefs, including proximate impacts such as breaking and abrading coral (e.g., Zakai and Chadwick-Furman 2002), as well as indirect impacts from re-suspension of sediment (Rogers 1990). Moreover, diver impacts can be cumulative, not only affecting coral cover but community structure (e.g., Hawkins et al. 1999) and species diversity (e.g., Tratalos and Austin 2001).

Researchers have explored ways to minimize these impacts in three main ways. First, some studies have looked strictly at the relationship between the number of users and the amount of degradation to determine appropriate carrying capacities for various coral reef dive sites (e.g., Zakai and Chadwick-Furman 2002). Second, research has looked at diver characteristics and behavior to identify groups of divers that may have greater impacts on reefs. For example, while "naïve" divers who used cameras were not more likely to impact reefs than divers without cameras, "specialized" underwater photographers with more and bulkier equipment were the most damaging of all divers as observed by Rouphael and Inglis (2001). Third, some research has looked at modifying diver behavior. For example, Medio et al. (1997) found that an in-depth briefing significantly decreased damaging contact with reef substrate.

In previous studies examining impacts, authors provide indirect and direct management strategies they expect to enhance reef protection while still allowing use. Indirect strategies include better education of both instructors and guides as well as the divers themselves (e.g., Medio et al. 1997, Tratalos and Austin 2001, Zakai and Chadwick-Furman 2002). Direct strategies include zoning (Schleyer and Tomalin 2000), restricting the number of dives per year (e.g., Zakai and Chadwick-Furman 2002), and lessening the pressure from high-use dive sites by resting the site (Tratalos and Austin 2001), or shifting use to artificial sites (Zakai and Chadwick-Furman 2002). Additionally, Walmsley and White (2003) emphasize the need for formal enforcement of regulations while Barker and Roberts (2004), for example, suggest that divemasters need to intervene to reduce diver-caused reef damage. Regulatory strategies proffered include the use of permits (Tratalos and Austin 2001) and user-pay strategies (e.g., Green and Donnelly 2003).

Multiple-use MPAs serve as a conservation tool as well as a tourism and recreational resource (Salm et al. 2000). MPAs are increasingly challenged to maintain or increase benefits (i.e., tourism experience and revenue) while protecting the resource (Dixon et al. 1993). Currently, impacts on coral reefs due to scuba diving continue because resource managers do not have a good understanding of users, their willingness to play a greater role in coral conservation, and an effective means for dealing with their impacts. To successfully enhance coral reef conservation while maintaining the site as a tourism attraction, managers must know which of the aforementioned strategies and tactics are preferred and not preferred, as well as which *combinations* of strategies (i.e., management scenarios) are most preferred.

Past research on management preferences has utilized traditional opinion measurement in which a sample of the population is asked to provide their preferences in a series of single-item questions. However, the *Stated Preference Discrete Choice Model* (SPDCM) offers a more holistic approach to opinion measurement because it is drawn from the assumption that complex decisions are based on several factors considered jointly rather than on one factor or criterion. Thus, the SPDCM can identify tradeoffs divers are willing to make and provide managers with a predictive understanding of how divers are likely to respond to new policies.

An increasing number of studies dealing with environmental use and protection have used a choice model framework to better understand preferences and predict responses. In this study, a SPDCM required participants to choose their preferred management strategies from a range of hypothetical choices. Once preferences were determined, policy scenarios based on probability estimates were created and user policy preferences predicted.

Choice models have been employed previously to understand user preferences for environmental resources as well as estimate the value of associated non-market goods and services (Adamocwicz et al. 1998). For example, Lawson and Manning (2002) examined the relative importance overnight wilderness hikers place on various social, resource, and managerial management conditions. Based on this information they predicted that hikers generally prefer a management regime that is based on opportunities for solitude over one that permits greater freedom (i.e., less regulation). In this study, we wanted to understand how scuba divers would react to various combinations of coral reef conservation management strategies. The study objectives were to:

i) Identify realistic management measures for protecting coral resources;
ii) Estimate the relative importance of each management measure to divers; and,
iii) Estimate the aggregate importance of various management measures using scenarios.

## METHODS

Steps in using a SPDCM include identifying salient management attributes and level, administering the SPDCM experiment, analyzing the results using an appropriate model, and creating a scenario analysis to predict which management policies are preferred.

### Target Sample

Divers with saltwater diving experience constituted the target sample for this study. Because there are no lists of current divers, we used a two-pronged purposive sampling strategy to obtain divers with varying skill levels. First, we solicited scuba divers (n = 325) at the 2003 Seaspace Adventure Sports and Travel Exposition in Houston, Texas, USA. Second, we recruited participants via the internet by posting announcements on listservs, forums, and by emailing dive clubs/organizations (n = 321). Divers who did not scuba dive in saltwater in the previous 12 months were excluded from the sample.

### Identifying Management Attributes and Levels

Management attributes are the strategies being tested (e.g., amount of diver supervision) and levels are the alternatives for that strategy (e.g., no supervision to fully supervised). Initial attributes and levels were tentatively developed based on a review of the diving literature and subsequently revised via a focus group conducted with primary stakeholders from the Flower Gardens Banks National Marine Sanctuary, an MPA administered by the National Oceanic and Atmospheric Administration. In addition, the survey attributes and levels were further refined using two pretests with divers. The final survey included six attributes: five represented potential changes in management strategies (PEOPLE, AREA, SUPERV, FEE, and EDU) and one dealt with diver expectations for observing marine wildlife (EXP; Table 1).

**Table 1.** Attributes and levels used for in the SPDCM experiment..
S = Status quo.

| Attribute | Description | Level |
|---|---|---|
| PEOPLE | Number of people diving at a site at any one time | S. The usual number of people at the dive site<br>1. 15% fewer people at the dive site<br>2. 30% fewer people at the dive site |
| AREA | Amount of MPA open for diving | S. 100% of MPA open to diving<br>1. 50% of MPA open to diving<br>2. 25% of MPA open to diving |
| SUPERV | Level of underwater supervision for divers using an MPA | S. Divers not supervised<br>1. Divemasters supervise divers in the water<br>2. All dives are completely guided |
| FEE | Fee for accessing the MPA (in addition to the cost of the dive itself). All proceeds are invested in management of that particular MPA | S. No additional fee to access MPA<br>1. $15 additional fee to access MPA<br>2. $30 additional fee to access MPA |
| EDU | Time spent receiving education on coral reef protection and conservation prior to the dive | S. No coral reef conservation education provided<br>1. 30 minutes of coral reef conservation education<br>2. 1 hour of coral reef conservation education |
| EXP | The amount of marine life the diver expects to see on a diving trip | S. Expect to see usual amount of fish and coral-related marine life.<br>1. Expect to see 20% more fish and coral-related marine life<br>2. Expect to see 50% more fish and coral-related marine life |

### Experimental Design and Distribution

For each choice set (i.e., hypothetical scenario), respondents were asked to choose between two trips (or choose *neither* trip). Thus, there were 1,458 possible choice sets to compare. Because of the impracticality of asking respondents to evaluate all choice sets, we employed a fractional factorial design with blocking. This design included an effective random selection of the combination of all scenarios but maintained the orthogonality of the full factorial experiment by splitting the profiles into uncorrelated blocks (Bennett and Adamowicz 2001). This resulted in the generation of 72 choice sets (Figure 1 provides an example).

Participants were mailed a self-administered questionnaire using a slightly modified Dillman (1978) Total Design Method with three mailings and a thank you/reminder postcard. In order to collect data from the 72 choice sets, nine versions of the questionnaire were created and each participant was presented with eight choice sets. In addition, we collected data on their recent diving behavior, skill level, and their perceived level of commitment to diving as a leisure activity.

1. Suppose that you could only choose from the diving trips below (Trip A, Trip B or neither trip). Which would you prefer?

| TRIP A | ATTRIBUTES | TRIP B |
|---|---|---|
| *15% fewer people at the dive site* | NUMBER OF PEOPLE | *15% fewer people at the dive site* |
| *50% of MPA open to diving* | MPA AREA | *50% of MPA open to diving* |
| *Divemasters supervise divers in the water* | LEVEL OF SUPERVISION | *All dives are completely guided* |
| *$30 additional fee* | MPA ACCESS FEE | *No additional fee* |
| *30 minutes of coral reef conservation education provided* | CORAL REEF EDUCATION | *No coral reef conservation education provided* |
| *Expect to see usual amount of fish and reef-related marine life* | TRIP EXPECTATION | *Expect to see 50% more fish and reef-related marine life* |

I prefer... (check one box below)

| | | |
|---|---|---|
| ☐ TRIP A | ☐ I WOULD NOT TAKE EITHER TRIP | ☐ TRIP B |

**Figure 1.** One of 72 choice sets used in the choice experiment for scuba divers.

## Model

The stated preference choice model (SPDCM) is based on random utility theory, which posits that individuals consider the relative importance of two or more factors involved in making a decision about management preferences and make choices to maximize their utility (McFadden 1974). Thus, the model includes a deterministic component (i.e., the measurable utility as well as random error component (to account for unobserved influences). However, because utility cannot be directly observed, probabilities are used to predict whether one scenario will be chosen over another. We used a conditional logit model, which assumes the error terms to be independently and identically distributed as well as Gumbel distributed. The distributional assumptions for this model require the satisfaction of the independence of irrelevant alternatives (IIA) property so individual specific variables (ISV), which take into account interaction effects, were included to alleviate inaccuracies due to IIA violations.

### Scenario Analysis

Once the model was estimated, attributes could be changed to reflect possible management scenarios. A probability of selection was calculated for each scenario based on Bates et al. (2002) and Blamey et al. (1999) to gain insight on the degree of differences in diver preferences. A representative selection of scenarios was chosen by the authors for inclusion in this paper. They represent the status quo option, the most restrictive option and three intermediate options.

## RESULTS

Of the 646 questionnaires distributed, we received 476 replies for a raw response rate of 74%. Considering non-deliverable and unusable questionnaires, the effective response rate was 78%.

Divers responding to the survey generally considered themselves as skilled as or more skilled than other divers in general. Almost 70% of respondents were 40 years or older, 58% were male and 44% reported annual household incomes of greater than $100,000.

### Model

Table 2 shows the parameter estimates for the conditional logit models, including ISVs. The alternative specific constant (ASC), which represents the value of a diving trip to an MPA with everything else held constant, shows that divers favored taking trips in terms of current management strategies. Looking at ISVs in terms of the ASC, the table shows that younger divers, divers with higher annual household incomes, and divers who place more importance on diving as a priority leisure activity were more likely to choose a trip based on current management strategies. Gender and diving club membership had no significant influence on trip choice.

All primary attributes were significant except for the EDU2 variable; and, all estimated coefficients had expected signs except SUPERV1 and EDU2 variables. The implicit prices in Table 2 show that, in general, divers did not prefer regulatory strategies that increased restrictions on the number of people allowed to dive at a site (PEOPLE), the amount of an MPA available to dive (AREA), or that increased the amount of supervision (SUPERV). However, while divers did not prefer increased supervision overall, the coefficient associated with having divemasters in the water (SUPERV1) was positive indicating that they preferred this option over no supervision. Divers also did not prefer access fees (FEE). In contrast, they showed a preference for education as a management strategy. Required education (30 minutes) was favored over no education (EDU1), although the coefficient for requiring one hour of education (EDU2) was not significant. Finally, the expectation variable of seeing either 20% more marine life (EXP1) or 50% more fish (EXP2) was strongly preferred.

**Table 2.** Parameter estimates for conditional logit examining preferences of scuba divers for coral reef management options. A likelihood ratio test shows that this model is superior to a main effects-only model ($c^2$ = 83.65, $p < 0.001$). Note: Dummy variables are used for qualitative attributes. Variables ending with a "1" represent level 2 for that attribute while those ending with a "2" represent that attribute's level 3 condition.

| Model | Conditional Logit | | | |
|---|---|---|---|---|
| Attribute | Coefficient | Std. error | Z-value | Implicit Price ($) |
| ASC | 2.9219** | 0.314 | 9.32 | |
| PEOPLE1 | -0.6924** | 0.067 | -10.38 | |
| PEOPLE2 | -0.4424** | 0.072 | -6.12 | -23.2 |
| AREA1 | -0.1876** | 0.070 | -2.69 | |
| AREA2 | -0.5069** | 0.069 | -7.38 | -11.2 |
| SUPERV1 | 0.1590** | 0.066 | 2.42 | |
| SUPERV2 | -0.4985** | 0.072 | -6.92 | -2.3 |
| FEE | -0.0262** | 0.002 | -11.4 | |
| EDU1 | 0.3956** | 0.070 | 5.61 | |
| EDU2 | 0.0933 | 0.068 | 1.38 | 11.2 |
| EXP1 | 0.6761** | 0.070 | 9.67 | |
| EXP2 | 1.3233** | 0.071 | 18.73 | 34.0 |
| AGEASC | -0.0465** | 0.005 | -8.54 | |
| INCOMEASC | 0.0407** | 0.019 | 2.11 | |
| CLUBASC | 0.0868 | 0.113 | 0.77 | |
| IMPORTASC | 0.1176** | 0.046 | 2.55 | |
| GENDERASC | -0.0403 | 0.115 | -0.35 | |
| | **significant at a = 0.05 | | | |
| Model Statistics | | | | |
| number of choice sets | 3305 | | | |
| Log L | -2847.2 | | | |
| McFadden $\rho^2$ | 0.2158 | | | |

## Scenario Analysis

For this analysis, five possible scenarios were chosen from least to most restrictive under the assumption that divers could expect to see increased amounts of marine life as restrictions increased (and impacts decreased) (Table 3). Scenario 1 represents the status quo management conditions (i.e., no increased restrictions) and Scenario 5 contains the most restrictive management options. When presented with these five choices, we would expect divers to choose the status quo 31% of the time; this is the most preferred option by divers. Scenario 3 was the second-most preferred option with a selection probability of 30% and Scenario 4 was the least preferred with a selection probability of 11%.

## DISCUSSION

Previous studies using SPDCM show that, in general, natural resource users prefer the least amount of restrictions (e.g., Oh et al. in press). Scuba divers showed a similar predilection by preferring Scenario 1, the status quo over other more restrictive options. The fact that Scenarios 3 and 2 were the second and third most preferred (respectively) can be understood by looking specifically at the coefficients of the supervision (SUPERV1, SUPERV2) and education (EDU1, EDU2) variables.

As shown in Table 3, having divemasters in the water (SUPERV1) and 30 minutes of required education (EDU1) did not meet our *a priori* expectations that these options would be less preferred compared to the status quo of no supervision and no required education. Because these variables are associated with positive utility, scenarios incorporating these options will increase their probability of being selected. Moreover, because the coefficients for the amount of marine life expected (EXP1 and 2) are high, the selection probability of Scenario 3 is very close to Scenario 1, the most preferred option. One caveat here, however, is that managers cannot control diver expectations in the short term, nor can they control the change in the amount of marine life due to restrictions. With that understood, Scenario 3 provides a good example of the tradeoffs divers are willing to make to see more marine life; they are willing to have restrictions on the number of divers at the site, have somewhat restricted access, as well as pay a moderate access fee.

The fact that EDU1 and SUPERV1 had positive utility may reflect the willingness of divers to contribute to coral reef conservation. That is, divers appear to understand the need to protect the resource even from "non-consumptive" recreational uses like diving. This willingness may be explained by our sample, which tended to be older and have a high household incomes. Dunlap and Heffernan (1975) found that people with these characteristics who participate in nature-based activities tend to be more pro-environment. While our study is limited in that we used a purposive sampling strategy, similar diver characteristics have been found in previous studies (e.g., Ditton and Baker 1999, Thailing and Ditton 2001).

The other variable that did not meet our *a priori* expectations was one hour of required education (EDU2) which was not significant (Table 2). Nonsignificant attribute levels could mean that divers did not perceive a difference between one hour of education and the status quo situation of no education. However, because EDU1 was significant, this explanation is not logical. Thus, we suspect that either the amount of education in general was not of major importance in decision making relative to other factors, or that divers may have discounted one hour of education as an unrealistic amount when making choices.

**Table 3.** Scenario analysis showing predicted probability of selection for each scenario

| | PEOPLE | AREA | SUPERV | FEE | EDU | EXP | Conditional Logit Prob. (%) |
|---|---|---|---|---|---|---|---|
| S1 | Usual number | 100% open | No supervision | No fee | No education | Usual amount | 31.2 |
| S2 | 15% fewer | 50% open | Divemasters | $15 fee | 30 minutes of education | Usual amount | 15.2 |
| S3 | 15% fewer | 50% open | Divemasters | $15 fee | 30 minutes of education | 20% more | 29.9 |
| S4 | 15% fewer | 25% open | Guided | $15 fee | 1 hour of education | 20% more | 11.2 |
| S5 | 30% fewer | 25% open | Guided | $30 fee | 1 hour of education | 50% more | 12.5 |

We advise managers against generalizing the results of this model to specific MPAs Instead, this modeling approach can be used concomitantly with other scoping activities such as focus groups to get feedback from the relevant recreational diver constituency. Moreover, this specific model can be used as a basis for informed hypotheses against which actual behavior can be tested.

This study illustrates how managers can get a better understanding of divers, divers' willingness to accept restrictions, as well as the tradeoffs they make in doing so. In our model, it seems possible that divers are amenable to restrictions if environmental quality is improved and it means they can see more marine life. There may be other expectations that also mediate tradeoffs for restrictions (e.g., higher variety of marine life, greater visibility, more charismatic species, etc.) that can be addressed in future research.

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# Effects of Divers Fishing in the San Andres Archipelago: Considerations towards Fisheries Management and Conservation

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ABSTRACT

Divers in the San Andres Archipelago have been fishing in the last 20 years, but their operations have significantly expanded during last five years. This fishing technique has changing through time mostly in number of divers, fishing trips and fishing gears, accounting for a net increase in fishing effort. Diving techniques promote the use of scuba gears (including hookahs) and the spear guns which are of common use, even artesanal fishers are presently using these autonomous techniques which in the past were associated only to illegal industrial operations. However, there are many other aspects that divers are influencing the fishery in the Archipelago. Aspects related to use of new and shallower fishing areas, which contain higher percentage of corals contributing to greater impacts to benthic habitats. Similarly, new target species including spiny lobsters, groupers and snappers (potentially during reproductive season) or juvenile queen conch are of divers interest including sea turtles. Divers not following safety operations are suffering health problems, as had been reported for the region in the past. Perhaps, one of the most important effects of divers in the archipelago is related to the socio-cultural influences on island's customs, since majority of them came from Colombia's continent or are foreign. Conflicts between divers and line or trap fishermen are increasing, because there are believed to be responsible for the significantly reduction of demersal fish production. This paper discuss all the aspects described above and provide important considerations for the fisheries management and the definition of the MPA's management plan which is being elaborated in this moment.

KEY WORDS: Diver fishery, San Andres archipelago, effects of diving

# Efectos de la Pesqueria con Buzos en el Archipielago de San Andres: Consideraciones hacia el Manejo Pesquero y la Conservacion

Los buzos en el Archipiélago de San Andrés han estado pescando durante los últimos 20 años, pero sus operaciones se han expandido significativamente en los últimos cinco. Esta técnica de pesca ha cambiado a través del tiempo principalmente el número de buzos y características de los botes, generando un incremento neto del esfuerzo pesquero. En las operaciones industriales, las embarcaciones han cambiado el sistema de propulsión y en las artesanales el nivel de autonomía. El buceo promueve el uso de equipos autónomos (incluyendo compresores) y del arpón los cuales son usados comúnmente, incluso pescadores artesanales están usando estas técnicas autónomas ilegales las cuales en el pasado estaban asociadas sólo a operaciones industriales. Sin embargo, hay otros aspectos en los que buzos están influyendo en las pesquerías del Archipiélago, tales como el uso de nuevas áreas de pesca que por lo general son más someras y tienen mayores porcentajes de coral, lo que aumenta los impactos en los hábitats bénticos. Igualmente, hay nuevas especies objetivo incluyendo langostas espinosas, chernas y pargos (potencialmente durante temporada reproductiva) o juveniles de caracol reina son de interés de los buzos. La captura acompañante de esta pesquería industrial que no ha sido todavía documentada afecta especies protegidas (tortugas) y peces arrecífales no comerciales, pero de importante valor ecológico. Los buzos no siguen normas de seguridad y sufren problemas de salud, como ha sido reportado para la región en el pasado. Talvez, uno de los efectos más importantes de buzos en el Archipiélago esta relacionado con influencias socio – culturales sobre las costumbres nativas, dado que la mayoría de estos vienen del continente colombiano o del extranjero. Conflictos entre buzos y pescadores de línea o nasas se están incrementando, ya que los creen responsables de la reducción significativa de la producción de peces demersales. Este artículo discute todos los aspectos descritos anteriormente y provee consideraciones importantes para el manejo de las pesquerías y la definición del plan de manejo de las AMP's que se esta elaborando actualmente.

PALABRAS CLAVES: Pesquería de buzos, Archipiélago San Andrés, efectos del buceo

## INTRODUCTION

Divers in the San Andres Archipelago have been fishing in the last 20 years, but their operations have significantly expanded during the last five years. This fishing technique has changed through time mostly in number of divers, fishing trips and fishing gears, accounting for a net increase in fishing effort. Diving techniques promote the use of scuba gears (including hookahs) and spear guns which are commonly used; even artesanal fishers are presently using these autonomous techniques which in the past were associated only with illegal industrial operations.

The objective of this paper is to discuss all aspects related to operations of the diving fishery, base on three main issues — fishery aspects, socio-cultural conflicts and environmental concerns. It will focus more on industrial level fishing, which has the greatest impact, but also includes qualitative information of artesanal operations. Their presence on the islands and their effects will be of critical concern now that extensive areas of the archipelago have been declared as a system of multiple use marine protected areas, which are also within the Seaflower Biosphere reserve.

## STUDY AREA

This study refers to the participation of divers in the San Andres archipelago, which is composed by al least eight isolated shelves (atolls), which are fished at industrial as well as artesanal levels. San Andes (SAI), East-southeast (ESE), South-south-west (SSW) and Providence (PVA) are traditionally fishing grounds for artesanal fishermen located in the south or mid-archipelago's areas. In addition, larger areas located at north and including a section of the Nicaraguan rise, Quitasueño, Serrana, Roncador, Serranilla, and Alice and New banks are fished at industrial levels. These reef complexes are characterized by a well developed coral reef, which are being recognized as important fishing grounds in the context of the western Caribbean.

## METHODS

Three different aspects were considered when analyzing the effects of divers in the archipelago's lobster and conch fisheries. The first one reviewed the growing participation of divers in the lobster fishery following restrictions imposed on the conch fishery due to reduction of its global quota. The effects were characterized in terms of catch and effort data. Catch data on lobster and conch resulting from the diving fishery was obtained from a recent diagnostic elaborated with the participation of all stakeholders involved directly or indirectly with fisheries management (Prada 2004). Effort data included information on number of divers, duration of the trips, description of the boat and the fishing gear used; additional information resulted from interviews and existing reports on inspections done immediately after boat arrival by the Fisheries and Agriculture Department.

The second aspect analyzed the socio-economic context of the divers living/working the archipelago. Information to this regard evaluated peoples' origin, conflicts among fishers and with the local community, as well as the occurrence of decompression sickness.

The third aspect considered the ecological and biological impacts of divers, and examined the use of fishing habitats, changes in size and weight of lobsters, trends in CPUE during reproductive season, and finally reviewed the potential of divers capturing protected species. Using Arc View Vs.3.2, spatial analysis were conducted to determining habitats fished by divers using existing maps (Diaz et al. 2000) and positions of a single canoe participating in an industrial conch trip (a fishing boat regularly takes 10 - 12 canoes) during 12 effective days of fishing. On a broad scale, fishers identified conch sites by abundance within a social cartography process, and habitat information was also obtained from existing maps (Diaz et al. 2000). By the other hand, changes in size (weight) were obtained from the fishery diagnostic (Prada 2004). Undersize extractions of lobsters and conchs were included for the last four months in 2004. Finally, catches of protected species are referred to only qualitatively from observers.

## RESULTS

### Fishery Aspects

Traps utilized at industrial levels are the main fishing method in San Andres archipelago, although divers in the lobster fishery became important in the last five years. Divers working in industrial operations utilize a main boat for transportation and small canoes once they reach the fishing area. Each canoe fishes approximately five to six miles from the main boat, and carries onboard two to three divers. Each boat takes a total of 9-12 canoes. Landings from divers accounted for only 9.9% of total catches in 1998 but increased to 46.3% in 2003 (Figure 1). This increase is the result of divers shifting from the conch to the lobster fishery as a consequence of the significant reduction in conch quota (53%). Therefore, fishing effort presented a net increase mostly because more fishing trips were being conducted. Duration of the trips, the number of divers and number of boats have remained similar (Table 1). However, because an undetermined proportion of the divers are using hookahs, calculation of fishing effort is subject to error, resulting in a positive trend seen in the mean values of CPUE of lobsters for divers, due to underestimation of the fishing effort (Figure 2).

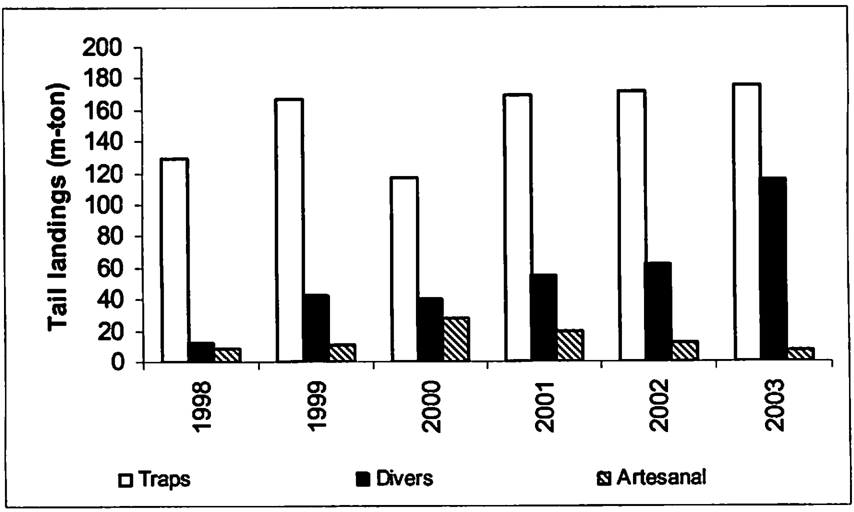



Figure 1. Industrial landings of spiny lobster in the San Andres Archipelago by fishing technique, showing a net increase in landings from divers.

**Table 1.** Characteristics of the industrial fishing effort of spiny lobster fishery in the San Andres Archipelago by fishing technique.

| Year | No. fishing trips | | Mean No. days | | Mean No. divers |
|---|---|---|---|---|---|
| | divers | traps | divers | traps | |
| 1998 | 26 | 66 | 20 | 54 | 19 |
| 1999 | 47 | 99 | 28 | 52 | 19 |
| 2000 | 57 | 83 | 25 | 32 | 19 |
| 2001 | 82 | 134 | 25 | 44 | 17 |
| 2002 | 80 | 116 | 28 | 54 | 18 |
| 2003 | 50 | 160 | 23 | 43 | 25 |

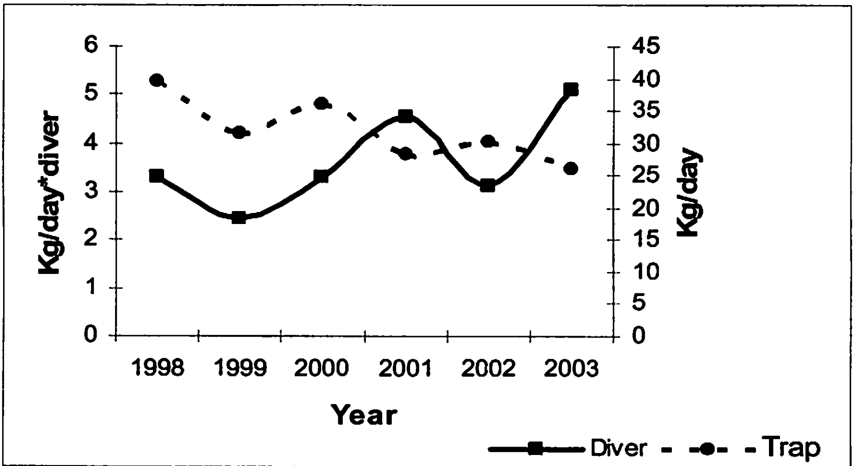



**Figure 2.** Catch per unit effort in the industrial spiny lobster fishery in the San Andres by fishing technique. Increase CPUE for divers respond to new fishing areas and increase in number of trips.

It is not possible to conduct a similar analysis for the participation of divers at artesanal levels, because there are not trips exclusively for them, but a combination of fishing techniques and gears. Medina (2003) in PVA reported that at least 40% of the time of the artesanal trips is dedicated to diving. On average, there are 25 artesanal boats in SAI and probably a similar number in PVA that spend more time in diving. It is known, that around 30 fishermen in PVA are regularly utilizing scuba tanks fishing for lobster, even though this is an illegal practice. The use of scuba tanks for SAI divers is rare, however there have been complaints about the use of hookahs by artesanal fishermen on both reefs.

On the other hand, significantly reductions in landings of the queen conch fishery have resulted from more than 20 years of divers operations, fishing with or without autonomous equipment. Present trends respond mainly to global quota established in 1997 at 200 metric tons but reduced to 96 tons in 2001 (Figure 3). In general, landings have exceeded the quota due to illegal fishing, lack of enforcement, and capture of sub-adults individuals, which in conjunction also put this fishery at serious risk. Additionally, the new trade for conch pearls is targeting mostly juvenile conchs, thereby increasing the illegal harvest of these already reduced stocks.

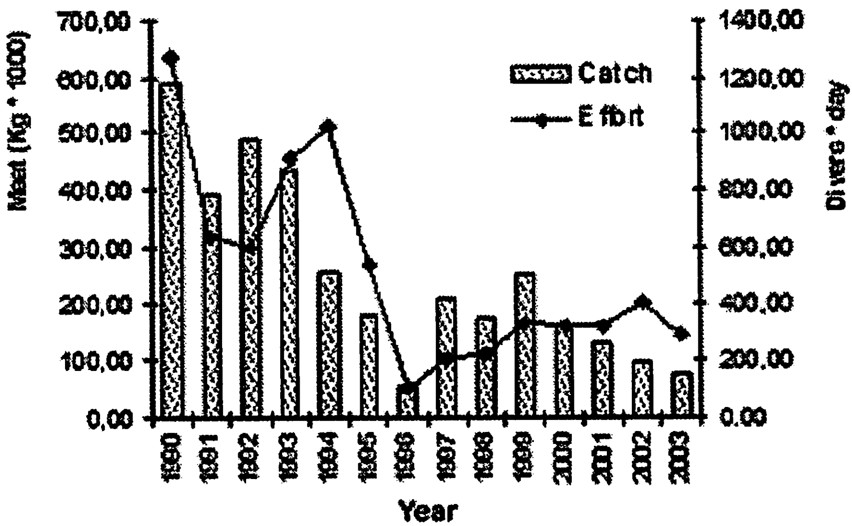



Figure 3. Catch per unit effort in the industrial spiny lobster fishery in the San Andres by fishing technique. Increase CPUE for divers respond to new fishing areas and increase in number of trips.

**Socio-Economical Conflicts**

Socio-economical issues related to the presence of divers in the archipelago's fisheries began considering their origin. Most divers fishing at industrial levels are not islanders (Figure 4). Indeed, during the 2004 season, the majority of them were Colombians (69%) from Cartagena and Rincón, who in general, are not legal residents to the islands. In addition, divers from the Dominican Republic and Honduras are participating in this fishery (22%).

The low enrollment of native people in this activity is unexpected considering the high unemployment rates (around 40%), and perhaps explained by several factors. On one hand, local fishermen are not willing to stay long and frequent periods of time at sea (artesanal fishing trips last not more than eight days). On the other hand, most local fishermen and seamen explain their low participation based on low salaries and lack of social security. Another factor is the minimal accommodation conditions; fishing boats do not have sufficient space to hold comfortably that many divers, hygienic conditions are minimal, and there is a need for space to store canoes (and illegal air compressors).

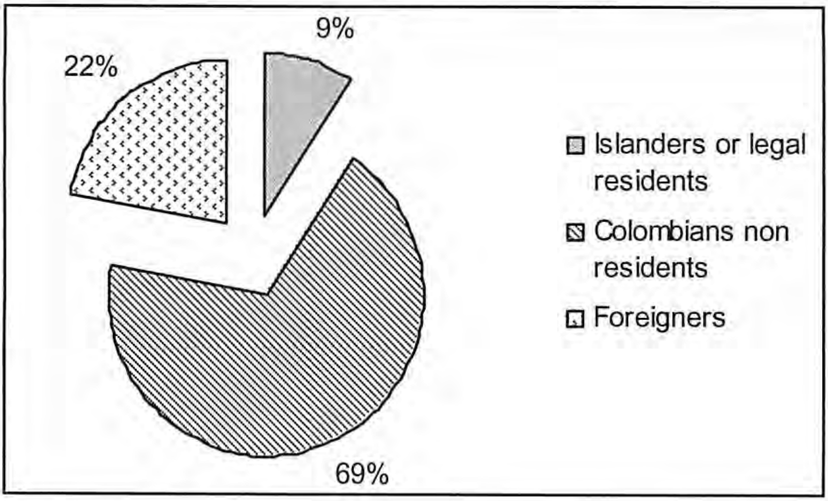



**Figure 4.** Origin of the legal divers fishing at industrial levels spiny lobsters and queen conch in the San Andres Archipelago.

Colombian divers are being asked to have a legal residence in the islands to work as fishermen since 2001. However, the office that controls the residence does not have efficient mechanisms to guarantee that people leave the islands once their temporary permit has expired, thus they become illegal residents. Usually, they bring their families with them, making the present overpopulation problem in SAI even worse.

Conflicts between non-resident divers and San Andres fishermen are increasing because if the boat stays in port for several weeks, they go out and fish in the traditional fishing areas using scuba gears. Trap fishermen have complained that divers working on industrial boats empty their traps. Other conflicts have emerged because non-resident divers spend most of their time in port around a traditional zone to the artesanal fishers, which is also a residential area. Therefore, the residential community is being degraded through increasing alcohol consumption, declining security, excess noise, and even prostitution.

The introduction of autonomous scuba gear by non-resident divers, including hookahs, is becoming more commonly used in artesanal operations. The Fishery and Agriculture Department confiscated two air compressors and one set of scuba gear from two industrial fishing boats between 2000 and 2004. In addition, two illegal conch vessels from the Dominican Republic and Honduras were captured with scuba gear onboard. Nevertheless, it is suspected that hookahs are widely used because there are insufficient enforcement resources in distant and isolated fishing areas. It is estimationed that around 25 to 50% of the licensed boats use hookahs frequently or at least have used them sometime during last two years.

However, given the vicinity of the Archipielago's fishing areas to Nicaragua and Honduras, the probability of illegal fishing by miskitos divers is high. It is possible that around 5,000 miskito divers fish in the region, and approximately 10% of them fish frequently and illegally within Colombian waters (around Quitasueño, Serranilla, and the Nicaraguan rise). This number doubles the number of legal divers in the area (maximum 250 people). Thus, an international legal framework and enforcement is in need.

Finally, the presence of divers using autonomous equipment is affecting their health. In the islands, not much information is available concerning deaths or injuries caused by decompression sickness. Fishermen mentioned that at least four people were severely injured from decompression sickness, and probably three persons have died because of that in the period of five year. Nevertheless, the majority of non-resident fishers suffering from decompression sickness are not recorded because they are transported to the mainland Just recently, one artesanal fishermen from PVA was at risk of being paralyzed due to unsafe diving.

Safety does not refer only to frequency of diving and bottom times, but also to the lack of equipment maintenance, which may result in interruption of air supply with dramatic consequences. Frequently, divers utilize homemade gear which are not designed be in compliance with safety procedures. Decompression sickness in the Islands is a critical concern for divers since fishing areas are distant from hyperbaric chambers, and the one located in SAI is not working properly.

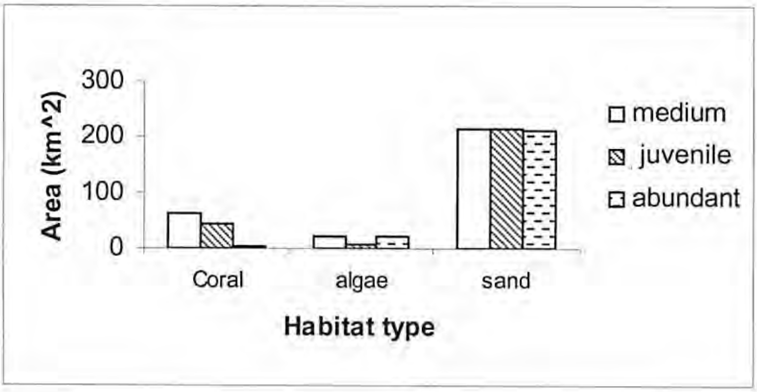
## ENVIRONMENTAL CONCERNS

### Habitat Aspects

Despite the absence of habitat maps for most fished areas located deep and far northern in the archipelago, habitat considerations regarding the impact of divers were estimated for both lobster and conch fisheries. Based on data from an observer on one conch trip, it was found that in addition to traditional unconsolidated habitats where this mollusk is most captured, coral habitats are also fished. For instance in Serrana, one of the most productive area in the Caribbean (Appeldoorn et al 2003), 10% of the fished sites happened on corals, and this percentage increased to a 66% in Roncador, a coral dominated atoll. It was not possible to get precise positioning in the case of lobster, but there are indications that divers utilized more the islands atolls than the section of the Nicaraguan rise belonging to the archipelago, which is the preferred area for the trap fishery (Medina et al 1996, Gallo et al 2002, Prada 2004).

In agreement to information from observers, the social cartography process identified a total of 13% of conch areas to be present in coral habitats in Serrana, and a total of 54.9% in Roncador. Fishermen also acknowledge that around 50% of the conchs found in coral habitats are juveniles (Figure 5). Unfortunately, there is no similar information for lobster divers.

To date, there is no information as to what extent this large number of divers may cause fragmentation and other mechanical alterations to corals.



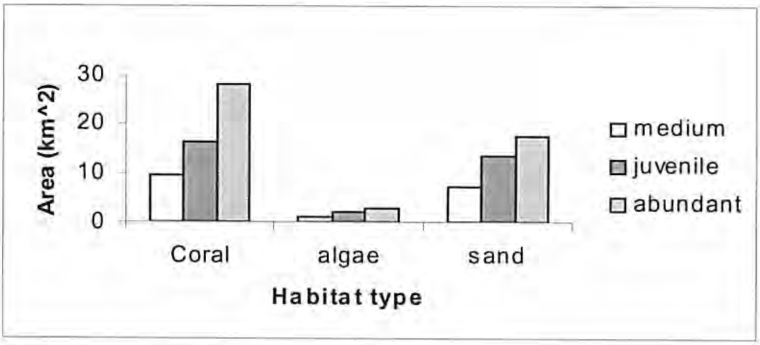
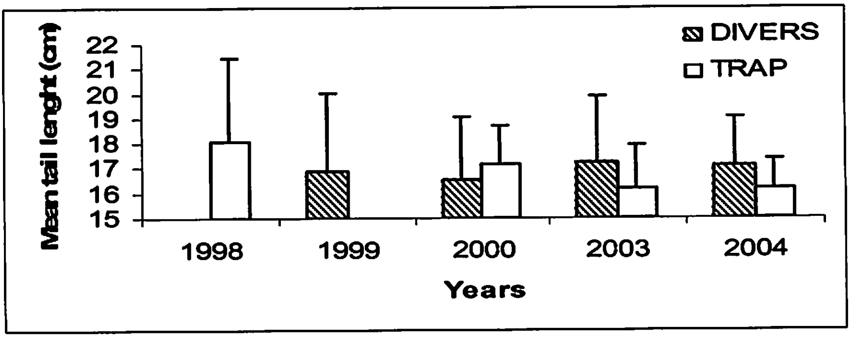




**Figure 5.** Identification of conch abundance according to fishermen perspective. Upper graph for Serrana, lower graph for Roncador.

**Biological Aspects**

Divers are affecting more the lobster population dynamics than is the trap fishery. On average, divers are capturing 14.7% (SD 15.6) undersized individuals, 7.73% (SD 10.8) of gravid females and 12% (SD 21.5) individuals with egg remnants, in comparison with 1.5 (SD 3.5), 2.51% (SD 3.4) and 4.7% (SD 6.9) respectively of the trap fishery. Changes of mean lobster size and weight through time did not proved to be statistically different by fishing method, despite a negative tendency in tail length for trap fishery was observed (Figure 6). Divers, apparently are getting larger lobsters since 2002, thus indicating that probably they are fishing deeper, where larger individuals are expected; therefore, most probably they are using autonomous (illegal) diving gear. Indeed, divers are being enticed to empty the traps (Prada et al In press). When comparing changes in lobster CPUE from the diving fishery through time, it was clear that a major abundance of lobsters were fished during May – July during 1990 - 1996. However, this pattern shifted to a more uniform variations since 1997, similarly to the observed for trap fishery.

Therefore, this data suggests that divers are not exclusively fishing the presumed shallow water stock, but also the deeper one (Prada et al. In press).



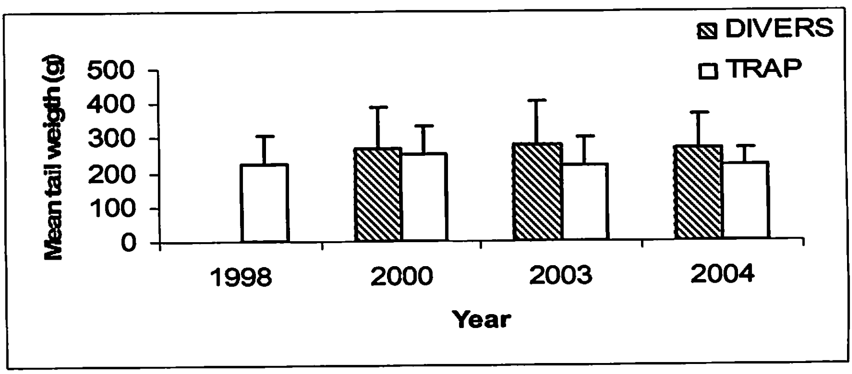




**Figure 6.** Changes in mean tail length (cm) and mean tail weight (g) in lobster fished at industrial level in the San Andres archipelago. Error bars illustrate one standard deviation.

## Captures of Protected Species

Reports made by observers indicate that divers capture and consume on-board several species subjected to different levels of protections. Usually they are not the target species, but they play a significant historical role in the local culture, such as all species of sea turtles, a delicacy in the Antillean culture. In addition, unidentified species of sharks, particularly juvenile individuals, are extracted. Reef fishes fished in spawning aggregations are also captured mostly from divers (Prada et al. 2004). It is important to remember that the use of spear gun for industrial divers was prohibited by CORALINA since 1998.

## CONCLUSIONS

Highly exploited spiny lobster populations in the San Andres archipelago began to show signs of over-fishing, and the participation of divers have significantly contributed to this situation. Their operations increased mostly as a consequence of reduction in the queen conch global quota, resulting in a shift of effort to a more valuable, less controlled trade. Apparent increments in lobster CPUE from divers may not be accurate since estimations of fishing effort are fraught with errors, due to no inclusion of the use of illegal autonomous diving gears, particularly hookahs. The queen conch stocks fished exclusively by divers already accounted for critical reductions in their populations, and at present are targeting juveniles looking for conch pearls.

The presence of divers have created additional socio-cultural conflicts, because they are a group of people (Colombian non-residents or foreigners) with different customs, and in most cases are not legally allowed to work in the islands. They brought their families with them, thus increasing the already existing over-population problems on San Andres. Conflicts with these people have extended to the local community, because they congregate within a residential sector, and transformed completely the style of life there. Divers using illegal gears generate conflicts with native divers because they compete for fishing areas with most traditional fishermen both at industrial and artesanal levels. Indeed, they have introduced the use of hookahs to artesanal fishermen, not previously reported. Using autonomous diving equipment and not following safety regulations, divers suffer decompression sickness which have caused serious injury or even death to an unknown number of people. The vicinity of the archipelago's fishing areas to Nicaragua and Honduras, where traditionally thousands of Miskitos kill themselves for the named "red gold" increases potential risks to the stability of our fishery resources.

Not only the fishery and socio-cultural aspects involved the situation of divers, but also environmental concerns. In fact, fishing out of small canoes they can reach shallow coral reef habitats affecting essential fish habitat as well as deep reproductive zones. Diver operations in the last two years were responsible for the capture of 14% of undersized lobster, 7% of gravid females, and 12% females with eggs remnants; these values represent ten times the proportion of undersized individuals, three times the proportion of gravid females and four times the proportion with eggs remnants of the trap fishery. Several species under protection are also being captured by divers, including all sea turtles, juvenile sharks, and groupers and snappers at spawning aggregation, thus contributing with the reduction of the islands biodiversity and productivity.

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# Integrating Aquaculture into Caribbean Development: Selection of Marine Species

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ABSTRACT

Many Caribbean nations have recognized the potential of mariculture to help meet local demand for fish and other marine products and to relieve pressure on fisheries. Governments and investors are especially interested in culturing species that are traditionally associated with the Caribbean, such as the spiny lobster, queen conch, and Nassau grouper. Commercial feasibility needs to be reviewed for these species and other candidate species. In some cases, the hatchery technology may be a major constraint, while in other species problems may exist in the nursery or growout phases of production. There are also candidate species for which the culture technology is well developed, but market prices are too low to allow for profitable production in the Caribbean. Expansion of Caribbean mariculture is critically dependent upon the identification of species with highest commercial potential.

To assist in determining commercial feasibility of a species, a scoring system was developed based on a mixture of technological, economic, and market-related factors. This system was used to rank nine species commonly considered as candidates for Caribbean aquaculture in order of their commercial feasibility. The species were rated in five different categories:

i) Hatchery technology,
ii) Nursery technology,
iii) Growout technology,
iv) Environmental impacts, and
v) Marketability.

Species rankings were highly dependent upon the culture technologies selected, as well as on individual marketing opportunities. The top five species ranked in order of their aquaculture commercial feasibility in the Caribbean were: cobia, sponge, shrimp, spiny lobster and queen conch. This ranking system is a tool that can assist in identifying species with the best commercial potential. However, investment decisions should also be based on detailed economic analyses.

KEY WORDS: Aquaculture, Caribbean development, marine species

# Acuacultura que Integra en el Desarrollo del Caribe: Selección de la Especie Marina

Muchas naciones del Caribe han reconocido el potencial del acuacultura de ayudar a resolver la demanda local para los pescados y otros productos del mar y a relevar la presión en industrias pesqueras. Los gobiernos y los inversionistas están especialmente interesados en cultivar las especies que se asocian tradicionalmente al Caribe, tal como la langosta espinosa, el caracol de la reina, y el grouper de Nassau. La viabilidad comercial necesita ser repasada para las estas especies y la otra especie del candidato. En algunos casos la tecnología del criadero puede ser un constreñimiento importante, mientras que en la otra especie los problemas pueden existir en las fases del criadero o de maduración. Hay también las especies del candidato para las cuales la tecnología de la cultura se desarrolla bien, pero los precios de mercado son demasiado bajos para permitir la producción provechosa en el Caribe. La extensión del acuacultura del Caribe es críticamente dependiente sobre la identificación de la especie con el potencial comercial más alto.

Para asistir a determinar viabilidad comercial de una especie, un sistema que anotaba fue desarrollado basó en una mezcla de factores tecnológicos, económicos, y relacionados con el mercado. Este sistema fue utilizado para alinear nueve especies consideradas comúnmente como candidatos a acuacultura del Caribe en orden de su viabilidad comercial. Las especies fueron clasificadas en cinco diversas categorías: tecnología del criadero, tecnología del cuarto de niños, tecnología del maduración, consecuencias para el medio ambiente, y comerciabilidad. Las graduaciones de la especie eran altamente dependientes sobre las tecnologías de la cultura seleccionadas, así como en oportunidades individuales de la comercialización. Las cinco especies superiores alineadas en orden de su viabilidad comercial de la acuacultura en el Caribe eran: cobia, esponja, camarón, langosta espinosa y caracol de la reina. Este sistema de graduación es una herramienta que puede asistir a identificar especie con el mejor potencial comercial. Sin embargo, las decisiones de la inversión se deben también basar en análisis económicos detallados.

PALABRAS CLAVES: Acuacultura, desarrollo del Caribe, especie marina

## INTRODUCTION

Many Caribbean nations have recognized the potential of mariculture to help meet local demand for fish and other marine products and to relieve pressure on fisheries. Mariculture also has the potential to create jobs and much needed export income. Expansion of Caribbean mariculture is critically dependent upon the identification of species with highest commercial potential. To assist in determining commercial feasibility of a species, a scoring system was developed based on a mixture of technological, economic, environmental, and market-related factors. This system was used to rank eight species commonly considered as candidates for Caribbean aquaculture in order of their commercial feasibility. The candidate species considered in this analysis were:

queen conch (*Strombus gigas*), spiny lobster (*Panulirus argus)*, marine shrimp (*Litopenaeus vannamei)*, Nassau grouper (*Epinephelus striatus*), cobia (*Rachycentron canadum*), red drum (*Sciaenops ocellatus*), Florida pompano (*Trachinotus carolinus*), and sea sponge (*Hippospongia spp.*)

## METHODS

Species were scored in five different categories: hatchery technology, nursery technology, growout technology, environment impacts, and market considerations. Within each category a variety of criteria were identified that provided a basis for judging the commercial feasibility or potential for the different species. For each criterion rated, a score was given ranging from 1 to 4, where: 1 = Poor; 2 = Fair; 3 = Good; and 4 = Excellent. Average scores were calculated for each category.

### Scoring Criteria

The criteria used for rating the hatchery technology for a given species included:

i) Maturation facility capital cost,
ii) Larval rearing facility capital cost,
iii) Reliability of egg production,
iv) Larval rearing survival rates,
v) Year-round availability of seedstock,
vi) Hatchery labor costs,
vii) Hatchery energy costs, and
viii) Expected cost of seedstock.

No hatchery score was given for sponge culture because hatcheries are not required for sponges. In the case of spiny lobster, seedstock (pueruli) would be obtained from the wild. Therefore, no scores were given for many of the spiny lobster hatchery criteria. However, scores were given for year round availability of seedstock and cost of seedstock, as these criteria also relate to wild seedstock collection.

The criteria used for rating the nursery technology for a given species were: nursery facility capital cost; survival in the nursery phase; nursery labor cost; nursery energy cost; and, nursery feed cost. Nurseries are not required for sponges, so no score was given for sponges in this category.

Growout technologies were rated based on:

i) Growout facility capital cost,
ii) Survival in the growout phase,
iii) Growout labor cost,
iv) rowout energy cost, and
v) Growout feed cost.

The criteria for scoring the environmental impacts associated with the aquaculture of a given species reflect the different ways that aquaculture activities can impact the environment. Environmental impact scoring was based on:

i) Habitat impacts,
ii) Natural resource depletion,
iii) Non-native species impacts,
iv) Effect on bio-diversity, and
v) The effectiveness of available mitigation procedures.

In this category higher scores were awarded to culture systems with lower degrees of environmental impact.

The market potential for each of the candidate aquaculture species was rated based on the following criteria:

i) The degree of processing required,
ii) Whether or not the product has a Caribbean identity,
iii) Availability of niche markets,
iv) Size of niche markets,
v) The degree of competition in the marketplace,
vi) The difference between wholesale price and production cost, and
vii) The difference between retail price and production cost.

**Weighting of Category Average Scores**

The relative impacts of the different categories on the economic feasibility of the aquaculture of a species are not all equal. For example, the growout stage of production will usually have a greater impact on the economics of producing a species than the nursery stage. A weighting factor was used to adjust for the relative importance of the different categories to the species selection process. The weighting factors, which are entirely subjective, provide a way to give additional weight to those categories deemed most important in the species selection process and less weight to categories deemed less important. Weighted category average scores were calculated by multiplying the category average scores by the weighting factor associated with the category. The following weighting factors were used for the different categories:

| Category | Weighting Factor |
|---|---|
| Hatchery technology | 8 |
| Nursery technology | 6 |
| Growout technology | 10 |
| Environmental Impacts | 10 |
| Market considerations | 10 |

In cases where no category average score was given (e.g., no hatchery or nursery average scores were calculated for sponge culture), the weighting factors for the hatchery and nursery were added to the weighting factor for the growout. In effect, the growout score received all of the weight associated with the production process. Thus, the average score for the sponge growout was multiplied by a weighting factor of 24 (8 + 6 + 10).

**Composite Scores and Species Rankings**

The resulting weighted ratings for each of the four categories were then summed for each species to yield a composite score. The composite score is a single number that is derived from all of the different criteria that were used to rate the commercial feasibility for a given species. The eight species considered here as candidates for Caribbean aquaculture were ranked based on the composite scores. Species receiving the highest composite scores should have the greatest potential for commercial success.

## RESULTS

The scores given for each of the aquaculture feasibility criteria to the eight candidate species for Caribbean aquaculture are presented in Table 1. This table also shows the average scores for each of the five feasibility categories. Weighed category average scores and composite feasibility scores are presented for each of the eight species in Table 2.

Based on the results of this scoring system, the eight candidate species were ranked according to their feasibility for commercial aquaculture in the Caribbean. Species receiving higher composite feasibility scores should have the greatest potential for commercial success. The species are listed in Table 2 in order of their commercial feasibility ranking.

## DISCUSSION

**Sea Sponge**

Based on the species ranking system, the best candidate for commercial aquaculture in the Caribbean is the sea sponge. While this result might be surprising to some, sponge culture has many favorable attributes. Foremost among these is the low capital cost associated with sponge culture. Adams et al. (1995) estimated the initial capital costs for establishing a 0.4 ha sponge farm to be under $3,000. Operating costs for sponge farming are also very low. Labor is the primary input. Because sponges are filter feeders and no feeding is required, the environmental impact of a sponge farming enterprise would be minimal. The technology for culturing sponges is relatively simple and reliable. The major factor limiting the commercial feasibility of sponge farming is the relatively small market for bath sponges. However, there may be opportunities for culturing sponges for biomedical and pharmaceutical applications (Duckworth 2001).

Sponge farming has potential as a means of providing supplemental income for artesanal fishermen. The low initial investment and operating costs makes entry into sponge farming feasible for individuals with low income. Marketing cooperatives would probably be required for small-scale sponge farmers to gain access to markets.

**Table 1.** Aquaculture feasibility scoring matrix for eight candidate Caribbean aquaculture

| Feasibility Scoring Criteria | Species | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Queen Conch | Spiny Lobster | Marine Shrimp | Grouper | Cobia | Red Drum | Pom-pano | Sponge |
| **Hatchery Technology** | | | | | | | | |
| Maturation capital cost | 4 | NA | 2 | 3 | 3 | 3 | 3 | NA |
| Hatchery capital cost | 3 | NA | 2 | 2 | 2 | 2 | 2 | NA |
| Reliable egg production | 3 | NA | 4 | 2 | 3 | 3 | 3 | NA |
| Larval survival | 3 | NA | 4 | 1 | 2 | 3 | 2 | NA |
| Year-round seed supply | 2 | 2 | 4 | 2 | 3 | 4 | 3 | NA |
| Hatchery labor cost | 3 | NA | 3 | 2 | 2 | 2 | 2 | NA |
| Hatchery energy cost | 3 | NA | 3 | 2 | 2 | 2 | 2 | NA |
| Expected seed cost | 3 | 1 | 3 | 1 | 2 | 2 | 2 | NA |
| **Average Score** | **3.0** | **1.5** | **3.1** | **1.9** | **2.4** | **2.6** | **2.4** | **NA** |
| **Nursery Technology** | | | | | | | | |
| Nursery capital cost | 2 | 3 | 3 | 3 | 3 | 3 | 3 | NA |
| Survival in nursery | 2 | 3 | 3 | 3 | 2 | 3 | 3 | NA |
| Nursery labor cost | 1 | 2 | 3 | 3 | 3 | 3 | 3 | NA |
| Nursery energy cost | 1 | 3 | 3 | 3 | 3 | 3 | 3 | NA |
| Nursery feed cost | 2 | 2 | 3 | 2 | 3 | 3 | 2 | NA |
| **Average Score** | **1.6** | **2.6** | **3** | **2.8** | **2.8** | **3** | **2.8** | **NA** |
| **Growout Technology** | | | | | | | | |
| Growout capital cost | 1 | 3 | 2 | 2 | 3 | 2 | 1 | 4 |
| Survival in growout | 2 | 2 | 3 | 2 | 2 | 3 | 3 | 3 |
| Growout labor cost | 2 | 2 | 3 | 3 | 2 | 3 | 1 | 2 |
| Growout energy cost | 4 | 3 | 3 | 3 | 3 | 3 | 1 | 4 |
| Growout feed cost | 4 | 1 | 3 | 2 | 3 | 3 | 2 | 4 |
| **Average Score** | **2.6** | **2.2** | **2.8** | **2.4** | **2.6** | **2.8** | **1.6** | **3.4** |
| **Environmental Impacts** | | | | | | | | |
| Eutrophication potential | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 4 |
| Habitat impacts | 3 | 3 | 2 | 2 | 3 | 2 | 3 | 4 |
| Natural resource deple- | 4 | 4 | 3 | 3 | 4 | 3 | 3 | 4 |
| Exotic species impacts | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 4 |
| Effect on biodiversity | 3 | 3 | 3 | 3 | 4 | 3 | 4 | 3 |
| Mitigation effectiveness | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 |
| **Average Score** | **3.3** | **3.2** | **2.5** | **2.8** | **3.3** | **2.8** | **3.5** | **3.8** |
| **Market Considerations** | | | | | | | | |
| Processing requirement | 2 | 4 | 4 | 3 | 3 | 3 | 3 | 1 |
| Caribbean product | 4 | 4 | 2 | 4 | 3 | 2 | 3 | 3 |
| Niche market potential | 4 | 4 | 2 | 4 | 3 | 2 | 3 | 2 |
| Size of niche market | 4 | 3 | 4 | 4 | 4 | 2 | 4 | 2 |
| Market competition | 4 | 4 | 2 | 3 | 4 | 3 | 4 | 2 |
| Wholesale Price-Total | 1 | 2 | 2 | 2 | 4 | 1 | 3 | 1 |
| Retail Price-Total Cost | 1 | 4 | 3 | 2 | 4 | 3 | 3 | 2 |
| **Average Score** | **3.0** | **3.5** | **2.5** | **3.2** | **3.7** | **2.2** | **3.3** | **2.0** |

**Table 2.** Weighted feasibility and composite scores for eight candidate Caribbean aquaculture species. The eight species are listed in order of their feasibility ranking, based on composite feasibility scores.

| Species | Hatchery Weighted Average Score | Nursery Weighted Average Score | Growout Weighted Average Score | Environ. Weighted Average Score | Market Weighted Average Score | Composite Feasibility Score |
|---|---|---|---|---|---|---|
| Sponge | 0.0 | 0.0 | 78.2 | 26.8 | 18.6 | 123.6 |
| Cobia | 16.6 | 16.8 | 26.0 | 23.3 | 35.7 | 118.5 |
| Marine Shrimp | 21.9 | 18.0 | 28.0 | 17.5 | 27.1 | 112.5 |
| Queen Conch | 21.0 | 9.6 | 26.0 | 23.3 | 30.0 | 109.9 |
| Red Drum | 18.4 | 18.0 | 28.0 | 19.8 | 22.9 | 107.1 |
| Pompano | 16.6 | 16.8 | 16.0 | 24.5 | 32.9 | 106.8 |
| Spiny Lobster | 10.5 | 15.6 | 22.0 | 22.2 | 35.7 | 106.0 |
| Grouper | 13.1 | 16.8 | 24.0 | 19.8 | 31.4 | 105.2 |

**Cobia**

Cobia received the second highest commercial feasibility ranking. Because of its astonishing growth rate (cobia can grow to 6 kg in one year) and excellent market potential, cobia has tremendous potential as a commercial aquaculture species. Cobia can be grown in ponds (Weirich et al. In press) or in submerged offshore cages (Benetti and Orhun 2002). The cage culture system would offer greater profit potential because the capital and energy costs are much lower than those associated with a pond culture system. In addition, better water quality can be maintained in cages, and the potential for disease outbreaks is likely to be significantly lower than in a pond culture system. Overall production costs for cobia reared in offshore cages are expected to be low, due to the relatively low capital investment requirement per kg of annual production capacity, and low expected FCR (Benetti and Orhun 2002).

The primary constraint for the commercialization of cobia aquaculture is the lack of availability of fingerlings. Any new cobia aquaculture venture would likely have to operate their own hatchery. Hatchery production of cobia fingerlings is technologically feasible (Arnold et al. 2002, Benetti et al. 2003, and Kilduff et al., 2002), but reported survival rates have been low (Schwarz 2004). Supplying enough live feed to the rapidly growing larvae appears to be the biggest challenge. There are environmental concerns related to the cage culture, including the potential for eutrophication of surrounding waters, and escapement of hatchery-reared fish and their impacts on wild populations. Proper site selection is critical to mitigate the pollution potential of these cages. Submerged cages should be situated in locations where the water depth is at least 25 m and currents are between 1.5 – 2.5 km/hr. Cages should also be situated over a sandy bottom, away from any coral reefs or other sensitive habitats.

## Marine Shrimp

The marine shrimp *Litopenaeus vannamei* received the third highest commercial feasibility score. The commercial feasibility of penaeid shrimp culture is well-established. However, the fact that this species is not indigenous to the Caribbean means that a high degree of biosecurity is required to prevent introduction of shrimp or exotic diseases into the wild. A hatchery capable of producing specific pathogen free (SPF) postlarvae would be required to prevent the introduction of shrimp viruses. The technology for production of SPF seedstock using has been described by several authors (Lotz, et al. 1995, Ogle and Lotz 2001, Wyban and Sweeney 1991). The environmental sensitivity of the Caribbean islands and the surrounding oligotrophic marine habitats also presents special problems for a marine shrimp farming operation. Lined ponds would be required to prevent saltwater contamination of freshwater aquifers. Offsite discharges would be eliminated either by managing the system as a Belize-style aerated suspension pond (McIntosh et al. 1999) or by recirculating the effluent from the shrimp ponds through a settling pond and a system of seaweed biofiltration ponds (Van Wyk and Davis Unpubl. report). Zero-exchange production systems have been demonstrated to be commercially feasible but are more capital intensive and require a higher degree of management expertise than traditional extensive and semi-intensive production systems. It is likely that the production costs for a Caribbean shrimp aquaculture venture would be relatively high, due to the high cost of importing the required inputs. Caribbean shrimp producers will need to identify marketing strategies that will allow them to compete with cheaper imported shrimp.

## Queen Conch

Queen conch (*Strombus gigas*) received the fourth highest feasibility score. It is assumed that hatchery, nursery, and growout technology used for queen conch production is the system described in Davis (2000). The past 20 years have witnessed major advances in techniques for egg mass production, larval rearing, induction of metamorphosis, nursery production of juveniles, and growout of juveniles to market size in enclosed off-shore pastures. Although most of the technical problems associated with conch culture have been resolved, conch culture has met with limited commercial success due to the high cost of hatchery and onshore nursery production of juveniles. Conch grow slowly, requiring approximately 12 months to reach a size suitable for stocking in offshore growout pastures (7 - 9 cm shell length). As a result, the labor and energy costs associated with the nursery phase are quite high. Growout to market size in the offshore pastures is also quite lengthy, requiring another 18 months. Predation in the offshore growout can be a major problem. Known predators of queen conch include fish, sharks, rays, octopus, spiny lobsters, crabs, and other gastropods. An exclusion fence is necessary to contain the conch, as well as to exclude predators. While the exclusion fence may effectively exclude pelagic predators, benthic predators must be trapped and removed. Conch growout requires enclosing large areas. At the typical stocking density (1 conch/$m^2$), one hectare is required for every 10,000 juveniles planted. The environmental impact of excluding pelagic predators from such large areas is an issue that needs to be addressed. From a market standpoint, the demand for queen conch is excellent. However, due to the high production costs, farm-raised conch are more expensive than wild-caught conch. A conch farm in the Turks and Caicos has developed markets for smaller conch (< 9 cm SL), which are cheaper to produce since the offshore growout phase is eliminated. Wild conch in this size range are not available in the marketplace because they are difficult to find in significant quantities.

**Red Drum**

Red drum received the fifth highest commercial feasibility ranking. From a technical standpoint, red drum culture is well-established. Red drum can be induced to spawn continuously over a period of months or even years using temperature and photoperiod controls (Arnold 1988). Fingerling production can be carried out either intensively in tanks (Holt et al. 1990) or extensively in ponds (Davis 1990a). In the U.S. commercial growout of red drum is usually carried out in ponds, with juveniles reaching a market size of 1 - 1.5 kg in about 16 months (Davis 1990b). The nutritional requirements of red drum are relatively well-known, and suitable growout diets are commercially available. A red drum pond culture operation in the Caribbean would have to be managed to minimize discharge of untreated effluents.

Despite the technological feasibility of red drum culture, there are only a few commercial red drum aquaculture facilities in operation. The reason for this is that the commercial red drum fisheries are supplying enough fish to meet the current demand. As a result, the wholesale market price for whole red drum is very low relative to the cost of aquacultural production of red drum. However, if markets can be identified that will bring significantly higher prices, then aquaculture of red drum could be commercially viable.

**Florida Pompano**

Florida pompano has attracted considerable attention as a candidate species for aquaculture. Because of its delicate flavor, pompano has a very high market price. In addition, Florida pompano grow very fast, reaching market size (1.5 lbs) in one year or less. The technology required for spawning, larval-rearing and nursery production (Hoff et al. 1978) of this species is similar to that required for other marine finfish, such as red drum. While there is certainly room for improvement in this technology, it does not represent a major obstacle to commercial aquaculture production of this species. Pompano are susceptible to infestations by external parasites, which can cause high rates of mortality. Recirculating tank-based culture systems appear to be the best system choice for pompano because parasites can be controlled with ultraviolet filtration and/or ozone. However, the capital and production costs of recirculating production system are much higher than for cage or pond production systems. Another barrier to the development of a successful commercial pompano enterprise is insufficient knowledge about the nutritional requirements for this species. Very high feed conversion ratios have been reported for pompano reared on high protein, high energy diets (Lazo et al. 1998).

**Spiny Lobster**

Spiny lobster (*Panulirus argus*) was ranked seventh in terms of its commercial feasibility. Entrepreneurs have long been interested in culturing spiny lobsters due to the high market demand, and concerns about the sustainability of the commercial fishery. However, aquaculture of spiny lobsters has been limited by the lengthy, difficult larval rearing process, lack of suitable growout diets, and the high cost of land-based culture systems. In recent years, the development of techniques to collect seedstock (pueruli) from the wild (Phillips and Booth 1994), and the demonstration of the potential for growing spiny lobsters in cages (Jeffs and James 2001) has resulted in renewed interest in Caribbean spiny lobster culture (Jeffs and Davis 2003). Nevertheless, the reliability of collecting pueruli from the wild in sufficient numbers to support a commercial aquaculture operation has yet to be demonstrated. While cage culture appears to hold promise as a production system, information on the performance of Caribbean spiny lobsters in floating cages is still lacking. Suitable feeds for spiny lobsters must also be developed before this species can be cultured commercially.

**Nassau Grouper**

Nassau grouper (*Epinephelus striatus*) received the lowest commercial feasibility score. Like queen conch and the Caribbean spiny lobster, many people are interested in culturing Nassau grouper because of its strong Caribbean identity and because the wild population has been over-exploited. Unfortunately, the technology for culturing Nassau grouper has not yet been demonstrated to be commercially viable. The principle constraint is the difficulty in producing grouper fingerlings in commercial quantities. Techniques for maturation and spawning of Nassau grouper (Tucker 1999) are similar to those employed for other marine finfish. Grouper can be induced to spawn naturally, but hormonal induction of spawning has thus far proven more reliable. The main barrier to a successful grouper aquaculture enterprise lies in the larval rearing phase of production. Grouper are among the most difficult marine fish species to rear in the hatchery due to the fragility of the larvae and their requirement for extremely small prey items (Tucker 1999). In the nursery phase, cannibalism is a major concern. Due to the lack of fingerlings, few growout production trials have been conducted with Nassau grouper. In Asia, other grouper species have been successfully grown out in ponds and in floating sea cages. Research is needed to identify the optimal production system for Nassau grouper.

## CONCLUSION

A scoring system such as reported here can be a useful tool to help rank the commercial aquaculture potential of multiple aquaculture species. The scoring system is a means of systematically examining the many factors that affect the feasibility of culturing a species, including technological, environmental and economic and marketing factors. Close examination of the scores received in the different categories can help illuminate both the strengths and weaknesses of a particular species as an aquaculture candidate.

Our analysis indicates that, of the species considered in this study, sea sponge, cobia, and marine shrimp have the best potential for commercial aquaculture development in the Caribbean. However, the rankings presented here are not the final word. A scoring system similar to the one presented here can help narrow the field of candidate species, especially if scores are adjusted to reflect the realities of a particular project. Ultimately, the decision whether to proceed with a given project should be based on a thorough feasibility study that takes into account location, site characteristics, available technologies, financial and human resources, environmental impacts, market opportunities, and risk factors.

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# Regulatory Policies to Promote the Development of Sustainable Aquaculture in the Caribbean

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ABSTRACT

The worldwide growth of aquaculture over the last two decades has generated a lot of interest in the development of aquaculture in the Caribbean nations. However, unregulated aquaculture development can result in environmental degradation, negative impacts of exotic species on native species, and resource conflicts. The creation of national aquaculture plans by Caribbean governments is a prerequisite for the development of sustainable aquaculture industries in the Caribbean. The national aquaculture plan should identify the national goals for aquaculture development and actions for achieving those goals. Rules for regulating aquaculture development must be established and the lead regulatory agency must be identified. Policies for permitting and monitoring aquaculture enterprises should be clearly defined. By providing a framework for orderly development of aquaculture, governments can create an environment in which aquaculture can flourish in the Caribbean while protecting the public interest.

KEY WORDS: Sustainable aquaculture, Policies, Regulations

# Polítas Reguladoras para Promover el Desarrollo de la Acuacultura Sostenible en el Caribe

El crecimiento mundial de acuicultura en la ultimas veinte años ha generado bastante interés en el desarrollo de acuicultura en las naciónes Caribes. Sin embargo, el desarrollo de acuicultura sin regulación pueda resultar en degradación ambiental, impactos negativos de especies exóticas contra las especies nativas, y conflictos de recursos. Creación de planes nacionales de acuicultura por los gobiernos Caribes es un prerrequisito para el desarrollo sostenible de industrias aquicolas en el Caribe. El plan nacional de acuicultura debe identificar las metas nacionales para el desarrollo de acuicultura y las acciones necesario para realizar estas metas. Se debe establecer as reglas para regular el desarrollo de acuicultura y identificar cuál agencia tiene responsabilidad principal para su regulación.

PALABRAS CLAVES: Acuacultura sostenible, políticas, regulaciones

## INTRODUCTION

The worldwide growth of aquaculture over the last two decades has generated a lot of interest in the development of aquaculture in the Caribbean nations. A successful and sustainable aquaculture industry would offer many benefits to the Caribbean countries. Aquaculture would provide desirable seafood products for island populations and would reduce dependence upon imported seafood products to meet the demands of the tourist industry. Aquaculture production could help relieve fishing pressure on threatened species, and might also provide a means of enhancing stocks of depleted populations. As a new industry, aquaculture would provide additional diversity to local economies and would offer new employment opportunities. Aquaculture also offers the potential for Caribbean nations to increase their export income.

However, poorly planned and unregulated aquaculture development can result in a number of problems, including resource conflicts, introduction of exotic species and diseases, genetic impacts on native species, and environmental degradation. The fragile island ecosystems and oligotrophic offshore waters present special challenges to Caribbean aquaculture project planners due to their sensitivity to nutrient discharges and other potential impacts of aquaculture production activities.

Governmental regulation of aquaculture is necessary to maximize the potential benefits and minimize the potential negative consequences of aquaculture development. Governments have an essential role to play in creating an environment in which aquaculture can flourish while protecting the public interest. The goal of regulating aquaculture is to provide an orderly and sustainable environment in which aquaculture can be developed (Ridler and Hishamunda 2001). By providing a framework for orderly development of aquaculture, regulations reduce negative externalities such as pollution or conflicts over water rights, land rights, and seabed areas caused by open-access property regimes.

In countries where there has been little effort to form a national aquaculture development policy, there has been little success in terms of growth of aquaculture (Wijkstrom 2001). In the interest of promoting sustainable aquaculture development, it is essential that each Caribbean nation develops an overall aquaculture policy. The aquaculture policy should be clearly stated in a national aquaculture plan. This plan will provide the basis for aquaculture legislation, and regulation. While national aquaculture policies will vary from one country to the next, there are essential elements that should be contained in each aquaculture plan:

i) A definition aquaculture,
ii) Designation of the regulatory authority (or authorities) and a description of their responsibilities,
iii) Identification of the rules that will govern the development of aquaculture,
iv) A description of how aquaculture activities will be permitted and monitored, and how rules will be enforced, and
v) Identification of the government's strategies for supporting and promoting aquaculture development.

### Defining Aquaculture

The first step in creating a legal framework for regulating aquaculture is to provide a clear definition of aquaculture and to distinguish it from fishing activities. An important requirement for aquaculture is the principle of ownership of the stocks being cultivated (Pillay 1977). The FAO (1997) provides an unambiguous legal definition of aquaculture that firmly establishes this principle: "Aquaculture is the farming of aquatic organisms, including fish, mollusks, crustaceans, and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, and protection from predators. Farming also implies individual or corporate ownership of the stock being cultivated." The principle of ownership distinguishes aquaculture stocks from fisheries stocks, which are exploitable by the public as a common property resource. Unless government regulations clearly establish the principle of property rights of the aquaculturist to the cultured organisms, few entrepreneurs will be willing to accept the risk of starting an aquaculture business (DeVoe 1991).

### Creation of a Regulatory Authority

An essential step in developing a sustainable aquaculture industry is to identify which agency will have regulatory authority over aquaculture. Because aquaculture impacts a wide variety of resources, aquaculture regulation may involve multiple government agencies. However, the regulatory process should only be as complex as necessary to adequately balance the needs of the government and its citizens (Devoe 1991). A cumbersome regulatory bureaucracy may become overbearing and burdensome, stifling aquaculture development. To streamline the regulatory process, governments should centralize the regulation of aquaculture by creating or designating a lead regulatory agency (DeVoe 1991). This agency would have primary responsibility for all aspects of aquaculture policy, including permitting, enforcement of regulations, and aquaculture industry promotion. The lead regulatory agency should be able to provide clear and complete information about the permitting and regulatory processes to applicants for aquaculture permits (Van Houtte 2001). An effective strategy for streamlining the permitting process is to unite applications for the permits required by the various regulatory bodies into a single universal aquaculture permit application. In the U.S., many state governments, including Florida (FDACS 2002) and Mississippi (Mississippi Code 2000), have adopted one-stop permitting for aquaculture. The regulatory authority might be placed in the Department of Agriculture, since aquaculture is so similar to farming domesticated terrestrial crops and animals.

### Establishment of Rules Governing Aquaculture

The purpose of governmental regulation of aquaculture is to encourage sustainable development of aquaculture while protecting the public interest. In fact, the concept of sustainability implies a balance of the needs of industry and the needs of society. The characteristics of sustainable aquaculture have been discussed by several authors (Tisdell 1996, Corbin and Young 1997, Ridler and Hishamunda 2001). To be sustainable, commercial aquaculture should:

i) Generate a stable return on investment competitive with similar alternate activities,
ii) Conserve natural resources and biodiversity,
iii) Minimize environmental degradation and pollution,
iv) Utilize technologies appropriate for the species and the site,
v) Minimize social disruptions and conflicts, and
vi) Provide for community needs

The rules and regulations governing aquaculture should be carefully crafted to promote the goal of sustainable aquaculture. Traditionally, environmental regulation has been enforced using a "command and control" approach (Van Houtte 2001). With this approach, a set of codified laws establishes environmental standards that must be met and penalties for failure to meet the established standards. Usually the regulation does not mandate the technology that must be used to achieve compliance (Boyd 2003). This approach can be very effective, but only if adequate resources are available for enforcement (Van Houtte 2001, Boyd 2003).

A different approach to regulation is to require that aquaculture businesses adopt specific practices called Best Management Practices (BMPs) designed to minimize the environmental impacts of their activities. A BMP is considered to be the best and most practical method available for minimizing a particular environmental impact while still allowing production to be conducted in an economically efficient manner (Boyd 2003). BMPs are frequently developed by industry associations and stakeholders, then adopted by producers on a voluntary basis. However, in recent years some government regulatory agencies have required adoption of BMPs as part of the permit or licensing conditions (Bay 1995, FDACS 2002). Combining BMPs with required environmental standards may be the most effective regulatory approach to minimize the environmental impacts of aquaculture. With this combined approach, the environmental standard establishes the target, and the BMP establishes effective strategies for reaching the target.

Different sets of BMPs are not necessary for every aquaculture species. However, different types of production systems do require different sets of BMPs. For example, different sets of BMPs would be required for pond production systems, recirculating tank systems, flow through tank systems, and cage culture systems. The BMPs should address a full range of aquaculture activities, including:

i) Site selection,
ii) Facility construction,
iii) Water resource utilization,
iv) Effluent management and treatment,
v) Feeding practices,
vi) Chemical usage,
vii) Disease management,
viii) Genetic diversity of cultured stocks,
ix) Collection of wild animals for broodstock and/or seedstock,
x) Release of cultured organisms,

xi) Introduction and culture of exotic species,
xii) Procedures for natural disasters, and
xiii) Clean up procedures when closing the business.

Ideally, BMPs should be developed with stakeholder involvement (Sen 2001), including the different government regulatory agencies, aquaculture industry, aquaculture researchers, and environmental groups. It is not necessary to create the BMPs from scratch, as there are some very good existing BMPs that can serve as models. The Florida aquaculture BMP (FDACS 2002) was one of the first aquaculture BMP to be adopted into law by a state government, and has served as a model for other government BMPs. The U.S. Environmental Protection Agency (EPA) has drafted a set of BMPs (EPA 2002) to provide technical guidance for aquaculture production facilities to meet the requirements of EPA effluent limitations standards. The EPA BMPs are designed for recirculating systems, flow-through systems, and net-pen and cage culture systems.

**Permitting and Monitoring of Aquaculture Activities**

The aquaculture permit is the most effective instrument available to regulators for guiding the development of the aquaculture industry towards sustainability. The power to grant or decline license applications provides a means for governments to prevent undesirable aquaculture projects from being initiated (Howarth 1995). In addition, the permitting process gives the government a mechanism for placing conditions on the establishment of an aquaculture business. The permit may give the government some control over many critical aspects of aquaculture development, including where aquaculture can be practiced, what species can be cultured, what technologies are acceptable, and how potential environmental impacts will be mitigated. Requiring that aquaculture operations adhere to specified sets of BMPs as a permit condition should lessen the environmental impacts of aquaculture development.

Incorporation of Environmental Impact Assessments (EIAs) into the permitting process is another effective way of making sure that the environmental and socioeconomic consequences of an aquaculture project are identified early in the planning process, thus enabling proper environmental management measures to be incorporated into the project design and management (Phillips 1998, Pardee and Davis 2006). Such measures ultimately lead to more sustainable aquaculture development. The FAO (FAO Fisheries Department 1997) recognized the importance of EIAs and specifically recommended that governments should take measures to assure that environmental impact assessments are undertaken prior to establishment of aquaculture farms. However, the cost of conducting an EIA may be prohibitive for smaller scale aquaculture developments. Many governments exempt small scale projects from EIA requirements, reasoning that small scale projects are unlikely to have significant impacts on the environment (Corbin and Young 1997). The focus of EIAs on the environmental impact of a single enterprise may overlook the potential cumulative effects of many small-scale farms concentrated in one area. Problems of this sort may best be addressed through an integrated coastal management approach (Phillips 1998).

Land tenure and water rights are key issues that must be addressed and resolved during the permitting process (Devoe 1991). This is especially true for projects in leased public areas where use conflicts may exist. If not, the aquaculturist faces an unstable and riskier environment which could undermine the viability of the operation. Leases should be of suitable size and duration to attract the industry. The leasing program should convey the necessary degree of exclusivity to minimize the risks of pollution, vandalism, theft, and other forms of encroachment, while protecting the rights of the public.

The process for reviewing and approving aquaculture permit applications should be as quick and transparent as possible. This reduces the potential for corruption and increases the likelihood of investment (Ridler and Hishamunda 2001). Transparency is created by publishing the details of the permit application review process. Deadlines should be imposed and each agency involved in the review process should screen only within its area of competence and jurisdiction.

The permitting process is only the first step in controlling potential negative impacts of aquaculture development. An effective framework for monitoring aquaculture activities and enforcement of the regulations is essential to ensure compliance with the conditions imposed by the aquaculture permit. In fact, weak enforcement, rather than the absence of regulations, may be the primary factor leading to unsustainable practices in aquaculture (FAO 1999). Operation of aquaculture enterprises without a permit or failure to comply with the conditions imposed by the aquaculture permit should be made a legal offence (Howarth 1995). Penalties for non-compliance may include warnings, fines, and revocation of the permit. Compliance is generally monitored by the lead regulatory agency through a combination of required reports, site inspections, and response to complaints from the public. Monitoring and enforcement of aquaculture regulations can be time-consuming and expensive. Therefore, the regulatory framework and monitoring systems should be kept as simple as possible.

## Policies to Promote Sustainable Aquaculture Development

In most countries where successful aquaculture industries have developed, governments have implemented a variety of policies to stimulate aquaculture development. The following are some policies which can help stimulate aquaculture development.

*Aquaculture leasing policies* — Some types of mariculture projects by their very nature can only use bottom leases to culture organisms, such as clams and queen conch. Others such, as seaweed farms and cage culture of fish, need to use the water column. These types of aquaculture can only develop if governments create leasing programs to grant aquaculturist usage rights to publicly owned offshore areas. Coastal and offshore areas that are suitable for aquaculture should be identified, taking into account environmental sensitivity and potential conflicts with other uses. These areas can be zoned for aquaculture development as part of an overall integrated coastal management plan.

*Investment incentives* — A variety of policies can help stimulate investment in aquaculture projects. Many of the raw ingredients for aquaculture production, such as capital equipment items and feed, must be imported. Governments can help lower the cost of these items by waiving import duties for aquaculture businesses. Tax breaks can be offered to businesses for hiring local workers or for generating export income. Grants and low-interest loans can also be effective in stimulating aquaculture development.

*Public support of aquaculture research* — The rapid growth of the aquaculture industry over the last thirty years would never have happened without government support for applied aquaculture research. Aquaculture research is expensive, and new businesses cannot afford to conduct their own research programs. Aquaculture has flourished in countries such as Japan, Chile, Norway, and Thailand where governments have supported research to address industry needs (Corbin and Young 1997). Publicly funded research should focus on issues related to the sustainability of aquaculture.

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# Integrating Aquaculture into Caribbean Development: Environmental Impact Assessment

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ABSTRACT

An Environmental Impact Assessment (EIA) is a multifaceted review process that involves consideration of all aspects of development activities and how that development will affect and blend into the existing environment. It also acts as a link between the concerns of governmental bodies/regulatory agencies and the needs and priorities of the developer. For aquaculture development, an EIA can also be a tool in discerning the most appropriate species, system design, and management practices for ensuring that the environment needed for a successful culture venture remains sustainable.

Some of the unique environmental concerns faced by aquaculturists in the Caribbean include limited freshwater supply, sensitive island habitats, oligotrophic waters, and coral reefs. Therefore, when reviewing the environmental impact issues for aquaculture development in the Caribbean, it is important to cover potential habitat loss, resource depletion, introduction of non-native species, and eutrophication from nutrient waste. Developing appropriate Terms of Reference along with mitigation and monitoring procedures will aid in governmental guidelines and regulatory parameters, while incorporating the aquaculture developer's needs for production. An environmental matrix that incorporates the culture species and systems considerations can be used for evaluating aquaculture development environmental impact issues, while providing an assessment guide for the government and the aquaculture developer.

KEY WORDS: Environmental impact assessment, Caribbean aquaculture

# Acuacultura que Integra en el Desarrollo del Caribe: Impacto en el Ambiente

Un gravamen del impacto al ambiente (EIA), es un proceso de la revisión de facetas multiples que implica la consideración de todos los aspectos de las actividades del desarrollo y cómo ese desarrollo afectará y entremezclará en el ambiente existente. También actúa como acoplamiento entre las preocupaciones de las agencias gubernamentales y de las necesidades y las prioridades de ésos que desarrollan un negocio de la acuacultura.

Para el desarrollo de la acuacultura, un EIA también puede estar de uso en la determinación del la mayoría de la especie apropiada, el diseño del sistema y las prácticas de gerencia más apropiados para asegurarse de que el ambiente necesitó para un restos acertado de la empresa de la cultura sostenible.

Algunas de las preocupaciones ambientales por el agricultor en el Caribe incluyen agua dulce limitada, habitat sensibles de la isla, oligotrophic aguas, y filones coralinos. Por lo tanto, cuando el repaso de las consecuencias para el medio ambiente publica para el desarrollo de la acuacultura en el Caribe es importante cubrir pérdida potencial del habitat, el agotamiento del recurso, la introducción de la especie extranjera, y el eutrophication de la basura del alimento. Establecer Términos de la Referencia junto con la mitigación y de los procedimientos de la supervisión ayudarán en pautas gubernamentales y parámetros reguladores, mientras que incorporan las necesidades de produccion de el agricultor de acuacultura. Una matriz ambiental que incorpora la especie de la cultura y las consideraciones de los sistemas se pueden utilizar para evaluar el desarrollo de la acuacultura que las consecuencias para el medio ambiente publican, mientras que proporciona a una guía del gravamen para el gobierno y al revelador de la acuacultura.

PALABRAS CLAVES: Acuacultura, desarrollo del Caribe, impacto en el ambiente

## INTRODUCTION

Environmental Impact Assessments (EIA) are typically used as part of the government evaluation process in determining whether a given development is suitable for a particular area. This multifaceted review involves consideration of all aspects of a development's activities including how the development will affect the existing environment, whether it complies with local planning and regulatory measures, and whether the socio-economic benefits are substantial enough to warrant the changes made by the development. In short, will the particular development maximize the potential use of a given resource (whether land, sea, harvestable product, human resource, or otherwise) in a sustainable manner.

For aquaculture related developments, there are a number of specific issues that should be addressed within the EIA. These include type of culture species, source of seed stock, site selection, rearing system, nutrition/feed sources, diseases, economics, and marketing. These issues are also the same concerns of any serious aquaculture developer. Depending upon the above parameters, some of the impacts to the marine and terrestrial environments can include habitat loss/degradation, changes in biodiversity, introduction of species, water quality problems, and natural resource depletion. Social impacts can be positive including creation of employment opportunities, enhanced infrastructures or services, and better utilization of the labor resource pool. Monitoring, management and mitigation measures may amend for some impact issues, or lead to alternative plans. Defining the parameters, issues, impacts and mitigation measures in a qualitative / quantitative summary aids both the developer, EIA specialist and the decision maker in addressing issues and refining appropriate alternatives for sustainable development.

## ENVIRONMENTAL IMPACT ASSESSMENTS – A BRIEF REVIEW

In most countries, a potential developer is asked to submit an EIA in the initial stages of the development application process. This EIA is usually done by a team of scientists approved by the government. The governing body in charge of this process then issues a Terms of Reference (TOR) to the EIA team for that development. The TOR acts as a guideline and format for the issues that need to be addressed in the EIA.

A typical TOR includes:

i) Executive Summary,
ii) Introduction that outlines areas of assessment, scoping, and methodology,
iii) Description of the Environment to be Affected,
iv) Description of the Development,
v) Potential Impacts of the Development (Marine, Terrestrial and Social),
vi) Monitoring, Management, and Mitigation Measures,
vii) Alternatives/Recommendations,
viii) Conclusion,
ix) Appendices including reference materials, CV's of EIA team members, and other relevant info.

The EIA team scientists are responsible for collecting baseline data on the existing environment. Both quantitative and qualitative analyses are used to describe the immediate and surrounding areas under consideration for development. The three main sections for assessment are Marine, Terrestrial and Social. The Marine and Terrestrial sections are then further divided into descriptions of the Physical and Biological/Ecological Environments. The social sections typically include current demographic information, available infrastructure, and human resource components.

The Terrestrial Physical aspects would include topography, hydrology, climatic and other physical characteristics of the site, including inland water/ wetland features. The Marine Physical would include information on coastal and oceanic parameters such as winds, tides, currents, waves, bathymetry, and water quality. The Biological/Ecological aspects of both Terrestrial and Marine would include quantitative analysis of the existing flora and fauna with particular emphasis on endemics, rare, commercial or endangered species, ecologically sensitive habitats, and conservation/preservation areas.

A description of the development under consideration then follows for reference within the potential impact section. This information is usually provided by the developer for inclusion within the EIA and should include construction and operation phase activities with expected time frames. Since almost all type of developments will have both construction and operation phases, it is often useful to delineate between the two when addressing associated impacts. The construction phase often deals with acute physical and biological changes with social influxes of employment and infrastructure needs not associated with the ongoing operations phase.

Impacts can then be addressed separately based on the particular phase and the type of activity involved. Physical impacts may include changes to the topography, hydrology or other terrestrial features, or in the case of marine, littoral changes, or even aesthetics of an area. Biological/Ecological impacts for terrestrial and marine can include habitat degradation, loss, fragmentation, isolation; reduced species population or changes in biodiversity; pollution of air, water and land via specific factors such as sedimentation and run-off of sewage, fresh and grey water or hazardous chemicals; increased use of resources/ resource depletion. Social impacts may include changes to the demographics of an area, employment and infrastructure impacts, and such things as stress bearing levels on local recreation areas. Impacts are often described in terms of whether they may be cumulative or synergistic, positive or negative, direct or indirect, immediate or long-term, and unavoidable or irreversible.

All of this information can then be used to identify areas where monitoring, management or mitigation is needed or in some cases where alternatives / recommendations may be suggested. Where possible, impacts should be defined in financial terms showing losses/gains for comparison. Otherwise, a summarization of the potential impacts, ranking of their estimated level of impact (eg., positive/negative-- high, medium, low,) is often helpful to decision makers in their review process. These findings then can be compiled for short review in an Executive Summary and Conclusions.

## ISSUES/CONFLICTS FOR AQUACULTURE DEVELOPMENT

All potential aquaculture developments face the same set of parameters when establishing their plans. What species to culture and where? What type of system to use, and where will the seed stock come from? What are the nutritional requirements, is a feed source readily available, and what are the disease concerns? Finally, what and where are the markets, and is this whole venture going to be economically viable? These same criteria are also questions when evaluating an aquaculture venture from an EIA standpoint.

Identifying an appropriate ***culture species*** that will grow well in a given area is a chief priority of the developer, but is cause for concern if the species is non-native and has the potential to become introduced. Although rearing systems and culture techniques may alleviate the problem, introduction of species, particularly in small island environments, is of grave concern.

The ***site selection*** process for the developer usually incorporates such factors as water accessibility, soil suitability, access to needed infrastructure, security, and real estate values. From another viewpoint, government would want to ensure that there are no conflicts with other developments in the area, particularly in coastal regions, where often high-dollar tourism development may pose more opportunities to the local economy. For offshore culture systems, there may be conflicts with usage of the "queen's bottom" where navigation / recreation for the general populace is an issue or possibly overlap with conservation/preservation areas. Both onshore and offshore ventures need to take into account any environmentally sensitive habitats, such as coral reefs, mangroves, seagrass beds, wetlands, and salinas. As island biogeography dictates, island ecosystems are often rife with "bio-hotspots" where endemics abound and preservation of this genetic biodiversity is a chief concern.

Source of reliable ***seed stock*** is another culture parameter that has to be addressed in every business plan. If seed is derived from local natural sources, the government must ensure that it does not conflict with local fisheries. Proof of "biological neutrality", stock enhancement or "put back programs", may be needed to mitigate for taking from local reserves.

The type of ***rearing system*** is also a major constituent in the development plan. Is it intensive or extensive culture, open or closed system, land or sea based or a combination of all? For impact evaluations, the primary concerns would be water sources and effluent controls. Well designed systems with frequent monitoring and good management plans are necessary for both the viability of the venture as well as to ensure the sustainability of the environment.

***Nutritional*** requirements of the candidate species and the availability of the feed source is another major consideration for the aquaculturist. Negative implications, again, include effluent disposal and the threat of eutrophication in surrounding areas. A positive attribute is if local fisheries products or by-products can be utilized. ***Disease*** introduction is another problem for consideration, as well as the use of antibiotics in feed and/or water resources.

Overlaying all culture components is the need for economic viability of the operation. Having a successful development is a priority, in particular for small island governing agencies, where land and resources are limited and must be utilized to their maximum potentials. Realistic business plans with good market potentials for local consumption or export, are important issues for consideration by both parties. Socio-economic impacts are often positive with the creation of employment opportunities and training, as long as it does not take away or compete with other local enterprises or traditional means. Other impacts may include increased use or enhancement of existing infrastructure, expansion of local markets, and opportunities or competition of the same.

## INTEGRATING AQUACULTURE INTO ENVIRONMENTAL IMPACT ASSESSMENTS

Integrating aquaculture into the EIA process can most easily be accomplished by categorizing the issues into the areas of potential impact. In doing so, one can more clearly define the issues/conflicts and potential losses and gains associated. These can then be quantified for comparison with other developmental activities or alternatives to the project design. Table 1 summarizes the aquaculture parameters, issues/conflicts and the associated impacts/risks for each. This section deals with operation phase impacts (not construction phase) only for aquaculture impacts.

The evaluation can be expanded to include whether the impacts are cumulative or synergistic, positive or negative, direct or indirect, immediate or long-term, and unavoidable or irreversible. Monitoring, management, and mitigation measures also need to be evaluated in terms of reducing impact implications and levels. A more complete overall analysis would include these measures and differentiate between impact levels for both positive and negative impacts and whether they can be considered as high, medium or low impacts. The positive and negative impact levels can also be given numeric values for a final tally of overall impacts when comparing differing scenarios.

Table 2 illustrates a hypothetical aquaculture scenario where spiny lobsters are to be grown in cages offshore. The site chosen is in a remote area with few employment opportunities, yet has seagrass beds in the culture site and reefs nearby, posing risk and degradation to sensitive vital habitats. Seed will have to be taken from the wild but a put-back program is planned. By-products from the local fishery will be used for a feed source. Effluent control could definitely pose problems, but strict monitoring protocols will be in place. Also, the economic viability is still uncertain, so plans are to begin with a pilot scale project that can be easily removed or expanded if it is successful. Employment opportunities and enhancement of local infrastructure is necessary to begin the project.

In evaluating this scenario, it is obvious there are a number of risks involved. Probable habitat degradation and loss, possibly increased effluent problems, with a combined risk of non-proven economic viability. Monitoring and mitigation plans do aid in reducing these risks, i.e. starting with a pilot scale venture to minimize expected impacts with the opportunity of rectifying potential problems (e.g., effluent controls) as they come on line. It is at this point that the EIA specialist may propose further recommendations / alternatives to reduce impacts. In this scenario, the specialist may recommend to the developer and government that a cage rotation management plan be implemented to help reduce deterioration of seagrass beds due to shading, and that the offshore site be moved further from the nearby coral reefs with a 1:1 habitat restoration plan for mitigating losses.

Another scenario, shown in Table 3, examines impacts for shrimp culture in ponds. In this plan, the species of shrimp used are non-native, yet other wild species of shrimp exist in the area posing potential introduction of species and possible disease risks. The site for the pond facility is already impacted with non-endemics, but a freshwater source is needed for diluting the saltwater systems an is from a local limited groundwater supply. Effluent disposal is also a problem and could possibly contaminate the groundwater supply if not properly handled. All seed and feed is imported, but the economic viability is good and easily supports import costs. There are a few employment opportunities, some local market competition with expansion into exports viable, but will add stress to local infrastructure. This scenario also has a number of potential impact problems, but with a few positive gains. Recommendations / alternatives could further reduce those impact risks; for instance, consideration of a closed recirculating system to minimize introduction of species and disease potentials, as well as more complete effluent control.

**Table 1.** Aquaculture Parameters, Issues and Associated Impacts

| Aquaculture Parameter | Issue/Conflict | Impact/Risk |
|---|---|---|
| Species Selection | Native or non -introduction of species | Reduced species population -changes in biodiversity |
| Site Selection | Conflicts with other development<br>Use of common land/water<br>Use of conservation area | Habitat loss, degradation, fragmentation, isolation<br>Biodiversity implications if in areas of endemics<br>Social implications if in conflict with other user groups |
| Seed Source | Conflict with fishery resources or balance of natural systems | Reduced species population –changes in biodiversity |
| Rearing System | Competition for water resources<br>Water Quality -effluent disposal | Increased use of resource – resource depletion<br>Pollution of water, land |
| Nutrition/Feed | Water Quality – effluent disposal<br>Positive use of local by-products | Pollution of water, land |
| Disease | Introduction of disease to natural populations<br>Use of antibiotics or other treatments | Reduced species population –changes in biodiversity<br>Pollution of water, land |
| Economics/ Market | Viability for sustainability<br>Employment opportunities<br>Local or export potentials<br>Staff/labor force<br>Infrastructure needs | Appropriate use of resources<br>Enhance and expand local economy<br>Changes in demographics<br>Increases in infrastructure or over utilization of existing |

Table 2. Aquaculture Impact Scenario 1- Spiny Lobster in Cages

| Parameter | Criteria / Issue | Monitoring/Mitigation | Impact Level |
|---|---|---|---|
| Species | Spiny Lobster - native | No intro of species | 0 |
| Site Selection | Primarily offshore<br>Remote area<br>Nearby reefs<br>Over seagrasses | No competition for land or sea space<br>Risk habitat loss/ degradation<br>Probable Habitat loss/ degradation | 0<br><br>-1<br>-2 |
| Seed Source | Collect local pu-erulus | Competes with local fishery<br>Plan put back program | -1<br>+1 |
| Rearing System | Cages/effluent control | Monitoring Plan | -1 |
| Nutrition/Feed | Local by-products<br>Effluent Control | Pos use of by-products<br>Monitoring Plan | +1<br>-1 |
| Disease | Not known in cul-ture | Monitor | -1 |
| Economics/Market | Viability unproven<br>Market – export whole live<br>Employment for depressed area<br>Enhance local infrastructure | Pilot scale first-easily re-moved<br>No compete/expands mar-ket<br>Need Employment<br>Need Enhanced Infra | 0<br>+1<br>+1<br>+1 |
| Totals | | | -7/+5 |

Table 3. Aquaculture Impact Scenario 2- Shrimp Culture in Ponds

| Parameter | Criteria / Issue | Monitoring/Mitigation | Impact Level |
|---|---|---|---|
| Species | Shrimp -introduced | Risk intro of species | -1 |
| Site Selection | Land already im-pacted<br>Freshwater from local source | No bio impacts<br>Risk resource use prob-lems | 0<br>-1 |
| Seed Source | Import | No bio impacts | 0 |
| Rearing System | Pond culture | Effluent control/disposal–monitoring | -1 |
| Nutrition/Feed | Import Feeds | No compete<br>Effluent control–monitoring | -1 |
| Disease | Several | Risk intro of disease to local | -1 |
| Economics/Market | Viability Proven<br>Market – local and export<br>Employment<br>Use local infra-structure | Positive economics<br>Competes local but ex-pands export<br>Positive<br>Strain on local infrastruc-ture | +1<br>0<br><br>+1<br>-1 |
| Totals | | | -6/+2 |

If the two scenarios were compared as they are, it would appear that even though there are more risks for the spiny lobster culture (-7), there are also more gains (+5). But unfortunately, not all scenarios are as simplistic and straightforward as these, nor are environmental and economic issues given the same weight in priority in most cases. Rather, a combination of needs and other interests (e.g., a 5 star resort at the site) will weigh into the balance. But by performing a complete EIA with thorough impact analysis, both the aquaculturists and approving agencies can better define the issues and impacts with opportunities to make adjustments or mitigate, while weighing the hazards and benefits to both.

## CONCLUDING REMARKS

To responsibly integrate aquaculture into the Caribbean, guidelines and protocols should be established that protect both the environment and the communities that rely upon it. The Environmental Impact Assessment process technically evaluates the pros and cons of differing developmental activities and is one way in which aquaculture developments can be responsibly addressed. The information detailed above summarizes the EIA process, attempts to pinpoint issues and impacts specific to aquaculture development and, describes a method for evaluation in an effort to guide both developer and decision maker in understanding and assessing the aquaculture development's potential benefits and losses.

Most aquaculture endeavors rely upon a healthy environment to be productive and thereby economically viable. Government and regulatory agencies are also seeking to achieve a healthy economy without over-utilization of their resources. Unlike many other types of developments, in aquaculture both the developer and decision maker are striving for a balance between economic and environmental health, which in itself can be considered a positive and beneficial impact.

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# Effects of Diet and Sex Ratio on the Reproductive Output of the Florida fighting conch, *Strombus alatus*

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ABSTRACT

Florida fighting conch, *Strombus alatus*, are currently being raised by ORA Inc., a subsidiary of Harbor Branch Oceanographic Institution in Ft. Pierce, FL. The conch in the hatchery are fed one of two diets which partially consist of koi chow or catfish chow. This study examined the reproductive output of adult conch fed these two diets and stocked at either a 1:1 or 2:1 female to male sex ratio. The study was conducted over a period of 6 weeks (June 6- July 17, 2003). There were six replicates per diet, and the replicates for each diet treatment were further divided into three replicates of each sex ratio treatment. Egg masses were counted and measured for egg strand diameter, egg capsule diameter, and number of eggs per mm. Four egg masses from each diet treatment were hatched and the veligers were raised until metamorphosis. Veligers were measured periodically for shell length. The average veliger growth rate was 30.7 µm/d for parental conch fed koi chow, and 32.4 µm/d for parental conch fed catfish chow. There was no significant difference in the number of egg masses laid for conch fed koi chow or catfish chow, or for conch stocked at a 1:1 or 2:1 sex ratio ($p > 0.05$). Egg mass measurements and veliger growth rates were similar for all treatments. Since there was no difference in reproductive output, adult broodstock can be fed either diet and can be stocked at a sex ratio of 2:1, so that fewer animals are needed.

KEY WORDS: Conch, diet, *Strombus alatus*

# Efectos del Cociente de la Dieta y del Sexo en las Capacidades Reproductivas del Caracol, *Strombus alatus*

El conch de la Florida se está cultivando por ORA, Inc., un subsidiario de Harbor Branch Oceanographic Institution en Ft. Pierce, la Florida. El conch en el criadero se alimenta una de dos dietas que consistan en parcialmente de *koi chow* o *catfish chow*. Este estudio examinó las capacidades reproductivas del caracol del adulto alimentado estas dos dietas y almacenado en cualquiera a 1:1 o 2:1 cociente hembra al masculino. El estudio fue conducido durante 6 semanas (6 de Junio hasta 17 de Julio de 2003). Había seis réplicas por dieta, y las réplicas para cada tratamiento de la dieta fueron divididas más a fondo en tres réplicas de cada tratamiento del cociente del sexo. Las masas del huevo fueron contadas y medidas para el diámetro del filamento del huevo, el diámetro de la cápsula del huevo, y el número de huevos por mm. Cuatro masas del huevo de cada tratamiento de la dieta fueron tramadas y los veligers fueron levantados hasta metamorfosis. Veligers fueron medidos periódicamente para la longitud de la cáscara. El promedio veliger la tarifa de crecimiento era 30.7 µm/d por caracol que han comido *koi chow* , y ellos que han comido *catfsh chow*, 32.4 µm/d. No había diferencia significativa en el número de las masas del huevo puestas para el conch que han comido el *koi chow* o *catfish chow*, el caracol almacenó a conciente del sexo 1:1 o 2:1 ($p>0.05$). Medidas totales del huevo y índices de crecimiento para veligers eran similar para todos los tratamientos. Puesto que no había diferencia en salida reproductiva del adulto se puede alimentar cualquier dieta y se puede almacenar en conciente del sexo 2:1 de modo que menos animales son necesarios.

PALABRAS CLAVES: Caracol, sustantivo, *Strombus alatus*

## INTRODUCTION

Six species of Strombidae can be found in the waters of Florida and the Caribbean: *Strombus. gigas, S. costatus, S. raninus, S. pugilis, S. gallus,* and *S. alatus* (Abbott 1974). The queen conch, *S. gigas,* and the milk conch, *S. costatus*, are the most economically valuable species (Davis 2000). Due to intense fishing, many conch populations throughout the Caribbean are in decline, especially populations of queen conch. As a result of declining conch populations, culture techniques have been developed for stock enhancement and for the food markets. Four of the six *Strombus* species (*S. gigas, S. costatus, S. raninus* and *S. alatus*) have been cultured in hatcheries and have laid viable egg masses in captivity (Shawl and Davis 2004). Currently, there is only one commercial *S. gigas* hatchery at the Caicos Conch Farm, TCI and one *S. alatus* hatchery located at Oceans, Reefs and Aquariums (ORA) in Ft. Pierce, FL.

The target species for this study is *S. alatus*, the Florida fighting conch. *S. alatus* is a small (7 - 10 cm) herbivorous conch found along the coasts of North Carolina to Florida and throughout the Gulf of Mexico (Shawl and Spring 2003). *S. alatus* have a similar life cycle and culture characteristics of queen conch, however, the adults tend to have a more complex breeding behavior. Multiple males have been observed copulating with one female at the same time (Reed 1995, Shawl and Davis 2004). Likewise, a male *S. alatus* often guards the female with which he mated, and may also encourage "sparring contests" with other males that attempt to mate with her (Shawl and Davis 2004). Males also tend to following females, and have even attempted to copulate with an unguarded female while she was laying an egg mass (Shawl and Davis 2004). These types of breeding competitions may be a cause of stress to egg laying females, and therefore may interfere with the egg laying process and thus the success of a commercial hatchery.

The purpose of this study was to look at the effects of diet and sex ratio on the reproductive output of *S. alatus*. The conch food used at ORA is produced exclusively at Harbor Branch Oceanographic Institution (Harbor Branch). One of the main ingredients in the adult conch food is koi chow, while catfish chow is used in the juvenile food. In order to help streamline the culture of conch, this study looked at the effects of using catfish chow to feed broodstock. In addition to the two diets, the conch were also stocked at different female: male sex ratios; 1:1 and 2:1. If the conch held at a 2:1 ratio laid as many or more eggs than those at a 1:1 ratio, then less animals (less males) need to be kept. Having fewer males could alleviate problems associated with the stresses of male guarding and sparring, and may also encourage more prolific egg laying for the commercial hatchery.

## MATERIALS AND METHODS

This study was conducted at Harbor Branch from June 5 to July 17, 2003, a period of six weeks. A total of 144 *S. alatus* individuals were used for the study. Seventy-one conch were collected April 14, 2003 from the Gulf of Mexico, and placed in troughs for the remainder of the study. These animals were randomly assigned to diet treatments, and feeding began on April 15, 2003. Prior to June 6, 2003, all conch in a diet treatment were kept in a single large holding trough, and no eggs were collected. The remaining 73 animals were taken from the broodstock tanks at Harbor Branch for the study and assigned to diet treatments.

Conch were assigned to diet and sex treatments by means of a random number generator. In each diet treatment, there were six replicates with 12 conch per treatment. In addition to the diet treatments, the animals in each replicate were stocked at one of two different sex ratios. Three of the replicates for each diet treatment were stocked at a female: male sex ratio of 6:6 (1:1), while the other three replicates were stocked at an 8:4 (2:1) ratio. The females for each replicate were then numbered with enamel paint in order to record egg laying activity for each female.

Conch were kept in 0.53 m x 2.36 m troughs with a raised aragonite sand substrate, at a density of 7.3 conch/$m^2$. The troughs were all part of a large recirculating system. The water in the system was drawn from a salt water well and then charcoal filtered, micron filtered, and UV sterilized. Each trough was divided in half with a polypropylene mesh (1 cm openings), allowing two treatments per trough. A water-jet provided air to one half of the trough and water flow for the whole trough, and an air-stone was used to provide air for the other half of the trough. The troughs were located inside a slightly shaded greenhouse. In order to reduce the growth of algae, screen covers were made and placed over the troughs. The conch were exposed to a natural 12 hour light cycle.

Temperature (°C) and pH were recorded daily for the system, and the salinity (ppt), dissolved oxygen (mg/L), ammonia (mg/L), nitrite (mg/L), and nitrate (mg/L) were measured once a week. All replicates in both diet treatments were fed the same amount of food daily - 20 g. Any variation from this amount was noted. Before feeding, any old food or fungus in the trough was broken up. The troughs were checked twice a day (morning and afternoon) for any egg masses. If an egg mass was found, it was collected, the replicate number was recorded, and, if possible, it was noted which female laid the egg mass. The egg masses were gently shaken to expel any loose sand, and then measured for overall length, width, and height to calculate the volume ($cm^3$). A small egg strand was pulled from the mass and used to measure the strand diameter (μm), egg capsule diameter (μm), and the number of eggs per mm of strand. These measurements were made using a 40X dissecting microscope with an eyepiece micrometer. The egg strand parameters were measured three times per egg mass.

After being measured, the collected eggs were placed in an incubator and kept at a temperature of 27-28°C for two to three days, after which they were placed in conical larval tanks for culture. Veligers were cultured according to the guidelines set forth in Davis (2000). Ten veligers from each tank were measured periodically throughout the larval cycle using a 40X dissecting microscope equipped with a micrometer. Veligers were raised through metamorphosis to juvenile stage.

A 2-way analysis of variance was used to compare the diet treatments and sex ratio treatments. The ANOVA tested differences between the two diet treatments, between the two sex ratios, and between the sex ratio and diet treatments.

## RESULTS

During the six-week experimental period (June 5 to July 17, 2003), there were 50 egg masses collected from all treatments. A total of 19 egg masses were collected from conch fed catfish chow, while 31 egg masses were collected from conch fed koi chow. The average number of egg masses laid per replicate was 5.16 ± 2.48 in the koi chow treatments and 3.16 ± 1.98 in the catfish chow treatments (Figure 1). The average number of egg masses laid per female was 0.12 ± 0.06 for conch fed koi chow, and was 0.08 ± 0.05 for conch fed catfish chow. There was not a significant difference between the two diet treatments ($p = 1.475$).

The average number of eggs laid per replicate for conch stocked at a sex ratio of 1:1 was 3.16 ± 2.13, with an individual average of 0.52 ± 0.36 egg masses per female. For conch stocked at a 2:1 ratio, the average per replicate was 5.16 ± 2.31 and the average per female was 0.64 ± 0.29 (Figure 1). There was no significant difference in the number of egg masses laid by conch stocked at the two sex ratios ($p = 1.475$).

Water quality parameters remained relatively constant throughout the experimental period. Over the six week experimental period, temperature averaged 29.9°C ± 1.6°, salinity averaged 33.2 ± 0.97 ‰, and pH averaged 7.7 ± 0.16. There appeared to be no correlation between temperature and the number of egg masses laid (Figure 2).

There was no indication that any one female laid the majority of eggs in a replicate. The egg strand diameter, capsule diameter, and the number of eggs per mm were similar for conch fed koi chow and catfish chow (Table 1). The data on egg strand diameter, capsule diameter, and the number of eggs per mm are similar to those reported by Shawl and Davis (2004) for captive raised *S. alatus*.

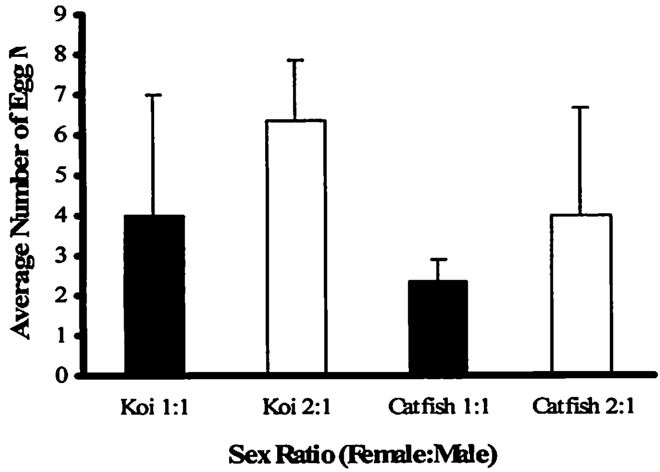


**Figure 1.** Average number of egg masses laid per conch per treatment during the six-week experimental period (June 5 – July 17, 2003).

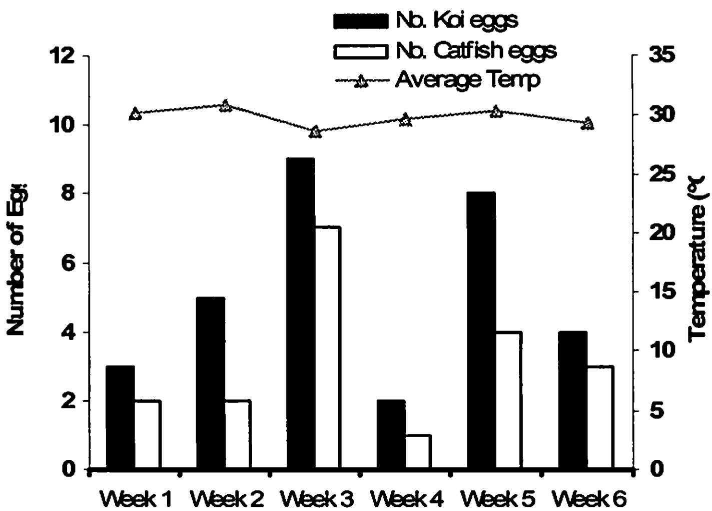


**Figure 2.** The weekly average number of egg masses laid per conch per treatment compared with weekly average water temperatures for the duration of the experimental period (June 5 – July 17, 2003).

**Table 1.** Summary of egg mass data from June 5 - July 17, 2003. Results are expressed as average ± standard deviation (n = samples).

| Variable | Koi Chow Diet | Catfish Diet |
|---|---|---|
| Volume of egg mass (cm) | 16.9 ± 9.7 (29) | 17.8 ± 8.7 (18) |
| Diameter of egg strand (µm) | 493.2 ± 56.3 (21) | 500.5 ± 49.7 (14) |
| Egg capsule diameter (µm) | 203.5 ± 24.7 (21) | 195.2 ± 13.4 (14) |
| No. egg capsules per mm | 12.1 ± 1.6 (21) | 12.5 ± 1.6 (14) |

Veliger size was recorded periodically throughout the culture period and the averages of all cultures from each diet treatment were combined (Figure 3). The average growth rate of veligers (µm/d) in the koi chow treatment was 40.2 ± 21.8, which was similar to the catfish chow treatment at 37.4 ± 18.5 (Table 2). All cultures reached developmental stages at approximately the same age, and metamorphic competency was reached around day 25. The number of days until metamorphosis and the shell length of veligers at metamorphosis were similar to the data presented for *S. alatus* in Shawl and Davis (2004).

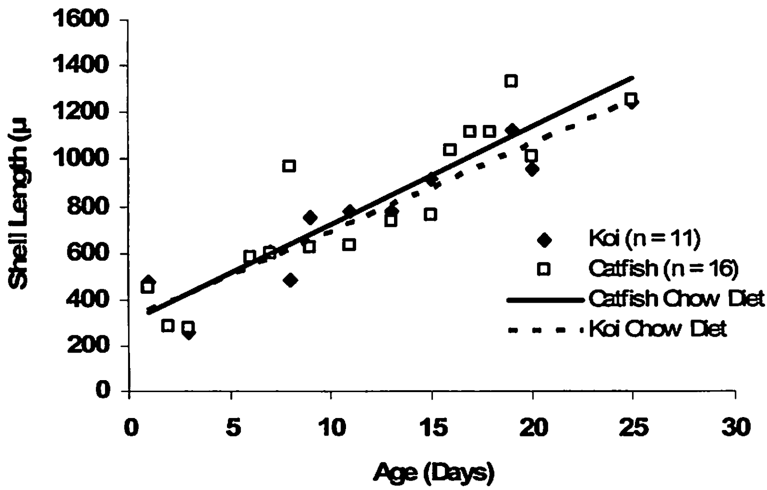


**Figure 3.** Average *S. alatus* veliger shell length in relation to age for each treatment.

**Table 2.** *S. alatus* veliger characteristics for the two diet treatments June 5 - July 17, 2003. Results are expressed as average ± standard deviation (n = samples).

| Variable | Koi Chow Diet | Catfish Diet |
|---|---|---|
| Shell length at hatch (µm) | 480 ± 21.2 (2) | 447.5 ± 81.3 (2) |
| Shell length at metamorphosis (µm) | 1247.5 (1) | 1258.3 (1) |
| Growth rate (µm/d) | 40.2 ± 21.8 ( 4 ) | 37.4 ± 18.5 ( 4 ) |

## DISCUSSION

Although visually there appears to be a difference in the number of eggs laid between the two diet treatments, an analysis of variance showed that there is no significant difference. The variance between replicates was very high, which helps to explain the insignificance of the results. Since there was not a significant difference between the diet treatments, broodstock can be fed either the koi chow or the catfish chow, and it will not have an effect on the number of egg masses produced nor on the health of the veligers.

There was no significant difference found between the number of eggs laid by females stocked at the two sex ratios either. Conch held at a 1:1 density statistically laid as many eggs as conch held at a 2:1 sex ratio. It can therefore be assumed that it would be advantageous to hold conch at a sex ratio of 2:1. Having two females to every one male would mean that hatcheries could stock a higher number of females, thus increasing the egg mass output for the hatchery.

There was no difference in any of the measurements taken of the egg masses or egg strands. There was also no difference found in the growth or health of veligers. It can be assumed that the eggs produced from both diet treatments were of the same quality. Veligers had similar growth rates and health between the treatments as in previous studies (Shawl and Davis 2004). There is no reason to believe there will be any difference in the health or survival of juveniles raised from broodstock and fed either diet.

## ACKNOWLEDGEMENTS

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# Effects of Dietary Calcium and Substrate on Growth and Survival of Juvenile Queen Conch (*Strombus gigas*) Cultured for Stock Enhancement

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ABSTRACT

The queen conch, *Strombus gigas*, is one of the most valuable fisheries species throughout the Caribbean, however, the populations have been declining for several decades. Research focused on aquaculture, restocking, and transplanting techniques is being conducted to help replenish wild conch populations. A 38 week experiment to determine the influence of diet and substrate on queen conch growth and survival began at Harbor Branch Oceanographic Institution, Ft. Pierce, Florida in December 2003. Hatchery-reared juvenile queen conch (32.3 ± 2.4 mm shell length) were stocked into six individual recirculating systems at 75 conch/m$^2$. There were three treatments, with two replicates per treatment: 1) aragonite sand substrate with 1x calcium feed, 2) aragonite sand substrate with 2x calcium feed, and 3) silicate substrate with 1x calcium feed. Calcium, alkalinity, and pH were measured once per week; and conch length and weight measurements were taken on a biweekly or monthly basis. Results indicate that there is no difference in the growth rate with additional dietary calcium, the 2x feed (0.07 ± 0.01 mm/d) compared to the 1x feed (0.08 ± 0.01 mm/d). However, there appears to be a slower growth rate in those animals stocked on the silicate substrate (0.04 ± 0.02 mm/d) in comparison to the conch grown on aragonite sand substrate (0.07 ± 0.01 mm/d). Calcium and alkalinity levels remained the same in all treatments. Conch grown on the silicate substrate had a significantly higher mortality (57%) than the 1X and 2x treatment on aragonite (18.7% and 25.8%, respectively). These results can be used to assist in choosing the husbandry techniques best suited to culture queen conch juveniles for stock enhancement purposes.

KEY WORDS: Aquaculture, conch, *Strombus*

# Efectos de Dietéticos de Calcio y del Substrato en Crecimiento y Fuerza de la Cáscara del Conch Juvenil de la Reina (*Strombus gigas*), Crecido en un Criadero

El caracol, *Strombus gigas,* es uno de la especie más valiosa de las industrias pesqueras a través del Caribe. Sin embargo, puesto que las poblaciones han estado declinando por varias décadas. Mucha de los focos actuales de la investigación en la acuacultura, volviendo a surtir, y técnicas de trasplante a ayudar a llenar las poblaciones salvajes del caracol. De acuerdo con un experimento conducido sobre un año para determinar la influencia de la dieta y del substrato en fuerza, morfología y crecimiento de la cáscara del conch de la reina comenzó en Harbor Branch Oceanographic Institution, en Ft. Pierce, la Florida, en Diciembre de 2003. La juvenil del caracol crecido en un criadero (32.3 ± 2.4 mm de la cascara) fueron almacenados en seis sistemas que recirculaban individuales en 75 conch/m$^2$. Hay tres tratamientos, con dos réplicas por el tratamiento: 1) substrato de la arena del aragonite con la alimentación del calcio 1x, 2) substrato de la arena del aragonite con la alimentación del calcio 2x, y 3) substrato del silicato con la alimentación del calcio 1x. El calcio, la alcalinidad, y el pH se miden una vez por semana; y las medidas de la longitud y del peso del conch se adquieren bisemanal o base mensual. Los resultados indican que no hay diferencia en la tarifa de crecimiento con calcio dietético adicional, la alimentación 2x (0.07 ± 0.01 mm/d) comparado a la alimentación 1x (0.08 ± 0.01 mm/d). Sin embargo, aparece ser una tarifa de crecimiento más lenta en esos animales almacenados en el substrato del silicato (0.04 ± 0.02 mm/d) en la comparación al substrato de la arena del aragonite (0.07 ± 0.01 mm/d). Los niveles del calcio y de la alcalinidad han seguido en todos los tratamientos. Las caracols en el substrato del silicato tiene mas mortalito (57%) entonces a la control y la alimentación 2x (18.7% y 25.8%). Estos resultados se pueden utilizar para asistir a los métodos usados para cultivar a juveniles del concha de la reina para los propósitos comunes del realce.

PALABRAS CLAVES: Aquacultura, concha, *Strombus*

## INTRODUCTION

The queen conch, *Strombus gigas,* is one of the most valuable fisheries species throughout the Caribbean, however, the populations have been declining for several decades. Research focused on aquaculture, restocking, and transplanting techniques is being conducted to help replenish wild conch populations (Creswell 1984, Davis and Dalton 1991, Stoner and Glazer 1998, Pardee Woodring and Boettcher 2001, Delgado et al. 2002, Shawl and Davis 2004, Davis and Shawl 2005). Determining ideal husbandry techniques for juvenile conch reared for stock enhancement purposes will ensure that hatchery-reared conch released in the wild will have a similar survival rates as their wild counterparts. Knowing optimal stocking density, substrate, water quality, diets, and systems will assist in growing conch with the shell strength and morphology equal to wild conch. Previous studies have indicated that hatchery-reared conch are more susceptible to predators due to a thinner shells and smaller spines (Stoner 1994, Stoner and Davis 1994). Hatchery-reared conch that are stocked at higher densities, tend to have lower growth rates, smaller shells, and shorter spires (Laughlin and Weil 1983, Appledoorn and Sanders 1984, Creswell 1984, Weil and Laughlin 1984, Spring and Davis 2003). However, conch grown at high densities on a calcium-based substrate tend to have a stronger shell than those conch grown with the same conditions at low densities (Spring 2003).

Culture methods, including stocking density, for grow out of queen conch are well known. Therefore, this study investigates the effect of dietary calcium and calcium substrate on growth and survival of juvenile queen conch. These results can be used to understand ideal culture techniques that will enhance the survival rate of restocked conch.

## MATERIALS AND METHODS

This experiment was conducted at Harbor Branch Oceanographic Institution (HBOI) in Ft. Pierce, FL from December 17, 2003 to September 1, 2004 (38 weeks). Six individual recirculating systems located inside a shaded greenhouse were constructed of a fiberglass trough (2.5 m x 0.5 m x), a 94 L polyethlyene sump (0.6 m x 0.5 m x 0.4 m), and a 1/30 HP Little Giant™ magnetic drive pump. Each system had a raised substrate with water entering both above and below the substrate (Shawl and Davis 2004). Aeration was added to all tanks. Every two weeks, the systems were drained completely for cleaning. There was no incoming water; however, water was added to the sumps twice per week to account for evaporation. The same amount of water was added to all six systems.

Three treatments were examined with two replicates each:

i) Aragonite sand substrate and 1x calcium diet,
ii) Aragonite substrate and 2x calcium diet, and
iii) Silicate substrate and 1x calcium diet.

The silicate substrate was chosen as a non-calcium based substrate to test for the effects of substrate on growth and survival. The 1x calcium diet was the standard diet used at HBOI to grow conch. The 1x calcium diet was made of dried *Ulva sp.*, catfish chow, calcium palmitate, and an alginate based binder. The 2x diet consisted of dried *Ulva sp.*, catfish chow, alginate, and twice the amount of calcium palmitate. The Harbor Branch Environmental Laboratories, Inc. tested several samples of the 2x diet and compared the results to the 1x diet to confirm that twice the amount of calcium was present. Initial feeding rate was 0.15g/conch/day, but was adjusted accordingly so that the animals were fed to satiation (0.40 g/conch/day). All treatments received the same amount of feed throughout the experiment.

Each replicate was stocked with 99 juvenile queen conch (at 75 conch/m$^2$). The hatchery-reared queen conch were cultured at the Caicos Conch Farm, Turks and Caicos Islands, BWI and were purchased from Oceans, Reefs and Aquariums in Ft. Pierce, FL. Initial length (mm) and weight (g) was measured for all conch prior to stocking. For each replicate, 20 animals (20%) were randomly chosen to be the permanent sampling group. A portion of the apex of the shell was painted with a non-water based acrylic paint to distinguish the group. Mortalities were recorded and immediately replaced with another conch to maintain density. These replacements were marked and were not included in any measurements. Length (mm) and weight (g) of the sample animals were taken twice per month for the first 29 weeks, and then once per month for the remainder of the experiment.

Water qualities were measured on a daily, weekly, or biweekly basis, and one sample from each replicate was taken. Temperature was taken daily, pH and salinity were measured once per week, and ammonia, nitrite, and nitrates were measured weekly or biweekly. Calcium and alkalinity were sampled twice per week for the first five weeks and then once per week for the remainder of the experiment. One sample from each replicate was used to measure water quality, and two samples per replicate were used to test calcium and alkalinity levels. On days when water was added to the sumps, a water sample for measuring calcium and alkalinity was taken before and after the addition.

A two way repeated measure ANOVA test was used to determine significant differences in the amount of calcium and alkalinity in the treatments. Due to the non-normal distribution of results for conch growth rate, wet weight gain rate, and percent survival, a non-parametric Kruskal-Wallace one way ANOVA on ranks was used.

## RESULTS

The final shell length was 53.7 ± 0.6 mm for the aragonite 1x diet, 42.2 ± 3.1 for the silicate treatment, and 49.6 ± 3.5 for the aragonite 2x treatment. The daily growth rates were similar for conch grown on aragonite substrate fed the 1x and 2x diets (Figure 1). The conch fed the 1x diet grew 21.4 mm for an overall growth rate of 0.08 mm/d, and the conch fed the 2x diet had a growth rate of 0.07 mm/d (17.0 mm increase). Conch grown on the silicate substrate did not grow as well (9.6 mm), therefore, had a much lower growth rate (0.04 mm/d). However, there were no significant differences in growth rate between the three treatments (p = 0.400).

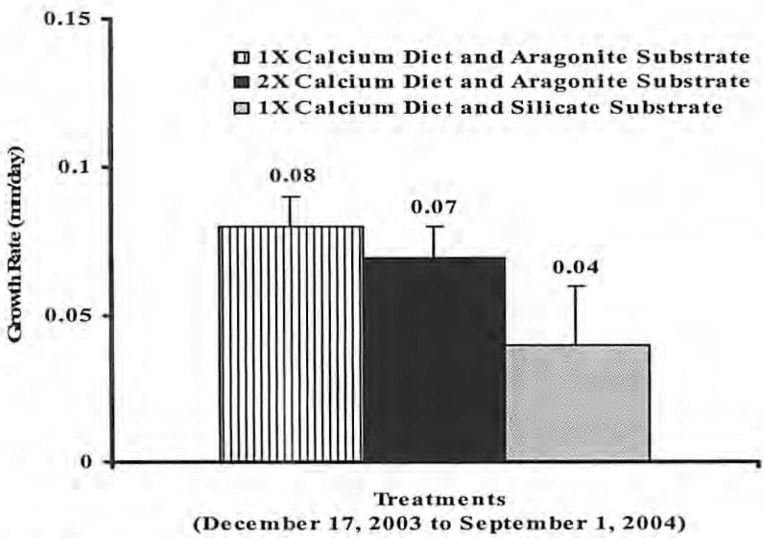


**Figure 1.** Overall growth rate (mm/d) for the three treatments (mean ± sd, n = 2).

The conch in the aragonite 1x diet treatment gained 12.9g of total wet weight, in comparison to 4.9 g and 10.3 g for conch grown on the silicate and fed the 2x diet, respectively. The final weight of the three treatments was 16.1 ± 0.2 for the aragonite 1x diet, 8.2 ± 2.9 for the silicate substrate, and 13.7 ± 2.3 for the animals fed the 2x diet. There was no significant difference in wet weight gain rate between all treatments ($p = 0.067$).

Water quality parameters remained relatively constant in all three treatments throughout the experiment (Table 1). There was a significant difference in the calcium levels between the 1x and 2x treatment ($p = 0.008$), and between the 2x treatment and silicate treatment ($p = 0.030$). However, there was no significant difference between the silicate treatment and the aragonite 1x treatment ($p = 0.107$). There was no significance difference for alkalinity levels in all three treatments ($p = 0.718$) (Table 2).

**Table 1.** Water quality for the experimental tanks from December 17, 2003 to September 1 , 2004. Results are expressed as mean ± sd and range. For each treatment the replicates were averaged and the expressed mean is the average of these replicate averages (n = sample times for each treatment).

| | Aragonite Substrate 1X Calcium Diet | Silicate Substrate 1X Calcium Diet | Aragonite Substrate 2X Calcium Diet |
|---|---|---|---|
| Temp (°C) | 27.2 ± 1.5 (520) | 27.1 ± 1.6 (520) | 26.9 ± 1.5 (520) |
| | 19.1 - 31.0 (520) | 18.4 - 30.2 (520) | 18.0 - 30.6 (520) |
| Salinity (ppt) | 33.6 ± 2.0 (112) | 33.6 ± 2.1 (112) | 33.9 ± 2.3 (112) |
| | 29 - 37 (112) | 29 - 37 (112) | 29 - 38 (112) |
| pH | 8.6 ± 0.1 (112) | 8.6 ± 0.2 (112) | 8.7 ± 0.1 (112) |
| | 8.0 - 8.8 (112) | 7.7 - 8.8 (112) | 8.3 - 8.9 (112) |
| Ammonia (mg/L) | 0.26 ± 0.61 (52) | 0.29 ± 0.61 (52) | 0.10 ± 0.37 (52) |
| | 0 - 1.9 (52) | 0 - 1.8 (52) | 0 - 1.8 (52) |
| Nitrate (mg/L) | 3.15 ± 0.70 (50) | 3.00 ± 0.67 (50) | 2.94 ± 0.68 (50) |
| | 2 - 5 (50) | 1 - 4 (50) | 1 - 5 (50) |
| Nitrite (mg/L) | 0.04 ± 0.02 (50) | 0.05 ± 0.04 (50) | 0.03 ± 0.02 (50) |
| | 0 - 0.10 (50) | 0 - 0.32 (50) | 0 - 0.17 (50) |

**Table 2.** Calcium and alkalinity measurements for the three treatments December 17, 2003 - September 1, 2004. Results are expressed as mean ± sd and range. For each treatment the replicates were averaged and the expressed mean is the average of these replicate averages (n = sample times for each treatment).

| | Aragonite Substrate 1X Calcium Diet | Silicate Substrate 1X Calcium Diet | Aragonite Substrate 2X Calcium Diet |
|---|---|---|---|
| Calcium (mg/L) | 426 ± 35.6 (86) | 440 ± 54.5 (86) | 456 ± 63.2 (86) |
| | 345 - 513 (86) | 218 - 547 (86) | 270 - 582 (86) |
| Alkalinity (mg/L as $CaCO_3$) | 114 ± 17.3 (86) | 110 ± 17.1 (86) | 120 ± 16.6 (86) |
| | 75 - 162 (86) | 55 - 168 (86) | 90 - 177 (86) |

Conch grown on the silicate substrate had a higher mortality (57% ± 39%, n = 2) than the 1x and 2x treatments (18.7% ± 4%, n = 2 and 25.8% ± 14%, n = 2, respectively), however, there was no significant difference in the final mortality levels in all three treatments ($p = 0.067$) (Figure 2). It also appeared that the conch on the silicate substrate did not feed as well and were less active. The feed conversion ratios (FCR) were fairly similar for the 1x and the 2x treatment (1.5 and 1.9, respectively). The FCR for the silicate treatment was higher (4.0), indicating slow growth and high mortality.

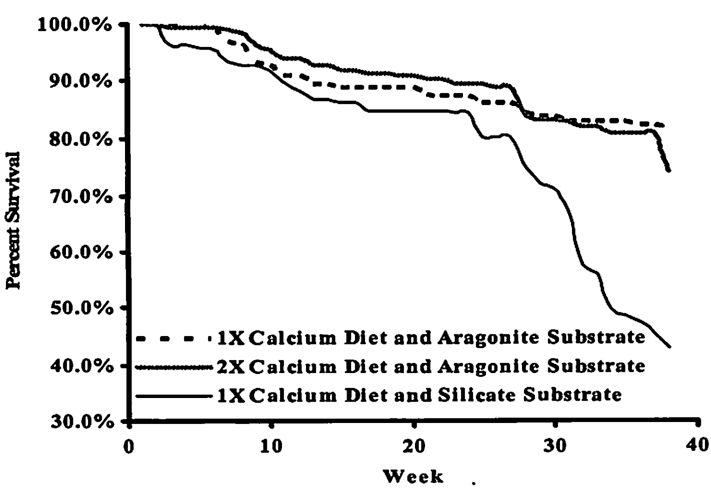


**Figure 2.** Average percent survival for the three treatments December 17, 2003 – September 1, 2004 (n = 2).

## DISCUSSION

Substrate, stocking density, diet, and water quality are important factors for the successful aquaculture of queen conch. The animals raised on the non-calcium based silicate substrate had a much slower growth rate and higher mortality. However, the amount of calcium in the water available to the conch did not differ from the other treatments. Even though the silicate substrate was rinsed thoroughly and was similar in grain size as the aragonite, it is possible that these animals were stressed and unwilling to feed due to a characteristic of the silicate. Previous studies have shown slower growth rates on substrates other than sand (Appeldoorn and Sanders 1984, Laughlin and Weil 1983).

There appeared to be little effect on growth rate with additional dietary calcium. Although there have not been any studies of this kind on Strombidae conch, there has been similar research conducted on terrestrial land snails. Studies have found a proportional increase in growth rate with increasing dietary calcium for *Acatina fulica* (Ireland 1991). However, the increased growth rate in *A. fulica* appeared to be directly correlated to food consumption (Ireland 1991).

The conch fed the 1x diet gained more weight overall, than the conch fed the 2x diet. This is contrary to the findings with *A. fulica* in which the snails fed a higher concentration of calcium, had a higher shell weight and greater shell thickness (Ireland 1991). Based on these results, it is recommended that conch be grown on an aragonite substrate and are fed the standard 1x calcium diet. It appears to be unnecessary for culturist to purchase excess calcium for the juvenile feed. However, the shells will be further analyzed using a Comten Industries digital force system, to determine if there are differences in shell strength between treatments when additional calcium is added to the diet.

In order for a restocking program to be successful, scientists must be able to produce a juvenile queen conch equal in shell strength to its wild counterparts to aid the conch in survival against shell crushing predators. Future research involving supplemental dietary calcium and aragonite substrate will aid in defining restocking guidelines.

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# Ciliated Protozoans as Alternative Live Food for First Feeding Red Snapper, *Lutjanus campechanus*, Larvae

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ABSTRACT

Ciliates are abundant in marine waters, but their significance as a first food for fish larvae is poorly understood, as many have no lorica to facilitate their identification in the gut of a larval fish. One of the major challenges of culturing of red snapper, *Lutjanus campechanus* is providing an appropriate food source at onset of feeding. Possible food organisms include species of *Fabrea, Strombidium* and *Strombilidium* with average sizes of 40 x 100, 33 x 41, and 35 x 80 µm, respectively. Optimum growth conditions evaluated were photoperiod, stocking densities of ciliates and algae, and algal food type. Techniques were developed for the consistent mass culture of *Fabrea salina* using 200 L solar tubes, resulting in 75 ciliates/ml in seven days.

Growth and survival of red snapper larvae was evaluated in a production setting using 1 m$^3$ tanks. Larvae were stocked at 10/L, 36 hours post hatch, and prior to functioning mouthparts. Three treatments were fed:

i) Copepod nauplii, 20-75µm only from days 1 to 10;
ii) Copepod nauplii from days 1 to 10 plus *Fabrea* from days 1 to 5; and
iii) *Fabrea* only from days 1 to 3 plus copepod nauplii from days 4 to 10.

Copepod nauplii were added at 2/ml and ciliates were added at 5/ml. Two larvae per tank were removed daily from day 1 to 5 and once per week thereafter and photographed for morphometrics. Survival after 28 days was 0.28% and 2.39% in treatment 1 and 2, respectively. Treatment 3 did not have any survival after six days post-hatch. Larvae were more active feeders in the tanks given *Fabrea* and copepods as first foods with 34.6 ± 58.1% average daily reduction in copepod nauplii compared to 15.8 ± 107% reduction when only nauplii were provided. Survival was positively related to the presence of *Fabrea* and nauplii at first feeding.

KEY WORDS: Ciliate, first feeding, larviculture

# Los Protozoos Ciliados como Alternative Viven Alimento para Alimentar Primero Larvas Pargo Rojo *Lutjanus campechanus*

Los ciliados son abundantes en aguas marinas pero su importancia como primer alimento para larvas de peces se desconoce escasamente, especialmente debido a que los ciliados no tienen un exoesqueleto que facilite su identificación en el intestino de una larva depez. Uno de los principales desafíos se encuentra en el levante de larvas de pargo rojo *Lutjanus campechanus*, en cuanto a que proporcione un alimento adecuado en su primera comida. Los organismos que pueden servir como posible alimento inicial incluyen especies tales como *Fabrea, Strombidium, y Strombilidium*, con tamaños promedio de 40x100, 33x41, y 35x80 µm respectivamente. Los condiciones ambientales que se evalvaron durante los experimento de crecimento fueron: temperatura, salinidad, intensidad de luz y fotoperiodo, aireación, densidad de cultivo y tipo de alga utilizada como alimento. Para los experimentos se usaron tubos solares de 200L de capacidad, con una producción promedio aproximada de 50 ciliados/ml en 7 días.

El crecimiento y la soberevivencia de las larvas de pargo rojo fueron evaluados en tanques de fibra de vidrio de 1m$^3$. Las larvas fueron sembradas en proporcion de 10/L, 36 horas post-eclosión, antes de la formación de las partes bucales. Se hicieron tres tratamientos alimenticios:

i) Nauplios de copepodo de 20-75 µm del dia 1 hasta el dia 10,
ii) Nauplios de copepodo del día 1 hasta el día 10 más *Fabrea* durante los días 1 hasta el día 5, y
iii) *Fabrea* solamente del días1 al 3 más nauplios de copepodo desde el día 4 al 10.

Los nauplios de copepodo se adicionaron en proporcion de 5/ml. Se extrajeron dos larvas por tanque por dia durante los dias 1 al 5 para ser fotografiados con fines morfometricos. La sobrevivencia despues de 28 días fue del 0.28% y del 2.39% en los tratamientos 1 y 2, respectivamente. En el tratamientos 3 no se observó ninguna supervivencia después del día 4 de haberse formado las partes bucales. Los larvas mostraron mayor actividad alimenticia en los tanques alimentados con *Fabrea* y copepodos como primer alimento con un promedio de reducción de 45.4 ± 18.7% en nauplios de copepodo comparado con el 15.7 ± 9.1% de reducción registrado en el tratamiento en el que se aplicaron solamente nauplios de copepodo. La sobrevivencia estuvo positivamente relacionada con el porcentaje diario de reducción en abundancia de nauplios ($R^2 = 0.81$; $p = 0.002$).

PALABRAS CLAVES: Ciliados, alimento para larvas de peces, pargo rojo, *Lutjanus campechanus*

## INTRODUCTION

Red snapper, *Lutjanus campechanus,* is the target of commercial and recreational fishing in the Gulf of Mexico. Culture and stock enhancement efforts are constrained due to low larval survival. Development of suitable feeding regimens for mass rearing of larval fish is one of the major barriers to successful propagation of this and other marine species. The problem lies with the relatively small mouth size, limited yolk reserve, and late development of functional mouthparts. Typically, rotifers or copepod nauplii are offered as first foods. The importance of other microplankton including dinoflagellates and ciliates as available prey is poorly understood. Ciliated protozoans may be important for first-feeding fish larvae because: 1) ciliates often dominate such communities and are more abundant than copepod nauplii in coastal waters (Kamiyama 1994), and 2) most of the ciliates in the plankton are of a similar or smaller size than copepod nauplii (Taniguchi 1978). Marine ciliates are conventionally divided into loricate (tintinnid) and aloricate (naked) forms and comprise a large proportion of total microzooplankton abundance and/or biomass (Sanders 1987, Kamiyama 1994). Naked ciliates may be more important food for fish larvae than tintinnids, because naked ciliates occur in considerably larger numbers than tintinnids (Pierce and Turner 1992).

There is little information on the predation of protozoans by fish larvae, except for the loricate tintinnids, which have indigestible hard parts that can be identified in the guts (review by Pierce and Stoecker 1992). There is less information about the predation of naked ciliates by fish larvae. Korniyenko (1971) described a relationship between protozoans and carp larvae; Howell (1972) reared lemon sole with protozoans; Nagano et al., (2000 a,b) detected feeding on *Euplotes sp.* by larval grouper and surgeonfish, respectively; and Ohman, et al. (1991) observed larval anchovy feeding on *Strombidium sp.* when presented as a first food. Fukami et al. (1999), investigated predation on naked protozoa by 52 different taxonomical groups of fish larvae collected in the field. They found fish in the group Acanthopterygii consumed the greatest quantity of protozoans (> 30 protists/individual). Red snapper have a small mouth gape at first feeding similar to the fish mentioned above. A protozoan may be of a more appropriate size than other marine organisms as a first food.

*Fabrea salina* is a heterotrich ciliate in the family Climacostomidae. It naturally occurs in estuarine environments and high saline areas. *Fabrea* is a relatively large protozoan, its size ranging from 120 - 220μm by 67 - 125μm. A few attempts have been made to culture it using single cell algae, bacteria or yeast (De Winter et al. 1975, 1976, Uhlig 1981, Rattan et al. 1999, Park and Hur 2001, Pandey and Yeragi 2004). The advantages of *Fabrea salina* as an alternative for rotifers or brine shrimp larvae were summarized by De Winter, 1975 as follows:

i) It is one of the few truly "pelagic" ciliates,
ii) It has the appropriate dimensions as a live food: depending on culturing conditions its size can vary from 50 - 500 μm,
iii) The smooth cell wall and the absence of appendages facilitate its uptake by the predators,
iv) The generation time is very short,
v) As a particle feeder it can be cultured on live algae as well as inert foods,
vi) According to the literature data its nutritional value for fish larvae seems to be excellent, and
vii) As many other protozoans it forms a tough cyst membrane when submitted to unfavorable environmental conditions. The cysts can be kept viable for a certain period of time without losing their hatchability.

The following work consists of two parts, 1) to develop culture techniques for ciliated protozoans and 2) evaluate the use of the ciliate *Fabrea salina* as a first food for larval red snapper.

## MATERIALS AND METHODS

### Ciliate Culture

Initially, several ciliates were considered for culture, and *Fabrea salina* showed to be more reliable in culture than *Strombilidium sp.* and *Strombidium sp* and is, therefore, the focus of this paper. The *Fabrea salina* culture was obtained from the University of Texas, Marine Science Institute, Port Aransas, TX. Stock cultures were maintained at Claude Peteet Mariculture Center, Gulf Shores, AL. Algae provided as food was cultured with Gulliard's F/2 in the laboratory. All of the experiments were carried out for seven days in 2 L Erlenmeyer flask initially containing 1 L of chlorinated then dechlorinated, 1 µm filtered seawater (32 - 34 ‰). Each treatment contained three replicates. No aeration was supplied, flasks were swirled before sampling to evenly distribute the ciliates and resuspend algal cells. The temperature was not controlled for the experiments; the normal range was 25 - 30°C. The trials were conducted under continuous light ranging from 1,240 to 1,680 lux. Daily counts for organisms were performed in triplicate using Sedgwick-Rafter slides on a compound microscope; samples preserved and stained using Lugol's iodine solution. Samples for water quality measurements including ammonia, temperature, salinity, dissolved oxygen, and pH were taken daily from each replicate.

Four trials were conducted to examine *Fabrea* stocking density, algal species *Isochrysis* and *Rhodomonas*, *Rhodomonas* algal density, and photoperiod. To determine stocking density of *Fabrea*, three treatments were used 3, 6 and 9/ml, being fed 120,000 *Isochrysis* cell/ml daily. Based on the results, the remaining experiments were initially stocked at 3 ciliates/ml. Determining the optimum food type and density was another series of studies. One trial compared growth when fed 90,000 *Rhodomonas* or *Isochrysis* cells daily. With *Rhodomonas* providing a better growth rate, the next trial compared the algal density of 90,000 to 135,000 cells/ml. Photoperiod was another variable, three treatments included 6 hours light and 18 hours dark (6L:18D), 12L:12D and 18L:6D. Continuous light was not compared with these three because the other trials were conducted at 24L:0D. Sampling was conducted as described earlier. Conditions selected for mass culture in 40 L bags or 200 L solar tubes included, stocking ciliates at 3/ml, 12 to 14 hours light/day, and feeding 90,000 *Rhodomonas* cells/ml/day.

### Snapper Rearing

Wild caught brood stock were induced to spawn using techniques described by Minton et al. (1983). Fertilized eggs were incubated in the hatchery. Larvae were stocked 12 - 24 hours post-hatch, prior to functioning mouthparts into 1 m$^3$ tanks at 10 larvae/L to evaluate the value of *Fabrea* as a larval food. Fish were fed according to one of the following protocols using four replicates/protocol. The feeding protocols were:

i) Copepod nauplii only, 20 - 75µm from days 1 to 10;
ii) Copepod nauplii from days 1 to 10 plus *Fabrea* from days 1 to 5; and
iii) *Fabrea* from days 1 to 5 plus copepod nauplii from days 4 to 10.

From days 7 to 21, all of the treatments were fed copepod nauplii ranging from 40 - 100µm. On day 12, when all treatments were being fed the same copepod diet and the ciliates were no longer present, the recirculation of water began. A commercial feed by INVE, Proton-1 was given starting on day 16. Adult copepods were added to all treatments from days 18 to 28.

Daily additions of *Isochrysis galbana* were made to maintain 90,000 cells/ml, which created a greenwater environment. Daily additions of zooplankton were made to maintain copepod nauplii at 2/ml and ciliates at 5/ml. *Fabrea* was produced in 40 L bags in the laboratory or 200 L solar tubes in the laboratory or greenhouse. Mixed zooplankton was collected from saltwater ponds following the procedures of Lam et al. (2000) for supplying copepod nauplii. Rotifers were collected along with the nauplii and were incidentally added to the tanks when nauplii were given. No attempt was made to maintain a specific rotifer density in the larval rearing tanks.

Five 10 ml samples were randomly collected using a Stempel pipette and pooled per tank. Counts of algae were performed using a hemacytometer and zooplankton counts including protozoans, rotifers, and copepod nauplii were conducted in triplicate using Sedgwick-Rafter counting slides. Water quality measurements including temperature, salinity, dissolved oxygen and pH were taken twice daily from each replicate using a YSI 556 MPS. Samples for ammonia were also collected twice a day and analyzed using Nesslerization method, read using a spectrophotometer. Two fish were randomly selected from each replicate daily from days 2 to 6 and weekly thereafter on day 12 and day 18. Each live larva was photographed with an Olympus digital camera outfitted to an Olympus stereomicroscope. Morphometric measurements of standard length and body depth at the anus were made using Image-Pro® Version 4.0.1, image analysis software calibrated with a stage micrometer. At harvest, total length was measured (± 1 mm) using a metric ruler. All statistical analyses were performed using SAS Version 8.2 software and/or StatView 5.0.

## RESULTS

### Ciliate Culture

Based on several *F. salina* culturing trials that altered stocking density, algal species and density, and photoperiod, the following results were found. After seven days of the stocking density trial, there were no significant differences ($p = 0.001$) in the growth when stocked at 3, 6 or 9 *Fabrea*/ml. The mean maximum density reached 97 ± 9/ml after five days. The ammonia production after seven days ranged from 1.4 to 2.0 ppm, the higher values were from the treatments stocked at higher densities. The flasks stocked at 9/ml had reached 96 ± 6/ml on day, 3 then growth slowed almost completely. There was a drop in dissolved oxygen corresponding to the spikes in ammonia. The flasks stocked at 3 and 6/ml grew more consistently through five days before starting to decline.

The trial comparing *Isochrysis* and *Rhodomonas* resulted in *Rhodomonas* providing higher growth. The density increased from 3/ml to 216 ± 34/ml for *Rhodomonas* compared to 66 ± 18/ml when being fed *Isochrysis* (Figure 1). When comparing 90,000 and 135,000 *Rhodomonas* cells/ml, the best density of algae to feed daily was found to be 90,000 *Rhodomonas* cells/ml. The treatment fed higher densities of algae had lower dissolved oxygen and higher ammonia and decreased growth. In the photoperiod trial, the three exposures to light had similar results. In all treatments, the density approximately doubled daily and peaked after seven days. The light controlled the algae from blooming, which had an effect on the overall water quality.

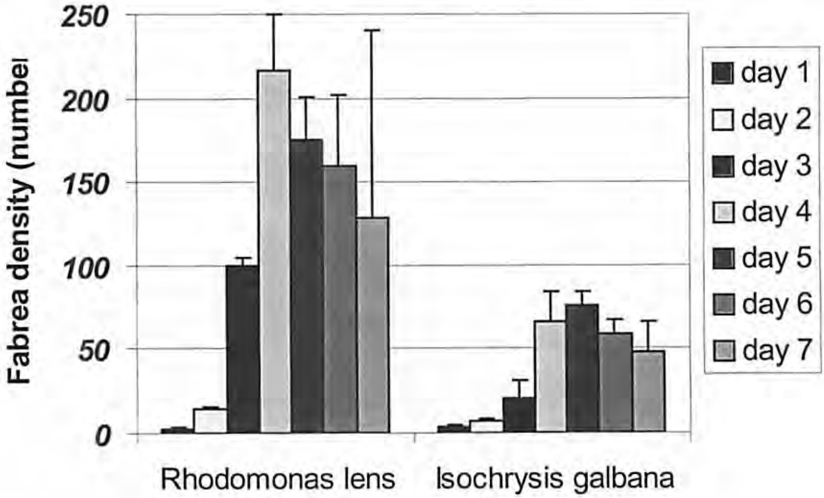


**Figure 1.** Results of *F. salina* growth trial when either *Rhodomonas* or *Isochrysis* was stocked at 90,000 cells/ml and Fabrea at 3/ml.

Optimum culturing conditions, stocking at 3/ml, 12 to 14 hours light/day, and feeding 90,000 *Rhodomonas* cells/ml were used to mass culture *Fabrea* in 40 L bags or 200 L solar tubes. These conditions lead to growth of at least 50 ciliates/ml in no more than seven days, in 100% of culture attempts. In 200 L tubes the overall mean density was 75 ± 31/ml with some variability in day of peak growth (Table 1).

**Table 1.** Average densities of mass cultures from past and present studies and the densities from culture trials (parameter with highest density cited).

| | Food type | No Days Cultured | Avg. density (#/ml) | Culture Volume (L) | Source |
|---|---|---|---|---|---|
| **Past** | | | | | |
| | Rice bran | 5 | 59 | 40 | Rattan, 1999 |
| | Egg custard | 5 | 60 | 50 | Pandey and Yeragi, 2004 |
| | Egg custard | 5 | 82 | 200 | Pandey and Yeragi, 2004 |
| | *Duniellia sp.* | 14 | 100 | 45 | Uhlig,1981 |
| | *Duniellia sp.* | 4 | 130 | 30 | De Winter and Persone, 1975 |
| **Present** | | | | | |
| | *Rhodomonas* | 7 | 70 ± 11 | 1 | Algal density trial-90,000 cells/ml |
| | *Rhodomonas* | 7 | 84 ± 9 | 1 | Lighting trial-18 hours light |
| | *Isochrysis* | 7 | 110 ± 12 | 1 | Stocking density trial-9/ml |
| | *Rhodomonas* | 7 | 216 ± 34 | 1 | Algal comparison trial |
| | *Rhodomonas* | 7 | 100 ± 36 | 40 | Bag cultures |
| | *Rhodomonas* | 7 | 75 ± 31 | 200 | Solar tube cultures |

## Snapper Rearing

Survival of red snapper after 28 days was 0.28 ± 0.15% in treatment 1, fed copepod nauplii only; 2.39 ± 2.75% in treatment 2, fed copepods nauplii and ciliates; no survival in treatment 3, fed *Fabrea* as the only food source for the first three days of feeding. Survival was highly variable within treatments, but the addition of *Fabrea* had a positive impact on survival $p = 0.12$. Standard lengths, and body depths length are reported for each treatment (Table 2). The final standard lengths were 11.45 ± 1.1mm and 13.45 ± 5.6mm for treatments 1 and 2, respectively ($p = 0.020$).

Larvae were more active feeders in the tanks given *Fabrea* and nauplii as first foods, with an average daily reduction in copepod nauplii of 34.6 ± 58.1%, compared to 15.8 ± 107.0% reduction when only nauplii were provided. Survival was positively related to the percent daily reduction in nauplii abundance ($p = 0.19$). The total number of nauplii available for days 1-7 was 2.49 ± 1.02/ml in treatment 2, nauplii and *Fabrea* and was significantly higher ($p = 0.05$) than treatment 1, containing nauplii only at 1.92 ± 1.03/ml.

The average daily reduction in *Fabrea* was 37.01 ± 50.05% in treatment 2 and 17.7 ± 49.36% in treatment 3 ($p = 0.18$). The average density was 3.12 ± 2.4/ml in treatment 2 and 6.51 ± 4.35/ml in treatment 3 ($p = 0.002$). There was a difference in the average density and a trend towards a difference in the daily reduction.

There was no difference in the average daily reduction of rotifers or total average density. The average daily reduction in rotifers was 14.4 ± 49.2% in treatment 1 and 9.78 ± 77.29% in treatment 2 (p = 0.80). The average density was 14.03 ± 4.99/ml in treatment 1 and 13.86 ± 5.14/ml in treatment 2 (p = 0.91).

**Table 2.** Growth of red snapper larvae reported in standard length and body depth in the three treatments fed 1=nauplii only, 2=nauplii and *Fabrea*, 3=*Fabrea* only.

| | Treatment 1 | | Treatment 2 | | Treatment 3 | |
|---|---|---|---|---|---|---|
| Day | Length (mm) | Depth (mm) | Length (mm) | Depth (mm) | Length (mm) | Depth (mm) |
| 1 | 2.81±0.09 | 0.20±0.02 | 2.81±0.09 | 0.20±0.02 | 2.81±0.09 | 0.20±0.02 |
| 2 | 2.72±1.08 | 0.18±0.11 | 2.68±0.25 | 0.19±0.02 | 1.90±0.15 | 0.19±0.17 |
| 3 | 2.66±0.09 | 0.20±0.02 | 2.57±0.29 | 0.18±0.01 | 2.34±0.21 | 0.16±0.05 |
| 4 | 2.47±0.80 | 0.20±0.01 | 2.57±0.54 | 0.19±0.03 | 2.48±0.59 | 0.19±0.02 |
| 5 | 2.78±0.17 | 0.20±0.04 | 2.55±0.27 | 0.18±0.02 | –[2] | –[2] |
| 6 | 2.16±0.39 | 0.17±0.02 | 2.33±0.25 | 0.17±0.02 | –[2] | –[2] |
| 12 | 3.47±0.36 | 0.39±0.09 | 3.63±0.26 | 0.44±0.08 | –[2] | –[2] |
| 20 | 8.34±1.10 | 2.37±0.43 | 7.17±0.41 | 1.91±0.22 | –[2] | –[2] |
| 28 | 11.45±1.1 | –[1] | 13.45±5.6 | –[1] | –[2] | –[2] |

[1]-Body depth was not measured on the final day.
[2]-Treatment 3 did not have any survival after day 4.

## DISCUSSION

*Fabrea* proved to be a relatively hardy protozoan that could be produced in a large volume (200 L) at densities of 75 ± 31/ml. The culture techniques determined for *Fabrea salina* yielded similar densities to other mass culture attempts ranging from 59 to 130/ml (Table 1). *Fabrea* multiplies relatively fast. Therefore, differences in initial stocking rates 3 to 9/ml had little impact on the final densities obtained. Mass cultures were initially stocked with 3/ml to decrease the initial volume needed to inoculate the culture. *Rhodomonas* supported better *Fabrea* growth than *Isochrysis.* These two algae species differ in size, *Rhodomonas* 9 - 12 µm versus 5 - 6 µm for *Isochrysis* and nutrient content (Repak 1983). Repak (1983) evaluated 45 species of algae as food for *Fabrea* and found *Rhodomonas lens* to provide the best growth rate; seventeen other species of algae also proved to be nutritious, including *Isochrysis.* Other authors have used non-algal diets such as egg custard, fermented rice bran, and wheat bran that provide bacteria and yeast (Table 1). Protozoans can grow often just as well on inert foods, which is easier for aquaculture purposes. However, Repak (1986) found bacteria to be of minimal value for *Fabrea* growth and yeast to have little to no value. Major fatty acids required for larval fish are present in high numbers in *Fabrea,* the nutritional value was found to vary with diet (Harvey et al. 1997, Pandey et al. 2004).

Lighting trials conducted by DeWinter and Persone (1975) using continuous light and continuous darkness, showed no difference. Pandey and Yeragi (2004) obtained densities of 120/ml when exposed to light and only 76/ml without light. No significant difference (p = 0.32) was found amongst the three treatments, 6, 12, or 18 hours light. This study did not contain a 24 or 0 hour light treatment. The photoperiod gives control over the algal growth, which affects the water quality.

The presence of *Fabrea* along with copepod nauplii gave an approximate 100% improvement in survival than when only copepod nauplii were added. However, *Fabrea* alone is not adequate to support snapper growth and development. Similar results were observed with the dinoflagellate *Gymnodinium splendens* as first food for the red spotted grouper and the Japanese stripe knife jaw (Rodriguez and Kirayama 1997). The survival was higher when fed both *G. splendens* and rotifers than when fed exclusively *G. splendens* or rotifers. The diversity of food organisms leads to better survival. Renè (1974) used *F. salina* as a successful substitute to young *B. plicatilis* to feed larval gilthead, *Sparus aurata*, 3 - 7 days after hatching. Barnabè (1974) reported no difference in survival when feeding larval sea bass, *Dicentrachus labrax*, rotifers or *Fabrea*. There were no other reports mentioning the use of *Fabrea* as a first food until Park and Hur (2001) found higher mortality of larval ayu, *Plecoglossus altivelis* when fed *F. salina* when compared *Brachinous plicatilis*. *F. salina* may be better suited for larval fish requiring a smaller first feed or the transition is so fast that larger food may be needed sooner.

The treatment containing both nauplii and *Fabrea* were more active feeders based on the reduction in copepod nauplii when compared to the treatment containing only nauplii and more active feeders on *Fabrea* when compared to the treatment being fed *Fabrea* only for the first three days. There was no difference in the average number of rotifers available to each treatment or the average daily reduction of rotifers. The fish lengths began to decrease in the treatment being fed *Fabrea* only as early as day 2 (Table 2); this is due to the fish using energy without acquiring enough nutrients from the food provided which results in resorption of tissues. The decrease in standard length during the first six days seen in Table 2 was described by Williams et al. (2004), as growth is channeled into further development of the jaw and increased body depth.

*Fabrea salina* can be important feed for marine fish larvae, particularly those with small mouth gapes when other foods are available to support additional growth. *F. salina* can be mass cultured, but higher densities must be achieved to facilitate it being more commonly used.

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# Recruitment of Spiny Lobsters, *Panulirus argus*, to Submerged Sea Cages off Puerto Rico, and its Implication for the Development of an Aquaculture Operation

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ABSTRACT

Spiny lobster, *Panulirus argus*, is an important fisheries species in Florida and the Caribbean region. The high value of this species and the limited extent of their wild fisheries make them an ideal candidate for commercial culture. One of the major constraints to spiny lobster culture is that the aquaculturist must rely on the steady supply of post larvae (pueruli) from the wild for nursery and growout. The focus of this research project was to advance the culture of spiny lobster through novel pueruli collection methods. Recruitment of 1000's of spiny lobster pueruli to submerged fish sea cages in Puerto Rico was first observed by Snapperfarm, Inc. in spring of 2003. With funds from NOAA SBIR Phase I, studies were conducted from July 2003 to January 2004 to determine the feasibility of collecting spiny lobsters from sea cages for growout. Results showed that year-round collection of pueruli from submerged sea cages is feasible, with the highest collection occurring in the spring and near the new moon phase. Newly settled pueruli and pigmented post larvae were observed during each month of the study. Over 400 juvenile lobsters were collected from the submerged sea cages; 40 were placed in a growout study and the rest were relocated to a nearby marine reserve. The findings from this study indicate that collection of lobster pueruli and juveniles from sea cages for growout is technically feasible and has potential to be developed into a commercial venture.

KEY WORDS: Pueruli, recruitment, spiny lobster

## Reclutamiento de la Langosta Espinosa, *Panulirus argus,* a Jaulas Sumergidas en Puerto Rico, y su Implicacion para el Desarrollo de una Industria de Acuicultura

La langosta espinosa, *Panulirus argus,* es una especie importante en las pesquerias de la Florida y la region del Caribe. El alto valor commercial de esta especie y la distribucion geografica limitada de su pesqueria la hacen un candidato ideal para cultivo a nivel comercial. Uno de los mayores factores limitantes al cultivo de la langosta espinosa es que el acuicultor depende en el continuo abastecimiento de post larvas (pueruli) silvestres para establecer viveros y crianza a la etapa de adulto.

El enfoque de este proyecto de investigacion es la innovacion de metodos de el cultivo de los puerulus de la langosta espinosa. Reclutamiento de miles de puerulus de la langosta espinosa a jaulas sumergidas en Puerto Rico fue observado por Snapperfarm, Inc. en la primavera del 2003. Con fondos de NOAA SBIR (Primera fase), estudios fueron realizados entre Julio 2003-Enero 2004 para determinar la posibilidad de coleccionar la langosta espinosa de las jaulas sumergidas para la crianza.

Los resultados demuestran que los pueruli se pueden coleccionar a traves del ano de las jaulas sumergidas, con las mayores cantidades obteniendose en la primavera cerca de la fase de luna nueva. Los pueruli recien llegados y post larvas pigmentadas fueron observadas cada mes del estudio. Mas de 400 langostas juveniles fueron coleccionadas de las jaulas sumergidas; 40 fueron asignadas a un estudio de crecimiento y el resto fueron transferidas a una reserva marina cercana al lugar del estudio. Los resultados de este estudio demuestran que la coleccion de pueruli y juveniles desde las jaulas sumergibles es tecnicamente posible y que hay potencial para desarrollar una industria a nivel comercial.

PALABRAS CLAVES: Acuacultura, langosta espinosa, coleccion de pueruli

## INTRODUCTION

The world market for spiny lobsters is approximately 80,000 metric tons annually and is supplied almost entirely by wild fisheries (FAO, 2005). The spiny lobster, *Panulirus argus*, is found throughout the Gulf and Caribbean and forms the largest commercial fishery for spiny lobsters in the world at around 38,000 metric tons. The high value of spiny lobsters and the limited extent of their wild fisheries are generating an increasing worldwide interest in aquaculture (Jeffs and Hooker 2000). The commercial aquaculture of spiny lobsters is estimated at 3,000 tons per year and is being cultured in a number of countries including Japan, Australia, Taiwan, and New Zealand with the vast majority grown in Vietnam (Jeffs and Hooker 2000). This spiny lobster aquaculture is based on the collection of post-larva and early juveniles from the wild.

The prospects for farming the Caribbean spiny lobster, *P. argus*, profitably are higher than for temperate spiny lobster species due to the greater availability of wild seed lobsters and a faster growth rate (Booth and Kittaka 2000, Jeffs and Davis 2003). At this time, the spiny lobster, *P. argus*, is not commercially cultured, however, a great deal of research has been accomplished on this species and similar species that is directly relevant to the development of aquaculture of *P. argus* (Lellis 1991, Jeffs and Hooker 2000).

One of the major constraints to spiny lobster culture is obtaining a steady supply of post larvae for nursery and growout. Spiny lobsters have been successfully mated and spawned in captivity. However, researchers have had difficulty rearing large numbers of phyllosoma larvae through the many stages of the year long complex cycle. An alternative is to bypass the larviculture stage and collect the pueruli from the wild as they drift to nearshore habitats. There has been good success with the collection of wild spiny lobster pueruli on floating artificial habitats (Witham collectors), in crevice collectors, or large plankton nets (Witham et al. 1964, Calinski and Lyons 1983, Reid et al. 1991, Gutierrez-Carbonell et al. 1992, Field and Butler 1994, Phillips and Booth, 1994). The transparent pueruli settle on the collectors during the new moon to the quarter moon phase. Currents, tides, wind, and season all play a role in settlement and collection numbers. In addition to lunar cycles, wind, tides, hydrological features and seasonality influence the timing and magnitude of lobster recruitment to artificial habitats.

Collection of pueruli from the natural environments will not put pressure on the fisheries stocks. There are indications from pueruli collection studies that collectors only remove a small fraction of the number of pueruli in the water column and that a very large number of pueruli are lost mainly due to predation or lack of appropriate settlement habitat (Ryther et al. 1988, Butler and Herrnkind 1989). In nature it is estimated that only 4% of post larvae survive to juvenile stage (Forcucci et al. 1994). Under controlled culture conditions survival could be as high as 50 - 75% during this stage (Lellis 1991).

Snapperfarm, Inc. has two 3,000 cubic meter sea cages used to culture marine fish off the coast of Culebra, Puerto Rico. This structure is located in 28 meters of water depth. Over the course of the first six months after deployment, the cage became covered in a fine layer of macroalgae and diatoms. In the spring of 2003, 1000's of spiny lobster pueruli recruited to these submerged sea cages. These juvenile lobsters were the first indication that these large sea cages are ideal settlement collectors for spiny lobster pueruli. With funds from NOAA SBIR Phase I, Snapperfarm, Inc. and researchers from Harbor Branch Oceanographic Institution, University of Miami - RSMAS, Florida Sea Grant Extension, and NMFS conducted studies from July 2003 - January 2004 to advance the culture of spiny lobster through novel pueruli collection methods.

## OBJECTIVES:

The main goals of the project were to determine methods to collect spiny lobster pueruli that recruited to offshore submerged sea cages in Puerto Rico, and to assess the commercial viability of a spiny lobster mariculture operation in association with fish sea cages.

## METHODS AND RESULTS

The study was conducted by Snapperfarm, Inc. and collaborators in Culebra, Puerto Rico. Snapperfarm has two SeaStation™ 3,000 cubic meter offshore cages off the coast of Culebra, Puerto Rico. Each cage is 15 m deep, 25 m in diameter and has a total surface area of 1,115 square meters. The cages are submerged in a water depth of 28 meters with the top 8 m below the sea surface. The site is fully exposed to the Atlantic Ocean to the northwest and the Caribbean Sea to the southeast. The site receives strong, open ocean currents (0.5 knots).

Scuba diving surveys of the sea cages for spiny lobster pueruli were conducted during each month of the study (July 2003 – January 2004) and showed that the majority of the lobsters recruited to the sea cages on the new moon and during the week following the new moon. Low numbers of pueruli were visually found during transect surveys of the seacages, due to the small size of the pueruli (6 - 7 mm CL) and their cryptic nature (e.g., clear to slightly pigmented). The most number of pueruli (total of 14) were seen while night diving with lights on a small section of the sea cage in August. Pueruli were also observed in the daytime during each month of the study (up to five pueruli per month). The pueruli were found near the chimney top of the sea cage, in the folds of the harvest net, and under clumps of red algae, *Laurencia* sp., which is known to trigger lobster settlement. This is the first time that lobsters of this size have been observed in the wild on large submerged sea cages.

Collection devices, such as PVC pipes and window screen pinwheels, were secured to the sea cages in an experimental array. Lobsters did not recruit to the PVC pipes, but were attracted to the screen pinwheels. Up to five pueruli and juveniles were found in the screen pinwheel collectors each month (October 2003 – January 2004). The best results were when the pinwheels were placed on the sea cages one week prior to the new moon for fouling. However, these collection devices (PVC pipes and pinwheels) were not ideal for pueruli and juvenile lobster collection, because of the crabs that also recruited to the collection devices.

Due to the cryptic nature of the pueruli, an alternative collection method used during the study included removing spiny lobster juveniles off the sea cages after they had gone through several molts (two months after settlement). Over 400 juvenile lobsters (two to eight months old) were collected from the two sea cages during the study. The majority were placed in a nearby marine reserve, however, 40 were removed for a preliminary grow out study. They ranged in size from 3 – 6 cm CL (five to eight months in age). The lobsters were placed inside a 55-gallon plastic barrel that had holes drilled in the sides and shelter inside. The barrel was secured to the sea cage mooring on bottom of the ocean (28 m deep). The lobsters were fed every five to seven days with a 7 – 9 kg cobia fish that had recently died in the sea cage. Lobster survival over the three month study period was 60%, however, growth was slow over the three months due to lack of adequate feed variety.

## DISCUSSION

There is every indication from this study that lobster pueruli and juveniles can be collected year round from submerged sea cages in Puerto Rico. Due to the cryptic behavior and clear color of the pueruli, it is not surprising that it was difficult to obtain an accurate count of the number of pueruli during the surveys. The results from this study show that year round collection of lobster pueruli and juveniles from sea cages is technically feasible and has potential to be developed into a pilot-scale venture. This is consistent with the purpose of NOAA SBIR Phase I to determine the technical feasibility of the proposed research. Recruitment of lobsters to the fish sea cages will provide Snapper-farm, Inc. with an added revenue source to support the fish farming operation. The company was awarded a NOAA SBIR Phase II to continue the research and development of pueruli collection on submerged sea cages and submerged cage growout of juveniles for market.

This is Harbor Branch Oceanographic Institution Contribution Number 1567.

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# The GCFI Education Initiative: Bridging Science and Community

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The Gulf and Caribbean Fisheries Institute recognizes that science education is critical for long-term conservation and well-informed management of marine resources in the region. As was made vividly clear during a special science education roundtable discussion held during the 56th annual GCFI Conference in Tortola, British Virgin Islands, it is imperative that science education needs be identified and that teachers, marine scientists, and governmental entities responsible for the management of marine resources be provided fundamental educational materials, teaching tools, and training opportunities to support, and in some instances initiate, marine science education throughout the region. The GCFI's long-standing mission of promoting the exchange of information on the use and management of marine resources in the region is now enhance through the newly developed Education Initiative which provides for open discussion of shared interests and concerns and for the identification of science education issues and needs of regional importance. The Education Initiative represents new opportunities to foster stewardship of the marine environment and facilitate wise and sustainable use of marine resources throughout the region through the formation of resourceful partnerships, dissemination of educational information and materials, and development and implementation of science education priorities and strategies.

# La Iniciativa en Educación del Instituto de Pesquerías del Golfo y el Caribe: Vinculando la Ciencia con la Comunidad

El Instituto de Pesquerías del Golfo y el Caribe (GCFI, por sus siglas en Inglés) reconoce que la divulgación del conocimiento científico es un elemento crítico en el manejo bien documentado de los recursos marinos, así como para su conservación en la región, en el largo plazo. Esta relevancia quedó bien establecida en la discusión que se llevó a cabo en el marco de la Sección Especial sobre Educación en el área de las Ciencias, sostenida en la 56ava Reunión Anual del GCFI (Tortola, Islas Vírgenes Británicas). En este evento se determinó que es imprescindible que se identifiquen las necesidades de educación en ciencias, y que los profesores, investigadores y entidades gubernamentales responsables en el manejo de los recursos marinos reciban los materiales fundamentales para la docencia, las herramientas para enseñanza y el entrenamiento para apoyar y en algunos casos para iniciar, programas de educación en las ciencias marinas en toda la región. A lo largo de su existencia, el GCFI ha mantenido como uno de sus objetivos el intercambio de información acerca del uso y el manejo de los recursos marinos en la región. Esta misión se ve ahora potencializada a través de la nueva iniciativa en Educación Marina, la cual ofrece un espacio para la discusión abierta en tópicos de interés y preocupaciones comunes, así como para la identificación de la temática y las necesidades para la educación en ciencias de interés regional. Esta iniciativa de la educación representa nuevas oportunidades para fomentar el manejo de los ambientes marinos y facilitar el uso apropiado y sostenible de los recursos marinos en toda la región. Para ello es necesario crear asociaciones entre los usuarios y las entidades participantes, fomentar la difusión de la información y el material educativo, así como el desarrollo e implementación de las estrategias y prioridades para la educación en ciencias.

# The Cape Eleuthera Island School: *Immersion*, *Involvement*, *Ownership*, and *Legacy* as Principles to Enhance Education in Marine Science and Beyond

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ABSTRACT

Developing a program that encourages students to connect with place can broaden the intrinsic value of an educational experience and ultimately create a passion for learning that transcends traditional classroom settings. Connecting to place is one of the primary goals of The Cape Eleuthera Island School – a semester-based, study-abroad program for high school sophomores and juniors located on Eleuthera, in The Bahamas. Our model applies four guiding principles to enhance the educational experience – *Immersion, Involvement, Ownership, and Legacy*. Research and outreach are two facets of our program that embody these principles. In both cases, students are immersed in their surroundings through place-based activities that focus on socioeconomic, environmental, and conservation issues important to communities on Eleuthera. Through research, students become involved in these issues by participating in projects that focus on topics such as the status of queen conch and Nassau grouper populations, coastal rehabilitation, and sustainable development. Students are involved in all aspects of their research project, from data collection and analysis to the presentation of their findings to local community members, government officials, and international scientists. In community outreach, Island School students are matched with students from local primary and middle schools. Our students apply and integrate their knowledge of local environmental and socioeconomic issues as they tutor school children in disciplines such as reading, writing, math, and computer skills. During research and outreach, our students develop a sense of pride and take ownership over their work (and interactions) because they are asked to address 'real-world' issues faced by local communities. Lastly, given that the research and outreach programs are ongoing and have long-term objectives, students become aware that they are contributing to a legacy that will continue beyond their time at The Cape Eleuthera Island School, further enhancing the educational experience. Students pursuing further learning opportunities in marine sciences and marine resource management is another form of educational legacy.

KEY WORDS: Experiential education, Cape Eleuthera Island School, Bahamas

# La Escuela de la Isla de la Capa Eleuthera: La Inmersión, la Participación, la Propiedad, y el Legado como Principios para Aumentar la Educación en la Ciencia Marina y Más Allá

Desarrollar un programa que alenta a estudiantes para conectar con el lugar puede ensanchar el valor intrínseco de una experiencia educativa y últimamente crear una pasión para aprender que sobrepasa los escenarios tradicionales de aula. Conectar para colocar es uno de las metas primarias de La Escuela de la Isla de Capa Eleuthera – un semestre-basado, el programa de estudio-al exterior para estudiantes de segundo año de preparatoria y menor localizados en Eleuthera, en Las Bahamas. Nuestro modelo aplica cuatro principios indicadores para aumentar la experiencia educativa – la Inmersión, la Participación, la Propiedad, y el Legado. Investigación y alcance son dos facetas de nuestro programa que personifica estos principios. En ambos casos, los estudiantes son sumergidos en sus alrededores por las actividades de lugar-basó que enfocan en socioeconómica, ambiental, y la conservación publica importante a comunidades en Eleuthera. Por investigación, los estudiantes se lian en estos asuntos por tomar parte en proyectos que enfocan en temas tales como la posición de caracola de reina y poblaciones de grouper de Nassau, de rehabilitación costera, y del desarrollo sostenible. Los estudiantes son implicados en todos aspectos de su proyecto de investigación, de la colección de datos y análisis a la presentación de sus hallazgos a miembros locales de comunidad, a funcionarios de gobierno, y a científicos internacionales. En el alcance de la comunidad, estudiantes de Escuela de Isla son emparejados con estudiantes de escuelas locales, primarias y medianas. Nuestros estudiantes aplican e integran su conocimiento de asuntos locales, ambientales y socioeconómicas como ellos dan clases privadas a niños de escuela en disciplinas tales como leyendo, escribir, las matemáticas, y las habilidades de la computadora. Durante investigación y alcance, nuestros estudiantes desarrollan un sentido del orgullo y toman la propiedad sobre su trabajo e interacciones porque ellos son pedidos dirigir 'mundo verdadero' los asuntos encarados por comunidades locales. Ultimamente, dado que los programas de investigación y alcance están a ir y tienen los objetivos a largo plazo, los estudiantes llegan a ser enterados que ellos contribuyen a un legado que continuarán más allá de su tiempo en La Escuela de la Isla de Capa Eleuthera, aumentando aún más la experiencia educativa.

PALABRAS CLAVES: La educación de experiencia, la Escuela de la Isla de Capa Eleuthera, las Bahamas

## ENHANCING EDUCATION

*"If you tell me, I will listen.*
*If you show me, I will see.*
*If you let me experience, I will learn."*

Lao Tzu – (6th Century BC).

Learning, or the process of gaining knowledge or skills, can be enhanced if students, regardless of age, are given the opportunity to connect with a particular experience (Penick 1995, Conner et al. 1996). Learning through experience, in combination with general concepts taught in traditional classroom settings, can help stimulate the acquisition of knowledge and skills via multiple senses (i.e., visual, auditory, tactile, and kinesthetic) and thus cater to a range of learning styles (Conner et al. 1996).

In 'experiential education', observations, actions, and hands-on activities, are tools in the dynamic process of learning. However, to be effective, students must be consciously affected by an experience, and recognize their observations, actions, and activities as sources of knowledge (Penick 1995, Conner et al. 1996). As such, students entering an experiential learning environment must do so with a positive attitude and willingness to become active participants in the world around them (Penick 1995).

Experiential education, in combination with a passion for learning, helps students become critical, logical thinkers as they work to make sense of the experiences they are having. This innovative teaching style encourages students to ask questions, and, in some cases, take action to develop solutions to problems they confront (Penick 1995). The satisfaction of solving a problem helps engrain the value of the learning process, especially if the problem is 'real'. Unfortunately, one drawback of experiential education is that rarely do students get to see the outcome of their actions, and thus, cannot reflect on them to effectively learn from the experience (Conner et al. 1996).

Marine science, and in particular, marine resource management, is one discipline where experiential education can help students effectively learn from the outcome of their actions. Essentially, experiential education that deals with helping people live sustainably with their environment adds a sense of purpose and promotes solution-orientated, critical thinking that enhances the process of learning (Braus 1995). Because marine science is interdisciplinary in nature, a learning-based approach that incorporates experiential education can help students better understand the complex interrelationships and processes that are often difficult to conceptualize in a traditional classroom setting.

## GUIDING PRINCIPLES TO ENHANCE EDUCATION

Four principles can be used to help guide the development of an experiential program that enhances education and fosters a passion for learning that transcends traditional classroom settings.

### Immersion

Anchoring learning opportunities to an immediate surrounding helps to create a connection to place. Place-based curriculum and hands-on, minds-on activities can facilitate the formation of this connection (Penick 1995). Once an initial connection to elements of the environment has been made, further cultivation of the relationship between person and place can help refine observation skills. Observations made by engaged learners can inspire the formation of questions and lead to deeper interest in the topic of inquiry.

### Involvement

Students who are encouraged to actively explore their physical learning environment are more likely to become aware of the subtlety of their role and interactions with 'place'. Asking students to get involved through student-driven inquiries allows the learner to test theories through the direct application of their knowledge. Activities that encourage students to think while they are doing (Penick 1995), such as identifying and solving problems related to 'real world' socioeconomic, environmental, and conservation issues, can develop awareness of multifaceted perspectives, issues, and biases (Braus 1995).

### Ownership

As interest, understanding, and awareness grow via experiences requiring the active and innovative application of knowledge (McTighe and Wiggins 1999), a sense of ownership and responsibility develops. A sense of ownership increases the value of an experience and students thus begin to take pride in their contributions. With ownership, students begin to critically reflect on challenges they have faced, which, in turn, promote the recognition of oversights in thinking and further advances a deeper understanding of issues (McTighe and Wiggins 1999, Sterling 2001). Once a learner takes ownership of 'real world' issues, they are prepared to recognize their role, and are more likely to generate potential solutions on a personal and community level (Sterling 2001).

### Legacy

Legacy refers to aspects of educational programs that build on previous work, where 'real world' projects initiated by students continue to produce tangible outcomes. Presenting students with the opportunity to contribute to long-term initiatives reinforces a sense of ownership. In addition, designing legacy into an education program ultimately helps to validate the learning experience since students, and even teachers, can later reflect on the true value of their work.

## CASE STUDY – CAPE ELEUTHERA ISLAND SCHOOL

The Cape Eleuthera Island School (IS) offers an innovative model for experiential education based on the guiding principles of *Immersion*, *Involvement*, *Ownership*, and *Legacy*. The IS offers international high school sophomores and juniors a semester-based experiential education program on Eleuthera, Bahamas.

### Immersion

Integral to the success of the IS place-based curriculum are the daily interactions students have with their surroundings. Their journey begins on a small plane flying from Florida across the mottled Bahamas Banks. Shortly after arriving on Eleuthera, guided explorations of the marine world through SCUBA diving, snorkelling, and multiple day kayak trips immerse students in the local environment and foster a personal connection to place.

Students continue to be immersed in place through the academic curriculum that strives to apply concepts learned in class to the environment around them. For instance, the marine environment off Cape Eleuthera is used to provide examples of ecological theories for science class. Another part of the curriculum involves interacting with people in local communities, whether it is through home stays or the Community Outreach Program. Interacting with people in local communities enhances the sense of place and deepens the understanding of what 'place' represents.

Immersion and connection to place at IS also includes an understanding of the systems that support our day-to-day lives. Each student is asked to take a leadership role in a small community that strives to have minimal impact on the environment. Systems such as renewable energy sources, water collection, wastewater management, and building design support the IS campus and have been assembled with considerable thought to our ecological footprint. Concepts related to sustainable systems have been incorporated into course specific projects, seminar discussions, outreach initiatives, journaling assignments, and day-to-day living.

### Involvement

The IS strives to ensure academic pursuits undertaken by our students can be applied outside the classroom. The Research Program and Community Outreach Program are two facets of the curriculum that involve students in learning opportunities that encourage critical thought and application of their knowledge. The scope of these programs extends beyond our institution and explores socioeconomic, environmental, and conservation issues.

The Research Program has student and faculty teams immersed and involved in focused research projects that explore environmental and socioeconomic challenges present on South Eleuthera. Several research projects focus on marine ecology and marine resource management. One focus is the health of queen conch, *Strombus gigas*, populations and whether a proposed marine protected area off Cape Eleuthera will be effective in conserving this important species. Students also monitor artificial reefs to assess their effectiveness at increasing habitat and the abundance of commercially valuable reef fish and spiny lobster.

The Community Outreach Program provides a venue for IS students to become teachers and mentors, and gain confidence in sharing their knowledge of marine resource management and conservation with children in the local community. An important part of the outreach program is that IS school students plan the lessons they facilitate. Many of these lessons link traditional academic skills, such as reading and mathematics, to experiences had during kayaking, camping, and swimming. In addition, lessons also incorporate material on marine resource management and conservation as a way to promote environmental awareness in local communities.

**Ownership**

Students take ownership over all nuances of their research and community outreach projects. Given the right training and tools, IS students have shown they have the capacity to ask informed questions, contribute to the development of methodologies, collect and analyze data, and work closely with peers to prepare a collaborative research paper. In addition, students synthesize their findings into oral reports, and at the end of each semester present to their parents, government officials, scientists from colleges and universities, and members of local communities. The culmination of the Community Outreach Program is an event where participants showcase their semester accomplishments by performing dramatic productions, sharing their poster creations, and giving oral presentations and slide shows.

**Legacy**

Research projects that build on the knowledge and conclusions of successive semesters helps deepen the significance of the student's work, further enhancing the educational experience. For example, queen conch has been the focus of ongoing student research project for over four years. During this period, students have interviewed community members about fishing practices, quantified the harvest of juveniles, performed habitat surveys, and identified and delineated a queen conch nursery grounds. Currently, students are employing ecological design principles to build environmentally friendly, inexpensive raceways, to be used for the grow out of hatchery-reared queen conch. Student research on queen conch has provided important information that will assist in the planning of a proposed marine reserve for South Eleuthera (Clark et al. In Press, Danylchuk In Press), offering a significant socioeconomic, environmental, and conservational legacy for future students of the IS, the community of South Eleuthera, and The Bahamas.

Community outreach also has a legacy in terms of the quality of relationships that form between IS and Bahamian students. Many IS students maintain contact with their partners after their semester concludes. The partners continue to share life-experiences and unique perspectives beyond the educational setting. In addition, the aim of community outreach is to create a legacy by promoting conservation and environmental awareness, which may ultimately assist in the effective management of local resources.

## CONCLUSIONS

The four principles of *Involvement*, *Immersion*, *Ownership*, and *Legacy* can work in concert to enhance education. Establishing and revisiting these principles when designing and implementing an educational program can encourage an enthusiasm for learning and promote the development of keen observation and critical thinking skills. As seen with the IS model, these skills help students achieve an advanced understanding of concepts taught in traditional classroom settings, while also promoting a solution-orientated reaction when confronted with complex issues. Based on our experience, marine science and marine resource management can be effective vehicles for experiential education.

## ACKNOWLEDGEMENTS

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# Conch in the Classroom: Integrating Queen Conch Activities into the Curriculum

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ABSTRACT

The Conch Heritage Network (CHN) was established in 2001 and is a leading organization for the exchange and dissemination of queen conch information on biology, fisheries, culture, research and education. The CHN has outreach tools available for educational and public use. They include a video, brochure, poster, educational modules, and an informative website. The Conch Heritage Network also developed "Conch in the Classroom" lesson plans for middle and high school teachers that cover the history, geography, biology, management, and aquaculture of the queen conch. The activities included in each lesson teach a relevant scientific concept using the queen conch as the example specie. For example, the students will learn about the importance of ocean currents for larval dispersal and the relationship of sea grass density and habitat quality for restocking. Students will also be able to participate in a virtual queen conch dissection. Each lesson lists the appropriate national and Florida state science standards that are met, enabling teachers to easily incorporate the lessons into their curriculum. Several teachers in Florida are using the "Conch in the Classroom" lesson plans and activities. All of these lessons are available on the website (www.savetheconch.org) in downloadable form.

KEY WORDS: Conch, education, *Strombus gigas*

# El Conch en el Aula: Actividades del conch de la reina que integran en el plan de estudios

El Conch Heritage Netowrk (CHN) fue establecida en 2001 y es una organización principal para el intercambio y la difusión de la información del conch de la reina sobre biología, industrias pesqueras, cultura, la investigación y la educación. El CHN tiene disponibles recursos para el uso educativo y público. Incluyen un vídeo, un folleto, un cartel, módulos educativos, y un Web site. El Conch Heritage Network se ha convertido " El Conch en el Aula" planea para los profesores de esculeas que cubren la historia, la geografía, la biología, la gerencia, y la acuacultura del conch de la reina. Las actividades incluidas en cada lección enseñan un concepto científico relevante usando el conch de la reina como el specie del ejemplo. Por ejemplo, los estudiantes aprenderán sobre la importancia de las corrientes del océano para la dispersión larval y la relación de la densidad de la hierba del mar y de la calidad del habitat para volver a surtir. Los estudiantes también podrán participar en una disección virtual del conch de la reina. Cada lección enumera los estándares apropiados de la ciencia de los Estados Unidos y del estado de la Florida se resuelven que, permitiendo a profesores incorporar fácilmente las lecciones en su plan de estudios. Varios profesores en la Florida están utilizando " El Conch en el Aula". Todas estas lecciones están disponibles en el website (www.savetheconch.org).

PALABRAS CLAVES: Concha, educacion, *Strombus gigas*

## INTRODUCTION

The queen conch, *Strombus gigas*, has been an important fisheries species throughout Florida and the Caribbean region for thousands of years. For the past few decades, queen conch populations have become severely depleted due to overharvesting, and therefore, many countries have taken actions to protect the remaining stocks. Conservation efforts have focused on fisheries management strategies, marine protected areas, aquaculture, stock enhancement, and education and outreach programs.

As part of a Caribbean wide conservation education program, the Conch Heritage Network (CHN) was established in 2001, and is headquartered at Harbor Branch Oceanographic Institution (Harbor Branch) in Ft. Pierce, Florida. The CHN is a leading organization for the exchange and dissemination of queen conch information on biology, fisheries, culture, research, and education. There are several research organizations, academic institutions, and public entities that are active partners in the CHN. The CHN has outreach tools available to the public, which include: a video, brochure, poster, educational modules, and an informative website.

With the aid of the Disney Wildlife Conservation Fund, the CHN has developed a "Conch in the Classroom" program for middle and high school students. This program includes: a collection of lesson plans, educational modules, a virtual queen conch dissection, queen conch Jeopardy, a step-by-step guide to setting up an aquarium, and other games and activities. This program is available online (www.savetheconch.org), on a CD, or in a printed and bound version. In addition to the online(www.savetheconch.org) resources, the CHN has also developed a supplemental teaching packet. This packet can be purchased at a discounted price for teachers and includes: a bound publications book (queen conch publications from Harbor Branch scientists), a "Conch's Life Story" video, a brochure, the Conch Life Cycle poster, the Conch Horn and Queen Conch Sea Stats (developed by Florida Fish and Wildlife), and a handful of juvenile queen conch shells for display in the classroom.

Several middle and high school teachers have adapted the "Conch in the Classroom" program into their marine science and biology classes. The queen conch lesson plans are designed in a way that incorporates state and national science standards so that teachers can easily fit them into their curriculum. Likewise, the lessons are flexible enough that teachers can use the plans as a guideline and adjust the level of difficulty according to the student's abilities or grade level.

## LESSON PLANS

There are eight lesson plans that cover queen conch history, socioeconomics, geography, habitat, biology, aquaculture, and research. At the beginning of each lesson is a list of relevant information that the teachers can use as a quick reference for curriculum design. With the focus of school districts shifting to a more integrated approach, the essential skills and integrated subjects covered in each lesson are listed. For teachers who have access to projectors, a downloadable education module in Powerpoint form is available on the website. These modules coincide with one to three lessons, and are a great source for pictures and more information.

The following is a sample lesson plan on queen conch history and socio-economics. The information and activity sheets are not included, however they are available on the CHN website.

### *LESSON 1.1 HISTORY AND SOCIO-ECONOMICS*

**Grades:** 9-12
**Integrated Subjects:** History, Science, Reading, Geography, Language Arts
**Essential Skills:** Research, Inferring, Compare/Contrast, Writing
**Sunshine State Standards:** SC.G.2.4.5, SC.G.2.4.6, SC.D.2.4.1, SC.H.3.4.5
**National Science Education Standards:** Meets Content Standards in 1) Science in personal and social perspectives; 2) History and nature of science; and 3) Science and technology
**Duration:** 1 – 2 class periods

**Objectives:**

Students will be introduced to the ways queen conch were used and how the fishery impacted Caribbean countries throughout history. In particular, students will learn:

i) How Indians utilized conch for their everyday activities,
ii) About the history of the queen conch,
iii) About today's conch market, and
iv) About the different ways to fish for conch

**Preparation:**

***Teacher Preparation:***

Duplicate appropriate materials

***Support materials:***

Tribal tool pictures
Lecture module with pictures/slides
Map of the Caribbean

*Information Sheets:*

No. 1 – Queen Conch Vocabulary List
No. 2 – The Arawak Indians
No. 3 – History of the Queen Conch Fishery
No. 4 – How are Queen Conch Used

*Activity Sheets:*

No. 1 – Queen Conch Pre-test
No. 2 – Animals as Tools
No. 3 – Fishing Methods

**Lesson Plan:**

**Activity 1. Introduction (20 minutes)**

Give the students the pre-test (Activity Sheet No. 1) in order to evaluate their understanding and knowledge of queen conch. Collect the tests and do not return them to the students until the end of lesson plans.

Ask the students to define some of the vocabulary words prior to distributing the list. Ask the students what other words they think are associated with queen conch. Hand out Information Sheet No. 1, the list of vocabulary words relevant to the queen conch lessons. Discuss the vocabulary words in class. You may choose to quiz them at the end of the lessons.

**Activity 2. The Arawak Indians (30 minutes)**

Long before Christopher Columbus discovered the West Indies, native Arawak Indians resided in many of the Caribbean islands. They were the first people to utilize queen conch for their every day needs.

Distribute and discuss Information Sheet No. 2 about the Arawak Indians. Discuss what native Indians were once present where the school is located. Have the students make a list of other animals that had been used as tools or food in other native Indian cultures throughout the world and compare to Activity Sheet No. 2.

**Activity 3. Queen Conch Fishery Economics (45 – 60 minutes)**

Distribute and discuss Information Sheet No. 3, about the queen conch fishery. Hang up a map of the Caribbean islands in your classroom. You may choose to have the students make the map themselves. Discuss what other species are fished throughout the world.

Ask the students to make a list of fishing methods that are used today or have been used in history. Distribute Activity Sheet No. 3 and compare. Distribute and discuss Information Sheet No. 4. Discuss what methods are used when fishing for queen conch and why some methods have been banned.

Assign students (groups or individual) a Caribbean country and have them research the status of the queen conch fishery. Have them examine the annual catch, quotas, regulations, and problems the fishery may be facing. Have the students put this info on an index card and attach it to the appropriate country on the map.

**Activity 4. What are Queen Conch used for? (20 minutes)**

Have the students list products that come from queen conch. Distribute Information Sheet No. 4 and discuss. Have students bring in pictures or objects that were made from queen conch.

**Conclusion for Lesson 1.1**

Discuss the importance of queen conch throughout history, and why this is such an important fisheries specie today.

**Bibliography for Lesson 1.1**

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## CONCLUSION

The queen conch is one of Florida's most precious natural resources. The CHN strongly supports the use of queen conch conservation education as a fisheries management tool. The "Conch in the Classroom" activities are available for anyone with access to the internet, and will soon be translated in Spanish and French. Using these lessons and growing queen conch in the classroom is fun and suitable for students of all ages. For more information, please visit the CHN website (www.savetheconch.org).

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# Caribbean Education Program for Sustainable Management of the Queen Conch, *Strombus gigas*

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ABSTRACT

The queen conch, *Strombus gigas,* is a large Caribbean gastropod mollusc which has been exploited for food and many other purposes since pre-Columbian times. It has also been used during slavery for remote communication. It is still being used as traditional food, and as a tourist attraction delicatessen. Its shell is used as music instrument, tourist curios and much more. Mainly because of over-fishing, but probably also because of destruction and pollution of its natural habitat, it is today an endangered marine resource. It is included in annex II of CITES (Convention for International Trade of Endangered Species). However CITES is in charge only of international trade and is not concerned with local trade and fisheries. Each country is responsible for its protection and enforcement of regulation. However in most countries, lack of respect of the main regulations is the rule.

Research workers at academic level, in Guadeloupe (French Caribbean) and in Yucatan (Mexico), cooperating with the education group of the private marine park of Xel-Há in Quintana Roo (Mexico), with the support of Puerto Rico's Caribbean Fisheries Management Council (CFMC), have joined their efforts to produce a whole set of documents at school and general public level. These documents, published in English, French and Spanish, comprise a booklet, a slide presentation and a large set of games, all accessible on four internet sites and in CD edition, distributed for free at the Gulf and Caribbean Fisheries Institute (GCFI) meetings and through the *Strombus* net site. They may be reproduced, used to print paper booklets and cardboard games for school and public information. They are designed to be adapted in each country to popularize the idea that *Strombus gigas* is a common natural resource and a cultural and economic heritage for all the Caribbean people. Children have to be involved in protecting it.

KEY WORDS: Caribbean, education, endangered species, Queen conch, *Strombus gigas*

# Programa Educativo de Manejo Sustentable del Caracol, *Strombus gigas*

El caracol rosa *Strombus gigas* es un molusco gasterópodo, inofensivo, habitante de aguas someras del Caribe. Su impacto económico en esta región ha sido estimado en 60 millones de dólares americanos. Su carne es suave, rica en proteínas y ácidos grasos no saturados, atributos que lo sitúan en uno de los platillos favoritos del Caribe. Estas características han derivado en una extracción desmedida del recurso, al grado de ser considerado por la Convención para el Comercio de Flora y Fauna Silvestre en Peligro de Extinción (CITES), como una eespecie vulnerable a la sobre explotación, que se encuentra amenazada (apéndice II). En respuesta a esta situación se han implementado programas de manejo con regulaciones; tales como, tallas mínimas de captura, vedas, cuotas de captura, restricción en los artes de pesca y el cierre total de la pesquería. Pese a estas medidas, las poblaciones naturales no se han recuperado, ya que también ha surgido un mercado negro de caracol, proveniente de la pesca ilegal.

A fin de sensibilizar a la sociedad de la necesidad de proteger y conservar esta especie marina amenazada y su hábitat, se presenta un programa de educación ambiental sobre la vida, usos, importancia económica, ecológica y cultural del caracol rosa en el Caribe. Este programa que educa a través de juegos, está dirigido principalmente a los niños; sin embargo, también ha resultado interesante para consumidores, pescadores, dueños de restaurantes, funcionarios y empresarios, que de alguna manera están ligados al recurso.

PALABRAS CLAVES: Caracol, *Strombus gigas*, programa educativo, manejo sustentable

## INTRODUCTION

The queen conch, *Stombus gigas,* is a large gastropod mollusk distributed along the Caribbean Sea from Brazil and Venezuela in the south, to Florida and to the Bahamas in the north, including all the minor and large Caribbean islands, representing overall 30 different countries. The fishery for this species has been an important source of food for the inhabitants of Caribbean coasts and islands, since pre-Colombian times. Today, queen conch represents one of the most valuable benthic resources in the region, exceeded only by the spiny lobster. Landings were recently estimated at 6,000 metric tons, with a value of 6,000,000 US $ (Chakalall 1997). The volume catch reached 6,520 tons in 1992 but collapsed to 3,132 tons in 2002 (CITES 2002). Therefore, *S. gigas* is now an over-exploited resource.

International management measures were taken to slow down over-exploitation. Queen conch was included in Appendix II under CITES (Convention on International Trade of Endangered Species) in 1992. Since 1994, it has also been included in the red list of the International Convention for Nature Conservation. In 2002, it was included in Annex II of SPAW (Specially Protected Areas and Wildlife in the Wider Caribbean region).

The landings of queen conch in various Caribbean countries (Bahamas, Belize, Colombia, Cuba, Dominican Republic, Honduras, Jamaica, Turks and Caicos...) are mainly exported to USA and to France. Seventy-eight percent of these landings are exported to Puerto Rico, Florida, and the US Virgin Islands, and 18% to the French West Indies (Guadeloupe and Martinique). Only 3% of the registered catch volume is consumed in the countries where queen conchs are captured. However, if CITES regulates the international market, it remains up to each country to take up adequate protection measures. For example, in Florida, *S. gigas* fishery has been closed for over 10 years, but the queen conch population still has failed to recover; in Guadeloupe, queen conch fishery is closed eight months each year. In most Caribbean countries where queen conch meat is an appreciated staple food, illegal catches and poaching are widely practiced to meet the local market. Protection measures cannot be efficient unless both fishermen and consumers feel involved. In order to control over-fishing due to these illegal practices, it is therefore urgent to promote a dedicated education program as well as to enforce management regulations.

## LANDINGS AND IMPORTS OF *S. GIGAS* IN THE CARIBBEAN

Queen conch resources occur throughout the Caribbean Sea and in the Atlantic Ocean northward up to Bermuda, but populations in several areas are decidedly over-fished and need management measures. Queen conch is extremely vulnerable to harvest especially during the spawning season. Estimates covering a range of three years (from 1988 through 1991), represent annual landings for most of the major conch producing nations in the area. The resulting total was 4,168 metric tons. The information indicated:

i) That over one-third of the catch was used solely in the Cuban bait fishery, and
ii) That landings from Colombia, Mexico, and Puerto Rico all declined considerably (47 - 140%) in recent years. Cuba led the area in production and was followed in order of decreasing landings by Jamaica, Turks and Caicos Islands, Bahamas, Venezuela (all illegal), Colombia, and Belize; landings of other nations were substantially lower than 100 tons each.

To curb over-fishing (defined as a population level that is below 20% of the unfished spawning stock biomass per recruit) of queen conch, the Caribbean Fisheries Management Council has proposed a management program designed to reduce the mortality on spawning adults and prevent the harvest of immature individuals. The management program contains provisions for total or temporal closures, but favors effort reduction as the socio-economic impacts are less severe. The program would:

i) Impose a 24cm overall minimum size limit or 10mm shell-lip thickness limitation on the possession of queen conch;
ii) Require that all species in the management unit be landed in the shell and prohibit the sale of undersized queen conch and queen conch shells;

iii) Establish a bag limit of 3 queen conch/day for recreational fishers, not to exceed 12 per boat, and 150 queen conch/day for licensed commercial fishers;
iv) Close the harvest season from July 1 through September 30 of each year coincident with the peak spawning period (Aldana Aranda, 2005); and
v) Prohibit harvest of queen conch by scuba diving and hookah gear to protect deep-water spawning stocks. These measures should resolve over-fishing problems in the queen conch fishery and optimize production in the management area. However, if recruitment is dependent on nations in the eastern arc of the Caribbean basin, cooperative efforts by other communities will be required to effectively manage queen conch resources throughout their range. Landing queen conchs and other mollusk species in the shell in the management unit is an enforcement tactic designed to protect immature or juvenile conchs. Other problems in the fishery, such as insufficient data, insufficient knowledge about life history life, information dissemination to educate the public, and habitat degradation will require additional efforts by both local and federal entities.

A difference does exist between landings and imports (CITES 2002). Two hypotheses can be explaining this situation: a re-expedition of queen conch meat between countries or illegal catches of queen conch incoming to quotes established by CITES. To regulate catch of *S. gigas*, different management measures are applied; however the heterogeneity of management regulations for this fishery promoted illegal catch and poaching. To avoid these illegal catches, it is necessary to enforce management regulations and to promote an educative program directed at the communities involved in the conch fisheries, to emphasize the importance of the resource and the severe damage of over-harvesting that could result in stock collapse.

## CARIBBEAN EDUCATION PROGRAM OF QUEEN CONCH

This education program was initiated by the Marine park Xel-Há, the CINVESTAV-IPN research center in Mexico and the association Archipel des Sciences in the French West Indies with the grant and support of governmental agencies such as: Caribbean Fisheries Management Council, Mexican Academy of Science, the French embassy and No Governmental Organizations.

In this Caribbean education program, research teams and teachers produced a wealth of documents and elaborated a "teaching package" in the form of compact disk entitled ***"Education for the conservation and safeguard of the queen conch, Strombus gigas, in the Caribbean Area".*** The aim is to involve Caribbean people and especially children in the protection and recovery of queen conch populations and to keep queen conch alive in its natural habitat, as a cultural, ecological and economic common heritage, through research and education, to make the citizens aware of the urgent need for insuring the protection and rescue of an endangered species and its habitats.

The project is designed to transmit to the general public and particularly to the children, information about the biology and ecology of *S. gigas*, the state of current over-fishing and possible solutions for protection, conservation, and sustainable exploitation of the queen conch.

The education package for the conservation and safeguard of the queen conch, *Strombus gigas*, in the Caribbean region is published as a CD which comprises five sections. The first section entitled "*The Queen Conch Life Story*" is an illustrated life cycle description of *S. gigas*, and of its ecological importance, followed by a description of its state of current over-fishing and of the various strategies for its protection, conservation and sustainable exploitation. The second section comprises a slide show entitled "*The Life of Conchita and Caracolito*", which constitutes a direct usable material for a lively power point presentation. In the third part *"Learn by Playing with Conchita and Caracolito"*, eleven activities allow to reinforce the knowledge issued from the first and second part. Each activity contains an introduction, its objectives, the age of the children concerned, the material included and the instructions to carry out the game. In the fourth part, *"Materials Allowing to Prepare the Activities"*, all the illustrations which make it possible to carry out the games that form the "teaching package" are gathered. They are readily printable on cardboard to be used with pupils. In the fifth part *"Annex"*, the teachers will find forms that allow evaluation of the educational package by the pupils and teachers to give hints for further improvement. A special postcard and a poster of this education program are included in this section. The authors shared the "know-how knowledge to do" scientific studies, education and games.

The aim of this package is to transmit the necessary knowledge to the children who are the future of the Caribbean countries, and to their parents, allowing them to understand the importance of rules and precautions for a reasonable and sustainable use of the queen conch. We hope everybody will help to preserve this valuable species as a common cultural and economical heritage for the Caribbean people.

Since March 2004, 200 primary school teachers and 9,000 pupils from public schools of Quintana Roo (Mexico) received the training in Xel-Há park with the education program for the conservation of the queen conch. In order to promote the scientific education, this program collaborates with the Mexican Academy of Science and Ministry of Education in different programs: *Hands on, Sciences in the school, Sciences at the beach, week-end of science, and scientific summer.*

The education CD is offered for free with all rights for reproduction for educational purposes. It is now used in various countries: Colombia, French Caribbean, Honduras, Mexico, Nicaragua, Puerto Rico and Venezuela.

## LIFE STORY OF THE QUEEN CONCH, *STROMBUS GIGAS*, A CARIBBEAN EDUCATIONAL PROGRAM

This education program has two mascots: the veliger larva named "*Conchita*" and its brother named *"Caracolito"* which is a young metamorphosed queen conch. They explain their life cycle story with a series of questions and answers: Where queen conch lives? How are little queen conch born? Why queen conch has a planktonic and benthic life cycle. How do I grow up? How do I reach sexual maturity? Why parents produce a large number of eggs but few of these reach the adult reproductive stage? Why am I an important species in the Caribbean? Am I an important fishing resource? How I am inserted in the marine food web? Why, people take out of the sea more and more queen conchs without taking in account the necessary renewal of populations? Which other ways for conservation and sustainable exploitation of queen conch have been found by biologists ?

The mascots explain that the queen conch is a very important fishery but also an important part of the marine food web in the plankton as well as in seagrass beds and sandy grounds. When *S. gigas* was a planktonic larva, it was food for some fishes and crustacean larvae; it is inserted in the marine food web when juvenile or adult. Moreover, humans collect us as staple food and to sell us and make big money. Mascots explain that queen conch is an endangered over-exploited species, in danger to disappear from Caribbean fishing grounds; but it is a renewable resource as long as it has the opportunity to reproduce and carry out its life cycle, and as long as fishermen practice a limited fishing under control. The powerpoint presentation explains also that biologists have found other ways for the conservation of queen conch in Marine Parks. These parks are sanctuaries for the reproduction of the queen conch and the other marine animals and serve to educate the society and especially children to respect the protected areas and the endangered species. We ask all children to make the adult society conscious of the importance to protect the queen conch in the Caribbean and its habitat because of the biological, ecological, economic, and cultural status of this species for all the Caribbean countries.

## HANDS ON

Eleven activities allow in a simple and creative way to reinforce the knowledge acquired from the queen conch story and from Conchita and Caracolito slide show.

*The queen conch life cycle* — the objective of this activity is identifying the life cycle of the queen conch and its main predators at each stage with twelve card set. It is recommended for children eight years and older.

*Pyramid of survival of the queen conch* — represents the queen conch survival rate at each stage of its life cycle. Children will build a pyramid with the number of individuals that pass from a stage to the next one. On one face, it features the stage of life, on another face, the number of individuals at this stage, on the third face, the size of queen conchs and on the fourth one, the duration of each stage. The objective is to understand the stages of the life cycle of *S. gigas* and establish the relationship between the number of individuals alive at each stage and those which survive at the next one and thus until the adult size. The recommended age is nine years and older.

*Who eats who* — by using cards with a short description of the species which forms part of the marine food web in which queen conch is implied; players build some possible food chains and identify main predators. Queen conch is an herbivorous animal which feeds on algae living on sea grass leaves. They have many predators, from larval to adult stage. The objective is to identify participants of the food web involving queen conch and marine turtles. The recommended age is nine years and older.

*Hand in hand* — in this game, children have to match pairs of cards on the topics of biology and ecology, on fishing and on the solutions for protection, conservation and sustainable exploitation of *S. gigas*. The purpose is to associate cards as identical pairs and to learn essential topics about the life of queen conchs such as life cycle, distribution, taxonomy, common and scientific names, predators, uses, over-fishing, non-respect of rules and bans, destruction of the habitats, restoration, education and research. The recommended age is seven years and older.

*You will not catch me!* — it is a dynamic game in which participants represent the main predators of the queen conch, at various stages of its life cycle as well as various adverse environmental conditions. A group of children featuring predators and adverse conditions try to catch the opposing team representing the queen conch population. Out of millions larvae which hatch each year, few of them reach adulthood. This situation is due partly to the environmental conditions which can be unfavourable. Objective is to identify the main predators and adverse conditions and their impact on the populations of this species, responsible for the poor survival of queen conchs. The recommended age is nine years and older.

*Timetable of queen conchs* — in this game, children compare the activities which they carry out during the year with the activities along the year and various stages of life cycle of queen conchs, in order to know how they grow, how they reproduce and relate this knowledge with main fishing regulations. The purpose is to establish a comparison between the stages of life of queen conchs and the seasonal activities of a pupil along the year. Age recommended from 9 years on.

## CONCLUSION

The Holistic program of queen conch *Strombus gigas* for sustainable management has developed an education program in the Caribbean region for teaching the communities involve with the conch, the importance of this endangered resource. This education program was initiated by the Marine park Xel-Há, the CINVESTAV-IPN research center in Mexico and the association Archipel des Sciences in the French West Indies with the grant and support of Caribbean Fisheries Management Council, Mexican Academy of Science, the French embassy and No Governmental Organizations. Research teams and teachers produced this Caribbean education program, and elaborated a "teaching package" in three languages: French, English and Spanish in a compact disk entitled *"Education for the conservation and safeguard of the queen conch, Strombus gigas, in the Caribbean Area"*. Since 2004, this program is applied and distributed in West French Antillean Indies, Mexico, Honduras, Nicaragua, Puerto Rico, Colombia. The education CD is offered for free with all rights for reproduction for educational purpose. In order to promote the scientific education this program collaborates with the Mexican Academy of Science and Ministry of Education in different programs: *Hands on, Sciences in the school, Sciences at the beach, week-end of science and scientific summer.* Besides it is possible to access a this program in various web sites:

http://www.mda.cinvestav.mx/biblioteca.htm
http://bellsouthpwp.net/c/u/culpsb/conchnews/welcome.html
http://www.strombusgigas.com/cfmc.htm
http://perso.wanadoo.fr/a.d.s/index.html
http://www.xelha.com.mx
http:// www.savetheconch.org/

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# ABSTRACTS FROM

# POSTER SESSION

# Surgical Implantation of Acoustic Transmitters in Juvenile Red Drum, *Sciaenops ocellatus*

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Reliable surgical methods for implanting acoustic transmitters in juvenile red drum Sciaenops ocellatus (180-320 mm TL) were developed. Evaluations of fish implanted with acoustic pinger transmitters (Sonotronics, Tucson, Az) using these methods took place in 2002 and 2003. The seven-month transmitter weighed 4 g (water weight) and measured 32 mm x 12 mm diameter. Sonotronics modified the transmitter case so both the anterior and posterior ends were rounded. Pre-surgical evaluations determined the fish to be parasite and pathogen free. Surgical preparations included cleaning instruments with Betadine and a sterile seawater rinse. Fish were transferred directly from the holding tank into an induction bath (Tricaine-S ™ 70-80 ppm). During surgery, fish were inverted onto a V -shaped cradle and a soft rubber tube provided an uninterrupted flow of oxygenated seawater and anesthesia (50 ppm) over the gills. Medial integument and muscle incisions extended from the posterior pelvic fin for 10-12 mm. Incisions were proximal and lateral (1-3 mm) to the medial ventral abdominal wall. Transmitter insertion was sub-visceral, forward and anterior through the incision. Four to five interrupted sutures (Maxon ™ sterile synthetic absorbable suture) closed incisions. Antibiotic ointment (Bacitracin ™) was applied to the sutured area. Post-surgical assessment of the incision documented that tissue regeneration was sufficient within ten to fifteen days (temperature dependant) for the fish to be released after evaluation by an accredited veterinarian.

After seven months, fish survival and transmitter retention was 100 percent. Fish exhibited expected growth, swimming performance and feeding activities. The modified transmitter case appeared to minimize post-surgical complications related to pressure necrosis on internal organs and the body wall. Additionally, necropsies and histological evaluations revealed tissue regeneration with no pathology associated with the implants.

KEY WORDS: Red drum, acoustic telemetry, surgical techniques

# Implantación Quirúrgica de Trasmisores Acústicos en la Corvineta Ocelada, *Sciaenops ocellatus*

Se desarrollaron métodos quirúrgicos confiables para el implante de transmisores acústicos en organismos juveniles de corvineta ocelada, *Sciaenops ocellatus* (180-320 mm de longitud total). En los años 2003 y 2004 se realizaron evaluaciones de peces implantados con transmisores acústicos (Sonotronics, Tucson, Az) usando estos métodos. La transmisor de siete meses peso 4 gramos (paso del Aqua) y mide 32 mm x 12 mm de diametro. Sonatronics modificó la caja del transmisor redondeando ambos extremos, anterior y posterior. Evaluaciones prequirúrgicas determinaron que los peces estaban libres de parásitos y otros elementos patógenos. Las preparaciones quirúrgicas incluyeron la limpieza de instrumentos con Betadine y un enjuague estéril de agua marina. Los peces se transfirieron directamente del tanque de mantenimiento al baño de inducción (Tricaine-S ™ 70-80 ppm). Durante la cirugía los peces se colocaron en posición invertida en una cuna en forma de V, y mediante un tubo de hule suave se les proporcionó ininterrumpidamente flujo de agua marina oxigenada y anestesia (50 ppm) a través de las branquias. Las incisiones se realizaron a través del tegumento y músculos extendiéndose 10 a 12 mm desde la aleta pélvica posterior. Las incisiones fueron proximal y lateral (1-3 mm) en la pared media ventral abdominal. La incersión del transmisor fue subviceral realizándose en la parte anterior de la incisión y hacia adelante. Se realizaron de cuatro a cinco suturas distribuídas a lo largo de la incisión (Maxon ™ de sutura sintética absorvente). Se aplicó unguento antibiótico (Bacitracin ™) en el área suturada. La evaluación postquirúrgica de la incisión, para la liberación de los peces, fue realizada por un veterinario acreditado, documentando que la regeneración tisular fue suficiente a los diez a quince días (dependiendo de la temperatura).

Después de siete meses, la sobrevivencia de los peces y la retención de los transmisores fue de 100%. Los peces mostraron crecimiento, capacidad de nado y actividad alimenticia de acuerdo a lo esperado. La caja modificada del transmisor parece minimizar complicaciones postquirúrgicas relacionadas con necropsis en órganos internos y en la pared del cuerpo. Adicionalmente, las necropsis y la evaluación histólogica revelaron regeneración tisular sin patología asociada con los implantes.

PALABRAS CLAVES: *Corvineta ocelada*, telemetría acústica, técnicas quirúrgicas

# Tobago Cays Marine Park: How is this MPA Doing?

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The Tobago Cays are a cluster of tiny uninhabited islands and shallow coral reefs situated in the St. Vincent and the Grenadines archipelago in the eastern Caribbean. Their sheltered mooring areas and outstanding natural beauty have made them a favourite tourist attraction in the Grenadines. The cays were declared a marine park and acquired by the government for management by a multi-stakeholder board. An announcement that government was considering a proposal from a foreign private firm to manage the Tobago Cays Marine Park (TCMP) prompted concerned citizens to form the Friends of Tobago Cays (FOTC) in order to stop this process and raise public awareness that the TCMP should be managed by Vincentians for the benefit of Vincentians. Among the activities of the FOTC is the collection of secondary data from reports and the popular press. Using the publication "How is your MPA doing?" as a guide to biophysical, socioeconomic and governance indicators, the secondary data were analysed and preliminary results were obtained. The data suggest the importance of socio-economic and governance matters to the NGO stakeholders in the TCMP. It is intended that additional research be done to complete the evaluation of management effectiveness and to investigate the potential of the area for co-management.

KEY WORDS: Tobago Cays, MPA, management

## Parque Marino Cayos Tobago: Como se encuentra esta APM?

Los Cayos Tobago son un conjunto de pequeñas islas deshabitadas y arecifes coralinos poco profundos situados en el archipielago de San Vicente y las Granadinas al Este del Caribe. Sus areas de amarraduras abrigadas y extraordinaria belleza natural la han convertido en una atracción turística favorita en las Granadinas. Los cayos fueron declarados parque marino y adquiridos por el gobierno para ser manejado por una junta compuesta de multiaccionistas. Un anuncio de que el gobierno estaba considerando una propuesta por parte de una firma privada foranea para el manejo del Parque Marino Cayos Tobago (PMCT) impulsó a consternados ciudadanos a formar el denominado Amigos de los Cayos Tobago (ACT) a fin de detener este proceso y despertar el interes publico de que el PMCT debe ser manejado por Vicentinos para el beneficio de los Vicentinos. Entre las actividades de los ATC figura

la recolección de datos secundarios provenientes de informes y de la prensa popular. Utilizando la publicación "Como se encuentra tu APM"? como guia de indicadoes biofísicos, socoeconómicos y de gobernabilidad, los datos secundarios fueron analizados y obtenidos los resultados preliminares. Los datos sugieren la importancia de asuntos socioeconomicos y de gobernabilidad para los accionistas de ONGs en el PMCT. Se pretende efectuar investigaciones adicionales para completar la evaluación de la efectividad del manejo y para investigar el potencial del area para co-manejo.

PALABRAS CLAVES: Cayos Tobago, APM, manejo

# Preliminary Comparisons Between Reef Fish Assemblages on Vessel-Reefs and Natural Substrate in Depths of 70 – 95 Meters

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Offshore of Broward County, Florida, below conventional SCUBA diving depths lies a deep escarpment between 70-95m that is relatively unexplored by research scientists. This escarpment is characterized by patchy sand and low-relief rubble substrate. Ten derelict vessels have been deployed as artificial reefs below 70m with the goals of increasing fish habitat and enhancing recreational fishing. Although reports from local fishers are positive, little quantitative data exists. Previous studies on vessel-reefs in 20m reported greater fish abundance and species richness than surrounding natural reefs. We hypothesized that a similar situation would exist on vessel-reefs in deeper waters. A remotely operated vehicle (ROV) was used to survey three deep-water vessel-reefs and the surrounding natural substrate using a combination of point-counts and timed transects to record fish on digital video. Preliminary results support findings from shallow vessel-reef research, and suggest that deep-water vessel-reefs also harbor greater abundance and species richness than the surrounding natural substrate. However, the deep-water vessel-reefs appear to support a different fish assemblage characterized by a lack of herbivores, lower diversity of haemulids, and the occurrence of several deep-water species such as *Prognathodes aya* and *Equetus iwamotoi*. Despite these differences, several species are common to vessel-reefs at both depths. A few species, such as *Lutjanus buccanella*, *Mycteroperca phenax*, and *Seriola dumerili* appear to undergo an ontogenetic shift in habitat with larger individuals found on the vessel-reefs in 70-95m. The lack of fishes on surrounding natural substrates, as well as the higher abundance and species richness on the vessel-reefs may be due to a paucity of suitable deep-water natural habitat off Broward County and thus may indicate an important role for vessel-reefs in resource management at these depths.

KEY WORDS: Artificial, ROV, deep-water, shipwreck, video surveys

## Comparación Preliminar Entre Ensamblajes de Peces de Arrecife en Embarcaciones-Arrecife y Substratos Naturales en Profundidades de 70 a 95 Metros

Mar afuera del Condado Broward, Florida, bajo profundidades convencionales de buceo con equipo SCUBA se encuentra una profunda escarpa entre los 70-95m que son relativamente inexploradas por investigadores científicos. Esta escarpa es caracterizada por parches arenosos y substrato escombrazo de bajo relieve. Diez embarcaciones decrépitas han sido desplegadas como arrecifes artificiales bajo los 70m con la meta de incrementar los hábitats para peces y la pesca recreativa. A pesar de los reportes positivos de pescadores locales, existe muy pocos datos cuantitativos. Estudios previos en embarcaciones-arrecifes en 20m han reportado una mayor abundancia y riqueza de especies que en los arrecifes naturales que los rodean. Nuestra hipótesis estipula que una situación semejante debe existir en embarcaciones-arrecife en aguas profundas. Un vehículo operado remotamente (ROV por sus siglas en Ingles) fue utilizado para inspeccionar tres embarcaciones-arrecife en aguas profundas y los substratos naturales que los rodeaban usando una combinación de punto-cuenta (point-count) y transeptos por tiempo en video digital para registrar peces. Los resultados preliminares sostienen los hallazgos en embarcaciones-arrecife en aguas llanas y sugieren que las embarcaciones-arrecife sostienen mayor abundancia y riqueza de especies que en los substratos naturales que les rodean. Sin embargo, la embarcación-arrecife aparentan sostener diferentes ensamblajes caracterizados por la falta de herbívoros, baja diversidad de haemulidos (haemulids) y la ocurrencia de varias especies de aguas profundas como lo son *Prognathodes aya* y *Equetus iwamotoi*. A pesar de estas diferencias, varias especies son común en embarcaciones-arrecifes en ambas profundidades. Algunas especies, tales como *Lutjanus buccanella*, *Mycteroperca phenax*, y *Seriola dumerili* aparentan experimentar un cambio ontogénico en hábitats encontrados individuos más grandes en embarcaciones-arrecife de 70-95m. La falta de peces en los substratos naturales circundantes, así como el incremento en abundancia y riqueza de especies en las embarcaciones-arrecife puede deberse a la escasez de hábitats apropiados en aguas profundas en las afueras del Condado Broward, lo que puede indicar el papel de importancia de las embarcaciones-arrecifes en los recursos manejados a estas profundidades.

PALABRAS 'CLAVES: Artificial, ROV, aguas profundas, naufragio, inspecciones en video

# The Nature Conservancy Gulf of Mexico Initiative

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The Nature Conservancy (TNC) has been engaged in coastal and marine conservation in the Gulf of Mexico for over a decade. Examples of work spanning the Gulf are: Mad Island Preserve habitat protection, Shamrock Island SAV restoration in Texas; Mike's Island Conservation project and shellfish restoration in Biloxi and Mobile Bays in Mississippi and Alabama; Florida Keys National Marine Sanctuary, turtle conservation projects in Florida. Because of this continued and ever increasing conservation work happening in the Gulf of Mexico, TNC has decided to start a Gulf of Mexico Initiative to help enhance the work already happening plus engage in large scale conservation projects involving more than one State and bringing Mexico and Caribbean partners into the mix. Working together with TNC's Mexico program, a conservation planning effort is currently being undertaken in Laguna de Terminos in southern Mexico.

KEY WORDS: Gulf of Mexico, The Nature Conservancy

# La Iniciativa del Nature Conservancy en el Golfo de México

El Nature Conservancy (TNC) esta activo en la conservación costera y marina en el Golfo de México por una década. Ejemplos de trabajo en el Golfo son la protección de habitat en Mad Island Preserve; la restauración de SAV en Shamrock Island, Tejas; proyecto de conservación de Isla Mike y restauración de mariscos en Biloxi y en el Bahía de Mobile en Misisipí y Alabama; proyectos de conservación de tortugas en el Santuario Marino Nacional de Florida. A causa de estos trabajos de conservación en el Golfo de México, TNC ha decidido empezar una Iniciativa en el Golfo de México a ayudar trabajos ya sucediendo y traer socios de México y del Caribe en la colaboración. Trabajando con el programa de México de TNC, un esfuerzo para la conservación de Laguna de Terminos en México se empezó.

PALABRAS CLAVES: Golfo de México, The Nature Conservancy

# Can Bonefish (*Albula* spp.) be used as a Model Species for Integrating the Management of Tropical Flats Environments?

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Flats are shallow, tropical marine environments comprised of several distinct habitat types that are used by many fish and invertebrate species during all or part of their lives. Bonefish (*Albula* spp.) are a group of highly prized sport fish that spend most of their adult lives moving among the various flats habitat types to forage. Given that these fish alter the physical structure of the substrate as they forage, bonefish likely play an important role in the structure and function of the flats environment. Equally, human-induced disturbances that affect the structure and function of flats habitats, such as shoreline development and tourist activities, might be detrimental to bonefish. In fact, even angling practices that do not maximize post-release survival of captured bonefish could reduce adult bonefish numbers to unsustainable levels. The purpose of the Cape Eleuthera Flats Ecology Program is to provide information that will aid in the sustainable use of flats and the conservation of bonefish. One component of the program is aimed at understating the movement of bonefish on the flats off Cape Eleuthera, including an assessment of how bonefish use various habitat types. To do so, ultrasonic transmitters are being implanted into bonefish inhabiting various tidal creek systems. Short-term (< 20 day) transmitters (gastric implants) are being used to track daily distribution, while long-term (> 1 year) transmitters (intraperitoneal implants) are being used to monitor annual or seasonal events such as migrations to breeding grounds. Preliminary findings indicate that bonefish are highly mobile, moving between adjacent creeks at regular subdaily intervals. In addition, the effects of catch-and-release on the short-term and long-term behavior and survival of angled bonefish is also being studied using telemetry. Finally, the indirect effects of angling, such as wading and boat traffic, on the productivity of flats habitats are being assessed using field manipulative studies.

KEY WORDS: Bonefish, telemetry, tropical flats, Eleuthera, Bahamas.

## ¿Puede Macabi (spp de *Albula*) sea Utilizado como una Especie Modelo para Integrar la Administración de Ambientes Plano Tropicales?

Plano son los ambientes marinos, tropicales y superficiales comprendieron de varios claro de tipo hábitat que es utilizado por muchas especie de pez e invertibrado durante todo o la parte de su vive. Macabi (spp de *Albula*) son un grupo de pez sumamente apreciado de deporte que gasta la mayor parte de su adulto vive mover entre el varios plano de tipo hábitat para adentrarse. Dado que éstos pescan altera la estructura física del sustrato como ellos se adentran, macabi el juego probable un papel importante en la estructura y la función del ambiente plano. Igualmente, alborotos de humano-indujo que afectan la estructura y la función de hábitates plano, tal como el desarrollo de costa y actividades de turista, quizás sean perjudiciales al macabi. De hecho, aún prácticas del comportamiento de los pescadores que no llevan al máximo sobrevivencia de poste-liberación de macabi capturado podrían reducir los números adultos de macabi a niveles insostenibles. El propósito de la Capa Eleuthera el Programa Plano de la Ecología deberá proporcionar información que ayudará en el uso sostenible de plano y la conservación de macabi. Un componente del programa se apunta a subestimar el movimiento de macabi en el plano de Capa Eleuthera, inclusive una evaluación de cómo uso de macabi varios de tipo hábitat. Para hacer transmisores así, ultrasónicos se implantan en habitar de macabi varios sistemas de la marea de riachuelo. A corto plazo (< 20 día) transmisores del día se utilizan para rastrear la distribución diaria, mientras a largo plazo (> 1 año) transmisores se utilizan para controlar los acontecimientos anuales o estacionales tales como las migraciones a criar el motivo. Los hallazgos preliminares indican ese macabi es sumamente móvil, moviendo entre riachuelos adyacentes en intervalos regulares. Además, los efectos del cogido y la liberación en la conducta y sobrevivencia a corto plazo y a largo plazo de macabi angulado se estudian también utilizar telemetría. Finalmente, los efectos indirectos del comportamiento de los pescadores, tal como vadeando y el tráfico del barco, en la productividad de hábitates plano se valora los estudios del manipulativo de campo que utilizan.

PALABRAS CLAVES: Macabi, la telemetría, tropical plano, Eleuthera, las Bahamas

# Seasonal Aggregations of Roper's Inshore Squid Associated with Coral Spawning

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Here we present documentation of seasonal aggregations of Roper's inshore squid, *Loligo roperi,* on the Flower Garden Banks in the northwest Gulf of Mexico. Previous reports of Roper's inshore squid are scarce, and we only first recorded sightings of them in the Gulf of Mexico in 2001. However, over the last three years (2001-2004), we have seen repeated aggregations of juvenile, sub-adult, and adult *L. roperi* over the Flower Garden Banks during the annual coral spawning event which occurs 7-10 days after the first full moon in August (and in September if there is a split-spawn). Analysis of the timing of these aggregations from the 2003 year suggests that the highest occurrence of squid shows a time-lag correlation with coral spawning, suggesting that squid may be attracted to the Flower Garden Banks by the coral spawning event. Moreover, detailed morphological examinations of adult individuals revealed that females had spermatophore packets protruding from the buccal lappet, as well as under the dorsal and ventral mantle. While the significance of this annual aggregation remains unclear, the presence of spermatophores on adult females suggests that the squid may be spawning during this time. Alternatively, squid may aggregate during the coral spawning event to capitalize on prolific food resources present during the coral spawning event. Either way, this aggregation of *L. roperi* is the first annual aggregation documented for this species, and it provides the opportunity to investigate the social and reproductive habits of this species in further detail.

KEY WORDS: Flower Gardens Bank, Gulf of Mexico, *Loligo roperi*

# Las Agregaciones Estacionales del Costera Sepia de Roper a la Coral Desovando

Aquí presentamos la documentación de agregaciones estacionales de costera sepia de Roper, *Loligo roperi,* en los Flower Garden Banks en el noroeste Golfo de México. Los informes anteriores de *L. roperi* son escasos, y primero registramos solamente sightings de ellos en el Golfo de México en 2001. Sin embargo, durante los tres años pasados (2001-2004), hemos visto repetidas agregaciones del juvenile, secundario-adulto, y adulto L. roperi sobre el Flower Garden Banks durante anual coral acontecimiento de desovando que ocurre 7-10 días después de la primera Luna Llena en Agosto (y en Septiembre si hay una doble- o fractura-desovar). El análisis de la sincronización de estas agregaciones a partir de los 2003 año sugiere la ocurrencia más alta del sepia

demuestre una correlación con coral desovando, sugiriendo sepia pueden ser atraído a la Flower Garden Banks por el acontecimiento de desovando por los corales. Además, el examen detallado de la morfología de individuos adultos mostró las hembras haber spermatophores en la zona bucal y en la capa dorsal y ventral. Mientras que la significación de las agregaciones anuales de *L. roperi* permanece sin resolver, la presencia de spermatophores en hembras adultas sugiere que sepia pudo desovando durante este tiempo. Otra hipótesis sería que *L. roperi* agregan durante coral desovando para capitalizar en la prolífica abundancia de recursos alimenticios durante este periodo. En cualquier caso, la agregación de L. roperi descrita en esta comunicación es la primera agregación anual documentada en la especie y proporciona una inmejorable oportunidad para investigar los hábitos sociales y reproductivos de *L. roperi* con mayor detalle.

PALABRAS CLAVES: Flower Garden Banks, sepia de Roper, *Loligo roperi*, Golfo de Mexico

## Flame Scallops: Ripe for Aquaculture?

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The reproductive cycle of the flame scallop, *Ctenoides scaber* (Born 1778), formerly *Lima scabra scabra*, from Boca Chica Key, FL was examined from January 1998 to September 1999 using qualitative and quantitative methods. Flame scallops have a high meat-to-shell ratio, are consumed throughout the Caribbean basin, and are commonly harvested for the marine aquarium industry, but difficulties in collecting them from their rocky and coralline habitats limit the increase of the commercial fishery. Economically they may be good candidates for aquaculture production.

In the wild, annual reproductive trends are related to seasonal changes in water temperature and food production. Gamete initiation occurs in winter with maximum ripeness observed in late summer. Synchronous spawning occurs in autumn with rapidly decreasing water temperatures and increased phytoplankton abundances. Partial spawning, observed in late spring, could not be related to environmental conditions.

Evidence of spawning was frequently observed in wild collected flame scallops 12-24 hours after collection in an uncontrolled environment. Spawning animals had ripe gametes; had densities of >20 animals/8L of seawater; had limited light for 12-24 hours, limited air exchange, <1-2°C temperature change, and had been subjected to mechanical vibrations during transport.

In the laboratory, temperature, salinity, density, and food availability were manipulated individually, combined, and with chemical stimulants to encourage spawning activity. We were not able to induce spawning. Larvae that were produced did not survive longer than 36-hours, though some developed into "D"-shaped veligers.

The data suggests that it may be possible to produce flame scallops in an aquaculture facility, however more research is needed to determine the factors that will induce spawning in a controlled hatchery environment. The production of these animals would provide alternative stock for the marine aquarium industry, alleviating the increasing stress on natural populations. It may also provide an alternative food source for humans.

KEY WORDS: Aquaculture, *Ctenoides scaber*, reproduction

## Flame Scallops: Madurez para la Aquacultura?

El ciclo reproductivo de los moluscos, *Ctenoides scaber* (Born 1778) antes *Lima scabra scabra*, de la Boca Chica Key, FL fue examinado desde 1998 a 1999 usando metodos qualitativos y quantitativos. Los moluscos tienen un alto porcentaje de carne en su concha son consumidos en cualquier parte de la Cuenca del Caribe y son comunmente cosechados por la Industria del Aquario Marino y la colleccion de ellos entre rocas es un poco dificil y los habitas de coralinos limitando el aumento de la pesca commercial.

Economicamente ellos podrian ser buenos candidatos para la produccion de la aquacultura.

En lo salvaje anualmente la reproductividad tiende a ser relacionado con los cambios de estaciones del agua temperatura y produccion de alimento. El inicio del gameto ocurre en invierno con una maxima madurez observada en lo ultimo del verano. Synchronous el desove ocurre en otoño con un grado de temperatura del agua reducido rapidamente y un incremento abundante de phytoplankton. El desove parcialmente se observa en primavera pero no podria relacionarse con las condiciones del medio ambiente.

Evidencias de desove fueron frecuentemente observadas en lo salvaje y colectados flame scallop 12-24 horas despues de la colleccion en un ambiente incontrolable. El desove de los animales tiene una madures de gametos y tiene una mayor densidad de 20 en los animales con 8 litro de agua salada, o agua marina tiene un limite de luz de 12 a 24 horas un limite de cambio de aire, menos 1-2 grados centigtrados en el cambio de temperatura, y ha venido siendo sugetado vibraciones mecanicas durante el transporte.

La temperatura en el laboratorio, salinidad, densidad, y disponibilidad de alimento fueron manipulados individualmente, combinados con quimicos

estimulantes para provocar o promover el desove. Nosotros no fuimos capaces de inducir el desoven o provocar. La larva que fue producida no logro sobrevivir mas de 36 horas sin embargo algunos desarrollaron en forma de "D".

Los resultados sugieren que esto seria posible producir flame scallop en un centro de aquacultura. Sin embargo es necesario hacer mas investigaciones para determinar los factores de la cual podrian inducir a un desove controlado en un ambiente de produccion de la cria. La produccion de estos animales proveeran una alternativa de abastecimiento para la Industria Aquarium Marina, aliviando el aumento del estres en poblaciones naturales. Esto tambien podria proveer una alternativa o fuente de alimentos para los humanos.

PALABRAS CLAVES: Aquacultura, *Ctenoides scaber*, ciclo reproductivo

# A Health Index for Hatchery-Reared Red Drum *(Sciaenops ocellatus)*

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The health of hatchery-reared red drum *(Sciaenops ocellatus)* has been monitored for over 15 years at the Florida Fish and Wildlife Conservation Commission's (FWC) Stock Enhancement Research Facility (SERF) in Port Manatee, FL. Routine health evaluations include external and internal examination of the major organs for overall condition, physical abnormalities, parasite infestations, microbiological infections, organosomatic indices, and condition factor. The health challenges of hatchery-reared fish are usually related to water quality and stocking densities. By using established protocols, data and parameters obtained from SERF's red drum health evaluations we have developed a health index (HI) to relate all quantitative and qualitative data associated with internal and external evaluations. The parameters were assigned based on the negative affects each had on the health of the fish. Conditions that caused severe complications or were lethal received lower values than those that had little or no affects on fish health. Healthy fish had computed HI values near 100, while those fish with HIs below 80 were health compromised and it was recommended to management that they not be released. The development of this health index will help establish defined limits for fish release protocols based on the overall health of the fish, by evaluating various health components using qualitative and quantitative methodologies. It is a simple tool that will help managers make more informed fish stock enhancement management decisions.

KEY WORDS: Disease, health index, *Sciaenops ocellatus*

## Un Indice de Salud Gloval para el Desarrollo de la Cria del Red Drum *(Sciaenops ocellatus)*

La salud del criadero alcanzada en el red drum (*Sciaenops ocellatus*). Ha sido monitoreado por mas de 15 años por los peces de la florida y la comision de conservacion de la vida salvaje (FWC) y el Centro de Investigaciones para una Mejor Reserva (SERF) Port Manatee, FL. Las evaluaciones rutinarias de salud incluyendo examinasiones internas y externas de los organos mayors, sobre todo en condiciones de anormalidades fisicas, infecciones de parasitos, infecciones microbiologicos, y un indice organosomatico y factores de condicion. Los retos de la salud alcanzados en la cria de peces son usualmente relacionados con la calidad del agua y la densidad del abastecimiento. Usando los protocolos establecidos, datos, y parametros obtenidos de SERF las evaluaciones de salud del red drum que nosotros hemos venido desarrollado con un indice de salud (IS) para relacionar todos los datos qualitativos y quantitativos con evaluaciones internas y externas. Los parametros fueron asignados basados en los efectos negativos que cada uno tiene sobre la salud de los peces. Condisiones que causan severas complicaciones o que fueron letalmente resividos o que han sido un poco devaluados o simplemente no afectan la salud de los peces. Saludablemente los peces han sido computarizado (IS) valores cerca de 100 mientras que estos peces con un indice de salud vajo 80 fueron comprometidos y recomenados para un manejo de ser liverados. El indice de desarrollo de salud podria ayudar a establecer o definir limites para la liberacion de peces, protocolo basado sobre todo en la salud de los peces por varias evaluaciones y los componentes de salud usando metogologias quantitativas y qualitativas. Es una simple herramienta que podria ayudar a los gerents o encargados del proceso ser major iformasdos en el manejo de desiciones para una mejor reserva de peces.

PALABRAS CLAVES: Salud gloval, corvina, *Sciaenops ocellatus*

# Preliminary Age and Growth Comparisons of Red Grouper (*Epinephelus morio*) from the West Florida Shelf and the Bay of Campeche

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Red grouper (*Epinephelus morio*) are an important component of commercial fisheries for both the United States and Mexico. Data useful for determining stock differences between two Gulf of Mexico regions (northeast, southwest) were collected during fisheries independent long-line surveys in 2001 and 2002. Surveys utilized standardized sampling designs with modified commercial long-line gear. Age, length, and weight for red grouper were compared between the two regions. Age determinations were completed by reading whole and sectioned otoliths. Red grouper from the Bay of Campeche were significantly older (ANOVA d.f. = 147, $F = 18.59$, $P < 0.001$), however, no significant differences in lengths or weights were revealed between the two regions (length: ANOVA d.f. = 154, $F = 0.02$, $P = 0.90$; weight: ANOVA d.f. = 154, $F = 1.72$, $P = 0.19$). Three age classes (5, 6, and 7 years old) were collected in sufficient numbers for comparisons. There were no differences in ages 5 and 6, red grouper from the Bay of Campeche were significantly smaller at age 7 (length: 491 mm; weight: 1.8 kg) when compared to age 7 red grouper from the west Florida shelf (length: 571 mm; weight: 3.1 kg). Differences in age between the two areas could be due to differences in historical fishing pressure, management regulations, environmental conditions (i.e., water temperature, habitat, and depth), or small sample sizes.

KEY WORDS: Age, *Epinephelus morio* growth, Mexico

# Comparaciones Preliminares entre la Edad y el Crecimiento del Mero Americano (*Epinephelus morio*) en la Plataforma del Eeste de Florida y la Bahía de Campeche

El mero americano (*Epinephelus morio*) es un componente importante de la pesquería comercial tanto del los Estados Unidos como del Golfo de Méjico. Los datos que se utilizan para determinar las diferencias de stock entre las dos regiones del Golfo de Méjico (Norte y Sur) fueros recogidos durante los estudios con palangre realizados por pesquerías independientes en los años 2001 y 2002. Para ello se utilizaron diseños estándares de muestreo con herramientas modificadas procedentes de la pesca comercial con palangre. Se compararon las edades, longitudes y pesos de los meros rojos entre ambas regiones. Las determinaciones de las edades se completaron con la lectura de los otolitos tanto enteros como seccionados. Los meros rojos de la bahía de Campeche fueros significativamente más viejos (ANOVA d.f. = 147, $F$ = 18.59, P < 0.001); sin embargo, no se encontraron diferencias significativas de longitud y peso entre las dos regiones del Golfo (longitud: ANOVA d.f. = 154, $F$ = 0.02, P = 0.90; peso: ANOVA d.f. = 154, $F$ = 1.72, P =0.19). Para las comparaciones, se recogieron un numero suficiente de peces de tres clases de edad (5, 6 y 7 años), No se observaron diferencias entre las edades 5 y 6. Los meros rojos de la bahía de Campeche eran significativamente más pequeños a la edad 7 (longitud: 491 mm; peso: 1.8 kg) comparados con los meros rojos de edad 7 de la plataforma del Oeste de Florida (longitud: 571 mm; peso: 3.1 kg). Las diferencias de edad entre las dos áreas pueden ser debidas a diferencias históricas de presión pesquera, regulaciones de gestión, condiciones ambientales (i.e., temperatura del agua, hábitat y profundidad) o el pequeño tamaño de las muestras.

PALABRAS CLAVES: Mero americano, *Epinephelus morio*, edad, Golfo de Méjico

## Biology of Wahoo in Florida and the Bahamas

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Despite the economic importance of wahoo, *Acanthocybium solandri*, in many regions of the world, its biology and life history have received infrequent attention. The Fishery Management Plan for Dolphin and Wahoo in the Atlantic Region reports that estimates of growth, reproduction, etc. are needed to better understand the implications of various options for managing the wahoo fishery. The study detailed here was initiated in 2003 and designed in response to the need for more and better data. Wahoo are collected year-round from fishing ports along Florida's east coast through tournament sampling, and angler-intercept and carcass-retrieval programs. Additional samples are taken in the Bahamas during the winter months. The relative utility of otoliths, scales, fin rays, fin spines, and vertebrae as ageing structures is discussed here. Whole otoliths and fin ray sections show the most promise for use as ageing structures. Reproductive seasonality and size and age at maturity characterized from gonad-somatic indices and patterns of gametogenesis revealed in histological preparations are described. In the first two years of our study, we

have collected relevant samples from more than 300 fish, which range in size from 6 to 98.5 lbs.; we have samples from another 100 fish that were archived and we plan one more year of active collecting to achieve adequate sample sizes. Our preliminary results appear consistent with the general paradigm that this species is a summer-spawning, short-lived pelagic with remarkable growth rates.

KEY WORDS: *Acanthocybium solandri,* wahoo, Florida, Bahamas

## Biología de Guaho en la Florida y las Bahamas

A pesar de la importancia económica de guaho, *Acanthocybium solandri*, en muchas regiones del mundo, su biología y historia de vida no han recibido mucho attencion. El plan para Administra la Pesquería del dorado y guaho en la region Atlantica informa que las estimaciones del crecimiento y reproducción se necesita entender mejor para manejar y mantener la pesquería deguaho. El estudio detallado aquí se inició en 2003 y fue diseñado en respuesta a la necesidad para más y mejores datos. Recibimos muestras de guaho durante todo el año en puertos por la costa Atlanitca de la Florida durante torneos de pescar y por donaciones de pescadores. Las muestras adicionales fueron collecionados en las Bahamas durante los meses de invierno. La utilidad relativa de otoliths, escalas, rayos de aleta, espinas de aleta, y de las vértebras como estructuras para obtener la edad y crecimiento anual de guaho se discuten aquí. Se ha demonstrado que otoliths enteros y secciones de rayos de aleta son las mejores estructuras para obtener la edad de guaho. La temporada y el tamaño reproductora y la edad de madurez caracterizados con índices de gónada-somáticas y de pautas de gametogenesis revelaron en preparaciones histológicas estan descritos. En los primeros dos años de nuestro estudio, nosotros hemos colleciando muestras pertinentes de más de 300 pescados, que recorren en tamaño de 6 a 98.5 lbs. Tambien obtenimos muestras de otros 100 pescados que estaban en los archivos de la Comisión de Pescados de Florida y planeamos uno año más de recoleccion de pez guaho para obtener un numero de muestras adecuados. Nuestros resultados preliminares son coherentes con el paradigma general que esta especia de pescado se reproduze durante el verano y es un pescado pelágico que vive pocos años y demuestra tasas de crecimiento notables.

PALABRAS CLAVES: Guaho, *Acanthocybium solandri*, Florida, Bahamas

## Preliminary Evaluation of Fish Settlement on GuSi Type Collectors, Santa Marta, Colombian Caribbean

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In order to study reef fish settlement in three localities of Santa Marta, Caribbean coast of Colombia, floating devices GuSi type were fixed between 10 and 12 m depth. Each structure was conformed by two polyethylene cylinders, fiber tassels resembling algae systems as attraction elements and concrete ballast. Considering the incidence of new moon, monthly collections were made between March 2003 and February 2004, after sorting the main groups, fish were identified, measured and weighted. Preliminary results of the work show a total of 1220 individuals grouped in 45 species, 23 families, 35 genera, and 16 unidentified individuals. Species richest families were: Serranidae, Apogonidae, Muraenidae, Pomacentridae and Monacanthidae; maximum abundance for Gobiidae (28%), Apogonidae (18%), Labridae (8%) and Scorpaenidae (8%). *Priolepis hipoliti* (28%), *Phaeoptyx pigmentaria* (12%) and *Scorpaenodes caribbaeus* (8%) were the dominant species. Space-time assessment variation was determined by the influence of local continental contributions and hard substrates proximity to sampling stations. Devices were effective in reproducing natural conditions; they collected 41% of the species previously reported for the region with other techniques like visual censuses and poisons, the lines favored the sampling of juvenil and prejuvenil fish fases, benthic and cryptic species, and even those of commercial interest.

KEY WORDS: Fish aggregating devices (FADs), settlement, Colombia, the Caribbean.

## Evaluación Preliminar del Asentamiento de Peces en Colectores Tipo GuSi, Santa Marta, Caribe Colombiano

Para estudiar el asentamiento de peces arrecifales en tres localidades de la región de Santa Marta, en la costa Caribe de Colombia, se fondearon dispositivos flotantes tipo GuSi entre los 10 y 12 m de profundidad. Cada estructura estuvo conformada por dos cilindros plásticos, borlas de fibra sintética semejando sistemas algales como elementos de atracción y lastres de fijación en concreto. La extracción se realizó mensualmente entre marzo de 2003 y febrero de 2004, teniendo en cuenta la incidencia de la luna nueva. Después de colectar cada estructura y separar por grupos los organismos asociados, los peces fueron identificados, medidos y pesados. Se presentan los resultados preliminares del trabajo, se reporta un total de 1220 individuos, agrupados en 45 especies, 23 familias, 35 géneros y 16 morfotipos. Las familias con mayor riqueza de especies fueron: Serranidae, Apogonidae, Muraenidae, Pomacentridae y Monacanthidae; los registros de máxima abundancia se encontraron para Gobiidae (28%), Apogonidae (18%), Labridae (8%) y Scorpaenidae (8%). Las especies dominantes fueron *Priolepis hipoliti* (28%), *Phaeoptix pigmentaria* (12%) y *Scorpaenodes caribbaeus* (8%). La varibilidad espacio-temporal del asentamiento de los peces estuvo determinada por la influencia local de los aportes continentales y por la cercanía de sustratos duros aledaños a las estaciones de muestreo. Los dispositivos mostraron ser altamente efectivos reproduciendo las condiciones naturales, se registró cerca del 41% de las

especies previamente reportadas para la región evaluadas con otras técnicas como los censos visuales y la aplicación de venenos, las líneas evaluadas favorecieron la captación de estados prejuveniles y juveniles, de hábitos bentónicos y crípticos e incluso de especies de interés comercial.

PALABRAS CLAVES: Dispositivo agregador de peces (DAP), asentamiento, Colombia, Caribe

## The Effect of Traps on Essential Fishery Habitat in the Florida Keys

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The development of ecologically sustainable fishing practices is a vital component of successful fisheries management. Trap-based fisheries, like the spiny lobster (*P. argus*) fishery in Florida, have the potential to maintain catch efficiency and reduce the impact on essential fisheries habitat, particularly coral reefs. Surveys of the distribution of traps indicate that few traps were placed on coral and that the placement and retrieval of traps on coral caused only a few relatively small injuries. However, injury to coral more commonly occurred when traps were moved during prolonged wind events greater than 17.5 knots. Several of these wind events generally occur each fishing season and in the winter of 2004 these events were observed to move traps an average of 4.5 meters (n=63 traps). Injuries to coral resulting from trap movement were generally larger and more frequent than injuries caused by trap placement and retrieval. By improving our understanding of the interaction between traps and coral reefs, fishery managers and fishermen may be able to reach an amenable solution to reduce the impact of traps on coral and promote more ecologically sustainable fishing practices.

KEY WORDS: Lobster traps, essential fish habitat, coral reefs

## El Efecto de Trampas sobre Habitat Esencial en los Cayos de la Florida

El desarrollo de prácticas de pesca ecológicamente sostenible es un componente esencial en el manejo de pesquerías. Pesquerías que usan trampas, como la pesquería de langosta espinsosa (*P. argus*) en la Florida, tienen el potencial de mantener la eficiencia de capturas y reducir el impacto sobre el habitat esencial de pesquerías, especialmente arrecifes. Estudios sobre la distribución de trampas indican que pocas trampas se colocaron en coral y que la colocación y la recuperación de estas trampas causó pocas heridas e heridas relativamente pequeñas en el coral. Sin embargo, heridas en coral ocurrió más comúnmente cuándo trampas se movieron debido a acontecimientos prolongados de viento más de 17.5 nudos. Varios de éstos acontecimientos de viento ocurren cada temporada de pesca y en el invierno de 2004, estos acontecimientos movieron las trampas un promedio de 4.5 metros (n=63). Las heridas en coral que resultaron del movimiento de las trampas fueron generalmente más grande y más frecuenta que las heridas causadas por la colocación y recuperación de trampas. Si mejoramos nuestra comprensión de la interacción entre trampas y arrecifes, los administradores del manejo de la pesquería y pescadores seran capaz de alcanzar una solución para reducir el impacto de trampas en el coral y promover la pesca ecológicamente sostenible.

PALABRAS CLAVES: Trampas de langosta, habitat esenciales de peces, arrecife coralino

# Effects of Two Open-water Submerged Cages Stocked with Cobia *Rachycentron canadum* and Red Snapper *Lutjanus analis* on the Benthic Macroinvertebrate Population at Culebra, Puerto Rico

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Two sediment core samples were taken bimonthly from (october 2002 at october 2003) southwest of Culebra Island, Puerto Rico. At each sample site (cage center and 40 m north, south, east and west) near two open-cages stocked with cobia (*Rachycentron canadum*) or red snapper (*Lutjanus analis*), and at a control site. Macroinvertebrate were separed with a 0.5 mm mesh sieve. Mean abundance of total soft-bottom invertebrates from all stations varied from a minimum of 694 ind/$m^2$ during october to 3.336 ind/$m^2$ during april 2003. A total of 72 families were identified from collections in project site, Culebra, Puerto Rico. Polychaetes (29), Mollusks (21) and Crustaceans (22). No general pattern of distribution between stations at both cages and control station has been observed in the soft-bottom macrobenthic communities in relation to he organic inputs. Only, central stations at both cages showed significant differences with respect to the other stations.

KEY WORDS: Cobia, *Rachycentron canadum*, red snapper, *Lutjanus analis*

# Los Efectos de Dos Jaulas Oceanicas Llenados con *Rachycen-*

# *tron canadum* y el Pargo, *Lutjanus analis*, sobre la Población de Macroinvertebrados Bentonicos en Culebra, Puerto Rico

Dos muestras de sedimento fueron tomadas bimensualmente por medio de un nucleador (octubre de 2002 a octubre de 2003) al suroeste de la Isla de Culebra, Puerto Rico. Los sitios de muestreo para cada una (centro de la caja, 40m norte, sur, este y oeste) se ubicaron cerca de dos jaulas cultivo de peces en mar abierto, sembradas con cobia (*Rachycentron canadum*) y pargo (*Lutjanus analis*), y un sitio control. Los macroinveretebrados fueron separados con un tamiz de 0.5 mm. La abundancia total de invertebrados de fondos blandos en todas las estaciones vario de un minimo de 694 ind/m$^2$ en octubre a 3336 ind/m$^2$ durante abril de 2003. Un total de 72 familias fueron identificadas en el sitio de estudio, Culebra, Puerto Rico. Poliquetos (29), moluscos (21) y crustáceos (22). No se determinaron patrones de distribución de la comunidad macrobentonica de fondos blandos relacionada con la entrada de materia orgánica entre estaciones, entre las jaulas y el sitio de control. Solo, las estaciones en el centro de ambas jaulas presentaron diferencias con respecto a las otras estaciones.

PALABRAS CLAVES: Jaulas, comunidad macrobentonica, acuacultura, cobia, pargo

# Current Monitoring Initiatives Combined with New Regional Biological Sampling Provide the Basis for Future Management of Florida's Common Snook (Centropomidae) Stocks

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Successful management of common snook requires knowing the catch rate, age composition, and sex ratio of the harvest and estimates of biological, reproductive, and genetic parameters for the entire population. Since 2002, biologists have intercepted snook anglers in nine regions of Florida to collect catch and effort data and biological samples for age determination, sex ratios, and reproductive condition of the catch. Fishing guides, recreational anglers, and tournament anglers complete logbooks that are used to define the size and age composition and catch rates of local stocks. This fishery-dependent data will serve as the basis for a comprehensive stock assessment to be conducted in 2005.

An unstudied component of the snook population occurs in Lake Okee-

chobee and other freshwater systems. If individuals older than 21 years occur in these areas, then maximum ages have been underestimated, which in turn may confound estimates of natural mortality and significantly bias stock biomass calculations. Moreover, the biological and genetic characteristics of resident freshwater snook must still be evaluated in order to assign them to appropriate unit stocks. A preliminary life history study of common snook in the Okeechobee system will be conducted as part of an ichthyological survey of the Caloosahatchee/St. Lucie waterway. All necessary biological and genetic material will be obtained from each snook collected via electro-shocking.

Finally, because juvenile common snook have not been found in historical ichthyological surveys of Florida Bay and the Florida Keys, adults there are assumed to spawn unsuccessfully and are assigned to the Gulf stock without any direct evidence. Histological observations of ovaries collected in these areas during the reproductive season will confirm if spawning occurs, and if so, demonstrate reproductive success or a lack thereof. Extensive genetic testing will also be conducted to determine the stock affinity of snook in these south Florida systems.

KEY WORDS: Management, snook

# Iniciativas Recientes de Monitoreo Combinadas con Nuevo Muestreo Biológico Regional Proveen la Base de Manejo Futuro de los Stocks de Robalo Blanco en la Florida

El manejo exitoso del robalo blanco requiere conocer el índice de captura, la estructura de edades y la proporción de sexos de la cosecha, y los estimados de parámetros biológicos, reproductivos y genéticos de la población entera. Biólogos han interceptado pescadores de robalo en nueve regiones de la Florida desde 2002 para colectar datos sobre captura y esfuerzo y muestras biológicas para determinar edad, proporción de sexos y condición reproductiva de la captura. Los guías de pescadores, pescadores recreativos y pescadores en torneos completan diarios que se utilizan para definir el tamaño y composición por edad y proporción de captura de los stocks locales. Estos datos dependientes-de-la-pesquería servirán como base de la evaluación comprensiva del stock que se realizará en 2005.

Un componente de la población del robalo sin estudiar se encuentra en Lake Okeechobee y otros sistemas de agua dulce. Si se encuentran individuos más viejos que 21 años en estas áreas, las edades máximas han sido subestimadas, lo que puede confundir los estimados de mortalidad natural e inclinar los cálculos de biomasa del stock. Además de que todavía las características biológicas y genéticas del robalo residente en agua dulce deben evaluarse para asignarles al stock apropiado. Se conducira un estudio preliminar de la historia de vida del robalo blanco en el sistema Okeechobee como parte del inventario ictiológico del Caloosahatchee/St. Lucie Waterway. Sé obtendrá todo el material biológico y genético necesario de cada snook capturado por medio de choque eléctrico.

Finalmente, porque el robalo blanco juvenil no ha sido encontrado históricamente en monitoreos de Florida Bay y los Cayos de la Florida, se presupone que los adultos desovan sin éxito y son asignados sin ninguna evidencia directa al stock del Golfo. Observaciones histológicas de los ovarios colectados en estas áreas durante la estación reproductiva confirmarán si el desove se lleva al cabo, y si es así, demuestre éxito reproductivo o la carencia de éste. Serán realizadas extensas pruebas genéticas para determinar la afinidad del stock de robalo en los sistemas del sur de la Florida.

PALABRAS CLAVES: El manejo, robalo blanco

# A Comparison of Reef Fish Assemblages on the East and West Sides of Central Eleuthera, Bahamas

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Eleuthera is a long, narrow crescent-shaped Atlantic margin island on the eastern extremity of the Great Bahama Bank in the central Bahamas. It is 144 km long and less than 5 km at its greatest width. Fringing reefs with substantial vertical relief (to 5 m in depths of 6 m) are found approximately 500 m offshore on the eastern side of the island facing the Atlantic Ocean. The western side of the island has stretches of rock cliffs and large fallen boulders providing substrate with similar vertical relief. No open passes exist between the two sides of the island and thus no direct larval transport from one side to the other appears possible. We compared post-settlement fish assemblages and larval supply on either side of central Eleuthera near Governor's Harbour quarterly from July 2003 until July 2004. Twelve point-counts were performed at two replicate sites on both sides of the island to census juveniles and adults. Abundance, as well as average, maximum and minimum lengths of species present were recorded. Three light traps were moored at each of the same sites 40-50 m from the reef for three to five nights around the new moon to examine larval supply. Fish collected in the light traps were preserved and transported to the lab. They were identified, enumerated, and standard length was measured. Preliminary analyses of point-count and light trap data indicate dissimilar assemblage structure between the two sides of the island, with significantly greater fish abundance and species richness on the eastern side.

KEY WORDS: Fish, larvae, Bahamas

## Una Comparación de Ensamblajes de Peces de Arrecife en Este y Oeste de Eleuthera Central, Bahamas

Eleuthera es una larga isla atlántica de borde en forma de luna creciente en la extremidad oriental del Gran Banco Bahamense, localizado en el centro de las Bahamas. Es 144 km de longitud y menos de 5 km en el lugar de mayor anchura. Arrecifes de borde con sustancial relieve vertical (de 5 m en profundidad a 6 m) se encuentran aproximadamente a 500 m mar afuera en el lado este de la Isla dando frente al Océano Atlántico. El lado occidental de la isla posee áreas de acantilados y farallones caídos que proveen substrato con similar relieve vertical. No existen espacios abiertos entre los dos lados de la Isla y como consecuencia el transporte de larva de un lado de la isla al otro aparenta ser imposible. Nosotros comparamos el ensamblaje de peces post-arreglo y suplido de larva en ambos lados de Eleuthera cerca de la Marina del Gobernador en base cuaternaria de Julio de 2003 a Julio de 2004. Doce "punto-cuenta" (point-count) fueron realizados en dos lugares replicados en ambos lados de la Isla, para hacer un censo de juveniles y adultos. Abundancia, así como el promedio, largo máximo y mínimo de las especies presentes fueron recopilados. Tres trampas ligeras fueron amarradas en cada sitio de 40 a 50 m del arrecife de tres a cinco noches alrededor de la luna nueva para examinar el suplido de larva. Los peses recopilados en las trampas ligeras fueron preservados y transportados al laboratorio. Fueron identificados, enumerados y la medida estándar fue tomada. Análisis preliminares de punto-cuenta y datos de trampa ligera indican disimilaridades significativas en la estructura de los ensamblajes entre los dos lados de la Isla, con más abundancia y riqueza en especies en el lado oriental.

PALABRAS CLAVES: Peces, larva, Bahamas

## Habitat Use, Feeding, and Reproduction of the Mayan Cichlid, *Cichlosoma urophthalmus* Günther, in the Alvarado Lagoonal System, Veracruz, Mexico

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The Mayan cichlid, *Cichlasoma urophthalmus* is a freshwater cichlid widely distributed in rivers, cenotes, and mesohaline coastal lagoons in the southeast of Mexico. Although little is known of its ecology, it is exploited commercially in the artesanal fishery and has the potential for native species aquaculture. In the Alvarado lagoonal system, Veracruz, they are mainly distributed towards the north in Camaronera Lagoon. Greatest abundance and biomass of this species was obtained during December to February with an affinity for oligohaline to mesohaline sites with submerged vegetation that is well-oxygenated, relatively-deep and transparent. Length-frequency shows two size classes during the dry and rainy seasons, corresponding to reproductive fish and young-of-the-year; during the nortes season there is only one modal size class of fish between 60–100 mm SL. The diet of Mayan cichlids consists principally of algae and plant material, suggesting it is an omnivore. Some females had elevates GSI values throughout the year, although most reproductive adults are found between April and December. The highest GSI values coincided with the peak in reproductive activity between May and July, with fecundity ranging from 1,556 – 3,348 eggs/female. These characteristics suggest it is a generalist with wide habitat ranges. Its use as a native aquaculture resource in Mexico is based on the assumption that there would not be any negative effects on native biodiversity. However, Mayan cichlids are one of the most abundant introduced species in south and southwest Florida, where they severely impact native substrate spawners like largemouth bass, warmouth and spotted sunfish through nest building habitat alteration and egg predation. Mayan cichlids also outnumber native species in northern Florida Bay. Thus, a greater understanding of the life history of the species in low salinity systems in its native range may aid management of introduced populations in south and southwest Florida.

KEY WORDS: Mayan cichlid, Cichlidae, Mexico

## Uso del Habitat, Alimentación, y Reproducción de la Mojarra del Sureste, *Cichlosoma urophthalmus* Günther, en la Sistema Lagunar de Alvarado, Veracruz, México

La mojarra del sureste, *Cichlasoma urophthalmus* es un ciclido de agua dulce distribuido extensamente en los ríos, los cenotes, y las lagunas costeras del mesohalino en el sureste de México. Aunque poco se sabe de su ecología, se explota comercialmente en la industria pesquera del artesanal y tiene el potencial para la acuacultura nativa. En la sistema lagunar de Alvarado, Veracruz, se distribuyen principalmente hacia el norte en la Laguna de Camaronera. La abundancia y la biomasa más grandes de esta especie fueron obtenidas durante diciembre a febrero con una afinidad para los sitios oligohalinos a mesohalinos con la vegetación sumergida que es bien-oxigenada, profundo y transparente. La longitud-frecuencia demuestra dos clases del tamaño durante las estaciones secas y de lluvias, correspondiendo a los pescados reproductivos y al jovenes; durante los nortes es solamente una clase modal del tamaño de pescados entre 60-100 milímetros SL. La dieta de mojarra del sureste consiste principalmente en algas y el material de planta, sugiriéndola es un omnívoro. Algunas hembras tenían valores de GSI elevados a través del año, aunque encuentran a la mayoría de los adultos reproductivos entre abril y diciembre. Los valores más altos de GSI coincidieron con el pico en actividad reproductiva entre mayo y julio, con la fecundidad extendiéndose a partir de 1,556 – 3,348 huevos/hembra. Estas características sugieren que sea internista con las gamas anchas del habitat. Su uso como recurso nativo de la acuacultura en México se basa en la asunción que no habría ninguna efectos negativa sobre biodiversidad nativa. Sin embargo, los mojarras del sureste están uno de las especies introducidas más abundantes del sur y el sudoeste la Florida, donde afectan seriamente peces nativos que desolven del substrato con la alteración del habitat del edificio de la jerarquía y la depredación de los huevos. Los mojarras del sureste también exceden en número especies nativas en la area norteña de la Bahía Florida. Así, una mayor comprensión de la historia de la vida de la especie en sistemas bajos de la salinidad en su gama nativa puede ayudar al manejo de poblaciones introducidas en el sur y el sudoeste de Florida.

PALABRAS CLAVES : La mojarra del sureste, *Cichlasoma urophthalmus*, México

# Diet of *Elagatis bipinnulata (*Quoy y Gaimard) (Carangidae) from Taganga Bay and Tayrona Natural National Park, Colombia, Caribbean Sea

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The diet of juveniles and adults of *Elagatis bipinnulata* (Rainbow runner), caught by artisanal fishermen between February 2003 and May 2004, is described from the content analysis of 20 stomachs. The size of fish ranged from 27.7 to 56.5 cm FL. The contribution of each prey item was determined by three Relative Measures of Prey Quantity (RMPQ): gravimetric (%W), frequency of occurrence (%F), and numerical (%N). In order to assess the significance of the various prey items, the Geometric Index of Importance (GII) was calculated using the three RMPQ's. Three major food categories were identified: bony fishes (Teleostei), dominated in all the metrics used, while crustaceans were important in number and occurrence and mollusks in weight. The GII for the whole sample showed two levels of importance, the first one composed by unidentified bony fishes (81.9) and *Jenkinsia lamprotaenia* (63.9) (Clupeidae). The prey items: Mysidacea (14.5), *Sepioteuthis sepioidea* (10.3) (Teuthoidea), *Coronis* sp. (7.7) (Stomatopoda), Unidentified

Clupeidae (7.4), Megalopae of Brachyura (5.6), *Portunus anceps* (5.4) (Brachyura), *Cavolinia uncinata* (4.6) (Thecosomata), Harpacticoida (4.6) Megalopae of Anomura (3.8) and Fragments of Crustacea, constituted the second level of importance in the diet of *E. bipinnulata*. Temporal variation in diet was detected. *J. lamprotaenia, S. sepiodea* and planktonic crustaceans (mysids and harpacticoids), appeared exclusively in march (windy, dry season), while *P. anceps, C. uncinata* and megalopae were only found in November (calm, rainy season). The analysis characterizes this species as a opportunistic carnivore.

KEY WORDS: Rainbow runner, *Elagatis bipinnulata*, diet, Colombia

## Dieta de *Elagatis bipinnulata (*Quoy y Gaimard) (Carangidae) de la Bahía de Taganga y Parque Nacional Natural Tayrona, Caribe Colombiano

La dieta de juveniles y adultos de *Elagatis bipinnulata,* capturados por pescadores artesanales entre febrero de 2003 y mayo de 2004, es descrita a partir del análisis del contenido de 20 estómagos. El rango de talla de los peces osciló entre 27.7 y 56.5 cm L.H. La contribución de las presas fue determinada mediante tres medidas relativas de cuantificación de presas (MRCP): gravimétrica (%W), frecuencial (%F) y numérica (%N). Con objeto de precisar la importancia de cada presa se calculó el índice Geométrico de Importancia GII, utilizando las tres MRCP. Se identificaron tres categorías alimentarias generales: peces teleósteos (Teleostei), dominó en todas las medidas usadas, mientras que crustáceos fue importante en número y ocurrencia y moluscos en peso. El GII para toda la muestra mostró dos niveles de importancia, el primero compuesto por peces teleósteos no identificados (81.9) y *Jenkinsia lamprotaenia* (63.9) (Clupeidae). Los ítems alimentarios: Mysidacea (14.5), *Sepioteuthis sepioidea* (10.3) (Teuthoidea), *Coronis* sp. (7.7) (Stomatopoda), Clupeidae no identificado (7.4), Megalopa de Brachyura (5.6), *Portunus anceps* (5.4) (Brachyura), *Cavolinia uncinata* (4.6) (Thecosomata), Harpacticoida (4.6) Megalopa de Anomura (3.8) y Fragmentos de Crustacea, constituyeron el segundo nivel de importancia en la dieta de *E. bipinnulata.* Se detectó variación temporal en la dieta. *J. lamprotaenia, S. sepiodea* y crustáceos planctónicos (mysidáceos y harpacticoides), aparecieron exclusivamente en marzo (de vientos, época seca), mientras que *P. anceps, C. uncinata* y las megalopas se encontraron en noviembre (de calma, época de lluvias). El análisis caracteriza a esta especie como carnívora oportunista.

PALABRAS CLAVES: *Elagatis bipinnulata*, dieta, Colombia

# A Preliminary Survey of the Commercial Snapper Fishery of the Central Bahamas

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Fisheries resources are being depleted globally by increased effort and efficiency of fishing gear. Due to the proximity of near-shore coastal shelf areas, tropical islands are particularly vulnerable to over fishing. In The Bahamas, Snappers are economically, culturally and ecologically valued. They are the most sought after finfish in the Bahamas next to grouper. In 2003, the total fishery product and resource landings for Snapper in The Bahamas were 1,544,032 pounds valuing US $ 2,823,444. (Dept. of Fisheries 2003).

Relatively little is known about the commercial snapper fishery in The Bahamas when compared to research that has been done on *Epinephelus striatus* (Nassau Grouper) and *Panulirus argus* (spiny lobster). This survey was initiated to collect basic fisheries data on snappers landed in New Providence in order to give some preliminary recommendations for the management of this fishery.

Data was collected on all Snapper species landed on the island of New Providence at landing sites: Potter's Cay Dock, Williams' Lane Dock, and Montague Ramp; as well as one food processing plant: Geneva Brass, in three main categories:

i) Profile of the fishers including age, and economic dependence on fishing,
ii) Fisher opinions regarding fishing regulations and abundance of Snappers, and
iii) Catch data for the fishing trip including total number of species caught, length, weight, fishing location, and total fishing hours.

From July 1-16 2004, 706 Snappers were measured and weighed at points of landing. Of all fish sampled, over 25% were immature. *Lutjanus analis* (Mutton Snapper) is one of the two snapper species that are listed as Threatned Species by the IUCN (Huntsman 1996). It was noted that of the four species sampled, *Lutjanus analis*, (mutton snapper), was the most caught immaturely. In order to sustain the Commercial Snapper Fishery in The Bahamas, effective management measures need to be implemented.

KEY WORDS: Snappers, Lutjanidae, commercial Fishery, Bahamas

# Un Estudio Preliminar de la Pesquería Comercial para Pargos de las Bahamas Centrales

Los recursos de pesquerías estan agotados globalmente por el aumento de esfuerzo y la eficiencia del equipo pesquero. Islas tropicales son especialmente vulnerables a la sobrepesca. En Las Bahamas, pargos son económicamente, culturalmente, y ecológicamente valorosos. Son el pez mas buscado en las Bahamas después de los meros. En 2003, los productos del pesquería para pargos y las capturas del recurso en Las Bahamas fue 1,544,032 libras valorando EEUU $2,823,444. (Dept. of Fisheries 2003).

Relativamente poco se sabe de la pesquería comercial para pargos en Las Bahamas comparado con los estudios que se han hecho sobre *Epinephelus striatus* (mero gallina) y *Panulirus argus* (langosta espinosa). Este estudio se inició para reunir datos básicos de las capturas del pesquería para pargos en New Providencia con el intento de dar algunas recomendaciones preliminares para el manejo de esta pesquería.

Los datos se colectaron sobre todas especies de pargos en estos sitios de captura: Potter's Cay Dock, Williams' Lane Dock, Montague Ramp, de Montague; así como una planta de procesamiento: Geneva Brass en tres categorías principales:

- i) El perfil del pescador inclusive la edad y su dependencia económica en la pesca,
- ii) Las opiniones del pescador con respecto a las regulaciones y abundancia de pargos, and
- iii) Datos decapturas para el viaje inclusive el número total de especies capturadas, el largo, el peso, la localidad, y horas pescando.

De julio 1-16 2004, 706 pargos se midieron en puntos de captura; 25% fueron inmaduro. *Lutjanus analis* es uno de dos especies de pargo listadas como amenazados por el IUCN (Huntsman 1996). De los 4 especies capturadas, *Lutjanus analis* fue la especie que se capturo mas frecuentamente inmaduro. Para sostener la pesquería comercial para pargos en Las Bahamas, el manejo efectivo se debe aplicar.

PALABRAS CLAVES: Pargos, Lutjanidae, pesquería comercial, Bahamas

# Photoperiod Effect in Embryonic Development of Queen Conch, *Strombus gigas* (Linnaeus)

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This scientific investigation is focused in the finding of basic biological mechanisms in the involved in the culture of *Strombus gigas* and the objective was to determine the direct effect of photoperiods during embryonary development until final evaluation: hatching. Seven egg masses of the queen conch, *Strombus gigas* still in their first cell divisions, were subjected to six different photoperiod treatments in two phases. The first phase used 3 egg masses and had a 5 hour advanced photoperiod and the second used 4 egg masses with a 7 hour advanced photoperiod. The photoperiods were advanced with respect to 18:00 hours (the normal time of sunset at the collection areas in Mexico). The experiment apparatus consisted of 6 wooden boxes, each containing five receptacles in which portions of each egg masses were placed. Seawater flow was 200 ml/min at a controlled temperature of 27.8 ± 0.2 °C. The number of larvae that hatched were counted in all treatments in intervals of one hour, from the beginning of eclosion in whichever treatment took the longest to complete hatching, with the objective of observing if embryos responded to the different photoperiods. The results indicated that eclosion depended on the alternation of light/dark, such that light could be programmed to advance up to 7 hours and that 3 cycles of artificial light/dark were enough to show enough endogenous control suggesting that this sequence can be compared to a biological clock regulated by photoperiod.

KEY WORDS: Mariculture, embryonic development, photoperiod

# Efecto del Fotoperíodo en el Desarrollo Embrionario del Caracol Reina *Strombus gigas* (Linnaeus)

Esta investigación científica esta enfocada en encontrar mecanismos biológicos básicos envueltos en el cultivo de *Strombus gigas* y el objetivo fue la determinación del efecto directo del fotoperíodo durante el desarrollo embrionario hasta el final de la eclosion. Siete puestas de masas de huevos del caracol reina, Strombus gigas en sus primeras divisiones, fueron sometidas a seis tratamientos de fotoperíodo en dos etapas. En la primera etapa se usaron tres puestas de masas con 5 horas de adelantamiento de fotoperíodo y en la segunda etapa se usaron cuatro puestas de masas con 7 horas de adelantamiento. Ambos fotoperíodos de adelantamiento se efectuaron tomando en cuenta como referencia el tiempo de 18:00 horas que es cuando normalmente ocurre la eclosión en condiciones naturales al iniciarse la penumbra en el sitio de

trabajo. El aparato experimental consistió de seis cajas de madera en la cual cada caja contenía seis botes de plástico en las cuales las porciones iguales de cada puesta de masa de huevos fueron colocadas, El flujo de agua de mar fue de 200 ml/min a una temperatura de 27.8 ± 0.2 °C. El número de larvas que eclosionaron fueron contadas en todos los tratamientos en intervalos de una hora, desde el comienzo de la eclosión en cualquiera de los tratamientos hasta que finalizó la eclosión con, el proposito de observar si los embriones respondieron a los diferentes tratamientos de fotoperíodo. Los resultados indican que la eclosión depende de la alternancia de luz/obscuridad, tal que el fotoperíodo puede ser programado por adelantado hasta 7 horas y que 3 ciclos artificiales de luz/obscuridad fueron bastante suficientes para mostrar un control endógeno, sugiriendo que esta secuencia puede ser comparada a un reloj biológico regulado por fotoperíodo.

PALABRAS CLAVES: *Strombus gigas*, fotoperíodo, desarrollo embrionario, maricultura

# Fatty Acid Profile and Lipid Composition Related to Spawning Cycle of Queen Conch *Strombus gigas* (Linnaeus), from the National Park Arrecife Alacranes, Yucatan, Mexico

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Although fishing regulation may help to recuperate populations of queen conch, other strong alternative that should be considered is mariculture. Studies on the lipid composition and fatty acid profile may help to a better understanding to culture queen conch. Thus, the objective of this work was to determine the lipid composition and fatty acid profile of the Queen conch *Strombus gigas* (Linnaeus) related to their spawning cycle. The experiment was carried out for two years (2202-2003). Sampling was performed in different organs before, during and after spawning in the protected area of Arrecife Alacranes. Extraction and determination of lipids was performed according the methodology of Privett *et al.* We found the highest percentage for phosolipids regardless the organ from which the samples were taken. Fatty acids profile was determined and related with the number of lays. We found that saturated fatty acids decreased and the unsaturated fatty acids increased as the number of lays increased. In conclusion, we found that the highest quantity of saturated fatty acids before and after spawning. During spawning the saturated fatty acid decreased. Contrary to saturated fatty acids, monosaturated and polyunsaturated increased during spawning and decreased after spawning. This information will be very valuable for an improved management of this resource as well as to encourage the development of aquaculture of Queen Conch in Mexico.

KEY WORDS: *Strombus gigas*, lipids, fatty acids

# Obtención del Perfil de los Ácidos Grasos y la Determinación de la Composición de Lípidos con Relación al Ciclo de Desove en el Caracol Marino *Strombus Gigas* (Linnaeus) en el Parque Nacional Arrecife Alacranes, Yucatán

La maricultura es una alternativa muy fuerte que debe considerarse y dentro de esta practica está la Bioquímica como una de las ciencias de apoyo para el manejo del recurso relacionando los resultados de los tipos y clases de lípidos con su ciclo de desove. Por lo que, el propósito de este trabajo fue determinar la composición de lípidos y obtener el perfil de los ácidos grasos presentes en el caracol marino adulto *Strombus gigas* (Linnaeus) adulto relacionado con su ciclo de desove. La metodología que se utilizó para la extracción y separación en clases de lípidos fue la de Privett *et al* y para determinar el perfil de los ácidos grasos se usó la cromatografía de gases acoplado a un detector de masas. Los resultados están comprendidos entre el período de dos años 2002-2203. En tres etapas del ciclo de desove se efectuaron los muestreos: antes, durante y al final en los encierros de caracoles en el Arrecife Alacranes. Se determinó la composición de lípidos totales en tres etapas del ciclo del desove por órganos. Se determinó y cuantificó el perfil de ácidos grasos en cuanto a la abundancia de ácidos grasos saturados, monosaturados y Poliinsaturados y se relacionó con el número de puestas en los meses de desove observándose que al aumentar el número de puestas disminuyen los ácidos grasos saturados y aumentan los insaturados. Se determinó y cuantificó la composición de los lípidos (clases de lípidos ) presentes en el caracol marino adulto *Strombus gigas* y se obtuvo el mayor porcentaje para los Fosfolípidos. Se compararon las clases de lípidos por órganos observando que el mayor porcentaje fue también para los Fosfolípidos no importando el órgano analizado. Se llegó a la conclusión que antes y después del desove hay una mayor cantidad de ácidos grasos saturados y durante el desove disminuyen y sucede lo contrario con los monosaturados y poli-insaturados que durante el desove aumenta y al final disminuyen. Esta información obtenida es valiosa pues contribuye a un mejor manejo del recurso así como al desarrollo de la maricultura del caracol reina en México.

PALABRAS CLAVES: *Strombus gigas*, lípidos, ácidos grasos

# Fisheries Oceanographic Study Using GIS for Understanding the Changes in the Distribution of Mahi Mahi Based on Tagging Data

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The main aspect of this research is to characterize the functional relationships that exist between dolphin fish (*Coryphaena hippurus*) and their oceanic ecosystem. GIS is being used as a tool to help identify and quantitatively characterize the environmental parameters that appear important in understanding changes in the distribution based on tag and recapture data. This research is a multi-disciplinary study involving fisheries biology, physical oceanography, and remote sensing. Part of this study is the development of image processing and visualization tools to evaluate and merge data that exist in different spatial and temporal resolutions, as well as, different spectral bands. Infrared and ocean color - chlorophyll data will be derived from the AVHRR and MODIS sensor on the NOAA, Aqua, and Terra satellites. Evaluation of the development and coherence in time and space of such physical parameters as ocean frontal boundaries (temperature, chlorophyll, turbidity, etc.) related to coastal plumes, as well as, Gulf Stream circulation features (e.g. meanders and eddies) is a critical aspect of this research. The ultimate goal is to provide diagnostic and predictive bio-physical models on the effects of ocean climate variability to fisheries resource managers and policy makers.

KEY WORDS: GIS, mahi mahi, *Coryphaena hippurus*, tagging data

# Estudio Oceanográfico de las Industrias Pesqueras Usando Sistema de Información Geografica para Entender los Cambios en la Distribución de Mahi Mahi Basada en Datos de Marcaje y Recaptura

El principal aspecto de esta investigación es caracterizar las relaciones funcionales que existen entre el dorado (*Coryphaena hippurus*) y su ecosistema oceánico. Se están utilizando el sistema de información geografica (GIS) como una herramienta para ayudar a identificar y a caracterizar y cuantificar

los parámetros ambientales que parecen importantes para entender los cambios en su distribución basados en datos de marcaje y recaptura. Esta investigación es un estudio multidisciplinario que involucra las areas de biología pesquera, la oceanografía física, y la detección remota. Parte de este estudio es el desarrollo de las herramientas del proceso y de la visualización de imagenes para evaluar y para combinar los datos que existen en diversas resoluciones espaciales y temporales, así como, diversas bandas espectrales. Infrarrojo y color del océano - los datos de la clorofila serán derivados del sensor del AVHRR y de MODIS en los satélites de NOAA, Aqua, y Terra. Evaluación del desarrollo y de la coherencia en tiempo y espacio de los parámetros físicos tales como los límites frontales del océano (temperatura, clorofila, turbiedad, etc.) relacionado con los plumes costeros, tan bien como, las características de la circulación de la corriente del golfo (e.g. meanders y los remolinos) son un aspecto crítico de esta investigación. La última meta es proporcionar modelos biofísicos de diagnóstico y predicion en los efectos de la variabilidad del clima del océano a los encargados de administrar los recursos pesqueros y a los encargados de crear las políticas de administración.

# The Distribution of Recreational Fishing Effort and Harvest in the Waters Around Puerto Rico

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The National Marine Fisheries Service's Marine Recreational Fisheries Statistics Survey (MRFSS) has elicited catch and effort data from anglers throughout the U.S. since 1979. However, the MRFSS collects little information about where anglers fish once they leave the shore. This information is needed to evaluate the spatial aspects of recreational fisheries, including the effects of management strategies such as marine protected areas.

As part of a pilot study in Puerto Rico, questions were added to the 2003-04 MRFSS asking anglers where they hooked the most fish and where they spent the most time. We describe the development of the interview maps for this project and report preliminary results for the winter months of data collection. A Geographic Information System (GIS) was created to maintain the project data and generate maps of fishing effort and harvest for the top ten recreationally harvested species in Puerto Rico. The GIS and related maps help identify spatial trends in fishing pressure and areas that might require heavier sampling. They also help evaluate the potential scope of influence for marine protected areas.

KEY WORDS: Recreational fishing, Puerto Rico, GIS, catch mapping, effort mapping

## La Distribución del Esfuerzo y Capturas Deportivas en Aguas Alrededor de Puerto Rico

La Encuesta de Estadística de Pesquerías Deportivas (MRFSS, por sus siglas en inglés) del Servicio Nacional de Pesquerías Marinas (NMFS, por sus siglas en inglés) ha recolectado información sobre capturas y esfuerzo deportivo en los Estados Unidos desde 1979. A pesar de esto, existe escasa información sobre las actividades de los pescadores deportivos una vez que se alejan de la orilla. Esta información es necesaria para evaluar aspectos de pesquerías deportivas, incluyendo los efectos de estrategias de gestión espaciales como el uso de reservas marinas.

Como parte de un estudio piloto, se añadieron preguntas a la encuesta del MRFSS del año 2003-04. Estas indagan donde los pescadores deportivos capturan la mayoría de sus peces y donde pasan la mayor parte de su tiempo. En este resumen, describimos como se desarrollaron mapas para las entrevistas, y presentamos resultados preliminares recolectados durante los meses de invierno. Un Sistema de Información Geográfica (GIS, por sus siglas en inglés) fue creado para almacenar la información y para generar mapas que detallan el esfuerzo pesquero y capturas de las diez especies deportivas más importantes de Puerto Rico. El GIS y los mapas contribuyen a identificar tendencias espaciales en el esfuerzo pesquero y áreas que podrían necesitar mayor muestreo. Esta información también ayuda a evaluar el área de influencia de reservas marinas.

PALABRAS CLAVES: Pesca deportiva, Puerto Rico, GIS, cartografia de capturas, cartografia de esfuerzo

# A Population Survey of the West Indian Topshell (*Cittarium pica;* Trochidae) in the U.S. Virgin Islands

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The West Indian topshell, *Cittarium pica* (Trochidae), is an intertidal gastropod that is commonly harvested for food throughout the Caribbean. In the U.S. Virgin Islands, *Cittarium* is caught by commercial, recreational and subsistence fishers. However little is known about *Cittarium* population structure, making it difficult to assess the impact of harvest upon local populations. In order to provide baseline data for fisheries management, we conducted intertidal surveys of *Cittarium* populations on St. Croix, St. John, St. Thomas, and associated offshore cays of the USVI. Our results showed considerable site-to-site variation in *Cittarium* population structure: average density and size varied both within and among islands. At most sites, larger adult *Cittarium* (> 62 mm shell width) were either rare or absent, and generally at densities of < 0.2 individual/m$^2$. Inaccessible sites and sites within no-take areas had higher densities of large *Cittarium.* These data suggests that harvesting has impacted population size structure by removal of the largest individuals. The abundance of young-of-the-year *Cittarium* (< 10 mm shell width) varied substantially among sites, but high densities (> 10 individuals/m$^2$) were not uncommon. This observation indicates that *Cittarium* recruitment levels may be relatively high but are spatially localized. We identify and discuss factors that may contribute to spatial variability in *Cittarium* population structure (*e.g.* substrate composition, habitat topography, exposure to wave action). We conclude that harvesting and variable recruitment patterns are two of the most significant determinants of variable *Cittarium* size distributions in the USVI.

KEY WORDS: West Indian topshell, *Cittarium*, whelk, rocky intertidal, ecology, fishery

# Un Muestreo de la Población de *Cittarium pica* (Trochidae) en los Islas Virgenes de los EE.UU

El caracol, *Cittarium pica* (Trochidae), también conocido como burgao, es un gastropod frecuentemente cosechado para comida en las aguas del caribe. En las islas Vírgenes de los Estados Unidos (USVI), el *Cittarium* se pesca para el comercio, recreación o para subsistencia. Sin embargo, poco se conoce acerca de la estructura de las poblaciónes del *Cittarium* por lo que resulta

dificil determinar el impacto que tiene la pesquería en las poblaciónes locales. De tal forma, hemos conducido estudios de las poblaciónes del *Cittarium* en las islas de Santa Cruz, Santo Tomas, San Juan y otros islotes pertenecientes a USVI. Obtuvimos resultados bastante variados entre las distintas localidades: el tamaño y densidad promedio varia entre localidades y dentro de una misma localización. En la mayoría de las localidades grandes *Cittarium* adultos (> 62 mm achura máxima) eran poco común, y generalmente con densidades menores de 0.2 individual/$m^2$. En las áreas en que el acceso es prohibido o restringido hay mayor densidad de *Cittarium* grandes. Estos datos indican que la pesquería ha impactado la estructura de la población del *Cittarium* por medio de la eliminación del individuo más grande. La abundancia del *Cittarium* joven del año (<10 mm anchura máxima) vario substancialmente entre localidades, pero densidades altas (>10 individuos/$m^2$) fueron común. Esta observación indica que los niveles del recrutamiento pueden ser relativamente alto, pero estan localizado esparcidamente. Indentificamos y discutimos los factores ecológicas que pueden contribuir a los variables esparcidos en las poblaciónes del *Cittarium* (*ej.* composición física del suelo, topografia del habitat, y exposicion del movimiento de las olas). Concluimos que la pesquería y patrones de recruitamiento variadas son dos de los factores principales en la estructura de los poblaciónes del *Cittarium* en el USVI.

PALABRAS CLAVES: Caracol, *Cittarium pica*, estructura de las poblaciónes, pesquería

## Diagnostic of the Recreational Scuba Diving Activity in the Marine National Park of Fernando de Noronha, PE.

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This paper's main goal is to characterize recreational SCUBA diving activity in Fernando de Noronha National Marine Park, located in Pernambuco, Brazil. To analyze SCUBA diving activity and the operating conditions of the scuba diving operators, a team from the laboratory of submarine diving from UNIVALI accompanied these divers while observing the following criteria: behavior of the divers during dives, observing whether organisms were touched or disturbed; the diver's floatability and swimming skills; the conditions of vessels used for scuba diving operations, and the availability of safety and live saving equipment. Each individual diver was profiled and their own level of satisfaction was evaluated via a semi-closed questionnaire. In addition, data on SCUBA diving impacts on the marine environment was obtained and divers were given an opportunity to suggest solutions for these impacts. During the expedition to Fernando de Noronha we observed increasing levels of

SCUBA-based tourism in the area in spite of a lack of adequate infrastructure and management nor enforcement by responsible Park authorities. We find it particularly necessary to restructure the existing management plan paying special attention to the impacts of recreational diving. Another problem observed regarding recreational SCUBA diving was the lack of legislation that assures the security and rights of all divers.

KEY WORDS: SCUBA diving, marine parks, Brazil

## Diagnóstico de la Atividad de Buceo Recreativo en el Parque "Nacional Marinho de Fernando de Noronha", PE.

El presente trabajo tuvo como objetivo diagnosticar la actividad de buceo recreativo en el "Parque Nacional Marinho de Fernando de Noronha", localizado en Pernambuco, Brasil. Para análisis de la actividad de buceo recreativo y de las condiciones de operación de las operadoras de buceo, un equipo del laboratorio de Buceo Submarino de UNIVALI, acompañó los buceos. Los criterios llevados en consideración fueron: el comportamiento de los buceadores durante el buceo, considerándose el toque en organismos o en el substrato, la forma de natación y el control de flotabilidad; las condiciones de la embarcación para la operación de buceo; los procedimientos y equipos de seguridad que acompañaban cada operación. Para conocer el perfil del buceador y evaluar su grado de satisfacción, fue aplicado un cuestionario de modelo semicerrado. Se buscó información sobre el impacto relacionado con la actividad de buceo y algunas soluciones de manejo para minimizarlo, por medio de consulta literaria. Se observó durante la expedición de estudio un desarrollo del turismo subacuático en Fernando de Noronha, sin embargo, sin manejo e infraestructura adecuados, además de la falta de fiscalización de los órganos responsables. Es necesario, entonces la urgente necesidad de reestructuración de los planes de gerencias vigentes, y que estos contemplen la actividad de buceo recreativo. Otro problema observado para el buceo recreativo fue la necesidad de una legislación que garantice la seguridad y el derecho de todos los buceadores.

PALABRAS CLAVES: Buceo recreativo, parque marinho, Brasil

# A GIS-based Characterization of Commercial Sponge Populations in the Florida Keys, Florida (USA)

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Nearshore hard-bottom communities constitute ~ 30% of the coastal zone of the Florida Keys, Florida (USA). Sponges are characteristic of these communities and several large sponges are commercially fished, representing approximately 1% of the total invertebrate harvest in 1999. *Hippospongia lachne* (sheepswool sponge), *Spongia barbara* (yellow sponge), and *Spongia graminea* (glove sponge) dominate the commercial sponge harvest in south Florida and were the focus of this study. Our goal was to determine the spatial structure of these communities with particular emphasis on the region distribution of commercial sponge species in the Florida Keys. Data were obtained as part of a survey conducted in 2002 of 117 GPS-positioned hard-bottom sites distributed throughout the Florida Keys in a double-stratified (region x depth) design. At each survey site, four 2m x 25m non-overlapping belt transects were surveyed and all sponges > 10cm diameter were enumerated. A GIS model was produced representing the spatial distributions and abundances of *H. lachne*, *S. barbara* and *S. graminea*. For each site, distance to land, water depth, and bottom type classification were used to determine the influence of these variables on the distribution, abundance, and co-occurence of the three sponge species. A kriging interpolation was used as a predictor of abundances in adjacent areas. This information, along with other data collected on hard-bottom community structure, sponge growth, and sponge fishery impacts, will be used to assess the efficacy of current management policy in maintaining a sustainable fishery and healthy sponge communities in the Florida Keys.

KEY WORDS: Sponges, GIS, population assessment, Florida

# Caracterizaci6n Basada en GIS de las Poblaci6nes de Esponjas en Florida Keys, Florida (USA)

Communidades cerca de la orilla de fondo duro constituen 30% de la zona costera de Florida Keys, Florida (USA). Esponjas son características de estas communidades y varias esponjas grandes son pescadas commercialmente, representando approximadamente 1% de la cosecha total de invertebrados en el año 1999. *Hippospongia lachne, Spongia barbara,* y *Spongia graminea* dominan la cosecha en el sur de Florida y son el foco de este estudio. Nuestra meta fue en determinar la estructura espacial de estas communidades con un emphasis en la distribución regional de las especies de esponjas commerciales en Florida Keys. Datos fueron obtenidos en parte de una encuesta realizada en el año 2002 con 117 GPS posiciones de fondo duro distribuidos por todo Florida Keys en un diseño region x profundidad. En cada sitio de la encuesta, cuatro zonas de tamaño 2m x 25m fueron creadas en los cuales todas las esponjas > 10cm fueron contadas. Un modelo GIS fue producido representando la distribución y abundancia de *H. lachne, S. barbara* and *S. graminea.* Para cada sitio, una clasificación de la distancia a tierra, la profundidad del agua, y el tipo de fondo fueron usados para determinar la influencia de estas variables sobre la distribución y abundancia de estas tres especies de esponjas. Una interpolacion kringing fue utilizada para predecir las abundancias en zonas adyacentes. Esta información, junto con otros datos collectados en la estructura de las communidades de fondo duro, crecimiento de las esponjas y impactos de la pesca de esponjas seran utilizadas para valorar la efficacia de la corriente póliza en la administración en mantener una pesca sostenible y una communidad de espongas sana en Florida Keys.

PALABRAS CLAVES: Esponjas, GIS, poblaciónes, Florida

# Using GIS to Measure Multiple Scales of Topographic Complexity for Reef Fish Assemblage Structure and Species Distribution Analyses

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The diverse variables involved in determining the spatial relationships of reef fish obfuscate predicting their distributions. Topographic complexity (rugosity) ranks high among these variables, influencing reef fish assemblage structure and species distribution. This relationship is scale dependent. Reef fish respond to different scales of topographic complexity according to their body size, habitat use, and behavior. The smaller, resident fishes, such as gobiids or pomacentrids, are influenced by rugosity on a much smaller scale than larger, transient fishes like Scarids or Acanthurids. Therefore, similar to reef fish population assessments, topographic complexity must be sampled at scales appropriate to the targeted organism(s). In most studies, this relationship has been overlooked. One explanation for this oversight is *in situ* rugosity measurements, such as the chain method, are easily attainable for small, linear survey areas (on the order of ten of meters); However, for larger, broader survey areas (on the order of hundreds of meters), they are cumbersome and less feasible. The work herein introduces a novel method utilizing remote sensing technology and landscape ecology GIS tools to obtain reef topographic complexity. A rugosity index calculated in GIS from remotely sensed data allows the comparison of fish species distributions to areas of differing complexities on multiple scales. This method may provide new perspectives for understanding the affects of rugosity on reef fish assemblage structure and distribution. This work will also contribute to the development of a predictive model resource managers can use to economically and accurately estimate fish densities.

KEY WORDS: Rugosity, GIS, topographic complexity, reef fish, remote sensing

## Utilización de GIS para Medir Múltiples Escalas de Complejidad Topográfica para Analizar la Estructura de Ensamblajes de Peces de Arrecifes y la Distribución de Especies

Las diversas variables envueltas en la determinación de la relación espacial de peces de arrecife ofuscan la predicción de la distribución de los mismos. La complejidad topográfica (rugosidad) es de alto rango entre estas variables, influenciando la estructura de ensamblajes de peces de arrecifes y la distribución de especies. Esta relación es dependiente de la escala. Los peces de arrecife responden a diferentes escalas de complejidad topográfica de acuerdo al tamaño del cuerpo, uso del hábitat y comportamiento. Los más pequeños, peces residentes, como los góbidos (gobiids) o pomacéntridos (pomacentrids), son influenciados por la rugosidad a una escala mucho menor que los peces más grandes, peces transeúntes como los escáridos (Scarids) o acantúridos (Acanthurids). Por lo tanto, de igual manera a los ensamblajes de peces de arrecife, la complejidad topográfica debe ser muestreada a la escala apropiada para el o los organismos interesados. En la mayoría de los estudios, esta relación ha sido obviada. Una explicación para este descuido son las medidas de rugosidad *in situ*, tales medidas, como el método de cadena, son fácilmente realizadas en áreas pequeñas, sondeos de áreas lineales (en el orden de decenas de metros). Sin embargo, para áreas grandes, sondeos en áreas extensivas (en el orden de centenas de metros), son incómodos y menos factibles. Este trabajo introduce un método novedoso que utiliza la tecnología de percepción remota e instrumentación de GIS para ecología de paisajes para obtener la complejidad topográfica de arrecifes. El índice de rugosidad calculado en GIS a través de datos percibidos remotamente permite la comparación de la distribución de especies de peces de áreas de complejidades diferentes en múltiples escalas. Este método puede proveer nuevas perspectivas para entender el efecto de la rugosidad en la estructura y distribución de ensamblajes de peces de arrecife. Este trabajo también contribuirá al desarrollo de un modelo predictivo que podrá ser utilizado por manejadores de recursos para estimar la densidad de peces de una manera económica y exacta.

PALABRAS CLAVES: Rugosidad, GIS, complejidad topográfica, peces de arrecie y percepción remota

# Study of the Relationship Between Ocean Environmental Parameters and Pelagic King Mackerel Fish Resources

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Environmental parameters detected by NASA satellites are used to study habitat and to characterize the relationship between habitat and economically important pelagic fish resource, namely king mackerel (*Scomberomorus cavalla*). King mackerel spend much of their life in the surface mixed layer of coastal marine water and along a narrow range of ocean temperatures. Changes in the surface ocean should affect the fish distribution and apparent abundance. Analysis of physical parameters, such as ocean frontal boundaries (temperature, chlorophyll, turbidity) related to coastal plumes and Loop Current circulation are correlated with the mackerel catch data collected through a collaboration with fishermen during tournaments. Historic and real-time sea surface temperature and ocean color data are obtained from the AVHRR and MODIS sensors for waters off Tampa Bay, Florida where fish are caught. These data are combined with other oceanographic data (wind, thermocline depth) to define quantitative relationships between mackerel distribution and their ecosystem. ArcGIS™ and its geostatistical analyst extensions provide the necessary tools to map, interpret and statistically quantify fish and ecosystem relationships. Other oceanographic products useful for future climate-based ecosystem research will be studied and tested. Initial results show a higher percentage and quantity of fish caught in areas with baitfish than without. Mackerel are observed at an average surface temperature of 21.3°C with a standard deviation of ±1.36°C. The study will help understand critical habitat for oceanic pelagic fish and the factors that determine their abundance. Ultimately, conceptual models on the effects of ocean climate variability and anthropogenic pressures on ecosystem dynamics of king mackerel in coastal waters off Tampa Bay will be developed and will serve as the basis for future climate-based ecosystem research in other areas.

KEY WORDS: Environmental parameters, king mackerel, *Scomberomorus cavalla*,

# Un Estudio de la Relación entre Parámetros Ambientales del Océano y el Carite Lucio

Parametros ambientales obtenidos por satelites de NASA se utilizan para evaluar y caracterizar la relación que existe entre el ambiente marino y los recursos pesqueros, específicamente el pez carite lucio (*Scomberomorus cavalla*). El carite lucio pasa gran parte de su vida en la capa mixta superior de aguas costeras y entre un rango estrecho de temperaturas oceánicas. Cambios en la superficie oceánica pueden afectar la distribución de peces y su abundancia aparente. Análisis de parametros físicos tales como la frontera oceánica frontal (temperatura, clorofila, turbidez) relacionados a plumas costeras, y la circulación costera superficial fueron correlacionados con datos de captura del carite se colectaron gracias a la colaboración de pescadores durante torneos de pesca. Histórico y el mar de tiempo real la temperatura de superficie y los datos del color de océano se obtienen del AVHRR y sensores de MODIS para aguas de la Bahía de Tampa, la Florida donde pesca se agarra. Estos datos se combinaron con datos oceanográficos (e.g. viento, profundidad del termoclino) para determinar cuantitativamente la relación entre la distribución del carite y su ecosistema. El programa ArcGIS$^{TM}$ y sus componentes geoestadísticos proveen las herramientas cartográficas necesarias para interpretar y cuantificar estadísticamente la relación pez-ecosistema. Otros productos oceanográficos considerados útiles para investigaciones futuras de ecosistemas climáticos son evaluados. Resultados preliminares muestran un mayor porcentaje de pesca en areas donde se encuentra peces carnada que donde estos no existen. El carite lucio se observá a un SST promedio de 21.3°C con una desviación estándar de ±1.36°C. El estudio ayudará a entender el hábitat crítico para pez pelágico oceánico y los factores que determinan su abundancia. Últimamente, los modelos conceptuales en los efectos de la variabilidad del clima de océano y presiones de antropogénica en la dinámica de ecosistema de la caballa de rey en aguas costeras lejos Bahía de Tampa se desarrollarán y servirá como la base para la investigación clima-basado futura de ecosistema en otras áreas.

PALABRAS CLAVES: Parametros ambientales, carite lucio, *Scomberomorus cavalla*

# Development of Pedro Bank Management Project: Reducing Human Impact on Remote Coral Reef Cays, Jamaica

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Live coral cover has declined dramatically along Jamaica's coastline from over 50% in the late 1970s to some 5% in the 1990s. The WCMC estimates that 99% of reefs in Jamaica are at risk. Due to its remote offshore location and relative isolation, the Pedro Bank (approximately 30 miles southwest of Jamaica) is one of the country's few relatively healthy reef systems. However intensive fishing and high human densities are impacting the area and rigorous conservation measures are needed if Pedro Bank is to remain a viable and functioning ecosystem. The Pedro Bank project aims to minimize coral reef degradation by providing solutions to two main threats not currently addressed on the Bank - direct overfishing of resources and degradation of coral reefs and coral cays due to unsustainable development. We aim to minimize these threats by working hands-on with multiple stakeholders (e.g. fishermen) and those agencies responsible for regulating and protecting reef resources (Fisheries Division and NEPA (National Environmental and Planning Agency). The two main project objectives are:

i) To fill critical data gaps to inform effective conservation strategies, and
ii) to assist regulatory bodies with the management of the area.

The Fisheries Division has specifically requested assistance with (a) an evaluation of current biological and human conditions on the Cays and surrounding areas and (b) a plan to begin developing effective and practical management and zoning strategies for the Pedro Bank beginning with the Cays. The project is global in concept and utility; located in Jamaica's Pedro Bank, but with application to the Caribbean region and other coral reef and offshore submerged bank ecosystems worldwide. In addition, the improved management of this area may have a positive effect on regional fishery (particularly conch) resources because of the high degree of connectivity associated with the Caribbean current.

KEY WORDS: Pedro Bank, Jamaica, offshore submerged banks, biodiversity, overfishing, community-based conservation

# Desarrollo del Proyecto de Gerencia de Pedro Bank: Reducción del Impacto Humano en los Arrecifes de Coral de los Cayos Remotos, Jamaica

La cobertura del coral vivo ha disminuido dramáticamente a lo largo de la costa de Jamaica desde por encima del 50% a finales de los años 70 a alrededor del 5% en los años 90. La WCMC estima que el 99% de los arrecifes de Jamaica se encuentran en peligro. Debido a su localización alejada de la costa, Pedro Bank (unas 30 millas de Jamaica) es uno de los pocos sistemas de arrecifes sanos de todo el país. Sin embargo, la excesiva pesca y las altas densidades de población humana están impactando el área, y rigurosas medidas de conservación son necesarias si se quiere que Pedro Bank siga siendo un ecosistema viable.

El proyecto Pedro Bank se centra en minimizar la degradación de los arrecifes de coral mediante el tratamiento de dos de sus principales amenazas que actualmente no son tenidas en cuenta en el Banco – la sobre-pesca de recursos y la degradación de los arrecifes y los cayos de coral debido al desarrollo insostenible. Pretendemos minimizar esas amenazas trabajando con múltiples accionistas (p.e. pescadores) y aquellas agencias responsables de regular y proteger los recursos de los arrecifes (Fisheries Division) y NEPA (Agencia Nacional de Medioambiente y Planificación). Los dos principales objetivos del proyecto son:

i) Rellenar vacíos de datos críticos para informar de estrategias efectivas de conservación y
ii) Asistir a los individuos reguladores con la gerencia del área.

La Fisheries División ha solicitado específicamente asistencia con (a) una evaluación de las situaciones actuales biológicas y humanas en los Cayos y las zonas adyacentes y (b) un plan para comenzar a desarrollar estrategias efectivas y prácticas de gerencia y zonas para el Pedro Bank, empezando por los Cayos. El proyecto es global en concepto y utilidad con aplicación a la región caribeña y otros arrecifes de coral y bancos sumergidos en todo el mundo.

PALABRAS CLAVES: Pedro Bank, Jamaica, bancos sumergidos, biodiversidad, sobre-pesca, conservación communitaria, planificación para la conservación de áreas, caracol, aves marinas