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**Cover photo of this issue**: Captive leucistic freshwater stingray *Potamotrygon leopoldi* from breeders in The Netherlands. More details at: www.freshwaterstingray.nl. Picture taken by Patricia Charvet-Almeida.

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## Research articles

## Scientific Notes

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# Inventory of elasmobranch species caught in the Lagoon of Bizerte (North-eastern Tunisia, central Mediterranean)

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**Abstract.** Eight elasmobranch species were reported for the Lagoon of Bizerte, north-eastern Tunisia, central Mediterranean. These species were: *Torpedo marmorata*, *Torpedo torpedo*, *Dasyatis chrysonota*, *Dasyatis pastinaca*, *Dasyatis tortonesei*, *Gymnura altavela*, *Myliobatis aquila* and *Pteromylaeus bovinus*. General and local distribution of these eight species are discussed and commented while morphological and biological data are provided. Of the eight species reported, only one could represent a locally established population, the common torpedo *Torpedo torpedo*, as it was constant inhabitant of this brackish, even acomplishing developement and reporducing there. Two of the three dasyatid species occurring in the Lagoon of Bizerte, could be considered as relatively abundant, *Dasyatis chrysonota* and *D. pastinaca*, the third *D. tortonesei* being rare. Their occurrence could be related with the mussels abundance in the Lagoon of Bizerte, as well as oysters and several gastropod species which constitute their main food. Similar observations could also explain the presence of *Gymnura altavela*, *Myliobatis aquila* and *Pteromylaeus bovinus* in the area in question, which were, by contrast, rather rare.

**Key words.** Morphology and meristics, size-mass relationship, reproduction, migration, diet

**Resumen. Inventario de especies de elasmobranquios capturadas en la Laguna de Bizerte (Noreste de Túnez, Mediterráneo Central).** Ocho especies de elasmobranquios fueron reportadas para la Laguna de Bizerte, noreste de Túnez, Mediterráneo Central. Estas especies fueron: *Torpedo marmorata*, *Torpedo torpedo*, *Dasyatis chrysonota*, *Dasyatis pastinaca*, *Dasyatis tortonesei*, *Gymnura altavela*, *Myliobatis aquila y Pteromylaeus bovinus*. La distribución local y general de estas ocho especies es discutida y comentada y datos morfológicos y biológicos son dados. De las ocho especies citadas solamente una población localmente establecida, el torpedo común, *Torpedo torpedo*, pues constituyó un habitante permanente en este ambiente estuarino, completando además allí su desarrollo y reproduciéndose. Dos de las tres especies de dasyatídeos que ocurren en la Laguna de Bizerte, podrían se consideradas como relativamente abundante, *Dasyatis chrysonota* y *D. pastinaca*, la tercera, *D. tortonesei* siendo rara. La ocurrencia de estas especies podría estar relacionada con la abundancia de mejillones en la Laguna de Bizerte, así como de ostras y varias especies de gasterópodos que constituyen su principal alimento. Observaciones similares podrían también explicar la presencia de *Gymnura altavela*, *Myliobatis aquila* y *Pteromylaeus bovinus* en el área en cuestión, que son, a diferencia de las anteriores, muy raras.

**Palabras clave:** morfología y mirística, relación tamaño-peso, reproducción, migración, dieta.

## Introduction

Inventories concerning elasmobranch species in the Tunisian coast allowed to state that 62 species are known in the area (Quignard & Capapé 1971, 1972, Capapé 1989, Bradaï *et al.* 2002, 2004, Ben Souissi *et al.* 2007). Some of them were recorded in brackish areas such as the Bahiret El Biban, hyperhaline lagoon from southern Tunisia (Capapé *et al*. 2004) and, northward, in Tunis Southern Lagoon (Ben Souissi *et al.* 2005 a, b, Mejri *et al.* 2004).

Surveys recently conducted in the northern Lagoon of Bizerte allowed recording eight elasmobranch species which are reported in the present paper. An overview of the distribution and occurrence of these species in Tunisian waters and in the lagoon is presented. In addition, data such as morphology, morphometric measurements, meristic counts, and on reproductive biology are provided. The paper also aids to assess the real status of these eight elasmobranch species in the area, in order to prepare a regional national plan for elasmobranch conservation and management.

## Materials and Methods

*Description of the study area.* The Lagoon of Bizerte is a brackish water body located in north-eastern Tunisia, between 37°8’ and 37°14’ N, and between 9°46’ and 9°56’ E (Fig. 1). The Lagoon of Bizerte appears as an ellipse, 11 km width and 13 km long, covering 15 000 ha and it is connected to the Mediterranean Sea by an artificial navigation channel, 12 km long, 650 m width and 12 m depth maximum (Fig. 2). The average and maximum depth of the Lagoon of Bizerte are 7 m and 12 m rspectively the latter close to the navigation channel, with sandy, muddy or detritic bottoms, and by places seagrass meadows (Zaouali 1974). The Lagoon of Bizerte receives a freshwater imput from eight ‘wadi’ (river in Arabic), unfortunately containing pesticides and both inorganic and organic material. It also receives marine water that increases water salinity from 33 (Zaouali 1974) to 36.09 (Aïssa 1991).

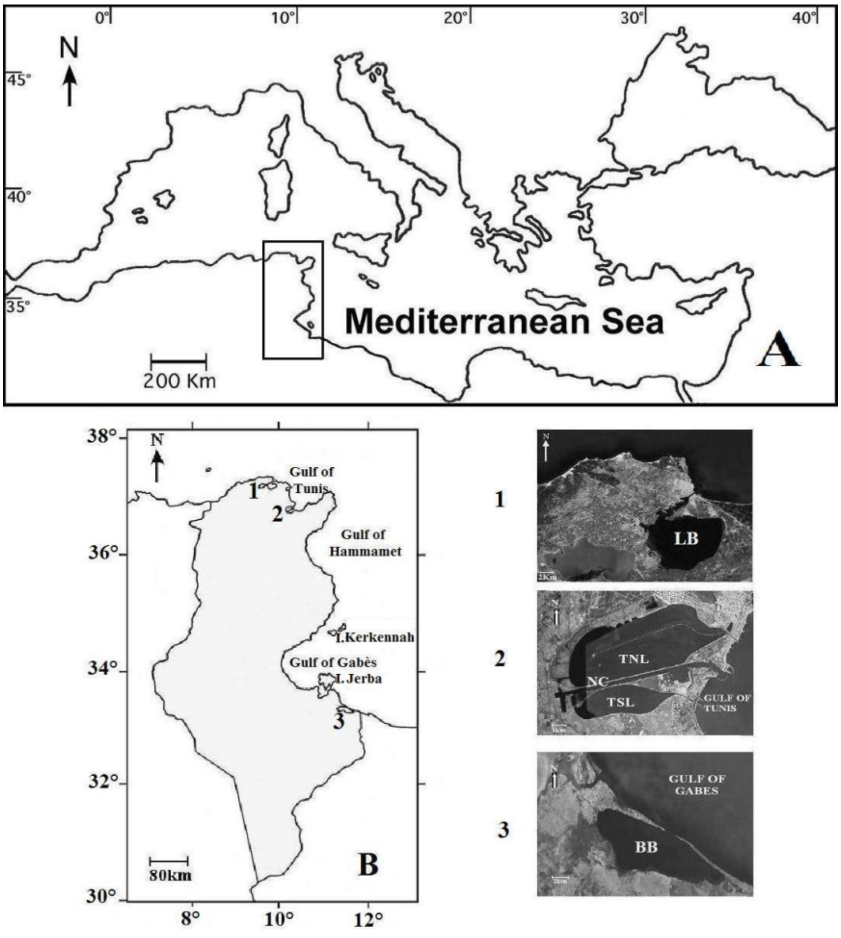

**Figure 1.** A. Map of the Mediterranean Sea showing Tunisia. B. Map of Tunisia showing the three main Tunisian lagoons. 1. Lagoon of Bizerte (LB). 2. Lagoon of Tunis divided in Tunis Northern Lagoon (TNL) and Tunis Southern Lagoon (TSL). 3. Bahiret El Biban (BB).

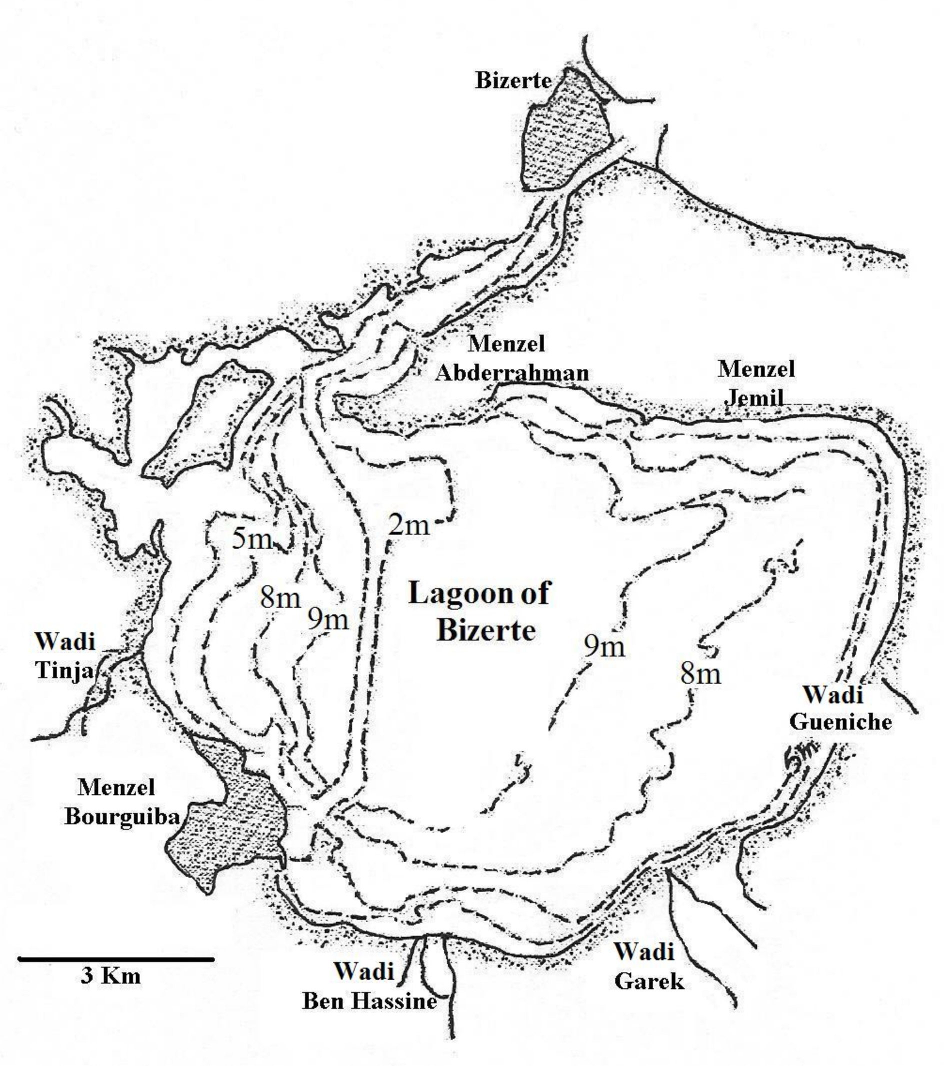

**Figure 2.** Map of the Lagoon of Bizerte.

*Local fisheries.* At least, thirty teleost species are known to be reported in the Lagoon of Bizerte (Harzallah 2003), among them syngnathid species, which found in the area favourable environmental conditions to develop and reproduce (Ben Amor *et al.* 2008). Additionally, the lagoon is commercially exploited by artisanal craft fisheries and oyster and mussel farms, landing fishery sites were at Menzel Abderrahman and Menzel Jemil (Aïssa 1991). Gastropods are collected in the area, such as the purple dye murex *Bolinus brandaris* (Linnaeus 1758) and the banded dye murex *Hexaplex trunculus* (Linnaeus 1758), both species, at present, exhibited development of imposex in females, a phenomenon linked to the use of organotin biocides, such as tributyltin, consequence of environmental pollution due to sea traffic (Lahbib *et al* 2004, Abidli *et al.* 2008). Bivalvs are also collected in the area such as the grooved carpet-shell clam *Ruditapes decussatus* (Linnaeus 1758) and the warty venus *Venus verrucosa* (Linaeus 1758) according to Trigui El Menif (1996, 2005). However, wild gastropods and bivalvs have low economical value.

*Sample collection.* Observations were made twice a week from January 2006 to November 2008. Identification of specimens were carried out using keys and field guides such as Tortonese (1956), Bini (1967), Fischer *et al.* (1987), and McEachran & Capapé (1984 a, b, c). Measurements were recorded to the nearest millimetre while total mass (TM) to the nearest gram. Total length (TL) was only considered in both torpedinid species as measurement of reference, while disc witdh (DW) was only used for the six other batoid species following Clark (1926).

*Data analysis.* In all species, for both male and female specimens, two maturity categories were considered: juvenile and adult. Reproductive condition in males was made by examination of claspers, following Collenot (1969), while some aspects of the testes and other reproductive organs are given following Hamlett *et al.* (1999), and Capapé *et al.* (2004). In juveniles, claspers were flexible, uncalcified and shorter than pelvic fins, while testes and genital ducts were unconspicuous, membranous and slightly developed. In adults, claspers were rigid, calcified larger than pelvic fins, while the testes were well-developed and exhibited spermatocysts externally visible. The genital duct was twisted and sperm was visible in the seminal vesicles. Size at sexual maturity was determined in females from the condition of ovaries, the reproductive tract morphology and the mass of oviducal glands (see Capapé *et al.* 2004, Callard *et al.* 2005). The juvenile females had whitish and undeveloped ovaries, thread-like oviducts and inconspicuous oviducal glands. The adult females exhibited ovaries containing batches of yolky oocytes and exhibited fully developed genital ducts. The oviducal glands were conspicuously rounded and the mass considerably increased in adults. In dasyatid species, a single uterus, the right one, was functional. The observed sample is presented including number of males and females, and for both sexes number of juveniles and adults. Both size and mass ranges are provided and when possible the relation size *versus* total mass is calculated. A morphological, meristic and morphometric description for all the species is given, following Golani & Capapé (2004) and Mejri *et al.* (2004).For each species, a subsample was preserved in 5% buffered formaline and deposited in the Ichthyological Collection of the Faculté des Sciences of Bizerte. The preserved specimens received catalogue numbers which are given in Tables I to VIII. Tests for significance ($p < 0.05$) were performed using ANOVA and chi-square test. The relationship between total length (TL) or disc width (DW) and total mass (TM) was calculated; such relationship being useful as an indication of species for condition or for stock assessment (Petrakis & Stergiou 1995, Froese 2006). Comparisons of curves were carried out by ANCOVA. The linear regression was expressed in decimal logarithmic coordinates. Correlations were assessed by least-squares regression.

## Results an Discussion

### Family Torpedinidae

*Marbled electric ray,* ***Torpedo marmorata*** *Risso 1810.* *Torpedo marmorata* is reported in the eastern Atlantic from off Scandinavia (Kattegat, Skagerrak) according to Muus & Dahlstrøm (1964-1966), off British Isles (Wheeler 1969), France (Quéro *et al.* 2003), Spain (Ortea & De La Hoz 1979) and Portugal (Albuquerque1954-1956). South Strait of Gibraltar, the species was reported off Morocco (Collignon & Aloncle 1972), Mauritania (Maurin & Bonnet 1970), it was frequently caught off Senegal according to Capapé *et al.* (2001), and occurred southward in the Gulf of Guinea (Blache *et al.* 1970) and in South Africa waters (Smith & Heemstra 1986). This species is also known throughout the Mediterranean Sea, in both western and eastern basins (Quignard & Tomasini 2000), occurring in the eastern Levant Basin (Golani 2005). However, the species seems to be more abundantly caught from northern areas of the western Mediterranean basin (Capapé, 1989). *Torpedo marmorata* also occurs off the Algerian coast (Dieuzeide *et al.* 1953, Hemida pers. comm.) and throughout the Tunisian coast (Capapé 1979, Bradaï *et al.* 2004). The species was first recorded by Le Danois (1925), then Quignard and Capapé (1971) considered the species more frequent in northern areas, these observations were furtherly confirmed by Capapé (1979) and Bradaï *et al.* (2004).

*Torpedo marmorata* was recorded for the first time in a Tunisian brackish area, Tunis Southern Lagoon by Mejri *et al.* (2004), in contrast, it was not recorded southward in the Bahiret El Biban (Capapé *et al.* 2004). All *T. marmorata* collected for this study were caught in the north-western region of the Lagoon of Bizerte, and represented the first record to date in the area (Fig. 3). Of the 16 electric marble rays examined, 7 were males ranging in size between 160 and 320 mm TL, and weighing between 122 and 430 g TM, whereas 9 were females ranging in size between 290 and 610 mm TL, and weighing between 163 and 2020 g TM. Females slightly outnumbered males, but the overall sex ratio was not significantly different from 1:1 ($\chi 2 = 0.98$, $p< 0.05$, df = 1). Of the 9 females collected 4 were juveniles and 5 adults, while for the 7 males collected 5 were juveniles and 2 were adults.

Females were larger and heavier than the males. Similar patterns were observed for *T. marmorata* from the Bay of Biscay (Mellinger 1971), off Tunisian coast (Capapé 1979), coast of Senegal (Capapé *et al.* 2001) and off Italian coast (Consalvo *et al.* 2007). The female found in the Lagoon of Bizerte (610 mm TL) is the largest electric marbled ray recorded in Tunisian waters. Mellinger (1971), Capapé *et al.* (2001), Consalvo *et al.* (2007) reported 630 mm, 580 mm TL and 553 mm in females from the Bay of Biscay, the coast of Senegal and the coast of Italy, respectively.

The relationship between total length TL and TM, plotted in Figure 4, showed significant difference between males and females (F = 169.68, p < 0.001, df = 1). The relationships were for the males: log TM = 3.09 log TL - 5.05; r = 0.98; n = 7, and for the females: log TM = 2.80 log TL - 4.33; r = 0.97; n = 9.

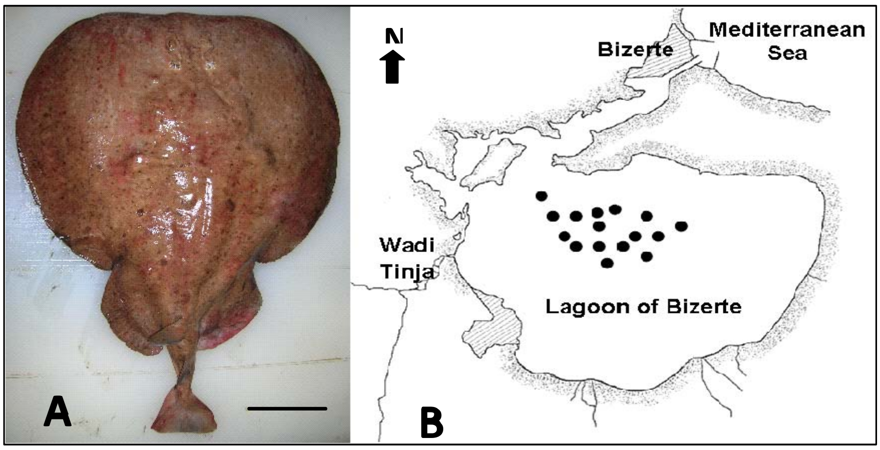

**Figure 3.** Specimen of *Torpedo marmorata* captured in the Lagoon of Bizerte, scale bar = 100 mm. B. Map of Lagoon of Bizerte showing the capture sites (black circles) of *Torpedo marmorata.*

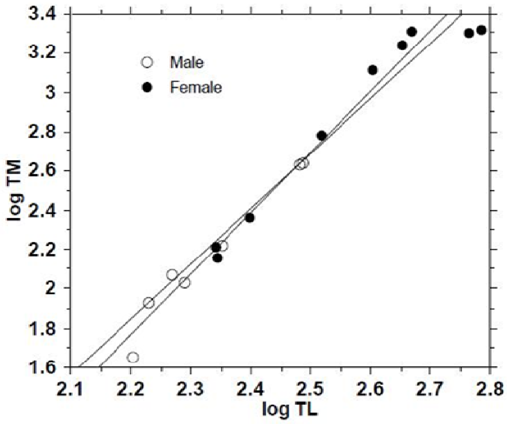

**Figure 4.** Relationship between total length (TL) and total mass (TM), expressed in decimal logarithmic coordinates, in *Torpedo marmorata* from the Lagoon of Bizerte.

Measurements were carried out on two specimens and are presented in Table I. Identification was made by skin entirely smooth, in both dorsal and ventral surfaces; disc rather rounded and sub-circular, snout short, subtruncate; pelvic fins quite separate from pectoral fins, subtruncate at distal end; tail distinct with two dorsal fins and caudal fin well-developed; spiracle with seven tentacles, one tentacle on posterior margin being the largest. Disc-width 63-68 %, disc-length 56-58 %, disc-depth 2-3 %, pre-oral length 9-11 %, pelvic span 35-36 %, pelvic fin anterior margin 10-11%, caudal careen 11-15 % all in total length. Dorsal surface uniform brownish with dark notches; belly beige with margin slightly brownish. Morphology, measurements and colouration are in agreement with those of Dieuzeide *et al.* (1953), Tortonese (1956), Bini (1967), Cadenat *et al.* (1978) and Mejri *et al.* (2004).

*Common torpedo,* ***Torpedo torpedo*** *(Linnaeus 1758).* *Torpedo torpedo* is known to occur in the eastern Atlantic from the Bay of Biscay (Quéro *et al* 2003), off Spain (Ortea & De La Hoz 1979) to Portugal (Albuquerque 1954-1956). In South Strait of Gibraltar, *T. torpedo* was reported off Morocco (Collignon & Aloncle 1972), Mauritania (Maurin & Bonnet 1970), off Senegal where it is the most abundant torpedinid species according to Capapé *et al.* (2000). Southward the common torpedo was reported off Guinea-Bissau (Sanchès 1991), in the Gulf of Guinea (Blache *et al.* 1970), and, probably, to South Africa waters (Smith & Heemstra 1986).

The species also occurs throughout the Mediterranean Sea, being more frequently caught in southern areas (Capapé 1989), especially off the Maghreb coast (Dieuzeide *et al* 1953, Capapé 1989, Bradaï *et al.* 2004). The common torpedo was also recorded in Tunisian brackish areas such as the Bahiret El Biban (Capapé *et al.* 2004) and Tunis Southern Lagoon (Mejri *et al.* 2004). *Torpedo torpedo* is frequently captured in the Bahiret El Biban where probably a sustainable population develop and reproduce. It is relatively less abundant in Tunis Southern lagoon which recently was the focus of an environmental restoration (Ben Souissi *et al.* 2005 b), records were recently reported in the area.

**Table I.** Measurements carried out in two specimens of *Torpedo marmorata* captured in the Lagoon of Bizerte.

| **References** | **FSB Tor-mar.01** | | **FSB Tor-mar.02** | |
|---|---|---|---|---|
| **Sex** | Female | | Male | |
| **Total mass (g)** | 205 | | 231 | |
| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
| Total lenth (TOT) | 580 | 100.00 | 250 | 100.00 |
| Disc-length | 335 | 57.76 | 140 | 56.00 |
| Disc-width | 370 | 63.79 | 168 | 67.20 |
| Disc-depth | 69 | 11.90 | 18 | 7.20 |
| Eyeball lenth | 12 | 2.07 | 8 | 3.20 |
| Cornea | 7 | 1.21 | 4 | 1.60 |
| Pre-orbital length | 40 | 6.90 | 21 | 8.40 |
| Inter-orbital width | 29 | 5.00 | 11 | 4.40 |
| Nasal curtain | 26 | 4.48 | 12 | 4.80 |
| Spiracle diameter | 8 | 1,38 | 3 | 1.20 |
| Inter-nasal width | 24 | 4,14 | 12 | 4.80 |
| Space between eye and spiracle | 19 | 3.28 | 10 | 4.00 |
| Inter-spiracular width | 26 | 4.48 | 12 | 4.80 |
| Pre-oral length | 55 | 9.48 | 27 | 10.80 |
| Mouth width | 37 | 6.38 | 16 | 6.40 |
| First gill slit | 16 | 2.76 | 6 | 2.40 |
| Second gill slit | 17 | 2.93 | 7 | 2.80 |
| Third gill slit | 19 | 3.28 | 7 | 2.80 |
| Fourth gill slit | 18 | 3.10 | 4 | 1.60 |
| Fifth gill slit | 13 | 2.24 | 4 | 1.60 |
| Width between first gill slit | 86 | 14.83 | 36 | 14.40 |
| Width between fifth gill slit | 88 | 15.17 | 33 | 13.20 |
| Snout tip to eye | 42 | 7.24 | 24 | 9.60 |
| Snout tip to mouth | 45 | 7.76 | 26 | 10.40 |
| Snout tip to first gill slit | 120 | 20.69 | 61 | 24.40 |
| Snout tip to fifth gill slit | 195 | 33.62 | 84 | 33.60 |
| Snout tip pelvic fin | 330 | 56.90 | 135 | 54.00 |
| Snout tip to vent | 352 | 60.69 | 150 | 60.00 |
| Pectoral fin posterior | 140 | 24.14 | 56 | 22.40 |
| Pectoral fin posterior margin | 220 | 37.93 | 90 | 36.00 |
| Pectoral fin inner margin | 17 | 2.93 | 8 | 3.20 |
| Pelvic fin anterior margin | 64 | 11.03 | 26 | 10.40 |
| Pelvic fin posterior margin | 110 | 18.97 | 42 | 16.80 |
| Pelvic fin inner margin | 26 | 4.48 | 10 | 4.00 |
| Span of pelvic fins | 205 | 35.34 | 88 | 35.20 |
| Tail base width | 36 | 6.21 | 18 | 7.20 |
| Tail base depth | 27 | 4.66 | 12 | 4.80 |
| Tail length | 184 | 31.72 | 80 | 32.00 |
| Snout tip to first dorsal | 394 | 67.93 | 163 | 65.20 |
| Snout tip to second dorsal | 450 | 77.59 | 188 | 75.20 |
| Snout tip to birth of dorsal caudal | 507 | 87.41 | 209 | 83.60 |
| Snout tip to birth of ventral caudal | 497 | 85.69 | 207 | 82.80 |
| Caudal superior edge | 76 | 13.10 | 39 | 15.60 |
| Caudal inferior edge | 94 | 16.21 | 33 | 13.20 |
| Caudal posterior edge | 58 | 10.00 | 46 | 18.40 |
| First dorsal anterior edge | 64 | 11.03 | 26 | 10.40 |

**Table I.** Measurements carried out in two specimens of *Torpedo marmorata* captured in the Lagoon of Bizerte (continued).

| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
|---|---|---|---|---|
| First dorsal posterior edge | 32 | 5.52 | 15 | 6.00 |
| First dorsal inner edge | 10 | 1.72 | 9 | 3.60 |
| First dorsal base | 30 | 5.17 | 12 | 4.80 |
| Second dorsal anterior edge | 50 | 8.62 | 22 | 8.80 |
| Second dorsal posterior edge | 25 | 4.31 | 12 | 4.80 |
| Second dorsal inner edge | 11 | 1.90 | 7 | 2.80 |
| Second base | 24 | 4.14 | 10 | 4.00 |
| Inter-dorsal distance | 19 | 3.28 | 9 | 3.60 |
| Second dorsal to caudal birth | 27 | 4.66 | 10 | 4.00 |
| Caudal careen | 87 | 15.00 | 29 | 11.60 |
| Clasper | - | - | 57 | 22.80 |

A total of 443 specimens were collected in the central region of the Lagoon of Bizerte (Fig. 5), 218 were males and ranged between 145 and 403 mm TL and between 50 and 522 g; 225 were females and ragned between 139 and 435 mm TL and between 48 and 722 g. The relationship between TL and TM, plotted in Figure 6, showed significant difference between males and females (F = 359.38, p < 0.001, df = 1). The relationships were for males: log TM = 2.39 log TL – 3.39; r = 0.92; n = 218, and for females log TM = 2.63 log TL – 3.94; r = 0.95; n = 225.

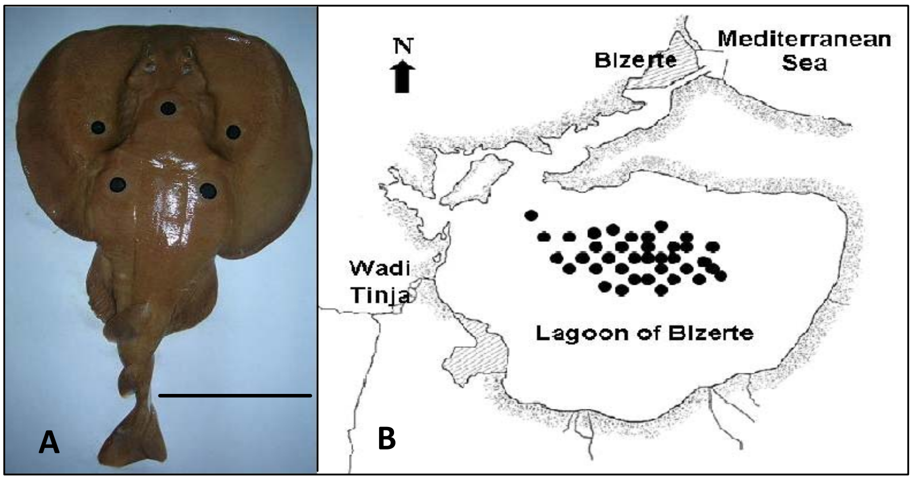

**Figure 5.** A. Specimen of *Torpedo torpedo* captured in the Lagoon of Bizerte, scale bar = 100 mm. B. Map of Lagoon of Bizerte showing the capture sites (black circles) of *Torpedo torpedo*.

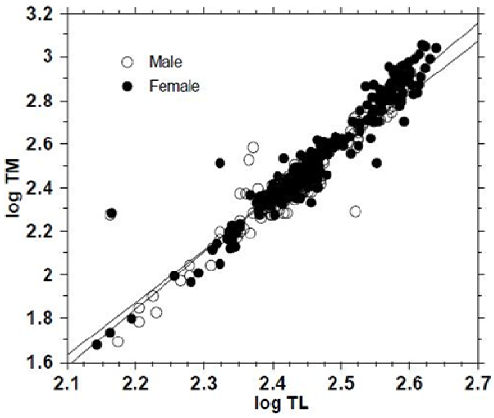

**Figure 6.** Relationship between total length (TL) and total mass (TM), expressed in decimal logarithmic coordinates, in *Torpedo torpedo* from the Lagoon of Bizerte.

**Table II.** Measurements carried out in two specimens of *Torpedo torpedo* captured in the Lagoon of Bizerte.

| **References** | **FSB T-torp.04** | | **FSB T-torp.02** | |
|---|---|---|---|---|
| **Sex** | Female | | Male | |
| **Total mass (g)** | 261 | | 252 | |
| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
| Total lenth (TOT) | 260 | 100.00 | 261 | 100.00 |
| Disc-length | 125 | 48.08 | 127 | 48.66 |
| Disc-width | 155 | 59.62 | 171 | 65.52 |
| Disc-depth | 22 | 8.46 | 26 | 9.96 |
| Eyeball length | 7 | 2.69 | 7 | 2.68 |
| Cornea | 4 | 1.54 | 3 | 1.15 |
| Pre-orbital length | 17 | 6.54 | 19 | 7.28 |
| Inter-orbital width | 13 | 5.00 | 14 | 5.36 |
| Nasal curtain | 14 | 5.38 | 15 | 5.75 |
| Spiracle diameter | 4 | 1.54 | 5 | 1.92 |
| Inter-nasal width | 12 | 4.62 | 14 | 5.36 |
| Space between eye and spiracle | 7 | 2.69 | 4 | 1.53 |
| Inter-spiracular width | 12 | 4.62 | 14 | 5.36 |
| Pre-oral length | 14 | 5.38 | 13 | 4.98 |
| Mouth width | 18 | 6.92 | 18 | 6.90 |
| First gill slit | 5 | 1.92 | 5 | 1.92 |
| Second gill slit | 4 | 1.54 | 7 | 2.68 |
| Third gill slit | 5 | 1.92 | 6 | 2.30 |
| Fourth gill slit | 5 | 1.92 | 5 | 1.92 |
| Fifth gill slit | 4 | 1.54 | 4 | 1.53 |
| Width between first gill slit | 35 | 13.46 | 37 | 14.18 |
| Width between fifth gill slit | 33 | 12.69 | 36 | 13.79 |
| Snout tip to eye | 20 | 7.69 | 22 | 8.43 |
| Snout tip to mouth | 22 | 8.46 | 24 | 9.20 |
| Snout tip to first gill slit | 50 | 19.23 | 54 | 20.69 |
| Snout tip to fifth gill slit | 75 | 28.85 | 82 | 31.42 |
| Snout tip pelvic fin | 120 | 46.15 | 124 | 47.51 |
| Snout tip to vent | 135 | 51.92 | 142 | 54.41 |
| Pectoral fin posterior | 52 | 20.00 | 59 | 22.61 |
| Pectoral fin posterior margin | 80 | 30.77 | 90 | 34,52 |
| Pectoral fin inner margin | 9 | 3.46 | 9 | 3.45 |
| Pelvic fin anterior margin | 30 | 11.54 | 34 | 13.03 |
| Pelvic fin posterior margin | 56 | 21.54 | 30 | 11.49 |
| Pelvic fin inner margin | 12 | 4.62 | 4 | 1.53 |
| Span of pelvic fins | 79 | 30.38 | 79 | 30.27 |
| Tail base width | 55 | 21.15 | 51 | 19.54 |
| Tail base depth | 18 | 6.92 | 15 | 5.75 |
| Tail length | 141 | 54.23 | 136 | 52.11 |
| Snout tip to first dorsal | 160 | 61.54 | 160 | 61.30 |
| Snout tip to second dorsal | 190 | 73.08 | 190 | 72.80 |
| Snout tip to birth of dorsal caudal | 216 | 83.08 | 218 | 83.52 |
| Snout tip to birth of ventral caudal | 210 | 80.77 | 214 | 81.99 |
| Caudal superior edge | 40 | 15.38 | 42 | 16.09 |
| Caudal inferior edge | 31 | 11.92 | 38 | 14.56 |
| Caudal posterior edge | 39 | 15.00 | 42 | 16.09 |
| First dorsal anterior edge | 32 | 12.31 | 32 | 12.26 |

**Table II.** Measurements carried out in two specimens of *Torpedo torpedo* captured in the Lagoon of Bizerte (continued).

| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
|---|---|---|---|---|
| First dorsal posterior edge | 20 | 7.69 | 23 | 8.81 |
| First dorsal inner edge | 2 | 0.77 | 3 | 1.15 |
| First dorsal base | 17 | 6.54 | 19 | 7.28 |
| Second dorsal anterior edge | 24 | 9.23 | 26 | 9.96 |
| Second dorsal posterior edge | 14 | 5.38 | 20 | 7.66 |
| Second dorsal inner edge | 2 | 0.77 | 2 | 0.77 |
| Second base | 12 | 4.62 | 13 | 4.98 |
| Inter-dorsal distance | 12 | 4.62 | 13 | 4.98 |
| Second dorsal to caudal birth | 13 | 5.00 | 14 | 5.36 |
| Caudal careen | 44 | 16.92 | 44 | 16.86 |
| Clasper | - | - | 51 | 19.47 |

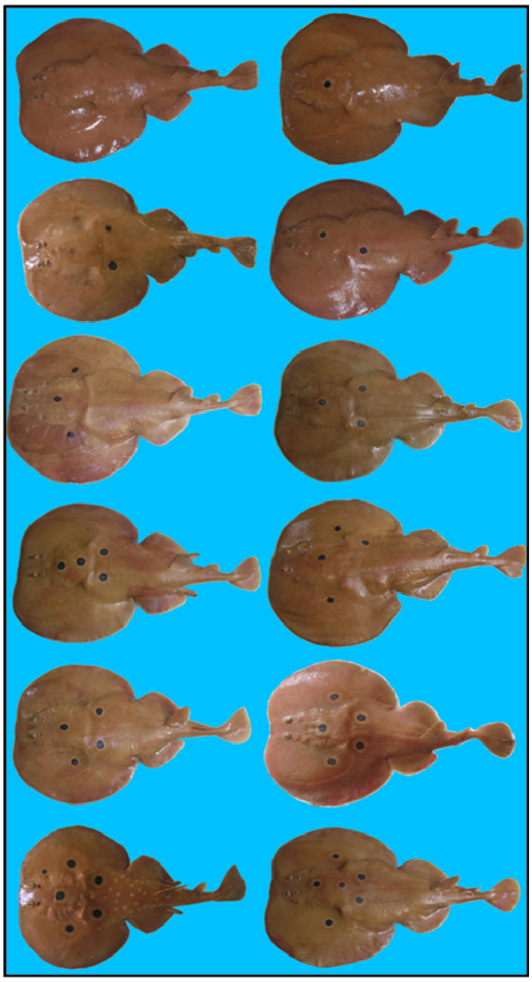

**Figure 7.** Specimen of *Torpedo torpedo* captured in the Lagoon of Bizerte, with different numbers of ocellae, from 0 to 6, on the dorsal surface.

Of the 218 males collected, 141 were juveniles and 77 adults, while of the 225 females collected, 77 were juveniles and 148 adults. Female adults significantly outnumbered male adults ($\chi 2$ = 22, p > 0.05, df = 1). Of the 148 female adults, 69 were pregnant. Additionally, the sample included 9 neonates.

The largest juvenile male was 263 mm TL and weighed 249 g TM, while the largest juvenile female was 275 mm TL and weighed 329 g TM. Sexual dimorphism in size and mass was observed, females being larger than males in *T. torpedo* from the Lagoon of Biban, such as in specimens from other Tunisian marine areas, the Gulf of Tunis (Quignard & Capapé 1974), the Gulf of Gabès (Ennajar *et al.* 2002), and elsewhere off Italian coast (Consalvo *et al.* 2007) and coast of Senegal (Capapé *et al.* 2000). Specimens of *T. torpedo* from the Lagoon of Bizerte were larger than those from other Tunisian marine areas. Quignard & Capapé (1974) noted that the largest male and the largest female recorded in the Gulf of Tunis were 390 mm and 410 mm TL respectively, while in the Gulf of Gabès, Ennajar *et al.* (2002) recorded 365 mm for males and 410 mm TL for females, respectively. Conversely,, larger sizes were observed by Consalvo *et al.* (2007), for common torpedo from the Italian coast, with records of 445 mm and 477 mm TL for males and females respectively, and by Capapé *et al.* (2000) for specimens from off the coast of Senegal, males and females reaching 445 mm and 550 mm TL respectively.

Measurements carried out on two specimens are presented in Table II. General morphology was similar to that described for *T. marmorata*, however the posterior tip of pelvic fin before second dorsal fin origin, spiracle with short tentacles or knobs. Disc-width 59-66 %, disc-length 48-49 %, disc-depth 8-9 %, pre-oral length 4-5 %, pelvic span 31 %, pelvic fin anterior margin 11-14%, caudal careen 17 % all in total length. These percents are generally used in systematics of torpdinids and should not be deleted, even if they do not appear in Table II, following Golani & Capapé (2004) and Mejri *et al* (2004). Other characteristics:

dorsal surface uniform brownish with whitish notches and five blue centred ocellae with yellowish margin, number of ocellae ranged from 0 to 6 in some specimens (Fig. 7); Capapé & Desoutter (1981) found 7 and 8 ocellae in specimens from the Gulf of Tunis, and Capapé *et al.* (2006b) described a specimen from the Languedocian coast (southern France) having 9 ocellae; belly beige with margin slightly brownish. Morphology, measurements and colour are in agreement with Dieuzeide *et al.* (1953), Tortonese (1956), Bini (1967), Quignard & Capapé (1974), Capapé & Desoutter (1981) and Mejri *et al.* (2004).

## Family Dasyatidae

*Blue stingray,* ***Dasyatis chrysonota*** *(Smith 1828). Dasyatis chrysonota* was previously considered as a synonym of the common stingray *D. pastinaca* (Linnaeus 1758), rather known in the north eastern Atlantic and in the Mediterranean (Ebert & Cowley 2008) and re-evaluated by Cowley & Compagno (1993). The blue stingray's preference for warm waters is evident from its geographic distribution (Capapé & Zaouali 1995). *Dasyatis chrysonota* is found in the eastern Atlantic southward of the Strait of Gibraltar. It was reported off Mauritania (Maurin & Bonnet 1970), Senegal (Capapé *et al.* 1995), Gulf of Guinea (Fowler 1936), Angola (Krefft 1968) to South Africa (Cowley & Compagno 1993). In the Mediterranean, the blue stingray was previously known to be only caught in the Gulf of Gabès, in southern Tunisia (Maurin & Bonnet 1970, Capapé & Zaouali 1995). More recently Golani & Capapé (2004) reported records of the species off the Mediterranean coast of Israel. With special regard to Tunisian waters, *D. chrysonota* was abundantly recorded in the Bahiret El Biban and in the close Gulf of Gabès where it developed and reproduced (Capapé & Zaouali 1995). In contrast, it was not recorded northward in Tunis Southern Lagoon, for instance. Consequently, the records of *D. chrysonota* in the central region Lagoon of Bizerte constitute its northernmost distributional range, not only for the Tunisian waters (Fig. 8), but also for the Mediterranean Sea.

Of the 12 specimens recorded in the area, 6 were males and 6 females, with sex ratio (M:F) being 1:1. Males ranged between 183 and 395 mm DW and weighed between 162 and 2600 g TM, while females ranged between 156 and 605 mm DW and weighed between 605 and 12,000 g TM. The largest juvenile male was 270 mm DW and 682 g TM, while the largest juvenile female was 305 mm DW and 966 g TM. The relationship between DW and TM, plotted in Figure 9, showed significant difference between males and females ($F = 865.31$, $p < 0.001$, $df = 1$). The relationships were for males: $\log TM = 3.38 \log DW - 5.41$; $r = 0.99$; $n = 6$, and for females $\log TM = 3.26 \log DW - 5.05$; $r = 0.99$; $n = 6$.

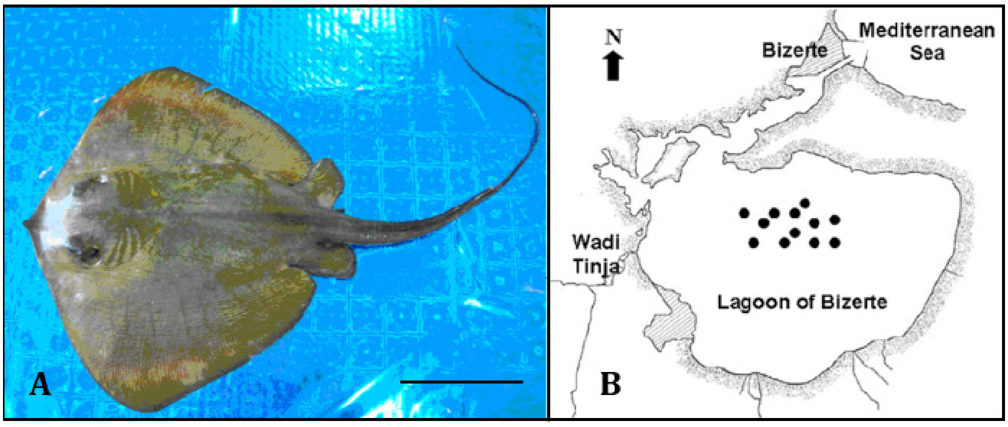

**Figure 8.** A. Specimen of *Dasyatis chrysonota* captured in the Lagoon of Bizerte, scale bar = 100 mm. B. Map of Lagoon of Bizerte showing the capture sites (black circles) of *Dasyatis chrysonota*.

Data were not enough to provide an estimation of size at sexual maturity in *D. chrysonota* from the Lagoon of Bizerte. Capapé & Zaouali (1995) noted that size at sexual maturity occurred for males and for females at about 300 mm and 320 mm DW, respectively, while the largest male and the largest female were 400 mm and 440 mm DW, respectively, from specimens collected in southern Tunisian waters. Off South African waters, Wallace (1967) reported that size at maturity occurred at 450 mm and 584 mm for males and females respectively. Ebert & Cowley (2008) noted that size at maturity occurred between 392 and 395 mm DW for males and between 500 and 505 mm for females, with maximum DW 531 mm (female) and 711 mm (male). In all areas, the females matured at a larger size than the males and reached larger maximum sizes. However, the specimens from Tunisian waters were clearly smaller than those from South African waters. Size at birth occurred at about 118 mm DW and 178 mm DW in Tunisian and South African waters respectively. The smaller free-swimming specimen found in the Lagoon of Bizerte was 156 mm DW.

Measurements were carried out on two specimens and presented in Table III and describe as follows: disc rhomboid with anterior margins slightly convex at level of eyes while the posterior margins rather straight posteriorly. Snout pointed. Pelvic fins quadrangular and with rounded outer corner. Tail slender and slightly depressed dorso-ventrally. Dorsal and ventral surface of the tail with fold posterior to the sting but not extending to the end of the tail. Dorsal fold of tail higher than ventral fold. Disc-depth 15%- 18.0%, disc-length 82-86.6%, preoral length 15.0-18%, pelvic span 40.0-48.0%, pelvic fin anterior margin 17.5-17.8 %, all of disc-width. Mouth slightly arched, skin flap on upper jaws with 24 oral papillae. Five elongated papillae, three central and a single papilla on both sides. Dorsal surface beige along the margin of the pectoral fin and toward the snout; pelvic fins also beige. Slightly darker between the eyes, along the center of the body and the length of the tail. Irregularly shaped, gray to slate blue blotches, some interconnected, bordered by a thin dark, flint gray margin, that spread along the central part of the back, from between the eyes to just before the beginning of the tail. Caudal sting beige. Belly off-white to beige. Ventral surface uniformly whitish to beige with margin grey to slightly brownish at tip of snout. Morphology, measurements and colour are in agreement with Cowley & Compagno (1993) and Golani & Capapé (2004).

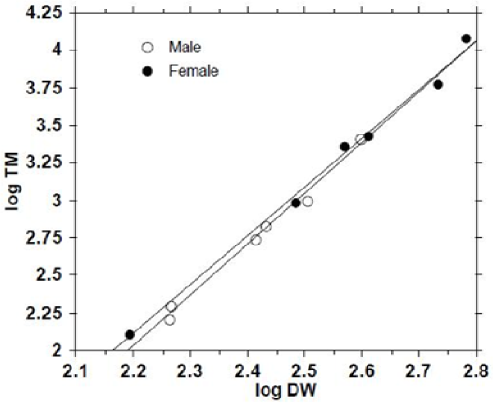

**Figure 9.** Relationship between total length (TL) and total mass (TM), expressed in decimal logarithmic coordinates, in *Dasyatis chrysonota* from the Lagoon of Bizerte.

**Table III.** Measurements carried out in two specimens of *Dasyatis chrysonota* captured in the Lagoon of Bizerte.

| **References** | **FSB D-chry 01** | | **FSB D-chry 02** | |
|---|---|---|---|---|
| **Sex** | Male | | Female | |
| **Total mass(g)** | 552 | | 2288 | |
| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
| Total length | 475 | 182.69 | 688 | 185.44 |
| Disc-length | 215 | 82.69 | 321 | 86.52 |
| Disc-width | 260 | 100.00 | 371 | 100.00 |
| Disc-depth | 39 | 15.00 | 65 | 17.52 |
| Eyeball width | 11 | 4.23 | 17 | 4.58 |
| Cornea | 11 | 4.23 | 15 | 4.04 |
| Pre-orbital length | 45 | 17.31 | 52 | 14.02 |
| Inter-orbital width | 26 | 10.00 | 48 | 12.94 |
| Spiracle length | 18 | 6.92 | 30 | 8.09 |
| Spiracle width | 13 | 5.00 | 20 | 5.39 |
| Inter-nasal width | 25 | 9.62 | 37 | 9.97 |
| Nasal curtain | 25 | 9.62 | 43 | 11.59 |
| Interspiracular width | 39 | 15.00 | 66 | 17.79 |
| Pre-oral length | 48 | 18.46 | 52 | 14.02 |
| Mouth width | 21 | 8.08 | 35 | 9.43 |

**Table III.** Measurements carried out in two specimens of *Dasyatis chrysonota* captured in the Lagoon of Bizerte (continued).

| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
|---|---|---|---|---|
| First gill slit | 10 | 3.85 | 15 | 4.04 |
| Second gill slit | 11 | 4.23 | 16 | 4.31 |
| Third gill slit | 11 | 4.23 | 15 | 4.04 |
| Fourth gill slit | 10 | 3.85 | 14 | 3.77 |
| Fifth gill slit | 8 | 3.08 | 11 | 2.96 |
| Width between first gill slit | 51 | 19.62 | 85 | 22.91 |
| Width between fifth gill slit | 33 | 12.69 | 52 | 14.02 |
| Snout tip to eye | 51 | 19.62 | 67 | 18.06 |
| Snout tip to mouth | 50 | 19.23 | 59 | 15.90 |
| Snout tip to fist gill slit | 72 | 27.69 | 88 | 23.72 |
| Snout tip to fifth gill slit | 105 | 40.38 | 141 | 38.01 |
| Snout tip to pelvic fin | 180 | 69.23 | 270 | 72.78 |
| Snout tip to sting | 285 | 109.62 | 437 | 117.79 |
| Sting length 1 | 62 | 23.85 | 125 | 33.69 |
| Sting length 2 | 10 | 3.85 | 119 | 32.08 |
| Snout tip to vent | 187 | 71.92 | 280 | 75.47 |
| Pectoral fin anterior margin | 170 | 65.38 | 239 | 64.42 |
| Pectoral fin posterior margin | 149 | 57.31 | 242 | 65.23 |
| Pectoral fin inner margin | 29 | 11.15 | 39 | 10.51 |
| Pelvic fin anterior margin | 45 | 17.31 | 60 | 16.17 |
| Pelvic fin posterior margin | 29 | 11.15 | 77 | 20.75 |
| Pelvic fin inner margin | 27 | 10.38 | 23 | 6.20 |
| Pelvic fin base | 34 | 13.08 | 60 | 16.17 |
| Span of pelvic fin | 107 | 41.15 | 177 | 47.71 |
| Clasper length | 44 | 16.92 | - | - |
| Tail base width | 22.3 | 8.58 | 35 | 9.43 |
| Tail base depth | 14 | 5.38 | 20 | 5.39 |
| Tail length | 277 | 106.54 | 390 | 105.12 |
| Ventral tail fold length | 185 | 71.15 | 265 | 71.43 |
| Dorsal tail fold length | 24 | 9.23 | 40 | 10.78 |

*Common stingray,* ***Dasyatis pastinaca*** *(Linnaeus, 1758). Dasyatis pastinaca* is known in the eastern Atlantic from off southern Norway according to Muus & Dahlstrøm (1964-1966), off British Isles (Wheeler 1969), France (Quéro *et al.* 2003), Spain (Ortea & De La Hoz 1979) and Portugal (Albuquerque 1954-1956). South Strait of Gibraltar, the species was reported off Morocco (Collignon & Aloncle 1972) and Mauritania (Maurin & Bonnet 1970). Southward, the occurrence of *D. pastinaca* is doubtful, because it was probably confused with the close relative blue stingray, *D. chrysonota* (Smith 1828). The occurrence of *D. pastinaca* remains also questionable in South African waters (Smith & Heemstra 1986, Capapé & Desoutter 1990).

*Dasyatis pastinaca* occurred thoughout the Mediterranean Sea according to McEachran & Capapé (1984a), but seems to be more abundant in southern and eastern areas (Capapé 1989). Previously known off the Mediterranean coast of France (Quignard *et al.* 1962, Capapé 1977a), it is no more recorded to date in the area (Capapé *et al.* 2006a). The species is rather abundant off the

Algerian coast (Dieuzeide *et al.* 1953, Hemida pers. comm.). The species is considered abundant in Tunisian waters (Capapé 1976, Bradaï *et al.* 2004), moving the estuaries to birth giving and was recently found in Tunis Southern Lagoon (Capapé *et al.* 2004, Mejri *et al.* 2004). There are no records of the common stingray in the Bahiret El Biban where (Capapé & Zaouali 1995, Capapé *et al.* 2004).

Of the 17 common stingrays collected in the north-western region of the Lagoon of Bizerte (Fig. 10), 11 were males and 6 females, however, the former did not significantly outnumbered the latter ($\chi2 = 1.8$, $p < 0.05$, df = 1). Males ranged between 169 and 400 mm DW and weighed between 145 and 2813 g TM, 10 specimens were juvenile and a single one, adult. The largest juvenile was 310 mm DW and 952 g TM. Females ranged between 250 and 441 mm DW and between 533 and 2974 g TM. The largest juvenile was 280 mm DW and 680 g TM. The relationship between DW and TM, plotted in Figure 11, showed significant difference between males and females ($F = 359.38$, $p < 0.001$, df = 1). The relationships were for males: log TM = 3.33 log DW –5.28; r = 0.98; n =11, and for females log TM = 3.03 log DW – 4.55; r = 0.99; n = 6.

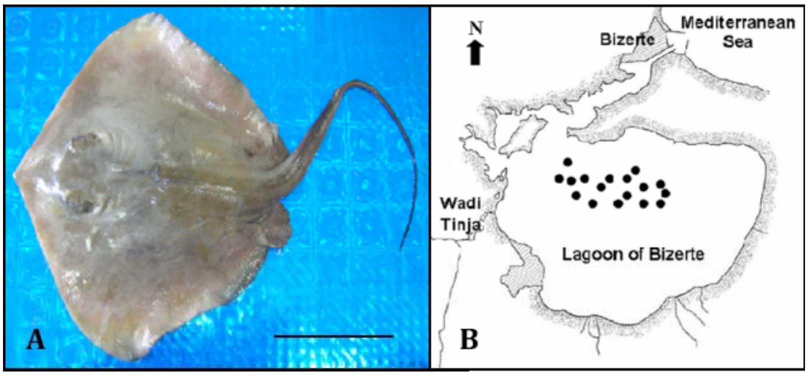

**Figure 10.** A. Specimen of *Dasyatis pastinaca* captured in the Lagoon of Bizerte, scale bar = 100 mm. B. Map of Lagoon of Bizerte showing the capture sites (black circles) of *Dasyatis pastinaca*.

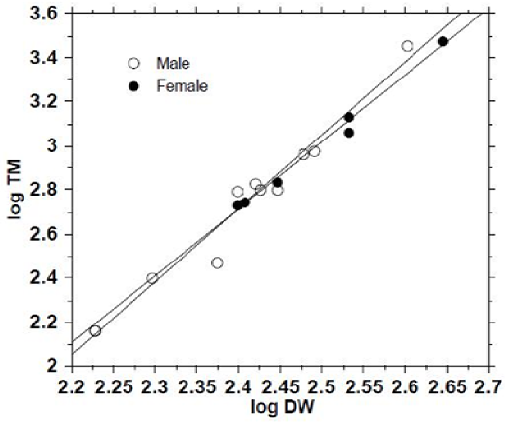

**Figure 11.** Relationship between total length (TL) and total mass (TM), expressed in decimal logarithmic coordinates, in *Dasyatis pastinaca* from the Lagoon of Bizerte.

No sufficient data were available to estimate size at maturity for male and female *Dasyatis pastinaca* from the Lagoon of Bizerte. However Capapé (1976) noted that males and females from Tunisian waters were adult at DW up to 310 mm and 380 mm, respectively, while the largest male and the largest female recorded were 570 mm and 680 mm DW, respectively. Similar sizes were found for specimens from the north-eastern Mediterranean, coastal waters of Turkey by Ismen (2003) and by Yeldan *et al.* (2008).

Measurements were carried out on two specimens and presented in Table IV. General morphology was similar to that of *Dasyatis chrysonota*, anterior margins of disc rather straight. Dorsal fold of tail lower than ventral fold. Disc-depth 12%- 14.0%, disc-length 80%, preoral length 16.0%-18%, pelvic span 37-48.0%, pelvic fin anterior margin 17.5%-18.0 %, all of disc-width.. Snout angle 120°. Mouth slightly arched, skin flap on upper jaws with 32 oral papillae. Five buccal papillae, three central elongated and a single one, verruca-like, on both sides. Dorsal surface rather olive-brown, fairly rosy along the margin of the pectoral fin and toward the snout; pelvic fins also beige with golden marks surrounding the eyes and along the mid-part of the pectoral. Caudal sting beige with margins grey and tip of snout brownish. Belly beige with margins grey and tip of snout brownish. Morphology, measurements and colour are in agreement with Tortonese (1956), Bini (1967), Capapé (1977b, 1983), McEachran & Capapé (1984a), Cowley & Compagno (1993), Golani & Capapé (2004) and Mejri *et al.* (2004).

**Table IV.** Measurements carried out in two specimens of *Dasyatis pastinaca* captured in the Lagoon of Bizerte.

| **References** | **FSB D-past 01** | | **FSB D-past 02** | |
|---|---|---|---|---|
| **Sex** | Male | | Female | |
| **Total mass (g)** | 635 | | 535 | |
| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
| Total length | 465 | 174.16 | 450 | 180.00 |
| Disc-length | 215 | 80.52 | 200 | 80.00 |
| Disc-width | 267 | 100.00 | 250 | 100.00 |
| Disc-depth | 35 | 13.11 | 32 | 12.80 |
| Eyeball width | 13 | 4.87 | 14 | 5.60 |
| Cornea | 11 | 4.12 | 12 | 4.80 |
| Pre-orbital length | 45 | 16.85 | 42 | 16.80 |
| Inter-orbital width | 29 | 10.86 | 29 | 11.60 |
| Spiracle length | 19 | 7.12 | 19 | 7.60 |
| Spiracle width | 14 | 5.24 | 13 | 5.20 |
| Inter-nasal width | 25 | 9.36 | 25 | 10.00 |
| Nasal curtain | 27 | 10.11 | 26 | 10.40 |
| Interspiracular width | 39 | 14.61 | 41 | 16.40 |
| Pre-oral length | 46 | 17.23 | 42 | 16.80 |
| Mouth width | 20 | 7.49 | 21 | 8.40 |
| First gill slit | 10 | 3.75 | 12 | 4.80 |
| Second gill slit | 13 | 4.87 | 9 | 3.60 |
| Third gill slit | 13 | 4.87 | 8 | 3.20 |
| Fourth gill slit | 12 | 4.49 | 9 | 3.60 |
| Fifth gill slit | 8 | 3.00 | 7 | 2.80 |
| Width between first gill slit | 54 | 20.22 | 50 | 20.00 |
| Width between fifth gill slit | 33 | 12.36 | 31 | 12.40 |
| Snout tip to eye | 55 | 20.60 | 47 | 18.80 |
| Snout tip to mouth | 44 | 16.48 | 44 | 17.60 |
| Snout tip to first gill slit | 69 | 25.84 | 65 | 26.00 |
| Snout tip to fifth gill slit | 106 | 39.70 | 99 | 39.60 |
| Snout tip to pelvic fin | 185 | 69.29 | 176 | 70.40 |
| Snout tip to sting | 300 | 112.36 | 272 | 108.80 |
| Sting length1 | 59 | 22.10 | 77 | 30.80 |
| Sting length2 | 7 | 2.62 | 47 | 18.80 |
| Snout tip to vent | 190 | 71.16 | 181 | 72.40 |

**Table IV.** Measurements carried out in two specimens of *Dasyatis pastinaca* captured in the Lagoon of Bizerte (continued).

| Measurements | mm | % of TL | mm | % of TL |
|---|---|---|---|---|
| Pectoral fin anterior margin | 161 | 60.30 | 145 | 58.00 |
| Pectoral fin posterior margin | 154 | 57.68 | 157 | 62.80 |
| Pectoral fin inner margin | 29 | 10.86 | 24 | 9.60 |
| Pelvic fin anterior margin | 49 | 18.35 | 29 | 11.60 |
| Pelvic fin posterior margin | 37 | 13.86 | 54 | 21.60 |
| Pelvic fin inner margin | 36 | 13.48 | 12 | 4.80 |
| Pelvic fin base | 32 | 11.99 | 39 | 15.60 |
| Span of pelvic fin | 100 | 37.45 | 109 | 43.60 |
| Clasper length | 31 | 11.61 | - | - |
| Tail base width | 21 | 7.87 | 21 | 8.40 |
| Tail base depth | 13 | 4.87 | 16 | 6.40 |
| Tail length | 272 | 101.87 | 250 | 100.00 |
| Ventral tail fold length | 176 | 65.92 | 112 | 44.80 |
| Dorsal tail fold length | 73 | 27.34 | 19 | 7.60 |

*Tortonese's stingray, **Dayatis tortonesei** Capapé 1975*. The description of *Dasyatis tortonesei* was given by Capapé (1975, 1977b) from specimens caught off the Tunisian coast. The specimen was considered as a junior synonym of the common stingray *D. pastinaca* (Séret & McEachran 1986), then re-assigned as valid species by Golani (1996, 2005) and Saad *et al.* (2005) from observations based on specimens collected in the eastern Levant Basin and by Neifar *et al.* (2000) on specimens caught in Tunisian waters. Kabasakal (2002) recorded *D. tortonesei* from Turkey. Outside the Mediterranean Sea, Diatta *et al* (2001) recorded the species off Senegal, while Beveridge *et al.* (2004) considered its occurrence as possible in Arcachon Basin (Atlantic coast of France). In Tunisian waters, Capapé (1978) noted that size at sexual maturity occurred for males and females at 380 mm and 460 mm DW, respectively, while the largest male and the largest female ever recorded in the area were 680 mm and 790 mm DW, respectively. Two specimens were caught in the Lagoon of Bizerte, an adult male, having 402 mm in DW and weighing 2321 g TM and an adult female having 420 mm in DW and weighing 2401 g, this latter was the smallest adult female *Dasyatis tortonesei* recorded to date. Both specimens were caught by trammel nets in the north-eastern region of the Lagoon of Bizerte (Fig. 12). Only two specimens were collected, so it is impossible to carry out a relationship size *versus* total mass.

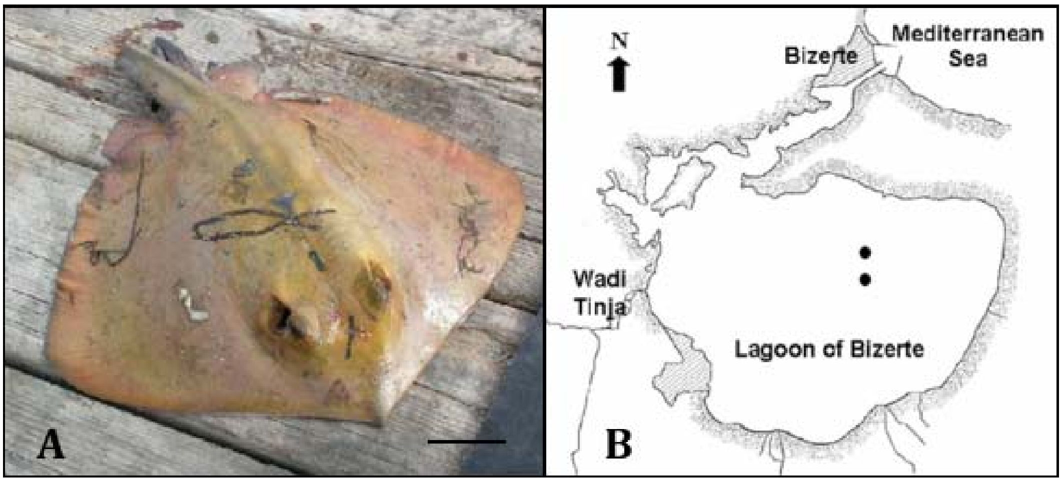

**Figure 12.** A. Specimen of *Dasyatis tortonesei* captured in the Lagoon of Bizerte, scale bar = 100 mm. B. Map of Lagoon of Bizerte showing the capture sites (black circles) of *Dasyatis tortonesei.*

Measurements were carried out on these two specimens and are presented in Table V. General morphology was similar to that described for *Dasyatis chrysonota* and *D. pastinaca* with anterior margins slightly convex at level of eyes while the posterior margins straight anteriorly and convex posteriorly. Carene or keel on dorsal surface of tail extending posteriorly behind sting to distal end of tail, fold on ventral surface lower than those of *D. chrysonota* and *D. pastinaca*. Disc-depth 12%-13.0%, disc-length 85%-86%, preoral length 18.0%-20%, pelvic span 33-42.0%, pelvic fin anterior margin 18%-20.0 %, all of disc-width. Snout angle 125°. Mouth slightly arched, skin flap on upper jaws with 32-36 oral papillae. Three elongated central buccal papillae, and a single one, verruca-like, on both sides. Dorsal surface rather olive-brown, fairly yellowish along the margin of the pectoral fin and toward the snout; pelvic fins also beige with golden marks surrounding the eyes and along the mid-part of the pectoral. Caudal sting beige with margins grey and tip of snout brownish. Belly beige with margins grey and tip of snout brownish. Morphology, measurements and colour are in agreement with Capapé (1977b, 1983), McEachran & Capapé (1984a) and Golani (1996).

**Table V.** Measurements carried out in two specimens of *Dasyatis tortonesei* captured in the Lagoon of Bizerte.

| **References** | **FSB D-tort 01** | | **FSB D-tort 02** | |
|---|---|---|---|---|
| **Sex** | Male | | Female | |
| **Total Mass(g)** | 2321 | | 2401 | |
| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
| Total length | 640 | 159.20 | 700 | 166.67 |
| Disc-length | 345 | 85.82 | 357 | 85.00 |
| Disc-width | 402 | 100.00 | 420 | 100.00 |
| Disc depth | 50 | 12.44 | 53 | 12.62 |
| Eyball width | 15 | 3.73 | 16 | 3.81 |
| Cornea | 14 | 3.48 | 15 | 3.57 |
| Pre-orbital length | 76 | 18.91 | 81 | 19.29 |
| Inter-orbital width | 47 | 11.69 | 47 | 11.19 |
| Spiracle length | 26 | 6.47 | 26 | 6.19 |
| Spiracle width | 19 | 4.73 | 20 | 4.76 |
| Inter-nasal width | 37 | 9.20 | 38.7 | 9.21 |
| Nasal curtain | 46 | 11.44 | 44 | 10.48 |
| Interspiracular width | 64 | 15.92 | 65 | 15.48 |
| Pre-oral length | 82 | 20.40 | 85 | 20.24 |
| Mouth width | 41 | 10.20 | 40 | 9.52 |
| First gill slit | 16 | 3.98 | 13 | 3.10 |
| Second gill slit | 14 | 3.48 | 17 | 4.05 |
| Third gill slit | 14 | 3.48 | 17 | 4.05 |
| Fourth gill slit | 15 | 3.73 | 17 | 4.05 |
| Fifth gill slit | 12 | 2.99 | 11 | 2.62 |
| Width between first gill slit | 78 | 19.40 | 79 | 18.81 |
| Width between fifth gill slit | 46 | 11.44 | 45 | 10.71 |
| Snout tip to eye | 87 | 21.64 | 95 | 22.62 |
| Snout tip to mouth | 85 | 21.14 | 89 | 21.19 |
| Snout tip to fist gill slit | 128 | 31.84 | 127 | 30.24 |
| Snout tip to fifth gill slit | 180 | 44.78 | 181 | 43.10 |
| Snout tip to pelvic fin | 300 | 74.63 | 310 | 73.81 |

**Table V.** Measurements carried out in two specimens of *Dasyatis tortonesei* captured in the Lagoon of Bizerte (continued).

| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
|---|---|---|---|---|
| Snout tip to sting | 457 | 113.68 | 475 | 113.10 |
| Sting length1 | 12 | 2.99 | 99 | 23.57 |
| Sting length2 | - | - | 59 | 14.05 |
| Snout tip to vent | 316 | 78.61 | 322 | 76.67 |
| Pectoral fin anterior margin | 252 | 62.69 | 270 | 64.29 |
| Pectoral fin posterior margin | 252 | 62.69 | 257 | 61.19 |
| Pectoral fin inner margin | 39 | 9.70 | 43 | 10.24 |
| Pelvic fin anterior margin | 73 | 18.16 | 82 | 19.52 |
| Pelvic fin posterior margin | 55 | 13.68 | 68 | 16.19 |
| Pelvic fin inner margin | 13 | 3.23 | 26 | 6.19 |
| Pelvic fin base | 59 | 14.68 | 61 | 14.52 |
| Span of pelvic fin | 167 | 41.54 | 138 | 32.86 |
| Clasper length | 134 | 33.33 | - | - |
| Tail base width | 39 | 9.70 | 37 | 8.81 |
| Tail base depth | 20 | 4.98 | 20 | 4.76 |
| Tail length | 305 | 75.87 | 371 | 88.33 |
| Ventral tail fold length | 173 | 43.03 | 240 | 57.14 |
| Dorsal tail fold length | 81 | 20.15 | 68 | 16.19 |

### Family Gymnuridae

*Spiny butterfly ray,* ***Gymnura altavela*** *(Linnaeus, 1758).* The spiny butterfly ray presents a widespread amphi-atlantic distribution (McEachran & Capapé 1984b). Off the western Atlantic, the species was recorded from New England (Bigelow & Schroeder 1953) to Argentina (Roux 1979). Off the eastern Atlantic, the species was recorded from the Bay of Biscay (Cazaux & Labourg 1971, Quéro *et al.* 2003), off Spain (Ortea & De La Hoz 1979), Portugal (Albuquerque 1954-1956). The species is known to be reported south Strait of Gibraltar, off Morocco (Collignon & Aloncle 1972), Mauritania (Maurin & Bonnet 1970), Senegal (Capapé *et al.* 1995) to the Gulf of Guinea (Blache *et al* 1970), and probably off Angola (Fowler 1936).

The species was known throughout the Mediterranean Sea according to McEachran & Capapé (1984b) where it was historically not uncommon, but abundance and landings fluctuated with marine area (Capapé 1981, Capapé *et al.* 1992). To date, a drastic decline of captures was reported not only in the Mediterranean Sea, but unfortunately throughout the world, and *G. altavela* is considered to date as an endangered species (Vooren *et al.* 2007). Captures of rare specimens were sporadically observed in marine areas such as in the Adriatic Sea (Dulcic *et al.* 2003) and the Tyrrhenian Sea (Psomadakis *et al.* 2005).

The spiny butterfly ray was regularly captured as by-catch species off the Tunisian coast, rather in southern areas according to Postel (1956) and Quignard & Capapé (1971). Through surveys conducted in the area, Capapé (1989) reported the species northward in the Gulf of Tunis. Capture of two specimens in the Lagoon of Bizerte constitutes the northernmost range extension of *G. altavela* in Tunisian waters and the first record in a perimediterranean lagoon (*sensu* Quignard & Zaouali 1980). Capapé *et al.* (1992) noted that for the Tunisian coast, female *G. altavela* matured at a larger size than males, 780 mm DW and between 680 and 1020 mm DW, respectively; moreover, the largest male and the largest female reached 1140 mm and 1620 mm, respectively. Elsewhere, a mature male of about 1068 mm DW was recorded from off Madeira by Günther (1870). Bigelow & Schroeder (1953) observed a young male (1208 mm DW) from off north-eastern coast of America while the largest specimen recorded in the area was a female 2082 mm DW.

Measurements were carried out on these two specimens and presented in Table VI. The specimens from the north-western region only, of course of the Lagoon of Bizerte were 366 mm and 370 mm DW, respectively, weighed 1186 and 1203 g TM and were juveniles (Fig. 13). Morphologic characteristics were: disc lozenge-shaped about twice as broad as long with anterior margins slightly sinuous and moderately convex at level of eyes while increasing convex posteriorly. Snout with blunted tip, snout angle more or less 135°. Slender tentacle-like process pointing backward from inner margin of spiracle. Pelvic fins quadrangular and with rounded outer corner. Tail short and slightly depressed dorso-ventrally. Dorsal and ventral surfaces of the tail with lower ridge posterior to the sting extending to the end of the tail. Dorsal fin absent. Disc-depth less than 3%, disc-length 50%-52%, preoral length 9%-10%, pelvic span less than 5%, pelvic fin anterior margin 5%, all of disc-width. Mouth slightly arched, skin flap on upper jaws. Dorsal surface brown-olivaceous reddish on posterior margin of disc, with small dark or whitish spots, pelvic fins also brownish. Slightly darker between the eyes, along the center of the body and the length of the tail. Tail with darkish transversal strips on dorsal surface. Caudal sting beige. Belly off-white to beige. Morphology, measurements and colour are in agreement with Bigelow & Schroeder (1953), Tortonese (1956), Bini (1967), Capapé (1981), McEachran & Capapé (1984b), Dulcic *et al.* (2003) and Psomadakis *et al.* (2005).

**Table VI.** Measurements carried out in two specimens of *Gymnura altavela* captured in the Lagoon of Bizerte.

| **References** | **FSB G-alta 01** | | **FSB G-alta 02** | |
|---|---|---|---|---|
| **Sex** | Male | | Female | |
| **Total mass (g)** | 1186 | | 1203 | |
| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
| Total length | 366 | 67.03 | 370 | 67.77 |
| Disc-length | 275 | 50.37 | 280 | 51.28 |
| Disc-width | 546 | 100.00 | 546 | 100.00 |
| Disc-depth | 23 | 4.21 | 25 | 4.58 |
| Eyeball width | 16 | 2.93 | 16 | 2.93 |
| Cornea | 8 | 1.47 | 8 | 1.47 |
| Pre-orbital length | 41 | 7.51 | 41 | 7.51 |
| Inter-orbital width | 39 | 7.14 | 40 | 7.33 |
| Spiracle length | 21 | 3.85 | 22 | 4.03 |
| Spiracle width | 12 | 2.20 | 12 | 2.20 |
| Inter-nasal width | 34 | 6.23 | 25 | 4.58 |
| Nasal curtain | 40 | 7.33 | 41 | 7.51 |
| Interspiracular width | 41 | 7.51 | 41 | 7.51 |
| Pre-oral length | 50 | 9.16 | 52 | 9.52 |
| Mouth width | 46 | 8.42 | 48 | 8.79 |
| First gill slit | 13 | 2.38 | 13 | 2.38 |
| Second gill slit | 14 | 2.56 | 15 | 2.75 |
| Third gill slit | 13 | 2.38 | 15 | 2.75 |
| Fourth gill slit | 13 | 2.38 | 13 | 2.38 |
| Fifth gill slit | 9 | 1.65 | 9 | 1.65 |
| Width between first gill slit | 85 | 15.57 | 86 | 15.75 |
| Width between fifth gill slit | 62 | 11.36 | 63 | 11.54 |
| Snout tip to eye | 48 | 8.79 | 49 | 8.97 |
| Snout tip to mouth | 52 | 9.52 | 53 | 9.71 |
| Snout tip to first gill slit | 68 | 12.45 | 70 | 12.82 |
| Snout tip to fifth gill slit | 115 | 21.06 | 117 | 21.43 |
| Snout tip to pelvic fin | 230 | 42.12 | 233 | 42.67 |
| Snout tip to sting | 180 | 32.97 | 183 | 33.52 |
| Pectoral fin anterior margin | 241 | 44.14 | 243 | 44.51 |
| Pectoral fin posterior margin | 330 | 60.44 | 331 | 60.62 |
| Pectoral fin inner margin | 260 | 47.62 | 261 | 47.80 |
| Pelvic fin anterior margin | 20 | 3.66 | 21 | 3.85 |

**Table VI.** Measurements carried out in two specimens of *Gymnura altavela* captured in the Lagoon of Bizerte (continued).

| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
|---|---|---|---|---|
| Pelvic fin posterior margin | 42 | 7.69 | 43 | 7.88 |
| Pelvic fin inner margin | 30 | 5.49 | 31 | 5.68 |
| Pelvic fin base | 8 | 1.47 | 9 | 1.65 |
| Span of pelvic fin | 26 | 4.76 | 27 | 4.95 |
| Clasper length | 57 | 10.44 | 57 | 10.44 |
| Tail base width | 31 | 5.68 | 32 | 5.86 |
| Tail base depth | 14 | 2.56 | 15 | 2.75 |
| Tail length | 7 | 1.28 | 7 | 1.28 |
| Ventral tail fold length | 104 | 19.05 | 106 | 19.41 |
| Dorsal tail fold length | 86 | 15.75 | 86 | 15.75 |
| Clasper length | 51 | 9.34 | 52 | 9.52 |

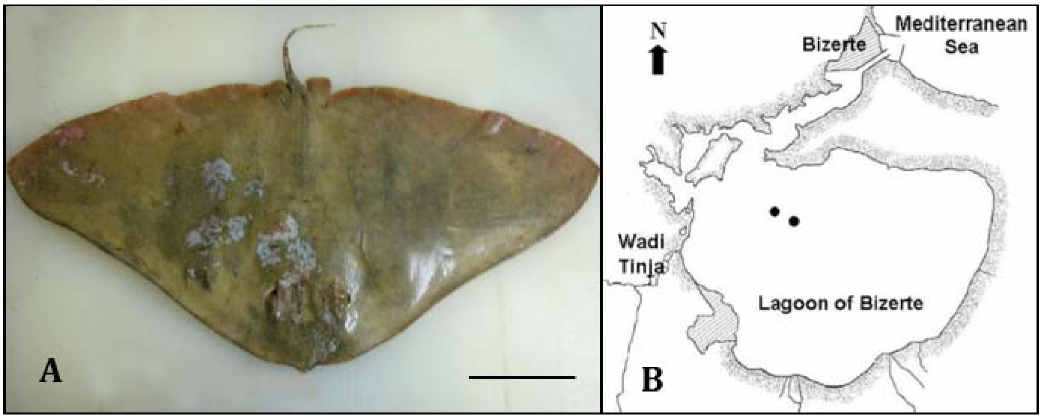

**Figure 13.** A. Specimen of *Gymnura altavela* captured in the Lagoon of Bizerte, scale bar = 100 mm. B. Map of Lagoon of Bizerte showing the capture sites (black circles) of *Gymnura altavela.*

## Family Myliobatidae

*Common eagle ray,* ***Myliobatis aquila*** *(Linnaeus, 1758).* The common eagle ray was reported in the north-eastern Atlantic from off Scandinavia Muus & Dahlstrøm (1964-1966), off British Isles (Wheeler 1969), France (Quéro *et al.* 2003), Spain (Ortea & De La Hoz 1979) and Portugal (Albuquerque1954-1956). South Strait of Gibraltar, the species was reported off Morocco (Collignon & Aloncle 1972) and Mauritania (Maurin & Bonnet 1970). *Myliobatis aquila* was also recorded off Senegal by Cadenat (1951), but recent observations reported only the occurrence of its close relative species, the bull ray *Pteromylaeus bovinus* (E. Geoffroy Saint-Hilaire 1817) by Seck *et al.* (2002). Fowler (1936) noted that the common eagle ray occurred off the western coast of Africa from Angola to South African waters (Smith & Heemstra 1986).

The common eagle ray occurred in the Mediterranean but captures seem to be rather rare (see Capapé 1989). The species was reported in several areas off the southern coast of France and was not uncommon in the Gulf of Lion (Capapé *et al.* 2007). The common eagle ray is frequently captured off the Maghreb coast: Morocco (Collignon & Aloncle 1972), Algeria (Dieuzeide *et al.* 1953, Hemida pers. comm. 2009) and it rather common to date in Tunisian waters according to Bradaï *et al.* (2004).

Off the coast of Languedoc, size at sexual maturity was attained at 500-540 mm DW for the males and 730 mm DW for the females. The largest male and female were 720 and 1140 mm DW, respectively. Sexual dimorphism in size was also observed in *M. aquila* from the Tunisian coast (Capapé & Quignard 1974). Nevertheless, in this latter area both males and females matured at a smaller size than off the coast of Languedoc. Tunisian male matured between 360 and 410 mm DW, and females between 480 and 580 mm DW. The largest Tunisian male was 550 mm DW and the largest female 830 mm DW. Common eagle rays from the coast of Languedoc were larger than those caught off the Tunisian coast. This suggests that two different populations occur in each area.

Two specimens were captured in the north-eastern region of the Lagoon of Bizerte (Fig. 14): an adult male having 524 mm DW and weighing 2138 g TM and an adult female having 765 mm DW and weighing 4230 g TM. Measurements were carried out on these two specimens and presented in Table VII. The specimen description was as follows: disc broad with pectoral slightly falciform continued along the side of the head to the end of the snout forming a single lobe. Head moderately prominent with snout broadly rounded. Spiracles large 3 times as long as width. Tail slender and elongated with dorsal fin beginning behind tips of pelvic fins. Disc-depth 13%-14%, disc-length 60%-62%, preoral length 9%-10%, pelvic span 16%-17%, pelvic fin anterior margin 17%, all of disc-width. Mouth slightly arched, with teeth fused in plates. Supra-orbitary horns in male adult. Dorsal surface naked with small tubercles down midline of disc. Brown-olivaceous reddish on posterior margin of disc, with small dark or whitish spots, pelvic fins also darkish. Slightly darker between the eyes, along the center of the body and the length of the tail. Caudal sting beige. Belly off-white to beige. Morphology, measurements and colour are in agreement with Bigelow & Schroeder (1953), Tortonese (1956), Bini (1967), Capapé & Quignard (1974) and McEachran & Capapé (1984c).

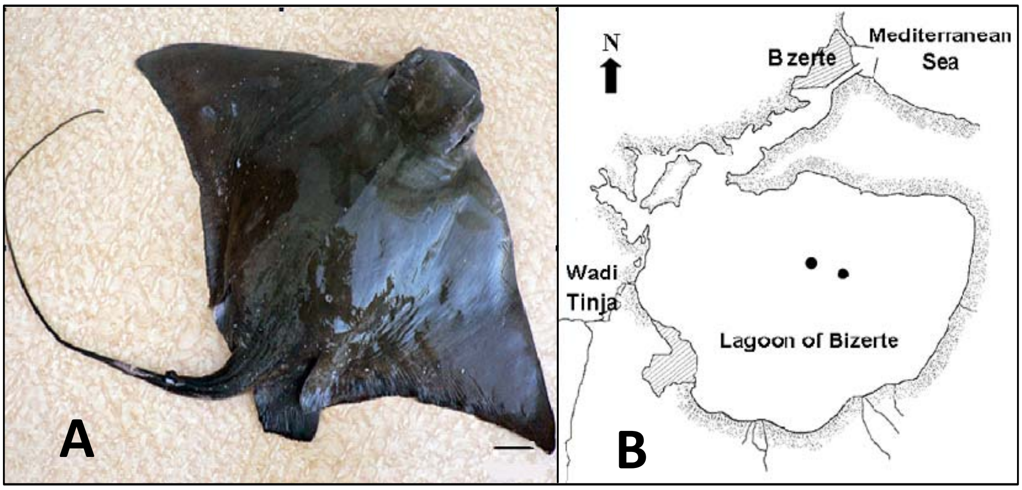

**Figure 14.** A. Specimen of *Myliobatis aquila* captured in the Lagoon of Bizerte, scale bar = 100 mm. B. Map of Lagoon of Bizerte showing the capture sites (black circles) of *Myliobatis aquila.*

**Table VII.** Measurements carried out in two specimens of *Myliobatis aquila* captured in the Lagoon of Bizerte.

| **References** | **FSB. M-aqu. 01** | | **FSB. M-aqu. 02** | |
|---|---|---|---|---|
| **Sex** | Male | | Female | |
| **Total mass(g)** | 2138 | | 4230 | |
| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
| Total length | 860 | 164.12 | 1162 | 151.90 |
| Disc-length | 320 | 61.07 | 475 | 62.09 |
| Disc-width | 524 | 100.00 | 765 | 100.00 |
| Disc-depth | 68 | 12.98 | 103 | 13.46 |
| Maximum snout width | 86 | 16.41 | 155 | 20.26 |
| Dorsal snout width | 73 | 13.93 | 98 | 12.81 |
| Snout length | 67 | 12.79 | 84 | 10.98 |
| Snout depth | 29 | 5.53 | 22 | 2.88 |
| Snout tip to pectoral | 66 | 12.60 | 110 | 14.38 |
| Anterior interspiracular width | 78 | 14.89 | 110 | 14.38 |
| Posterior interspiracular width | 75 | 14.31 | 104 | 13.59 |
| Eyeball length | 22 | 4.20 | 29 | 3.79 |
| Eyeball width | 22 | 4.20 | 22 | 2.88 |

**Table VII.** Measurements carried out in two specimens of *Myliobatis aquila* captured in the Lagoon of Bizerte (continued).

| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
|---|---|---|---|---|
| Cornea length | 13 | 2.48 | 16 | 2.09 |
| Cornea width | 14 | 2.67 | 14 | 1.83 |
| Pre-orbital length | 53 | 10.11 | 50 | 6.54 |
| Inter-orbital length | 84 | 16.03 | 87 | 11.37 |
| Spiracle length | 33 | 6.30 | 42 | 5.49 |
| Spiracle width | 10 | 1.91 | 16 | 2.09 |
| Inter-nasal width | 45 | 8.59 | 50 | 6.54 |
| Nasal curtain | 44 | 8.40 | 65 | 8.50 |
| Pre-oral length | 51 | 9.73 | 77 | 10.07 |
| Mouth width | 45 | 8.59 | 71 | 9.28 |
| First gill slit | 11 | 2.10 | 18 | 2.35 |
| Second gill slit | 12 | 2.29 | 21 | 2.75 |
| Third gill slit | 13 | 2.48 | 21 | 2.75 |
| Fourth gill slit | 13 | 2.48 | 21 | 2.75 |
| Fifth gill slit | 10 | 1.91 | 15 | 1.96 |
| Width between first gill slit | 73 | 13.93 | 135 | 17.65 |
| Width between fifth gill slit | 40 | 7.63 | 67 | 8.76 |
| Snout tip to eye | 53 | 10.11 | 82 | 10.72 |
| Snout tip to mouth | 46 | 8.78 | 80 | 10.46 |
| Snout tip to first gill slit | 96 | 18.32 | 140 | 18.30 |
| Snout tip to fifth gill slit | 144 | 27.48 | 215 | 28.10 |
| Snout tip to pelvic fin | 310 | 59.16 | 420 | 54.90 |
| Snout tip to sting | 470 | 89.69 | 615 | 80.39 |
| Snout tip to dorsal | 420 | 80.15 | 580 | 75.82 |
| Snout tip to vent | 340 | 64.89 | 455 | 59.48 |
| Pectoral fin anterior margin | 320 | 61.07 | 350 | 45.75 |
| Pectoral fin posterior margin | 260 | 49.62 | 370 | 48.37 |
| Pectoral fin inner margin | 33 | 6.30 | 41 | 5.36 |
| Pelvic fin anterior margin | 87 | 16.60 | 41 | 5.36 |
| Pelvic fin posterior margin | 47 | 8.97 | 82 | 10.72 |
| Pelvic fin inner margin | 20 | 3.82 | 55 | 7.19 |
| Span of pelvic fin | 88 | 16.79 | - | - |
| Clasper length | 19 | 3.63 | 46 | 6.01 |
| Tail base width | 16 | 3.05 | 27 | 3.53 |
| Tail base depth | 480 | 91.60 | 680 | 88.89 |
| Sting length | 17 | 3.24 | 23 | 3.01 |
| Dorsal anterior edge | 13 | 2.48 | 18 | 2.35 |
| Dorsal posterior edge | 3 | 0.57 | 5 | 0.65 |
| Dorsal inner edge | 23 | 4.39 | 32 | 4.18 |

*Bull ray,* ***Pteromylaeus bovinus*** *(E. Geoffroy Saint-Hilaire, 1817).* The bull ray is reported in the Eastern Atlantic from Portugal (Albuquerque 1954-1956) to Angola including Madeira and the Canary islands, from Saldanha bay to Natal (Wallace 1967) and also southern Mozambique (Compagno *et al.* 1989). In the Mediterranean, *Pteromylaeus bovinus* is more frequently captured in the eastern basin than in the western basin, rather in southern areas (Capapé 1989). For instance, the bull ray was only reported from the Mediterranean coast of France by Moreau in 1881, since further papers did report it (Capapé *et al.* 2006 a). The bull ray was previously reported as a rare elasmobranch species in the Adriatic Sea (Soljan 1975, Jardas 1985), however recent investigations allow Dulcic *et al.* (2008) to capture several specimens and to provide thorough data on the life history of *P. bovinus* from the area.

Southward, *Pteromylaeus bovinus* was reported throughout the Maghreb shore: Morocco (Collignon & Aloncle 1972), Algeria (Dieuzeide *et al*. 1953, Hemida personal communication 2009) and Tunisia (Capapé & Quignard 1975, Bradaï *et al.* 2004). Additionally, investigations conducted in Tunisian waters showed that *P. bovinus* migrated toward northern areas entering brackish waters areas such as the Lagoon of Bizerte (Neifar *et al.* 1999) and Tunis Southern Lagoon (Mejri *et al.* 2004). The captures of two specimens in the Lagoon of Bizerte confirm the migration to northern Tunisian areas.

Off the coast of Senegal adult males and females of *Pteromyaleus bovinus* were over 820 mm and 900 mm DW, respectively, while the largest and the largest female recorded being 1150 and 1480 mm DW, respectively, and weighed, 29.8 kg and 47.9 kg, respectively. The largest specimens ever recorded were from the northern Adriatic Sea; they ranged between 1540 and 2220 mm DW and weighed between 68 and 116 kg (Dulcic *et al.* 2008). Off the Tunisian coast, size at sexual maturity occurred for males at 800 mm DW, and for females between 900 and 1000 mm DW. Size at birth occurred between 250 and 270 mm DW for bull rays from Senegal, near term embryos weighed between 310 to 345 g TM, similar patterns were observed for near terms from off Tunisian coast, while Dulcic *et al.* (2008) recorded near term pregnant females that bore embryos having from 370 and 450 mm in DW and weighing from 740 to 1080 g TM.

The two specimens captured in the central Lagoon of Bizerte were 426 mm and 450 mm DW, respectively, and weighed 1020 g and 1005 g (Fig. 15). They bore a healed scar and probably, were recently born in the lagoon. Size at birth was probably underestimated for local bull rays by Capapé & Quignard (1975). Measurements were carried out on these two specimens and presented in Table VIII. General morphology similar to *Myliobatis aquila* but stouter.

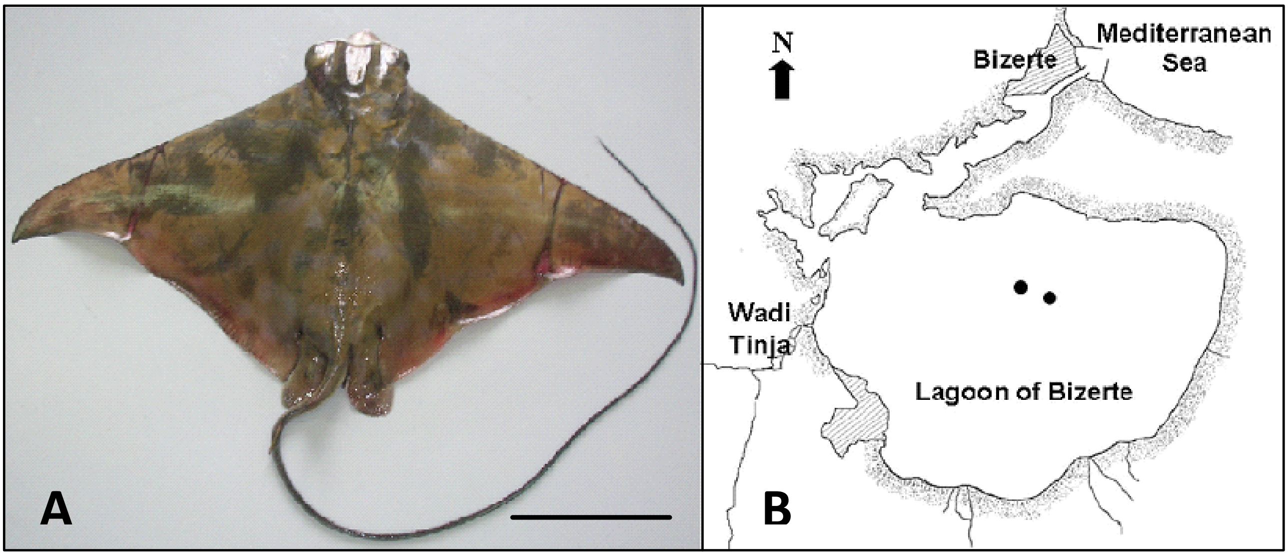

**Figure 15.** A. Specimen of *Pteromylaeaus bovinus* captured in the Lagoon of Bizerte, scale bar = 100 mm. B. Map of Lagoon of Bizerte showing the capture sites (black circles) of *Pteromylaeus bovinus.*

**Table VIII.** Measurements carried out in two specimens of *Pteromylaeus bovinus* captured in the Lagoon of Bizerte.

| **References** | **FSB P-bov. 01** | | **FSB. P-bov. 02** | |
|---|---|---|---|---|
| **Sex** | Male | | Female | |
| **Total mass (g)** | 1005 | | 1030 | |
| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
| Total length | 780 | 173.33 | 787 | 184.74 |
| Disc-length | 220 | 48.89 | 281 | 65.96 |
| Disc-width | 450 | 100.00 | 426 | 100.00 |
| Disc-depth | 45 | 10.00 | 53 | 12.44 |
| Maximum snout width | 65 | 14.44 | 62 | 14.55 |
| Dorsal snout width | 38 | 8.44 | 39 | 9.15 |
| Snout length | 24 | 5.33 | 34 | 7.98 |
| Snout depth | 14 | 3.11 | 19 | 4,46 |
| Snout tip to pectoral | 66 | 14.67 | 64 | 15.02 |
| Anterior interspiracular width | 60 | 13.33 | 62 | 14.55 |
| Posterior interspiracular width | 53 | 11.78 | 51 | 11.97 |
| Eyball length | 21 | 4.67 | 21 | 4.93 |
| Eyball width | 15 | 3.33 | 14 | 3.29 |
| Cornea length | 12 | 2.67 | 11 | 2.58 |
| Cornea width | 8 | 1.78 | 9 | 2.11 |
| Pre-orbital length | 35 | 7.78 | 40 | 9.39 |
| Inter-orbital length | 40 | 8.89 | 64 | 15.02 |
| Spiracle length | 21 | 4.67 | 38 | 8.92 |
| Spiracle width | 7 | 1.56 | 14 | 3.29 |
| Inter-nasal width | 21 | 4.67 | 19 | 4.46 |
| Nasal curtain | 31 | 6.89 | 25 | 5.87 |
| Pre-oral length | 51 | 11.33 | 49 | 11.50 |
| Mouth width | 27 | 6.00 | 32 | 7,51 |
| First gill slit | 9 | 2.00 | 8 | 1.88 |
| Second gill slit | 10 | 2.22 | 9 | 2.11 |
| Third gill slit | 10 | 2.22 | 10 | 2.35 |
| Fourth gill slit | 10 | 2.22 | 10 | 2.35 |
| Fifth gill slit | 7 | 1.56 | 6 | 1.41 |
| Width between first gill slit | 56 | 12.44 | 58 | 13.62 |
| Width between fifth gill slit | 38 | 8.44 | 40 | 9,39 |
| Snout tip to eye | 45 | 10.00 | 50 | 11.74 |
| Snout tip to mouth | 48 | 10.67 | 50 | 11.74 |
| Snout tip to fist gill slit | 78 | 17.33 | 82 | 19.25 |
| Snout tip to fifth gill slit | 118 | 26.22 | 112 | 26.29 |
| Snout tip to pelvic fin | 222 | 49.33 | 223 | 52.35 |
| Snout tip to sting | 305 | 67.78 | 292 | 68.54 |
| Snout tip to dorsal | 256 | 56.89 | 241 | 56.57 |
| Snout tip to vent | 235 | 52.22 | 229,5 | 53.87 |
| Pectoral fin anterior margin | 220 | 48.89 | 210 | 49.30 |
| Pectoral fin posterior margin | 218 | 48.44 | 200 | 46.95 |
| Pectoral fin inner margin | 31 | 6.89 | 31 | 7.28 |
| Pelvic fin anterior margin | 60 | 13.33 | 59 | 13.85 |
| Pelvic fin posterior margin | 24 | 5.33 | 33 | 7.75 |
| Pelvic fin inner margin | 16 | 3.56 | 36 | 8.45 |
| Span of pelvic fin | 84 | 18.67 | 77 | 18.08 |
| Clasper length | 30 | 6.67 | 58 | 13.62 |

**Table VIII.** Measurements carried out in two specimens of *Pteromylaeus bovinus* captured in the Lagoon of Bizerte (continued).

| **Measurements** | **mm** | **% of TL** | **mm** | **% of TL** |
|---|---|---|---|---|
| Tail base width | 13 | 2.89 | 15 | 3.52 |
| Tail base depth | 12 | 2.67 | 12 | 2.82 |
| Tail length | 540 | 120.00 | 552 | 129.58 |
| Sting length | - | - | 25 | 5.87 |
| Dorsal anterior edge | 26 | 5.78 | 22 | 5.16 |
| Dorsal posterior edge | 10 | 2.22 | 18 | 4.23 |
| Dorsal inner edge | 7 | 1.56 | 1 | 0.23 |
| Dorsal base | 32 | 7,.1 | 32 | 7.51 |

The species morphological characteristics were: head large prominent, snout produced, narrower than the skull, blunted at the end. Rostral fins at lower level and separate from the pectoral fins along the side of the head. Pectoral fins with outer angle acute strongly falciform. Spiracles large 3 times as long as width. Tail slender and elongated with dorsal fin beginning in front of tips of pelvic fins. Disc-depth 10%-13%, disc-length 48%-65%, preoral length 11%-12%, pelvic span 18%-19%, pelvic fin anterior margin 13%-14%, all of disc-width. Mouth slightly arched, with teeth fused in plates. Pre-orbitary horns in male adult. Dorsal surface naked with small tubercles down midline of disc. Dorsal surface of disc fairly brownish with 7 to 9 pale transverse streaks in juveniles, plain brown in adults. Slightly darker between the eyes, along the center of the body and the length of the tail. Caudal sting beige. Belly off-white to beige. Morphology, measurements and colour are in agreement with Tortonese (1956), Bini (1967), Capapé & Quignard (1975), McEachran & Capapé (1984c), Seck *et al.* (2002) and Dulcic *et al.* (2008).

## Conclusions

Of the 62 elasmobranch species reported in Tunisian waters 8 were recorded in the Lagoon of Bizerte. Seven species were strictly Atlanto-Mediterranean *sensu* Quignard (1978), a single species *Gymnura altavela* had a widespread amphi-atlantic distribution.

All were batoids, due to fact that the navigation channel constitutes a main obstacle at the entrance of sharks in the area. Similar pattern was also reported for Tunis Southern Lagoon which does not communicate directly with sea, no shark was recorded in this area (Mejri *et al.* 2004). In contrast, Capapé *et al.* (2004) recorded shark species in the southern Bahiret El Biban, communicating directly with the Gulf of Gabès, additionally considered as a potential nursery area for shark species (Bradaï *et al.* 2002, 2005). However, captures of sharks were considered as occasional, and generally small specimens were observed. A single small shark species appeared to inhabit the Bahiret El Biban, the oviparous small spotted catshark *Scyliorhinus canicula* (Linnaeus 1758). The Bahiret El Biban is also the largest brackish area, this explains why elasmobranch species are qualitatively and quantitatively more abundant in this area than in the two other areas.

Only one species the common torpedo *Torpedo torpedo* could be considered as an inhabitant of this brackish area where it develops and reproduces. So, a population seems to be definitively established in the area. The reasons for success are probably to fact that the species does not reach a large size and could live in a restricted area. *T. torpedo* lives buried in sandy-muddy bottoms and its capture is not very easy by fishing gears. The species has no commercial value and generally discarded alive in the lagoon soon after being captured. Additionally, *T. torpedo* is one of the most abundant species in the neighbouring shallow coastal waters, and find no difficulties to enter the lagoon through navigation channel. Its recruitment remains permanent. The marbled electric ray *T. marmorata* presented similar patterns that its congeneric species. However, *T. marmorata* is larger than *T. torpedo* and is less abundant in the neighbouring areas. This explains why we have found few specimens in the area. Moreover, an interspecific competition cannot be excluded between the two species.

Of the 3 dasyatid species occurring in the Lagoon of Bizerte, 2 only could be considered as relatively abundant, *Dasyatis chrysonota* and *D. pastinaca*, the third *D. tortonesei* is rare. Their occurrence could be explained by the abundance in the Lagoon of Bizerte of mussels, oysters and several gastropod species which constitute their main food (Capapé 1975), similar patterns could explain also the presence in the area of *Gymnura altavela*, *Myliobatis aquila* and *Pteromylaeus* *bovinus*.

These 6 species have not important economical value, however they are consumed by local population having low income, and they are not discarded as it was the case for torpedinid species. They are vulnerable to fishing pressure due to fact they adhere to K-selected life-histories and their recruitment remains difficult, these species are not very abundant in the neighbouring shallow coastal waters.

Consequently, *Torpedo torpedo* is a species of small size and it was abundantly and regularly caught in the area, so it could be considered as a sedentary species. *T. marmorata*, *D. chrysonota* could also be potentially considered as sedentary species, however, their real status in the aera needs to be assessed. *Gymnura altavela*, *Myliobatis aquila* and *Pteromylaeus bovinus* are species of which fry and juveniles enter the lagoon to find sufficient resources and to develop; they are rather regular migratory species. The relation size *versus* disc width corroborated this hypothesis.

Additionally, following both classifications of Compagno & Cook (1995) and Aidan Martin (2005), 6 species maximum could be considered as marginal species, inshore marine and marginal in fresh water. The three other species, all dasyatids are probably euryhaline species, they entered estuarine rivers to breed, such as the marbled stingray *Dasyatis chrysonota* and the common stingray *D. pastinaca* according to Capapé & Zaouali (1995).

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# Espectro trófico de la raya eléctrica *Narcine bancroftii* (Griffith & Smith 1834) (Elasmobranchii, Narcinidae) en playa Salguero, Santa Marta, Caribe Colombiano

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**Abstract. Trophic spectrum of the electric ray *Narcine bancroftii* (Griffith & Smith 1834) (Elasmobranchii, Narcinidae) in playa Salguero, Santa Marta, Colombian Caribbean.** The Bancroft's numbfish *Narcine bancroftii*, a common species in coastal fisheries as bycatch, has been scarcely studied. The poor knowledge about important biological aspects and life history do not permit to take control management measures to allow species conservation. We included one important aspect about the diet composition, which include the analysis of 198 stomachs to about the trophic spectrum. Number or prey organism (N), weigh (P), frequency of occurrence (FO), index of relative importance (IRI), diversity, prey uniformity, trophic niche amplitude (*Bi*), and diet overlapping ($C\lambda$) methods were used. The most important preys were: Sipunculidae, Callianassidae and Ophichthidae. The females shown higher prey diversity values and males had the highest uniformity values. The diet changed ontogenetically and feeding areas were common to both sexes and all stages of development. The Bancroft's numbfish is considered a specialist ray, eating mainly sipunculids, with a diverse diet including several benthic preys.

**Key words:** Ecology, Index of relative importance (IRI), Bancroft's numbfish, Feeding, Colombia.

**Resumen.** La raya eléctrica *Narcine bancroftii* ha sido poco estudiada a pesar de ser común en las capturas costeras como pesca incidental. El desconocimiento de aspectos biológicos importantes en su historia de vida no permite tomar medidas de control que ayuden a la conservación de esta especie. Uno de estos aspectos es la composición de su dieta, para ello se analizaron 198 ejemplares con el fin de generar información de su espectro trófico, teniendo en cuenta los métodos numérico (N), gravimétrico (P), frecuencia de aparición (FA) e índice de importancia relativa (IIR), además de la diversidad, uniformidad de presas, amplitud del nicho trófico (*Bi*) y superposición de la dieta ($C\lambda$). Las presas más importantes fueron las familias Sipunculidae, Callianassidae y Ophichthidae. Las hembras presentaron mayor diversidad de componentes alimentarios y los machos mayores valores de uniformidad. Se observó que la dieta cambia conforme aumenta la talla y que el área de alimentación es común para machos y hembras en todos los estados de desarrollo. En términos generales se consideró que *N. bancroftii* es una raya especialista consumiendo principalmente sipuncúlidos, con una dieta diversa compuesta por presas bentónicas.

**Palabras clave:** Ecología, Índice de importancia relativa (IIR), *Narcine bancroftii*, Alimentación, Caribe, Colombia.

## Introducción

Los peces cartilaginosos de la familia Narcinidae son reconocidos mundialmente por su capacidad de generar electricidad como método de protección y herramienta fundamental en la captura de sus presas. El representante principal en el Caribe colombiano es la raya eléctrica *Narcine bancroftii* (Griffith & Smith 1834) (McEachran & Carvalho 2002), que es capturada de forma incidental con diferentes artes de pesca, entre los que se encuentran las redes de arrastre camaronero y el chinchorro de jala (Acevedo *et al.* 2007, Grijalba-Bendeck *et al.* 2007), no posee ningún valor comercial y en la mayoría de las ocasiones son devueltas al mar.

Se han realizado algunos estudios tróficos en peces cartilaginosos, como los trabajos realizados por Babel (1967) en *Urolophus halleri* (Cooper 1863) y Smith & Merriner (1985) en *Rhinoptera bonasus* (Mitchill 1815). Entre los estudios puntuales para la familia Narcinidae se destacan el de Rodloe (1989) en *Narcine bancroftii* y Valadez *et al.* (2000) en *Narcine entemedor* Jordan & Starks 1895, que coinciden en que estas dos especies de rayas consumen principalmente poliquetos, sipuncúlidos y peces (Ophichthidae).

El comportamiento alimentario y la cinemática de la raya eléctrica *N. bancroftii* fue estudiada por Dean & Motta (2004), quienes establecieron que la protrusión de las mandíbulas es determinante en la captura de la presa. Además encontraron que la raya obtiene su alimento proyectando la mandíbula y generando presión oral para succionar las presas dentro de la boca, estas condiciones le dan un único mecanismo de protrusión entre los batoideos, que ayuda a mejorar el desempeño de la succión de la presa.

En el Caribe colombiano no se cuenta con estudios puntuales de los hábitos alimentarios de la raya eléctrica *N. bancroftii*, pero se mencionan algunos datos de las presas que consumen en trabajos como Dahl (1971), quien sugiere que esta especie consume principalmente poliquetos, mientras que Gómez-Canchong *et al.* (2004) registran el consumo de cangrejos y otros crustáceos, representando un 51,63 % y poliquetos con 26,73 % del peso de la dieta. Este estudio pretende generar información básica de la dieta de la raya eléctrica *N. bancroftii* en el área de playa Salguero, Caribe colombiano, mediante un análisis cualitativo y cuantitativo de las presas encontradas en los contenidos estomacales.

## Materiales y métodos

Los ejemplares de *N. bancroftii* estudiados fueron capturados entre agosto (2005) y octubre (2006), como pesca incidental de las faenas con chinchorro playero, con mangas de 150 m de longitud con 1,5 a 5 cm de ojo de malla en el copo. El área de estudio comprende dos playas de el sector de El Rodadero: la primera playa Salguero, ubicada entre 11° 10´ 56,97´´ N y 74° 14´ 15,59´´ W y 11° 11´ 37,13´´ N y 74° 13´ 49,93´´ W y la segunda entre 11° 11´ 47,05´´ N y 74° 13´ 45,52´´ W y 11° 11´ 51,35´´ N y 74° 13´ 43,22´´ W. Se efectuaron un total de 414 lances, dos a tres por día; las faenas duraron de una a dos horas y se calaron a una distancia de la costa de 350 a 400 m y una profundidad de 5 a 6 m. Se determinó el peso húmedo total y eviscerado de cada ejemplar, luego se realizó la disección ventral del animal, desde la abertura cloacal hasta la región cardiaca, en estas condiciones se analizaron algunos aspectos reproductivos como el estado de madurez teniendo en cuenta características como desarrollo gonadal, presencia de embriones en hembras y semen en machos. En cuanto al aspecto trófico se extrajo el estómago realizando un corte a la altura del esófago y otro donde termina la válvula espiral. El contenido estomacal se separó por grupos mayores, se evaluó el porcentaje de llenado de cada estómago y el estado de digestión de cada ítem encontrado, según las escalas propuestas por Stilwell & Kohler (1982). Se identificaron los componentes teniendo como referencia los trabajos de Meglitsch (1972), Barnes & Ruppert (1996) y Barreto & Mancilla (1999) en la ubicación de taxones superiores, para los poliquetos se usó Fauchald (1977), la familia Callianassidae Manning & Felder (1991), Ophichthidae McCosker *et al.* (1989) y para la familia Sipuncúlidae se tuvieron en cuenta los criterios de Saiz (1986).

Para determinar si el número de estómagos fue representativo, se realizó una curva acumulativa de especies presa, sometiendo los estómagos a 500 permutaciones en el programa Estimate 8.0 (Colwell 2006). Luego se ajustaron los datos al modelo de Clench (Jiménez-Valverde & Hortal 2003) en el programa Statistica 7.0 CAP (Community Analysis Package), calculando de esta forma algunos parámetros, como el coeficiente de determinación, el cual indica que cuando un valor es cercano a uno, los datos se ajustan al modelo, además de arrojar el valor de la pendiente de la curva, donde valores menores a 0,1 indican un número suficiente de estómagos para determinar gran parte de la dieta. En la determinación del nivel trófico a partir de las presas encontradas en los estómagos analizados, se utilizó el modelo propuesto por Cortés (1999), el cual nos brinda información con respecto a la posición trófica relativa de los organismos en la red trófica. El nivel trófico (TL) fue calculado como:

$$TL = 1 + (\sum_{j=1}^{11} Pj * TLj)$$

Donde Pj es la proporción de cada categoría de presas y TLj se considero como el nivel trófico de cada categoría de presas j, el cual fue obtenido de Cortés (1999) y Ebert & Bizzarro (2007). Para la caracterización de la dieta se determinó la frecuencia de aparición (FA), el número mediante el método numérico (N) y peso con el índice gravimétrico (P) (expresado en gramos) de cada presa (Hyslop 1980), además se calculó el índice de importancia relativa (IIR) como valor absoluto y en porcentaje (Pinkas *et al.* 1971) con el propósito de evaluar las variaciones mensuales de la dieta por sexos y estadio de desarrollo como:

$$IIR = (\%P + \%N) * \%\, FA$$

Donde IIR es el índice de importancia relativa, %P es el porcentaje en peso de la presa, %N porcentaje en número de la presa y %FA porcentaje de frecuencia de aparición (Hyslop 1980). Para la determinación de presas principales, secundarias y ocasionales se compararon los valores calculados (IIR) con los valores propuestos por Duarte & von Schiller (1997), valores de 0 a 20 corresponden a presas ocasionales, de 21 a 200 secundarias y de 201 a 20000 principales. La diversidad de presas se estableció mediante el índice de Shannon-Wiener (*H'*). La amplitud de la dieta se calculó utilizando el índice estandarizado de Levin (Krebs 1989), empleando la técnica propuesta por Labropoulou & Eleftheriou (1997) como:

$$Bi = \frac{1}{n} - 1[\left(\frac{1}{\Sigma JPij^2}\right) - 1]$$

Donde $Bi$ es el índice de Levin para el depredador $j$, $Pij^2$ es la proporción de la dieta del depredador $i$ sobre la presa $j$ y $n$ es el número de categorías de presas, los valores de este índice fluctúan de 0 a 1, menores a 0,6 indican que la dieta está dominada por pocas presas, por lo tanto se trata de un depredador especialista y mayores a 0,6 corresponden a dietas de depredadores generalistas (Krebs 1989, Labropoulou & Eleftheriou 1997). Se realizaron análisis de traslapo trófico por sexos, tallas y estadios de madurez, con el fin de determinar si existían diferencias en el tipo de alimento, se utilizó el índice de Morisita-Horn (Smith & Zaret 1982) como:

$$C\lambda = \frac{2\sum_{i-1}^{n}(Pxi * Pyi)}{(\sum_{i-1}^{n} Pxi^2 + \sum_{i-1}^{n} Pyi^2)}$$

Donde $C\lambda$ es el índice de Morisita–Horn entre sexo o estado de madurez $x$ y entre sexo o estado de madurez $y$, *Pxi* es la proporción de presa $i$ del total de presas consumidas por el sexo o estado de madurez $x$, *Pyi* es la proporción de presa $i$ del total de presas consumidas por el sexo o estado de madurez $y$ y $n$ es el número total de presas, este índice oscila entre 0 y 1, valores mayores a 0,6 indican traslapamiento en la dieta (Langton 1982).

Para los análisis de contenido estomacal se utilizó la prueba estadística de ANOSIM ($p < 0.05$) (análisis de similitud de una vía) con el fin de determinar si la composición específica de las presas fue diferente entre sexo. ANOSIM es un procedimiento no paramétrico, análogo al análisis de varianza, que se basa en el re-muestreo multifactorial utilizando permutaciones. La prueba estadística implica el cálculo de un estadístico global (R), el cual contrasta la varianza de la similitud dentro y entre los grupos.

Cuando los grupos de muestras son distintos unos de otros, la composición de la similitud dentro de los grupos son más grandes que las similitudes que pueda existir entre las muestras de diferentes grupos. El estadístico R, de ANOSIM, varía entre -1 y 1, alcanzando su valor máximo cuando todas las similitudes dentro de los grupos son mayores que las similitudes entre los grupos (hay separación perfecta en la estructura trófica entre los grupos); mientras que en caso contrario, R alcanza su valor mínimo e indica que no hay separación en la estructura trófica entre los grupos.

La significancia de la prueba estadística se determina comparando el estadístico R de la muestra con aquellos que resultan del procedimiento de asignar muestras aleatorias a los grupos a través del re-muestreo utilizando permutaciones (Clarke & Warwick 1994). La proporción del arreglo aleatorio con valores de R mayores que el valor R de la muestra es el nivel de significancia de la prueba (Clarke & Warwick 2001). Este análisis fue realizado mediante la utilización del paquete PRIMER V6.0 (Plymouth Routines in Marine Environmental Research programs) (Clarke & Warwick 2001).

## Resultados

Se analizaron 198 estómagos, 102 (51,52 %) presentaron algún tipo de contenido y los 96 (48,48 %) restantes se encontraron vacíos. La mayor cantidad de estómagos llenos se registró en septiembre (n=15) y octubre (n=16) de 2005 y sólo en agosto del mismo año se extrajeron estómagos sin contenido (Fig. 1). El número de estómagos analizados fue representativo, como lo demostró el valor de la pendiente de la curva $1{,}695^{e-5}$ describiendo el 86,81 % de la dieta, además dichos valores se ajustan al modelo de Clench (Jiménez-Valverde & Hortal 2003) ya que el coeficiente de determinación ($R^2$ = 0,964) incluye una correlación alta (Fig. 2). Se registraron 58,82 % de los estómagos con un porcentaje de llenado del 25 %, 39,22 % con el 50 % y sólo el 0,98 % con 75 % y 100 % de su capacidad; para ambos sexos el porcentaje de llenado más común fue el 25 % (el 51,90 % de las hembras y el 82,81 % de los machos); en cuanto al grado de digestión el estado mejor representado fue el tres con 49,02 %, presentando un mayor porcentaje en machos 65,22 % que en hembras (44,30 %).

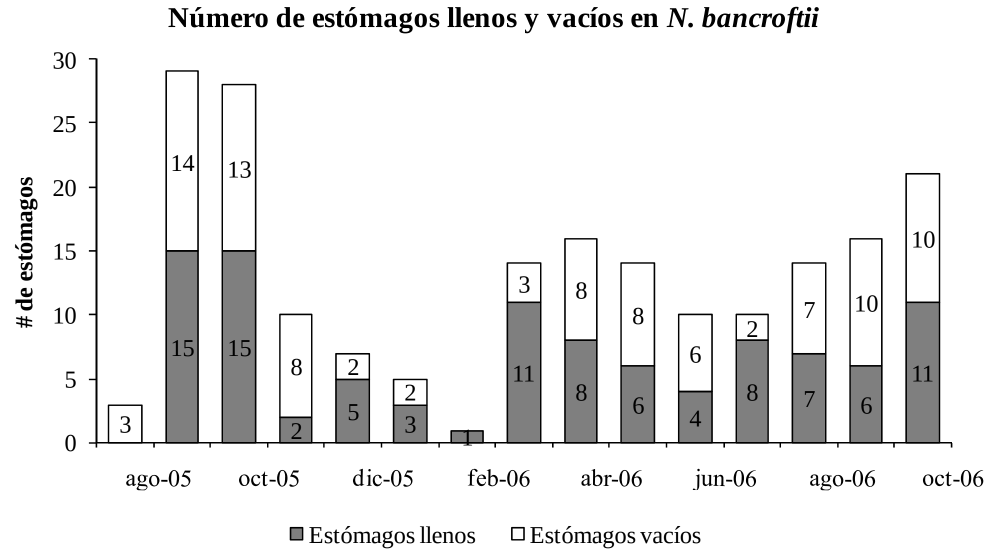

**Figura 1.** Número de estómagos llenos y vacíos en *N. bancroftii* capturada en playa Salguero Caribe colombiano**.**

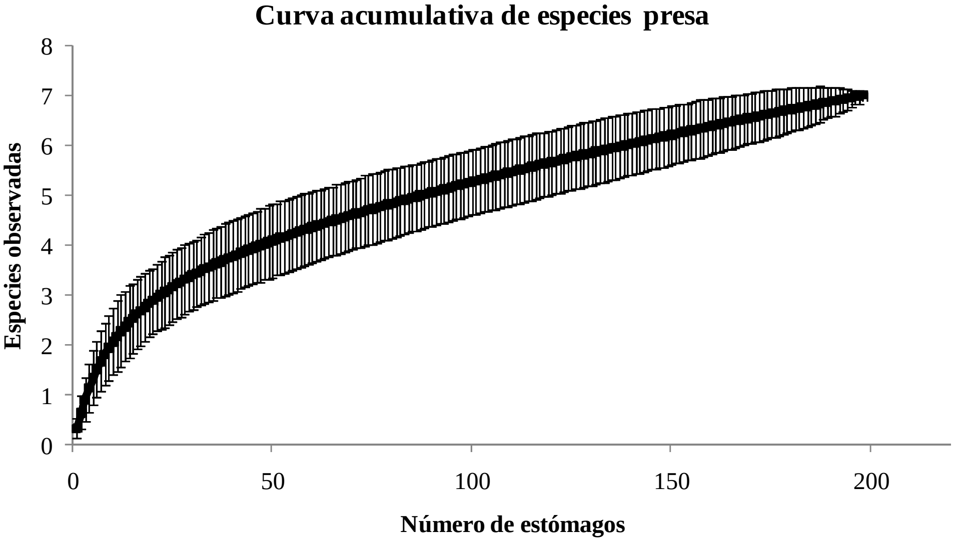

**Figura 2.** Curva acumulativa de especies presa para la raya eléctrica *N. bancroftii* en el área de playa Salguero Caribe colombiano.

Se diferenciaron siete tipos de componentes alimentarios a nivel de familias: Callianassidae, Sicyoniidae, Palaemonidae, Sipunculidae, Ophichthidae, Eunicidae y Terebellidae; además restos de gusanos y crustáceos. Teniendo en cuenta las presas encontradas se obtuvo que el nivel trófico general para *N. bancroftii* basados en la tabla propuesta por Cortés (1999) fue de 3,60, mientras que los valores por sexo fueron cercanos (hembras 3,61, machos 3,54); por otra parte los resultados tomando como referencia el estudio de Ebert & Bizzarro (2007), muestran valores similares aunque un poco mayores, el nivel trófico general fue de 3,65, hembras 3,66 y machos 3,61. Las hembras presentaron todos los componentes y exclusividad por camarones (Sicyoniidae y Palaemonidae) y poliquetos (Terebellidae), mientras que los machos consumieron principalmente sipuncúlidos (Sipunculidae), poliquetos (Eunicidae), gambas excavadoras (Callianassidae) y peces (Ophichthidae). Se registraron variaciones de la dieta con respecto al sexo y tallas, ambos sexos consumen sipuncúlidos durante toda su vida, ya que se encontró este ítem en todo el ámbito de tallas, desde las de nacimiento hasta adultos grandes (131-565 mm), a diferencia de las gambas excavadoras, poliquetos y peces, que fueron capturados por hembras mayores a 257 mm principalmente (Tabla I).

**Tabla I.** Número de presas capturadas por cada sexo e intervalo de talla (mm) en el que fueron registradas para *N. bancroftii*, capturada en playa Salguero, Caribe colombiano.

| **Presas** | **# presas en hembras** | **# presas en machos** | **Ámbito de tallas en hembras (mm)** | **Ámbito de tallas en machos (mm)** |
|---|---|---|---|---|
| Callianassidae | **28** | **6** | **257-545** | **332-457** |
| **Sicyoniidae** | **2** | | **334** | |
| Palaemonidae | **1** | | **334** | |
| **Terebellidae** | **1** | | **545** | |
| **Eunicidae** | **8** | **6** | **236-465** | **257-259** |
| **Sipunculidae** | **40** | **9** | **150-565** | **131-400** |
| Ophichthidae | **13** | **1** | **310-565** | **395** |

*Índices tróficos*. El método numérico (N) destacó la familia Sipunculidae como grupo dominante 42,61 %, seguido por Callianassidae 29,56 %, Ophichthidae y Eunicidae con 12,17 % cada una y por último Sicyoniidae 1,74 % y Palaemonidae 0,87 %. El análisis por sexo mostró que Sipunculidae es muy importante en número para ambos sexos (hembras 43,01 %, machos 40,09 %) al igual que las gambas excavadoras (hembras 30,10 %, machos 27,27 %) que figuran en segundo lugar, particularmente para las hembras los peces ocupan el tercer lugar de importancia con 13,98 %, mientras que para los machos fueron importantes los gusanos de la familia Eunicidae con 27,27 % (Fig. 3 y Tabla II). La frecuencia de aparición (FA) mostró a Sipunculidae como presa conspicua 40,20 %, seguida por Callianassidae 19,61 % y Ophichthidae 12,75 %. Tanto las hembras como los machos al parecer prefieren los sipuncúlidos, ya que fueron evidentes en la dieta de ambos sexos (hembras 41,77 % y machos 34,78 %), al igual que en el método numérico las gambas excavadoras fueron más frecuentes en la dieta de ambos sexos que los poliquetos (Eunicidae) y peces (Ophichthidae) (Fig. 3 y Tabla II).

**Tabla II.** Espectro trófico de *N. bancroftii*, expresado en valores porcentuales de los métodos numérico (N), gravimétrico (P), frecuencia de aparición (FA) e índice de importancia relativa (IIR).

| **Especies Presa** | **N (%)** | **P (%)** | **FA (%)** | **IIR** | **% IIR** | **Categoría** |
|---|---|---|---|---|---|---|
| Callianassidae | 29,56 | 6,39 | 19,60 | 705,10 | 15,34 | Principal |
| Sicyoniidae | 1,73 | 0,43 | 0,98 | 2,13 | 0,04 | Circunstancial |
| Palaemonidae | 0,87 | 0,11 | 0,98 | 0,96 | 0,02 | Circunstancial |
| Terebellidae | 0,87 | 0,91 | 0,98 | 1,75 | 0,03 | Circunstancial |
| Eunicidae | 12,17 | 6,61 | 7,84 | 147,39 | 3,20 | Secundaria |
| Sipunculidae | 42,60 | 42,21 | 40,60 | 3409,67 | 74,19 | Principal |
| Ophichthidae | 12,17 | 13,60 | 12,74 | 328,55 | 7,14 | Principal |

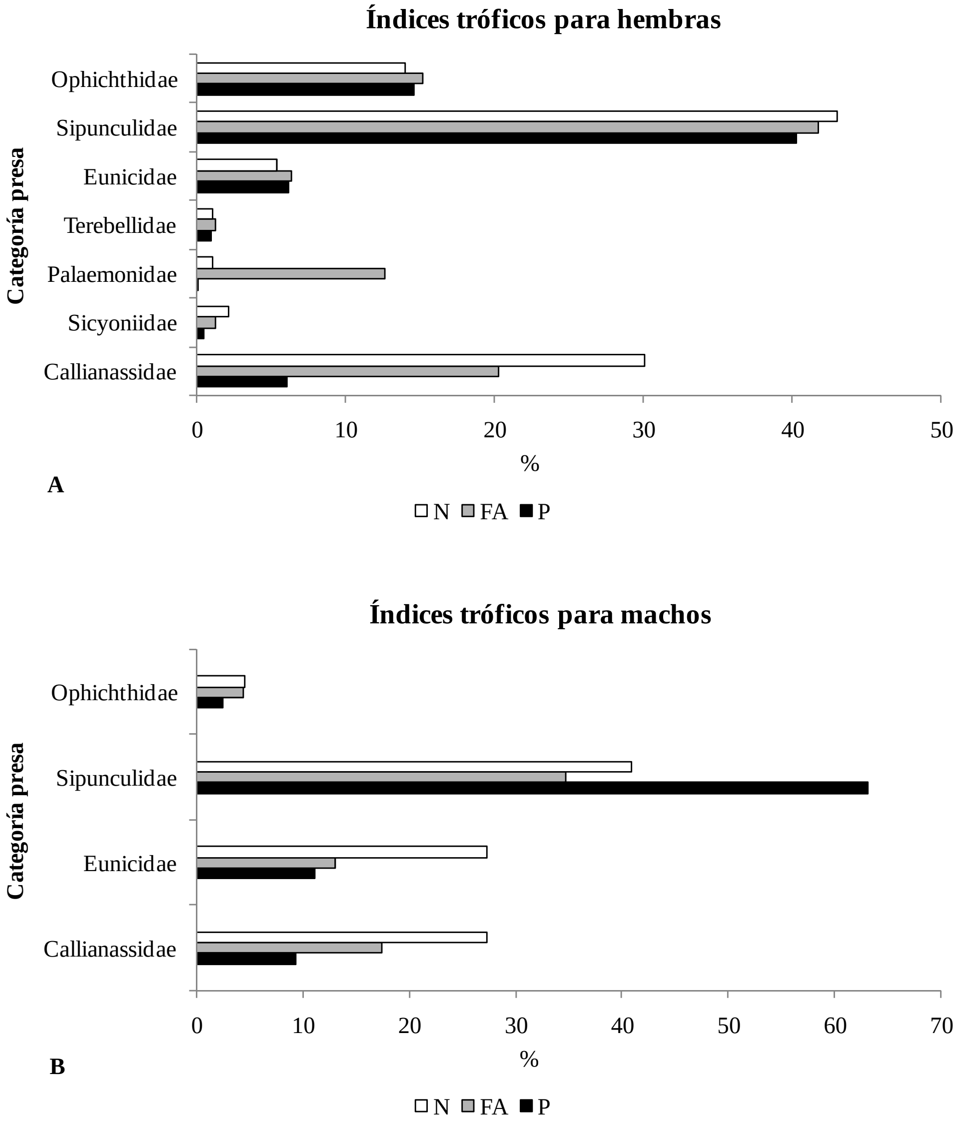

**Figura 3.** Índices tróficos y su representación en porcentaje en el espectro alimentario de *N. bancroftii*, capturada en playa Salguero Caribe colombiano, A hembras y B machos, frecuencia de aparición (FA), método gravimétrico (P) y método numérico (N).

El método gravimétrico (P) presentó la familia Sipunculidae como la mejor representada en peso 42,21 %, seguida por los peces Ophichthidae 13,60 % y Callianassidae 6,39 %. Estos datos contrastan con el porcentaje en N y FA, ya que en estos la importancia de Callianassidae fue mayor, pero su representación en peso no resultó significativa (Tabla II). Caso contrario de la familia Ophichthidae que obtuvo mayor importancia debido a su peso, para los machos fue más importante en peso Sipunculidae 63,07 % que para las hembras 40,31 %, al igual que la familia Eunicidae 11,07 % en machos y 6,21 % en hembras (Fig. 3).

Con el índice de importancia relativa (IIR) se determinó que la familia Sipunculidae fue la más importante en la dieta (3409,67) junto con Callianassidae (705,10) y Ophichthidae (328,55) se pueden considerar como presas principales según la escala de Duarte & von Schiller (1997), como presa secundaria se registró a Eunicidae 147,39 mientras que Sicyoniidae, Palaemonidae y Terebellidae fueron categorizadas presas ocasionaes (Tabla II). El % IIR por sexo mostró que para las hembras la familia Sipunculidae fue la más importante con el 73,38 %, valor un poco menor al observado para los machos 75,59 %, el segundo ítem de mayor importancia fue la familia Callianassidae con 15,47 % (hembras) y 13,31 % (machos); la familia Ophichthidae se ubicó en tercer lugar de importancia para las hembras 9,16 %, mientras que en los machos fue la familia Eunicidae con 10,45 %. Los resultados por sexo y estadios de desarrollo evidenciaron que los sipuncúlidos son consumidos en todas las etapas de desarrollo para ambos sexos, siendo muy importantes en la dieta de machos inmaduros 81,44 % y hembras maduras 72,32 % y en menor proporción aparece la familia Callianassidae para los estadios inmaduros de hembras 5,25 % y machos 2,10 %. Caso contrario ocurre con Eunicidae que se presentó en mayor porcentaje en maduros de ambos sexos y finalmente Ophichthidae tuvo relevancia en hembras 10,14 % y machos maduros 2,52 % (Fig. 4).

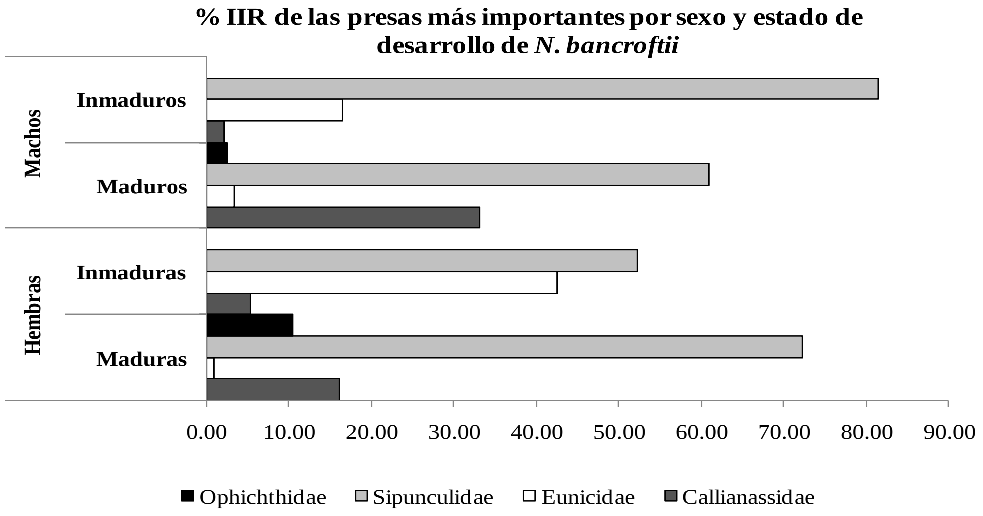

**Figura 4.** Porcentaje del IIR de las presas más importantes por estados de madurez para hembras y machos de *N. bancroftii*.

*Índices ecológicos.* La diversidad máxima estimada a nivel general fue 1,94 y la calculada para la dieta 1,36±0,05, indicando un espectro trófico diverso, dominado por Sipunculidae y Callianassidae. Los valores de la diversidad calculada y máxima por sexos y estadios de desarrollo corroboraron la hipótesis de que la dieta de esta raya es diversa pero con preferencias por algunas presas, además se encontraron variaciones entre sexos, siendo el espectro de las hembras más diverso, condición que fue evidente al comparar el valor de hembras 1,39±0,05 con el de los machos 0,58±0,01 (Tabla III). La uniformidad de presas en términos generales fue 0,70, los valores por sexo aumentan a 0,91 para hembras inmaduras y machos maduros mientras que en machos inmaduros fue de 0,81, indicando que esta raya eléctrica consume gran variedad de presas en proporciones similares, a pesar de tener preferencias (Tabla III).

**Tabla III.** Diversidad, uniformidad de presas y amplitud del nicho, general, por sexos y estados de desarrollo de *N. bancroftii*.

| Rayas | Shannon-Wiener ($H'$) | Diversidad Max | Uniformidad | Índice de Levin ($Bi$) | Índice de Morisita-Horn ($C\lambda$) |
|---|---|---|---|---|---|
| General | 1,36 ± 0,05 | 1,94 | 0,70 | 0,32 | |
| Hembras | 1,39 ± 0,05 | 1,94 | 0,71 | 0,33 | 0,93 |
| Machos | 0,58 ± 0,01 | 1,38 | 0,77 | 0,53 | |
| Hembras maduras | 1,36 ± 0,05 | 1,94 | 0,70 | 0,31 | 0,73 |
| Hembras inmaduras | 1,00 ± 0,02 | 1,09 | 0,91 | 0,52 | |
| Machos maduros | 1,27 ± 0,04 | 1,38 | 0,91 | 0,59 | 0,77 |
| Machos inmaduros | 0,90 ± 0,02 | 1,09 | 0,81 | 0,37 | |

La amplitud del nicho trófico (*Bi*) al igual que el IIR mostró que la raya eléctrica puede ser considerada especialista 0,32, con una dieta dominada principalmente por Sipunculidae. Entre sexos (hembras 0.33 y machos 0.53) y estadios de desarrollo se observó una clara especialización de la dieta (Tabla III). La superposición de dieta ($C\lambda$) entre sexos registró un valor de 0,93, representando un traslapo evidente, lo cual indica que comparten un área específica consumiendo las presas más abundantes, como los sipuncúlidos. Entre hembras maduras e inmaduras el valor registrado fue 0,73 y para machos maduros e inmaduros 0,77; lo anterior demuestra que entre estados de desarrollo existe traslapo, el cual fue corroborado nuevamente mediante el análisis de similitud ANOSIM, debido a que el R global de la prueba fue de 0,022, con un *P* valor de 0,05, indicando que no existe segregación alimentaria por sexo ni estadio de madurez ya que comparten una área de alimentación, consumiendo varios tipos de presas en diferentes proporciones.

## Discusión

Con base en los resultados, se propone que *N. bancroftii* se alimenta de animales bentónicos al igual que otras rayas de su género, como lo mencionan Valadez *et al.* (2000) para la raya eléctrica del Pacífico *N. entemedor*, quienes registraron dentro de los componentes más importantes a los poliquetos. Al igual que *N. bancroftii*, *N. entemedor* también presentó como presa representativa a los sipuncúlidos que aportaron significativamente en peso (P), confirmando que, a pesar de encontrarse en áreas geográficas diferentes, estas dos rayas guardan muchas similitudes, al punto que en algún momento se pensaba que podían ser la misma especie, registrando hábitos alimentarios similares (Bigelow & Schroeder 1953).

Según los resultados obtenidos en cuanto al nivel trófico, *N. bancroftii* se comporta como un consumidor secundario, al igual que otras especies de rayas (Cortés 1999, Ebert & Bizzarro 2007), sin embargo se observaron diferencias es los valores calculados, debido a discrepancias en los datos de los niveles tróficos de las presas, al parecer al incluir a poliquetos y otros gusanos marinos en los cálculos basados en el trabajo de Ebert & Bizzarro (2007), genero que el nivel trófico aumentara, esto se debe probablemente a la importancia de los gusanos marinos (donde estarían agrupados los Sipunculidos) en la dieta de esta raya eléctrica. Por otra parte los autores Ebert & Bizzarro (2007) proponen que rayas de tallas menores a 100 cm tienen la tendencia a comportarse como consumidores secundarios mientras que rayas con tallas superiores a este valor se ubican como consumidores terciarios, lo que concuerda con este estudio para *N. bancroftii*, la cual alcanza una talla máxima de 58 cm, sin embargo se debe considerar que el nivel trófico podría responder más a sus hábitos alimenticios y a la disponibilidad de alimento que consume.

De acuerdo al índice de importancia relativa (IIR), las familias más importantes en la dieta de *N. bancroftii* fueron Sipunculidae, Callianassidae y Ophichthidae que, a pesar de no ser numerosas, ni frecuentes, si fueron representativas en peso. Esto demuestra que la dieta de *N. bancroftii* en el área de estudio (El Rodadero-Colombia) al parecer no está dominada por poliquetos como lo mencionan McEachran & Carvalho (2002) y Dahl (1971), lo cual puede deberse a características puntuales de cada sector así como el microhabitat de las presas; al igual que su variabilidad espacial y temporal dentro de la comunidad bentónica. También es pertinente mencionar que los depredadores tienden a ser oportunistas capturando el recurso más abundante, convirtiéndose en especialista cuando este aumenta de forma evidente su abundancia en el entorno (Pyke 1984).

En términos generales, *N. bancroftii* se consideró una raya especialista consumiendo principalmente sipuncúlidos, sin embargo se observaron diferencias entre sexos y estadios de desarrollo, donde las hembras presentaron una dieta más diversa que los machos, los cuales al parecer fueron más selectivos. Los estadios inmaduro de ambos sexos consumen poliquetos (Eunicidae) en mayor proporción respecto a los ejemplares maduros, esto podría estar relacionado a los procesos de digestibilidad de los depredadores, los cuales pueden generar diferencias en la composición de la dieta por tallas; así, peces en estados juveniles no han desarrollado algunos mecanismos digestivos y por eso sólo consumen presas que puedan digerir (Gerking 1994). Además seleccionan las presas de acuerdo con su habilidad de captura y talla (Dean & Motta 2004), para los neonatos y juveniles puede ser más fácil la captura de gusanos pequeños y manejables como lo describe Rodloe (1989) para *N. brasiliensis* en cautiverio, ya que presas más grandes y rápidas pueden presentar cierto riesgo al momento de la captura.

Se podría mencionar que basado en los cambios de los valores de diversidad entre los estados inmaduros a maduros de ambos sexos, se encontró que esta raya amplia o diversifica su dieta a medida que avanza su estado de madurez, lo que ha sido observado en otros batoideos (Valadez *et al.* 2000), ya que esa diversificación de la dieta también podría estar relacionada con una mayor habilidad en la captura de las presas, ya sea por una mayor capacidad eléctrica o experiencia como depredador. Estas diferencias también se vieron reflejadas en la uniformidad que fue menor en las hembras, indicando que hay una mayor proporción de una presa frente a las demás, esto puede atribuirse a que en los sectores costeros de aguas entre 2-10 m de profundidad donde posiblemente se alimentan, la composición y la oferta del medio permiten dominancia de algunas presas que están perfectamente adaptadas a las condiciones variables de estas zonas, al presentarse en mayor número son más susceptibles a ser consumidas con mayor frecuencia. Es de notar que ambos sexos se alimentaron de gambas, pero sólo las hembras atrapan poliquetos (Terebellidae); esto puede ser un indicio de que la raya eléctrica puede diversificar su alimentación ya que las hembras tienen un espectro más amplio en comparación con los machos, lo que puede deberse a que la permanencia de las hembras cerca de la costa les permite acceder a mayor diversidad de presas; mientras que probablemente los machos están sujetos a la disponibilidad de alimento en aguas más profundas.

Al parecer la forma como la raya eléctrica captura las presas juega un papel importante en su dieta, ya que no sólo las elije por su palatividad, sino que también puede deberse a que son relativamente fáciles de capturar gracias a las adaptaciones de su mandíbula que le permiten literalmente succionarlas del sedimento (Dean & Motta 2004). Lo anterior hace de esta raya un depredador de presas bentónicas muy eficiente, a tal punto que le permite capturar sipuncúlidos, poliquetos y ophíchthidos completos sin dañar ninguna estructura, a pesar que estos se encuentren enterrados a varios centímetros en el sedimento (Dean & Motta 2004).

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# Distribuição e abundância de *Narcine brasiliensis* (Olfers, 1931) (Elasmobranchii, Narcinidae) no litoral norte do Estado de Santa Catarina, Brasil

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**Abstract. Distribution and abundance of *Narcine brasiliensis* (Olfers, 1931) (Elasmobranchii, Narcinidade) off northeast coast of Santa Catarina State, Brazil.** The aim of this work is to establish the bathymetric and seasonal distribution of *Narcine brasiliensis* in the north coast of the Santa Catarina State, Brazil. The analyses were proceeding from capture data of *N. brasiliensis* collected on the continental shelf off Babitonga Bay (26°S). The species has its constant abundance during all seasons, being represented by individuals in different phases of life cycle. It can predominantly be characterized as resident of the area, being distributed between 10 and 20 m in depths. A standard was observed which reflects the preference of occupation of shallow waters (10 m), during the summer. In autumn/2006 and winter/2006 the species concentrate in 20 m, presenting higher latitudinal and longitudinal distribution. Considering the totality of *N. brasiliensis* distribution area, highlighting its constant abundance during the studied period, the population ontogenetic composition and the propitious hydrological features generated by fluvial systems of Baía da Babitonga, it can be suggested that the north coast of the State of Santa Catarina, constitutes *N. brasiliensis* nursery and grow area in south Brazil.

**Key-words**: demersal elasmobranch, distribution area, Baia da Babitonga.

**Resumo.** O presente trabalho tem como objetivo determinar a distribuição batimétrica e sazonal de *Narcine brasiliensis* no litoral norte do Estado de Santa Catarina, Brasil. As análises foram provenientes de dados da captura de *N. brasiliensis* coletados na plataforma continental adjacente a Baía da Babitonga (26°S). A população tem sua abundância constante durante todas as estações do ano, sendo representada por indivíduos em diferentes fases de ciclo de vida. Pode ser caracterizada como residente da área, distribuindo-se predominantemente entre 10 e 20 m em profundidades. Observou-se um padrão que reflete a preferência de ocupação de áreas mais rasas (10 m), durante os meses de verão. No outono/2006 e inverno/2006 a espécie mostra tendência de concentração nos 20 m, apresentando maior distribuição latitudinal e longitudinal. Considerando a totalidade da área de distribuição de *N. brasiliensis*, destacando a sua presença constante durante o período estudado, a composição ontogenética da população e as características hidrológicas propícias geradas pelo aporte fluvial do complexo hídrico da Baía da Babitonga, sugere-se que o litoral norte do Estado de Santa Catarina, constitua área de berçário e crescimento de *Narcine brasiliensis* no sul do Brasil.

**Palavras-chave**: elasmobrânquios demersais, área de distribuição, Baía da Babitonga.

## Introdução

As espécies do gênero *Narcine* são amplamente distribuídas pela plataforma continental de águas tropicais e subtropicais ao redor do mundo (Carvalho & Randall 2003). Em revisão do gênero *Narcine* realizada por Carvalho (1999), a espécie *N. brasiliensis* foi subdividida em três espécies, *i.e. Narcine* sp., *N. bancroftii e N. brasiliensis*, em função de diferenças fenotípicas e distribuição ao longo do Oceano Atlântico. Assim, os trabalhos de Bigelow & Schroeder (1953), Rudloe (1989) e Dean & Motta (2004), que foram desenvolvidos com espécimes da América do Norte, possivelmente tratam da espécie *Narcine bancroftii*, enquanto os estudos realizados no sudeste e sul do Brasil se referem *N. brasiliensis*.

Na América do Sul, a raia elétrica *Narcine brasiliensis* distribui-se do Espírito Santo (Brasil) ao norte da Argentina (Carvalho 1999), sendo uma espécie encontrada em águas costeiras e estuarinas brasileiras de fundos lodosos (Figueiredo 1977, Lessa 1998, Carvalho 1999, Vianna & Vooren 2009). Suas presas constituem-se principalmente de anelídeos poliquetas e crustáceos (Goitein *et al.* 1998, Bornatowski *et al.* 2006).

A plataforma sudeste e sul do Brasil, principalmente nas regiões de Bom Abrigo (24º S), São Francisco do Sul (26º S) e Imbituba (29ºS), sustenta uma alta pressão pesqueira por parte da frota demersal de arrasto duplo (Valentini *et al.* 1991, Perez & Pezzuto 1998, Borzone *et al.* 1999, Perez *et al.* 2001). Em Santa Catarina a produção desembarcada de captura acidental da frota de arrasto duplo é cerca de 2,5 vezes maior que o total capturado de camarão-rosa, sendo estimado um adicional de 9 kg de rejeito a bordo para cada quilo de espécie-alvo (Kotas 1998, Perez & Pezzuto 1998). Segundo Kotas (1998), 14 gêneros e 21 espécies de peixes cartilaginosos fazem parte da captura acidental da pesca do camarão-rosa, constituindo 5,8% da captura total. Destas, 17 espécies são aproveitadas comercialmente, 5 espécies são aproveitadas comercialmente ou rejeitadas a bordo, dependendo do tamanho, da aceitação no mercado e de problemas de conservação a bordo, e 9 espécies são rejeitadas a bordo pois não possuem valor comercial, dentre elas, a raia *N. brasiliensis*.

Em razão da estratégia de vida *k*, os elasmobrânquios não suportam uma elevada pressão pesqueira, sendo mais suscetíveis à sobre-explotação em comparação aos teleósteos, fato associado a baixa taxa de reposição populacional. O conhecimento de parâmetros do ciclo de vida destes organismos são importantes ferramentas para a tomada de decisão em manejo pesqueiro, permitindo a manutenção da capacidade reprodutiva em níveis de recrutamento suficiente para manter a pescaria a cada ano, *e.g.* tamanho máximo e de primeira maturação, sazonalidade reprodutiva e distribuição espaço-temporal da abundância e estrutura populacional.

A tendência de que grande parte dos estudos sobre os impactos pesqueiros concentra-se principalmente em espécies para a qual a pesca é direcionada, se traduz na falta de conhecimento sobre as espécies de menor interesse econômico, capturadas acidentalmente ou rejeitadas a bordo. No caso de espécies sem valor comercial e rejeitadas a bordo, a utilização de cruzeiros científicos propicia a coleta de dados para uma melhor compreensão da dinâmica destes organismos marinhos, suprindo a falta de estatística pesqueira adequada. Neste contexto, o presente trabalho tem como objetivo determinar a distribuição batimétrica e sazonal de *Narcine brasiliensis*, na plataforma interna do litoral norte de Santa Catarina, avaliando sua abundância e estrutura populacional, utilizando dados provenientes de cruzeiros científicos.

## Material e Métodos

O material analisado por este estudo é proveniente do projeto "Levantamento e avaliação das populações de *Litopenaeus schimitti*, *Farfantepenaeus paulensi*s e *F. brasiliensis*" (CAMBA), realizado pelo CEPSUL (Centro de Estudo e Gestão Pesqueira do Sudeste e Sul do Brasil) – ICMBio (Instituto Chico Mendes para a Biodiversidade) em parceria com a UNIVALI (Universidade do Vale do Itajaí), UNIVILLE (Universidade Regional de Joinville) e FURG (Fundação da Universidade do Rio Grande).

A área de estudo está situada no litoral norte do Estado de Santa Catarina, entre as latitudes 25º30'S e 27º00'S, na plataforma continental adjacente a Baia da Babitonga (Fig. 1). Um total de oito cruzeiros de pesca científica foram realizados entre os anos de 2004 e 2006, pelo Navio de Pesquisa "Soloncy Moura" do ICMBio/CEPSUL, adaptado com uma rede de arrasto camaroeira de 24 m de comprimento total, com 30 mm de malha no ensacador.

A unidade amostral utilizada nas análises foi o cruzeiro de pesca, sendo este associado a uma estação do ano, com o seguinte formato: verão (janeiro a março), outono (abril a junho), inverno (julho a setembro) e primavera (outubro a dezembro). A relação dos cruzeiros com as respectivas estações do ano é apresentada na Tabela I.

Durante cada cruzeiro de pesquisa, as coletas foram realizadas em 19 estações, distribuídas da seguinte forma: quatro na isóbata de 10 m e quinze dispostas em três perfis perpendiculares a linha costa, cada um com estações nas isóbatas de 20, 40, 60, 80 e 100 m. Foram efetuados dois lances de pesca em cada estação de coleta, um no período diurno (6:00 às 18:00) e outro no noturno (18:01 às 05:59), totalizando 38 lances por cruzeiro. A duração média de cada arrasto foi de 30 minutos, a uma velocidade média de 3,0 nós.

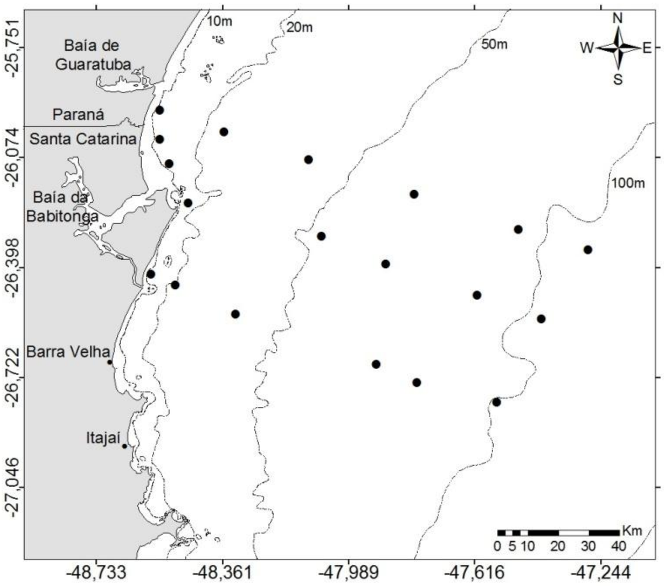

**Figura 1.** Mapa da área de estudo indicando a batimetria e os pontos amostrais no litoral norte do Estado de Santa Catarina, Brasil.

**Tabela I.** Relação dos cruzeiros do Projeto CAMBA realizados no litoral norte do Estado de Santa Catarina, Brasil, com respectivos períodos de coleta.

| **Cruzeiro** | II | III | IV | V | VI | VII | VIII | IX |
|---|---|---|---|---|---|---|---|---|
| **Data** | 28/06/04<br>a<br>02/07/04 | 30/08/04<br>a<br>02/09/04 | 06/01/05<br>a<br>10/01/05 | 18/03/05<br>a<br>22/03/05 | 17-18/10/05<br>e<br>17-19/11/05 | 06/03/06<br>a<br>09/03/06 | 24-25/04/06<br>e<br>03-05/05/06 | 10/07/06<br>a<br>13/07/06 |
| **Estação do ano** | Outono-Inverno/ 2004 | Inverno/ 2004 | Verão I/ 2005 | Verão II/ 2005 | Primavera/ 2005 | Verão II/ 2006 | Outono/ 2006 | Inverno/ 2006 |

As frequências de comprimento e abundância dos indivíduos capturados foram analisados em relação à sazonalidade e profundidade. O comprimento total (CT, cm) foi considerado para as análises de frequência de comprimento. O índice de abundância empregado foi a captura por unidade de esforço (CPUE), padronizada em 1 hora de arrasto e calculada com base na captura por lance, sendo representada por duas unidades, *i.e.* biomassa (kg/h) e número de indivíduos (n/h). O período de maior capturabilidade (D - diurno e N - noturno) foi analisado para ambas as unidades de CPUE, considerando os cruzeiros agrupados.

Diferenças nas distribuições de frequência de comprimento para sexos agrupados foram testadas entre as estações do ano através do teste de “Kruskal-Wallis”. Diferenças nas proporções macho/fêmea (M:F) foram testadas a partir do teste Qui-quadrado ($X^2$), para cruzeiros, profundidades e cruzeiro/profundidade). O teste de “Kruskal-Wallis” foi também aplicado para verificar se existem diferenças nas CPUE entre as estações do ano, e separadamente entre os estratos de 10 e 20m de profundidade, confrontados com as estações do ano. Diferenças nas distribuições de CT para as profundidades foram testadas separadamente para cada estação do ano através do teste “U de Mann-Whitney”, assim como o período de maior capturabilidade. Para as análises estatísticas, as CPUEs foram transformadas em Log (x+1) (Sokal & Rohlf, 1995), sendo p=0,05 o nível de significância empregado. Após uma pré-análise dos dados, foi constatado que *N. brasiliensis* se distribui preferencialmente entre os 10 e 20 m de profundidade (ocorrendo em apenas 2 lances fora desta amplitude batimétrica). Desta forma foi considerado para as análises estatísticas apenas os lances efetuados nas profundidades de 10 e 20 m.

Para a confecção dos mapas de abundância, utilizou-se a densidade relativa (kg/km²) como índice, considerando cada unidade de arrasto como uma amostra dos elasmobrânquios existentes em um quadrilátero. A captura e a distância percorrida durante o arrasto foram padronizadas em uma hora, a uma velocidade de 3,0 nós, sendo a densidade (d) calculada pela expressão:

$$d_x = c / aa_x$$

onde, $d_x$ é a densidade na área arrastada durante o lance *x*; *c* a captura total no arrasto; e *aa* a área varrida pela rede em 1 hora ($km^2/h$). Sendo *aa* calculada a partir da equação (Okonsky & Martini 1987):

$$aa = AB \times L$$

onde, AB é a abertura da boca da rede utilizada (km); e L a distância percorrida pela rede durante o arrasto (km).

## Resultados

Foram capturados 153 indivíduos de *Narcine brasiliensis* com comprimento total (CT) variando entre 8,4 e 45 cm. Observa-se que a proporção sexual se mantém próxima de 1 até os 35 cm CT, sendo que a partir deste comprimento somente fêmeas foram capturadas (Fig. 2). Diferenças nas proporções macho/fêmea foram estatisticamente significantes no outono-inverno/2004 (M:F=1:3,25; p=0,03; $X^2$=4,29; g.l.=1), ocorrendo a predominância de fêmeas. Quando esta proporção foi testada entre as profundidades para cada estação do ano, também observou-se predominância significativamente maior de fêmeas na profundidade de 10 m durante o outono-inverno/2004 (M:F=1:5; p=0,02; $X^2$=5,3; g.l.=1) e nos 20 m durante o verão I/2005 (M:F=1:3; p=0,006; $X^2$=7,5; g.l.=1). Um predomínio de fêmeas também foi constatado durante o outono/2006 na isóbata de 10 m (M:F=1:2; p=0,05; $X^2$=3,7; g.l.=1).

Dos 294 lances efetuados na área de estudo, *N. brasiliensis* ocorreu em 49, com frequência de ocorrência de 16,7%. Se consideramos apenas os lances nas isóbatas de 10 e 20 m de profundidade, a espécie ocorreu em 42% dos 112 lances analisados, variando entre 28 e 36% na primavera e verão, e 36 e 57% outono e inverno.

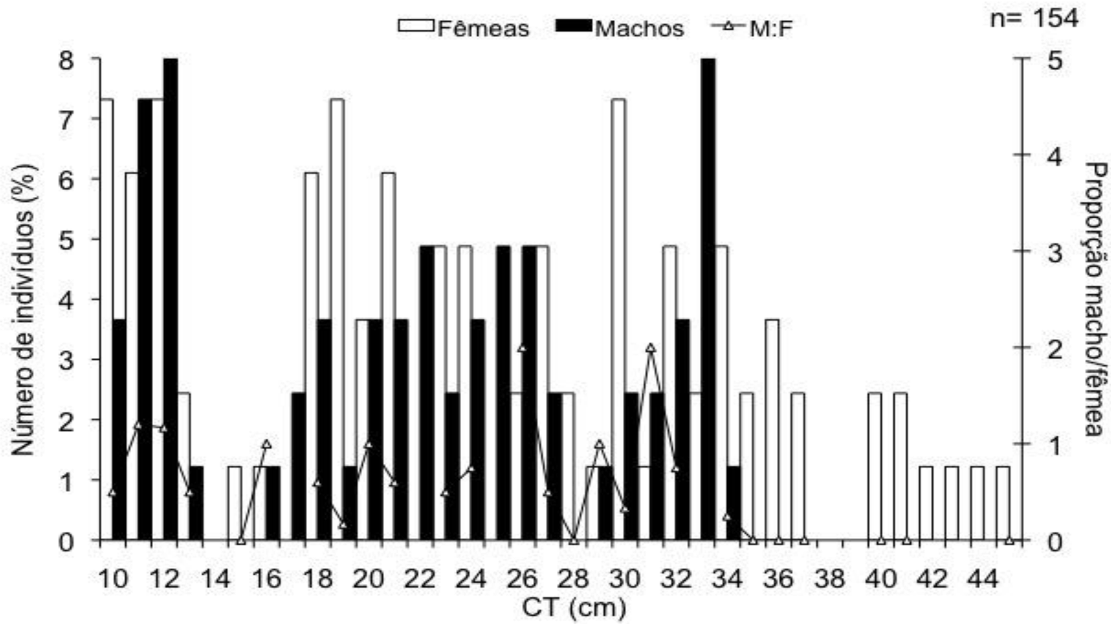

**Figura 2.** Frequência de ocorrência por classe de comprimento de *Narcine brasiliensis* e proporção sexual (M:F), capturadas entre junho/2004 a julho/2006 no litoral norte do Estado de Santa Catarina.

Na variação da CPUE (kg/h e n/h) em relação aos períodos do dia é possível observar que o período de maior capturabilidade de *N. brasiliensis* é o noturno, tendo sido significativamente maior para ambas unidades de CPUE (U-Mann-Whitney; $N_{Diurno}$=54; $N_{Noturno}$=68; n/h, U=1192,5; p=0,029; e kg/h, U=1221,5; p=0,044) (Fig. 3a,b). A frequência de ocorrência da espécie em lances noturnos foi de 48%, enquanto para lances diurnos foi de 30%.

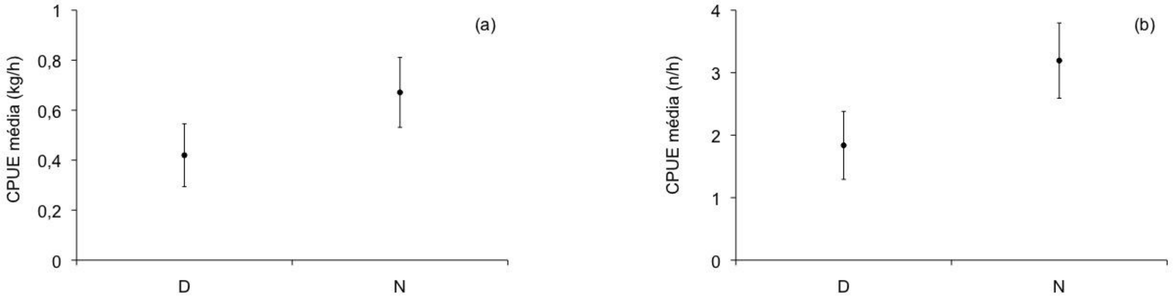

**Figura 3.** Variação da CPUE média em kg/h (a) e n/h (b) por período do dia (D=dia e N=noite), no litoral norte de Santa Catarina, entre junho/2004 a julho/2005. Pontos indicam as médias e as linhas verticais indicam o erro padrão.

A análise da variação sazonal das CPUEs médias para *N. brasiliensis* na área de estudo mostrou haver diferenças entre as duas unidades de CPUE (Fig. 4). Entretanto, o teste de Kruskal-Wallis indicou não haver diferenças significativas entre as médias das CPUEs em kg/h (H=3,20; g.l.=7; p=0,86; n=112) e n/h (H=4,38; g.l.=7; p=0,73; n=112), ao longo dos períodos analisados. Contudo, para a unidade kg/h observou-se um pico durante o verão I/2005 e outro menor no verão II/2005, enquanto para a unidade n/h foram evidenciados valores maiores no outono/2006 e verão I/2005. Ambas as unidades de CPUE apresentaram comportamento similar para os estratos de profundidade de 10 m e 20 m, embora, quando comparados, ser possível observar uma tendência de maior abundância de *N. brasiliensis* na isóbata de 10 m durante o verão I e II/2005, e no estrato de 20 m durante o outono/2006 (Fig. 5a, b).

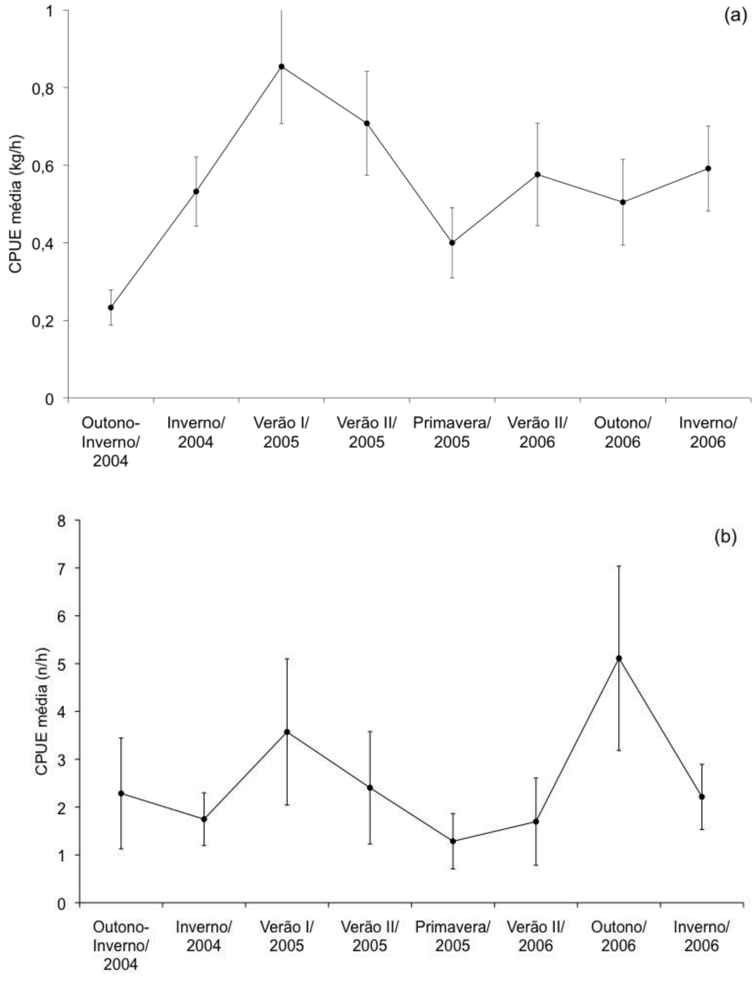

**Figura 4.** Variação sazonal da CPUE média de *N. brasiliensis* em kg/h (a) e n/h (b) o litoral norte do Estado de Santa Catarina, no período de junho de 2004 a julho de 2006. Os pontos indicam a médias e as linhas verticais o erro padrão.

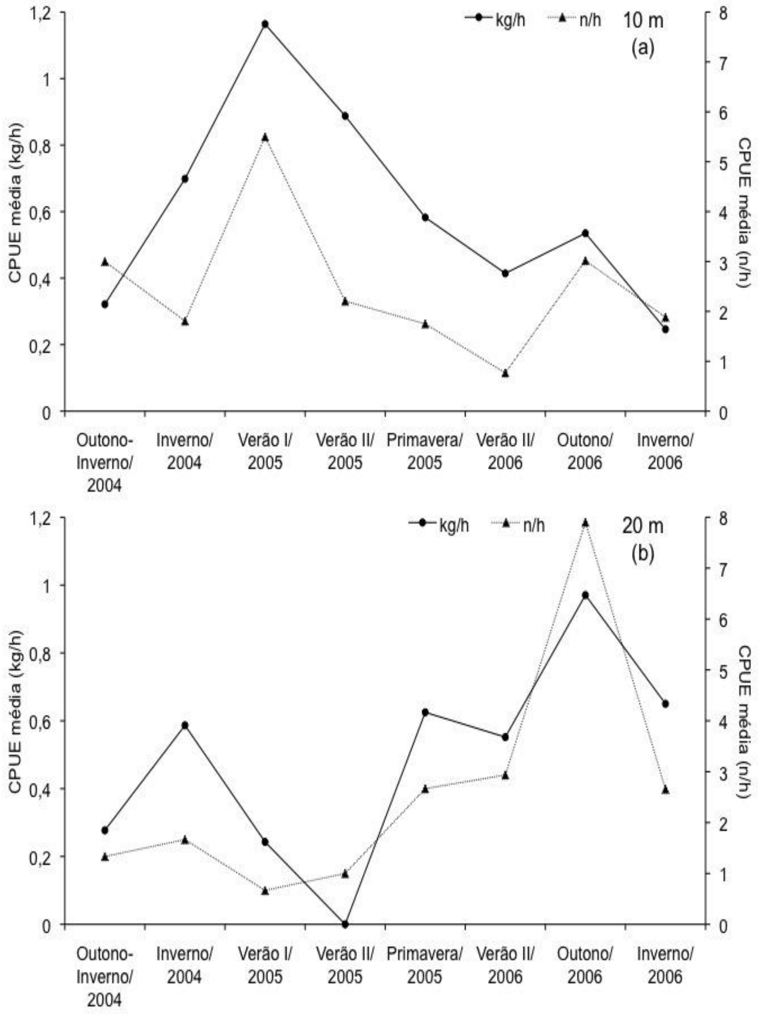

**Figura 5.** Variação sazonal da CPUE média (kg/h e n/h) de *N. brasiliensis* por estrato profundidade no período entre junho/2004 e julho/2006, para o litoral norte do Estado de Santa Catarina nos estratos profundidade 10 m (a) e 20 m (b).

A distribuição de *N. brasiliensis* na área de estudo pode ser observada nas Figuras 6a e b, evidenciando valores elevados de densidades no estrato de 10 m de profundidade no verão I e II/2005 e verão I/2006, e nos 20 m no outono/2006. A análise dos mapas revela a preferência desta espécie pelo setor norte da área de estudo, acima da desembocadura da Baía da Babitonga. Durante o outono/2006 é possível observar grande concentração de indivíduos nas áreas próximas a abertura da Baia da Babitonga, enquanto na porção sul os indivíduos ocorrem de forma escassa e somente nos meses de outono/2006 e inverno/2004 e 2006. Nestes períodos, observou-se a captura de *N. brasiliensis* em 2 lances na isóbata de 80 m.

As distribuições das frequências de comprimento de *N. brasiliensis* (Fig. 7) nas profundidades de 10 e 20 m, no litoral norte do Estado de Santa Catarina, demonstram que a área foi ocupada por indivíduos de diversas classes de comprimento durante todo o período estudo. No verão I/2005, início da estação, pode-se observar uma grande concentração de indivíduos acima de 17 cm na profundidade de 10 m. A partir do verão II/2005 é possível observar o surgimento de indivíduos com CT menor que 13 cm na isóbata de 10 m, enquanto uma parcela de indivíduos maiores mostra uma tendência de deslocamento para os 20 m de profundidade, sendo que um padrão similar foi observado para o verão II/2006. No outono/2006 observa-se uma moda de indivíduos menores que 13 cm CT distribuindo-se nas isóbatas de 10 e 20 m, com a ocorrência de exemplares de maior porte nos 10 m de profundidade e de indivíduos entre 17 e 23 cm CT na isóbata de 20 m. No inverno/2006, uma moda de indivíduos menores que 13 cm CT continua a ser observada nos 10 m de profundidade, sendo detectada uma tendência de desocupação da isóbata de 20 m; padrão semelhante ao observado no outono-inverno/2004. Durante o inverno/2004 e primavera/2005 verifica-se uma ocupação por indivíduos entre 22 e 41 cm CT na isóbata de 10 m, enquanto que em menor concentração são detectados indivíduos entre 17 e 29 cm CT na isóbata de 20 m.

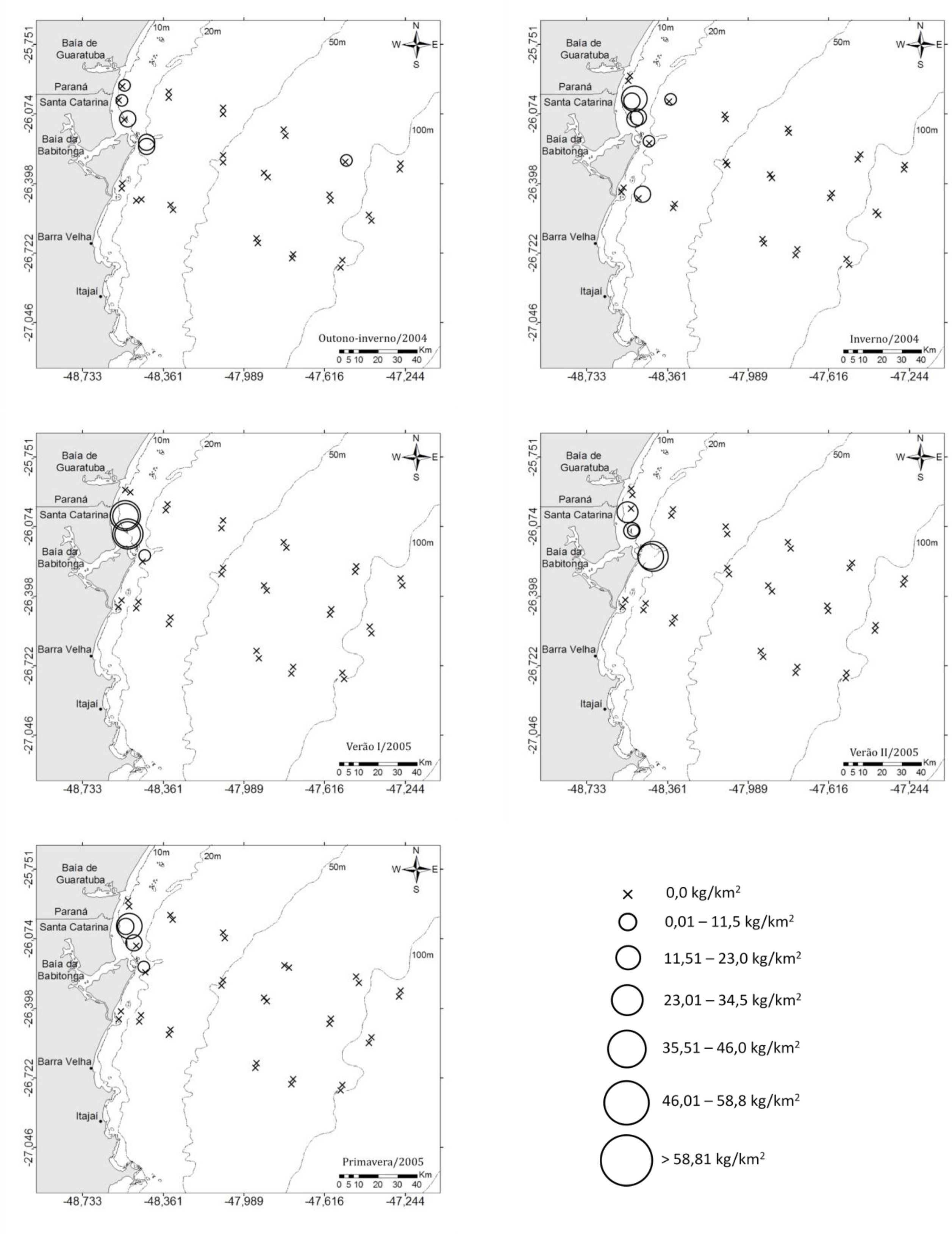

**Figura 6a.** Distribuição espaço-temporal da densidade (kg/km²), de *N. brasiliensis* no litoral norte do Estado de Santa Catarina, nos períodos de outono-inverno/2004, inverno/2004, verão I/2005, verão II/2005 e primavera/2005.

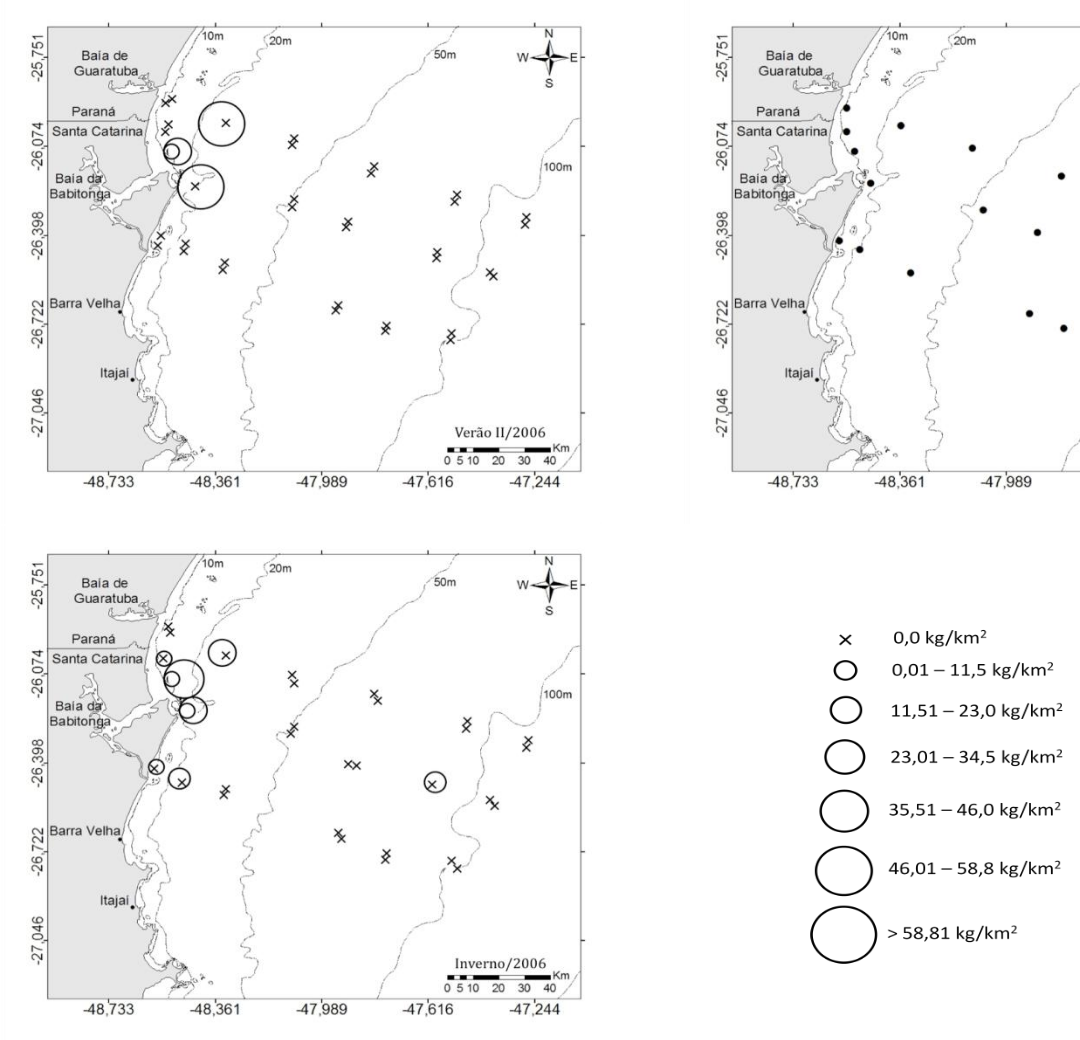

**Figura 6b.** Distribuição espaço-temporal da densidade (kg/km²), de *N. brasiliensis* no litoral norte do Estado de Santa Catarina, nos períodos de verão II/2006, outono/2006 e inverno/2006.

## Discussão

*Narcine brasiliensis* constitui a quarta espécie de elasmobrânquio demersal mais abundante no litoral norte do Estado de Santa Catarina, atrás de *Zapteryx brevirostris*, *Atlantoraja cyclophora* e *A. platana* (Martins 2007). A estrutura populacional desta espécie é composta por indivíduos entre 8,4 e 45 cm CT, o que indica organismos de diferentes fases de ciclo de vida. Além disso, observa-se a presença de neonatos entre 8,4 a 13 cm e de fêmeas grávidas durante os meses de verão e primavera (*observação pessoal*).

Esta espécie caracteriza-se como residente desta área, uma vez que não foram detectadas variações significativas de sua abundância ao longo do ano. Entretanto, uma tendência de maior abundância em biomassa e numérica de *N. brasiliensis* na área de estudo foi observada para o verão I/2005 e outono/2006, respectivamente. Este fato sugere predominância de indivíduos de grande porte na área de estudo durante o verão I/2005, enquanto que no outono/2006 ocorre uma maior concentração de indivíduos de pequeno porte. Por outro lado, no outono/2006 e inverno/2006 a espécie apresentou as maiores frequências de ocorrência nas capturas, evidenciando um contraste entre baixa frequência de ocorrência e elevada abundância em biomassa para o verão I/2005.

Os dados sugerem que esse contraste pode estar associado a uma aglomeração de indivíduos em uma área restrita, próxima a desembocadura da Baía da Babitonga e ao norte desta, ocorrendo capturas significativas em um número menor de lances. Vianna & Vooren (2009) relatam este tipo de aglomeração em locais determinados dentro da área de distribuição da espécie na costa do Rio Grande do Sul. Esse comportamento parece ser característico do gênero *Narcine*, uma vez que também foi registrado em populações da Flórida (Rudloe 1989).

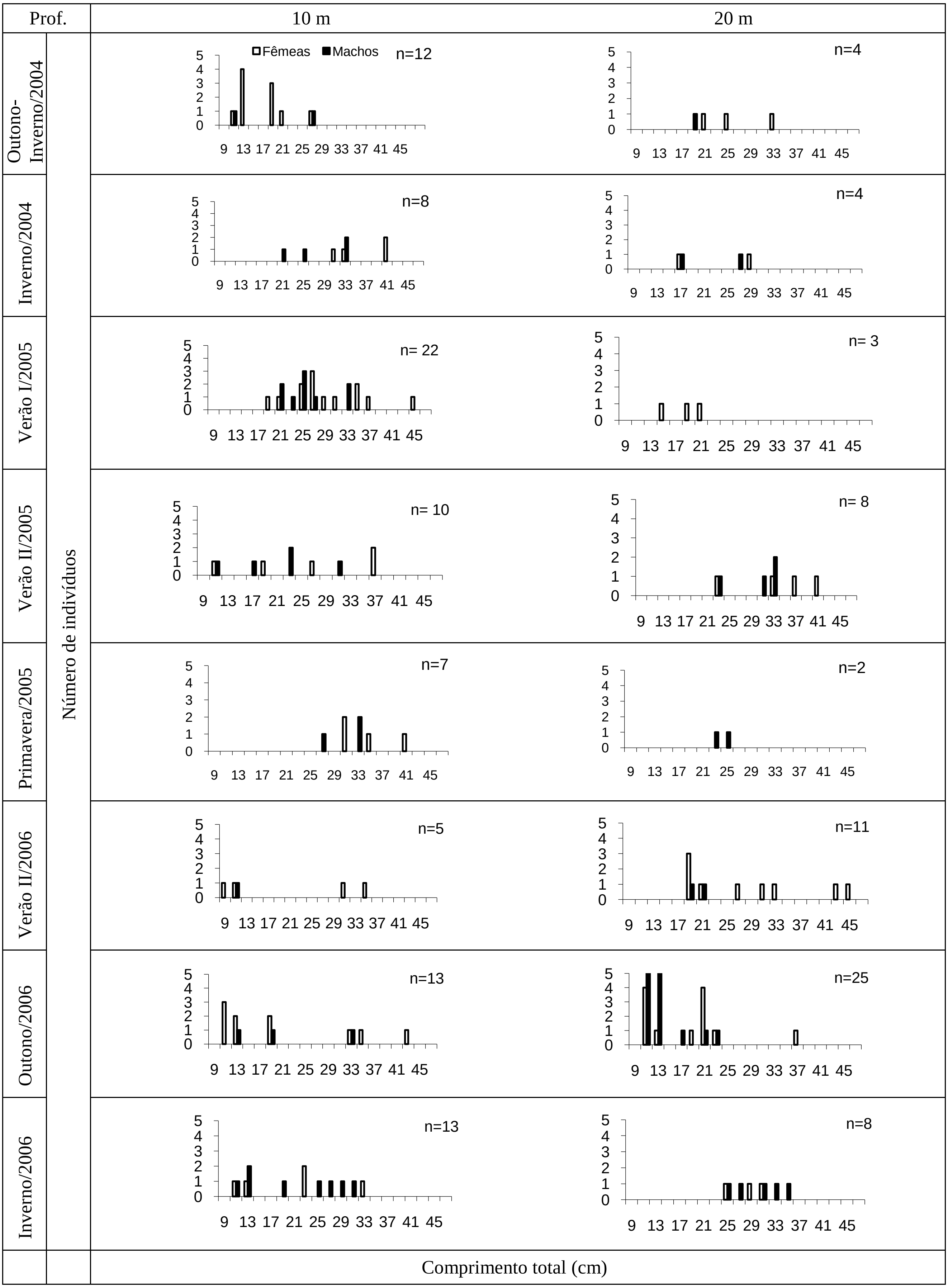

**Figura 7.** Distribuição da frequência de comprimento de *N. brasiliensis* no litoral norte do Estado de Santa Catarina, no período de junho de 2004 a novembro de 2005, para as profundidades de 10 e 20 m.

Tendências de maior abundância na isóbata de 10 m durante o verão I/2005 e nos 20 m durante o outono/2006 foram observadas durante o período estudado. Ao analisar a sazonalidade da estrutura populacional, observa-se indivíduos significativamente maiores no verão I/2005. Indivíduos neonatos, ocorrem na isóbata de 10 m no final do verão (verão II/2005 e verão II/2006), outono-inverno/2004, inverno/2006 e outono/2006, quando são observados também em maiores concentrações nos 20 m. A partir da análise sazonal da composição por sexo das capturas, observou-se o predomínio de fêmeas no outono-inverno/2004, corroborando os resultados de Costa & Chaves (2006), o que pode estar associado ao ciclo de vida desta espécie.

Apesar da abundância constante na área de estudo, *N. brasiliensis* mostrou uma tendência de desocupação da área durante o outono-inverno/2004 e primavera/2005, meses característicos de águas frias. Na costa do Rio Grande do Sul, Vianna & Vooren (2009) correlacionaram elevadas abundâncias desta espécie em áreas com influência da AT, cuja salinidade é maior que 36 e a temperatura acima de 20$^{o}$C, confirmando estudo de Vooren (1997), que caracteriza a espécie como migrante de verão no sul do Brasil.

Estudos de Marafon-Almeida *et al.* (2008), durante a mesma série de cruzeiros analisada pelo presente trabalho, revelaram a dominância da Água Costeira (AC) durante o inverno na plataforma adjacente à Baía da Babitonga, com temperaturas médias de fundo na ordem de 19$^{o}$C. Durante os meses verão, esta região esta sofre influência da Água Central do Atlântico Sul (ACAS) e dominância da Água de Plataforma (AP), *i.e.* mistura da Água Tropical (AT) com a ACAS, apresentando temperatura média de fundo de 23,9$^{o}$C. A salinidade em ambos os períodos variou ente 35,5 na superfície e 36,8 no fundo.

Como visto, as águas do litoral norte do Estado de Santa Catarina não sofrem grande variação de temperatura no fundo, nem de salinidade, como registrado para o sul do Brasil. Muito embora tenham sido observadas tendências sazonais de abundância, este padrão pode explicar a presença constante de *N. brasiliensis* na área de estudo.

O período noturno apresentou as maiores taxas de captura para a espécie. Benoit & Swain (2003) também observaram uma maior capturabilidade no período noturno para raias demersais. Pode-se levantar três hipóteses a respeito deste fato. A primeira seria acerca do hábito alimentar desta espécie. Embora Figueiredo (1977) tenha caracterizado essa espécie como de hábito diurno, a maior capturabilidade observada para o período noturno pode indicar que *N. brasiliensi*s apresente hábito noturno, se alimentando preferencialmente a noite, como observado para *Zapteryx xyster* por Navia *et al.* (2007). *N. brasiliensi*s é uma espécie bentônica, e assim como outras do gênero *Narcine* se mantém enterrada no substrato (Bigelow & Schroeder 1953, Rudloe 1989). Quando está a procura de alimento, nada sobre o substrato fazendo movimentos com o rostro, e então ela projeta a mandíbula para succionar a presa enterrada no substrato (Dean & Motta 2004). Esta estratégia torna a espécie mais vulnerável à rede de pesca. A segunda hipótese seria em função da visualização e consequente fuga do artefato de pesca, durante o período diurno. E a terceira hipótese estaria relacionada a migrações diárias da espécie.

Vianna & Vooren (2009) caracterizaram *Narcine brasiliensis* como uma espécie que habita preferencialmente águas rasas com profundidades inferiores a 20 m e ocasionalmente ocorrendo até os 50 m. O mesmo comportamento foi observado no presente estudo, porém registrando-se ocorrências até os 80 m de profundidade. Como relatado por Vianna & Vooren (2009), esta espécie apresentou maior distribuição longitudinal durante os meses de água fria na costa do Rio Grande do Sul. Este padrão foi confirmado no presente estudo, com as capturas na isóbata de 80 m ocorrendo no fim do outono/2006 e inverno/2006, períodos onde observa-se a maior distribuição latitudinal desta espécie, e quando os indivíduos ocupam a porção sul da área de estudo, abaixo da desembocadura da Baía da Babitonga.

No litoral de Barra Velha (26°37’S), região ao sul da área de estudo, Mazzoleni (2006) mostra que *Narcine brasiliensis* é capturada pela pesca artesanal durante o ano todo, sendo 60% da captura composta predominantemente por neonatos, jovens do ano e jovens. O autor descreveu a espécie como abundante durante a primavera e rara nas outras estações do ano. Esse padrão é oposto ao observado no presente estudo, fato que pode indicar uma migração para o sul durante a primavera.

Costa & Chaves (2006) descrevem a ocorrência desta espécie durante todo o ano nas capturas da pesca artesanal no litoral norte de Santa Catarina e sul do Paraná (26°07’S), sendo encontrados indivíduos em todas as fases do ciclo de vida, com a presença de fêmeas grávidas restrita aos meses de verão e neonatos aos meses de outono. Embora tenha sido registrada uma tendência de menor frequência nas capturas durante verão, esses autores relatam que as capturas podem estar subestimadas, uma vez que espécies sem valor comercial, como *N. brasiliensis*, muitas vezes são descartadas ao mar. Por outro lado, também seria possível que durante o verão, uma parcela destes indivíduos se deslocaria para o sul, área do presente estudo, o que poderia ser evidenciado pela elevada abundância observada neste período.

Com base no exposto acima, presume-se que exista uma única população de *N. brasiliensis* habitando o litoral norte do Estado de Santa Catarina e o sul do Paraná, sendo que os indivíduos desta população realizam pequenas migrações latitudinais dentro de sua área de distribuição, motivadas tanto por fatores abióticos, como também em função de seu ciclo de vida. Estudos mais detalhados sobre a biologia reprodutiva destes indivíduos seriam essenciais para reforçar essa afirmação.

Por muitos anos, a presença de fêmeas grávidas e indivíduos neonatos e jovens em uma determinada área eram suficientes para caracterizar uma área de berçário (Castro 1993, Mazzoleni 2006, Yokota & Lessa 2006). Entretanto, segundo Heupel *et al.* (2007), inúmeras áreas identificadas como berçários podem tirar o foco de manejo de outras áreas cujas características a tornam prioritárias. Neste sentido, os autores definiram três outros aspectos que auxiliam a priorização de uma área de berçário como foco de ações de manejo: 1 - áreas de longa residência das espécies; 2 - áreas onde os indivíduos retornam anualmente, e 3 - áreas onde há maiores chances de encontrar uma determinada espécie em comparação a outros locais. Sob o aspecto físico, estas áreas geralmente são caracterizadas por serem de baixa profundidade, abrigadas e com grande disponibilidade de nutrientes. Neste contexto, considerando a totalidade da área de distribuição de *N. brasiliensis*, e destacando a sua presença constante durante o período estudado, a composição ontogenética da população, e as características hidrológicas propícias geradas pelo aporte fluvial do complexo hídrico da Baía da Babitonga e da Baía de Guaratuba, sugere-se que o litoral norte do Estado de Santa Catarina e o sul do Estado do Paraná, constituam uma área de berçário de *Narcine brasiliensis* no sul do Brasil.

Os efeitos da pesca sobre as populações de elasmobrânquios podem alterar a estrutura e os parâmetros destas populações em função das mudanças na abundância destas espécies (Stevens *et al*. 2000), visto que são organismos de baixo potencial reprodutivo e baixa capacidade de reposição populacional, o que os torna muito vulneráveis à pressão pesqueira. Por conseguinte, a pesca em área de berçário constitui-se uma das maiores ameaças para as populações de elasmobrânquios, uma vez que são utilizadas por indivíduos em estágios iniciais do ciclo de vida, podendo ser também chaves para o recrutamento e a manutenção da população adulta (Bonfil 1997).

Muito embora dados e ferramentas de manejo estejam disponíveis, a vulnerabilidade dos elasmobrânquios exige medidas conservativas de ordenamento das pescarias, visando a sustentabilidade das populações e redução do nível de ameaça à extinção das espécies (Mazzoleni 2006). Atualmente, medidas de manejo da pesca do camarão-rosa são regidas pela Instrução Normativa N° 92 de 7 de fevereiro de 2006, na qual a captura desta espécie é proibida no período de defeso compreendido entre 01 de março e 01 de maio. Esta medida contribui para outras populações residentes na área, reduzindo as taxas de captura durante neste período. Espécies como *N. brasiliensis* podem ser beneficiadas por esta medida, uma vez que são organismos residentes e seu período de parto está compreendido neste intervalo de tempo (*observação pessoal*). Entretanto, o litoral norte do Estado de Santa Catarina não sofre pressão exclusiva da pesca de arrasto de camarão, sendo também área de pesca da frota artesanal, até os 20 m de profundidade (Costa & Chaves 2006, Mazzoleni 2006), da frota de arrasto duplo e arrasto de parelhas direcionadas a peixes demersais (Perez *et al.* 2003). Esta situação mostra que a sustentabilidade da população de *N. brasiliensis* pode estar comprometida nesta região, devendo os resultados do presente estudo serem considerados em futuros planos de manejo multiespecífico da pesca de arrasto na região.

## Agradecimentos

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# Trophic ecomorphology of *Potamotrygon falkneri* and *Potamotrygon motoro* (Chondrichthyes - Potamotrygonidae) on the upper Paraná river floodplain, Brazil

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**Abstract.** In this paper the the null hypothesis of absence of ecomorphological diversification was tested between *Potamotrygon falkneri* and *Potamotrygon motoro* (Chondrichthyes, Potamotrygonidae) on the upper Paraná river floodplain, Brazil. In the Principal Components Analysis, the five ecomorphological indices were positively correlated with axis 1. Their most relevant contributions were relative width of the mouth and relative opening of the spiracle. The Discriminant Canonical Analysis indicated that the width of the spiracles, followed by the width of the mouth, are the linear measurements that contributed the most to the morphological segregation between the two species. The Mantel test revealed that there is a significant correlation ($Z = 0.27$; $p = 0.0002$) between the ecomorphological distance matrix and the feeding habit model matrix, indicating dependence of the feeding habitats of species in relation the body shape of stingrays. *P. falkneri* presented comparatively larger spiracles, mouth, and pelvic and pectoral fins than *P. motoro*, which may influence in the capture of mobile prey (fishes), while *P. motoro* can use of the suction mechanism, favoring the consumption of prey with little evasive capacity. Ecomorphological diversification culminated in the exploitation of different food resources and provided the coexistence of *P. falkneri* and *P. motoro* in Parana river.

**Key words**: Ecomorphological diversity, feeding, potamotrygonid, Paraná basin, freshwater stingrays.

**Resumo. Ecomorfologia trófica de *Potamotrygon falkneri* e *Potamotrygon motoro* (Chondrichthyes-Potamotrygonidae) na planície alagável do alto rio Paraná, Brasil.** Neste trabalho objetivou-se testar a hipótese nula de ausência de diversificação ecomorfológica entre *Potamotrygon falkneri* e *Potamotrygon motoro* (Chondrichthyes, Potamotrygonidae) na planície alagável do alto rio Paraná, Brasil. Na Análise de Componentes Principais os cinco índices ecomorfológicos mostraram-se correlacionados positivamente com o eixo 1, sendo que suas contribuições mais relevantes foram: largura relativa da boca e a abertura relativa do espiráculo. A Análise Discriminante Canônica indicou a largura dos espiráculos, seguido da largura da boca como as medidas lineares que mais contribuíram para a segregação morfológica entre as duas espécies. O teste de Mantel revelou que há correlação significativa ($Z= 0,27$; $p=0,0002$) entre a matriz de distância ecomorfológica e a matriz modelo de hábito alimentar, indicando dependência da forma do corpo das raias em relação aos seus hábitos alimentares. *P. falkneri* apresentou-se com espiráculos, boca e nadadeiras pélvicas e peitorais maiores, comparativamente a *P. motoro*, o que pode interferir na captura de presas móveis (peixes), enquanto *P. motoro*, por sua vez, pode fazer uso do mecanismo de sucção, propiciando o consumo de presas com pouca capacidade evasiva, como os insetos aquáticos. A diversificação ecomorfológica entre *P. falkneri* e *P. motoro* no rio Paraná culminou na exploração diferenciada dos recursos alimentares e proporcionou a coexistência de ambas as espécies.

**Palavras-chave**: Diversidade ecomorfológica, alimentação, potamotrygonídeos, rio Paraná, raias-de-água-doce.

## Introduction

Ecomorphology is the study of the interactions between the morphological and ecological diversities of the organisms in the present and over evolutionary time. These interactions can be studied at various levels: among individuals, species, guilds and communities (Motta *et al.* 1995), analyzing the correlations between the body shape of the organisms and the environmental factors (Oliveira 2005).

Ecomorphological studies are currently based on the argument that adaptive variations in the phenotype of the species may promote differences in their performance, and thus produce variations in the use of the available resources (Wainwright 1994). In this context, there are indications of strong relationships between body shape and the ecological function of morphological structures in fishes, allowing several comparative studies (Winemiller 1992), as related in Gatz Jr. (1979), Wikramanayake (1990), Fugi & Hahn (1991), Delariva & Agostinho (2001) and Oliveira (2005). Ecomorphological analyses are commonly evaluated using indices, which express the shape of the morphological structures and consequently reveal their ecological roles (Gatz Jr. 1979, Winemiller 1991). This procedure allows the evaluation of information restricted to the differences between shapes, since the indices, representing proportions, reduce the dependence of the analyses as regards the size of the individuals.

After the formation of Itaipu reservoir in 1982 (in the upper Paraná river region), three species of Potamotrygonidae Garman, 1877 began to be recorded (Agostinho *et al.* 1997). It is the only family among the Chondrichthyes that includes representatives restricted to freshwater (Rosa, 1985). The group is widely distributed in South American rivers that drain toward Atlantic and presents great diversity, having about 19 to 21 valid species, distributed in three genera: *Plesiotrygon*, *Paratrygon* and *Potamotrygon* (Rosa 1985, Carvalho *et al.* 2003).

The group is derived from marine ancestors that colonized freshwater through sea forays during the Miocene Epoch (5 to 23 million years ago) in South America. This had profound effects on the diversification and structuration of the Neotropical communities, mainly the Amazonian (Lovejoy *et al.* 1998), where the greatest diversity of potamotrygonids is found. One of the first studies about the freshwater stingrays was in the middle Paraná river (Santa Fé, Argentina), with Achenbach & Achenbach (1976), which characterized the species of potamotrygonids of the region and supplied preliminary biological information.

Lonardoni *et al.* (2006) verified differences in the feeding habit and low trophic overlap between *Potamotrygon falkneri* and *Potamotrygon motoro* in the upper Paraná river. They present segregation in the use of food resources, despite of being phylogenetically very close, the former piscivorous and the latter insectivorous. The diet composition was different in drought and flood seasons possibly because of availability variation of food resources in the floodplain. This features trophic flexibility these species. As *P. fakneri* and *P. motoro* live in simpatry in the Paraná river, is believed they have access to same type of prey. Thus diet differences of species in drought season can be result of differences strategies in food exploration in order to avoid competitive interactions.

Considering, therefore, the premise that changes in the exploitation of food resources may be the result of the morphological diversification among species, this study tested the null hypothesis of absence of ecomorphological diversification between *Potamotrygon falkneri* Castex & Maciel, 1963 and *Potamotrygon motoro* (Natterer in Müeller & Henle, 1841) (Chondrichthyes, Potamotrygonidae) on the upper Paraná river floodplain (Brazil).

## Material and methods

*Study area.* The Paraná river is the second largest in South America (4,695 km long, drainage area of 3.1 x $10^6$ km$^2$ and flow peaks of 65 x $10^3$ m$^3$.s$^{-1}$ (Bonetto 1986). The Paraná river basin in Brazil covers a vast area of 891,150 km$^2$ or 10.5% of the total area (Agostinho *et al.* 2007). The studied area is in the last undammed stretch of the Paraná River in Brazil. The samplings were carried out by Long-Term Ecological Research (LTER-site 6) Program developed by Núcleo de Pesquisa em Limnologia, Ictiologia e Aquicultura (Universidade Estadual de Maringá) in the upper Paraná River floodplain, between the States of Paraná and Mato Grosso do Sul.

*Sampling.* Stingrays were collected at three stations in the Paraná River (Fig. 1). Station 1 (22°46'53.59"S / 53°21'19.97"W) was sampled in August/2004 (in the dry period), in a channel formed at the edge of Mutum Island. Stations 2 (22°45'02.27"S / 53°18'00.09"W) and 3 (22°44'57.10"S / 53°16'37.69"W) were sampled in January/2005 (in the rainy period), on the right bank of the Paraná River (Mato Grosso do Sul State) and in a channel between the islands of Porto Rico and Mutum, respectively.

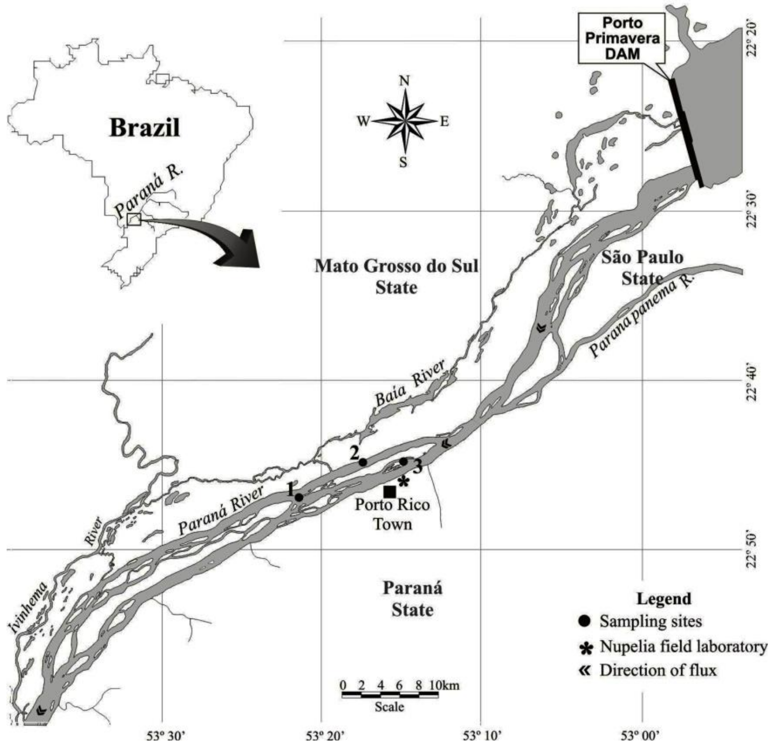

**Figure 1.** Study area with sampling stations (1,2 and 3) in the upper Paraná river floodplain.

Hook and line, rod and reel, harpoons and long lines were used to capture the stingrays (effort of five hours per day). The baits for the hooks and long lines were specimens of *Astyanax spp.* and fragments of Oligochaeta (earthworms). Species identification and the taking of morphometric measurements were carried out according to Rosa (1985). An analogical caliper (0.1 mm precision) was used to measure recently caught specimens, always by the same researcher. The estimated linear morphometric measurements were: total length (TL), pectoral fin length (PecL), disk width (DiW), tail length (TaL), length and width of the spiracles (SpL and SpW), mouth width (MoW) and pelvic fin length (PelL) (Fig. 2).

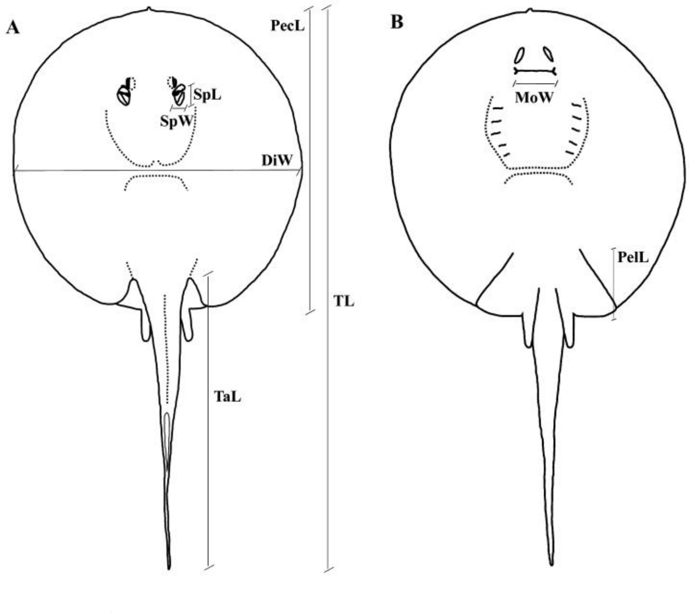

**Figure 2**. Schematic representation of the linear morphometric measurements. Dorsal measurements (A): TL = total length, PecL = pectoral fin length, DiW = disk width, TaL = tail length, SpL = spiracle length, SpW = spiracle width. Ventral measurements (B): MoW = mouth width, PelL = pelvic fin length.

The linear measurements were transformed (log x + 1), and five ecomorphological indices were calculated from them (Table I). The ecological interpretations of indices were based on the literature about the functional morphology of fish (Alexander 1967, Harder 1975, Lagler 1977, Bond 1979, Gatz Jr. 1979, Compagno 1990, Winemiller 1991, Hahn *et al.* 1997).

**Table I**. Ecomorphological indices developed for potamotrygonids and their respective ecological interpretations.

| **Ecomorphological Indices** | | |
|---|---|---|
| **Indices** | **Formulas** | **Ecological interpretations** |
| 1. Relative length of the pectoral fin | RLPec = PecL/TL | The pectoral fins are the main structures responsible for locomotion (Alexander 1967, Lagler *et al.* 1977, Compagno 1990, Dorit *et al.* 1991, Breda *et al.* 2005) and promote propulsion. The longer the relative length of the pectoral fin, the longer the propulsion will tend to be. |
| 2. Relative length of the pelvic fin | RLPel = PelL/PecL | The pelvic fins in Chondrichthyes offer stability, and guide and break movements (Harder 1975). In addition, the stingrays can use the pelvic fins to create friction and to help stabilize themselves in the substrate (Bond 1979). |
| 3. Relative length of the tail | RLTa = TaL/TL | The tail acts in swimming balance, providing stability in movement (Patrícia Charvet-Almeida, personal communication). |
| 4. Relative width of the mouth | RWMo = MoW/DiW | The mouth is located ventrally and its size is directly related to the potential amplitude of prey size. In this way, larger values of relative width of the mouth indicate larger prey (Gatz Jr. 1979, Balon *et al.* 1986, Winemiller 1991, Hahn *et al.* 1997). |
| 5. Relative opening of the spiracle | ROSp = SpL*SpW | Relatively larger spiracles can indicate greater capacity for the entrance of water in the gill chamber, suggesting greater resistance to low oxygen concentration. The communication of the spiracles with the mouth may help process to increase efficience in the exploitation of food resources (Rand, 1907). |

Principal Components Analysis (PCA) was applied to the correlation matrix (Pearson) formed by the five ecomorphological indices for the both species, using PC-ORD v.4.01 (McCune & Mefford 1999). This ordination is used to summarize a collection of data with wide variability and to reduce their dimensionality. The selection of the axes for interpretation was carried out according to the broken stick model (Jackson 1993), which recommends that only the axes with eigenvalues greater than those expected by chance should be retained. Analysis of Variance was applied to verify if there were significant differences between the species scores produced by the PCA.

Canonical Discriminant Analysis (CDA) with the residuals standardized from the linear measurements by disk width was carried out later to identify the morphological variables that most contributed to the segregation of the two species. In addition, the CDA model reclassified the individuals that compose the observed groups based on the distances between each observation and the centroids of each group (Gotelli & Ellison 2004). In this case, the percentage of correct reclassification is an indication of correct identification of the species. This analysis was carried out using Statistica 7.0.

A Mantel test (Legendre & Legendre 1998) was carried out with the objective of to test the null hypothesis of independence between body shape and feeding habit (Legendre & Legendre 1998). It calculated the correlation between the ecomorphological distance of the individuals and the feeding resources used. The morphological distance was obtained from the Euclidian distances among the canonical scores derived from partial CDAs. These analyses were carried out with two groups of ecomorphological indices that represent distinct ecological roles. The first group was formed by RLPel (relative length of the pelvic fin) and RLTa (relative length of the tail) due to the large contribution these indices to the stabilization of swimming, while the second group was composed of RLPec (relative length of the pectoral fin), RWMo (relative width of the mouth) and ROSp (relative opening of the spiracle) because it is more related to the potential use of different food resources.

Euclidian distance was calculated using Statistica 7.0 and is given by the expression (Gotelli & Ellison 2004):

$$\text{Euclidian distance} = \left[\sum_{i=1}^{n}\left(x_{ij} - x_{ik}\right)^2\right]^{1/2}$$

In which: $n$ = number of ecomorphological indices; $x_{ij}$ and $x_{ik}$ = values of the ecomorphological index $i$ for the pair of scores produced by partial CDAs for the first and second groups.

The diet model matrix for the Mantel test was constructed from the stomach contents information (Lonardoni *et al.* 2006) from the same individuals analyzed in this study. The value 1 (one) was attributed to a pair of species constituted by the same species, i.e. individuals that possess the same feeding habit, while the value 0 (zero) was attributed to a pair formed by different species, in which individuals presented different feeding habits. This analysis was carried out using NTSYS-pc (Rohlf 1988) and the statistical significance was estimated using 20,000 model matrix permutations.

## Results

Forty-eight specimens of *Potamotrygon falkneri* and thirteen of *Potamotrygon motoro* were collected (Table II).

Only the first PCA axis was retained for interpretation because it presented an eigenvalue greater than that expected by chance by the broken stick model (explained variability = 66.42%). ANOVA revealed segregation between *P. falkneri* and *P. motoro* in the first principal component (PC 1), based on the five proposed ecomorphological indices (F = 6.88; p = 0.011) (Fig. 3).

**Table II**. Total number of individual collected (N), males and females numbers, average and standard deviation for total length (TL), and variation coefficient (VC).

| | N Total | Males | Females | TL | VC |
|---|---|---|---|---|---|
| *P. falkneri* | 48 | 24 | 24 | 56,7 ± 14,62 | 25,78% |
| *P. motoro* | 13 | 8 | 5 | 41,33 ± 14,44 | 34,94% |

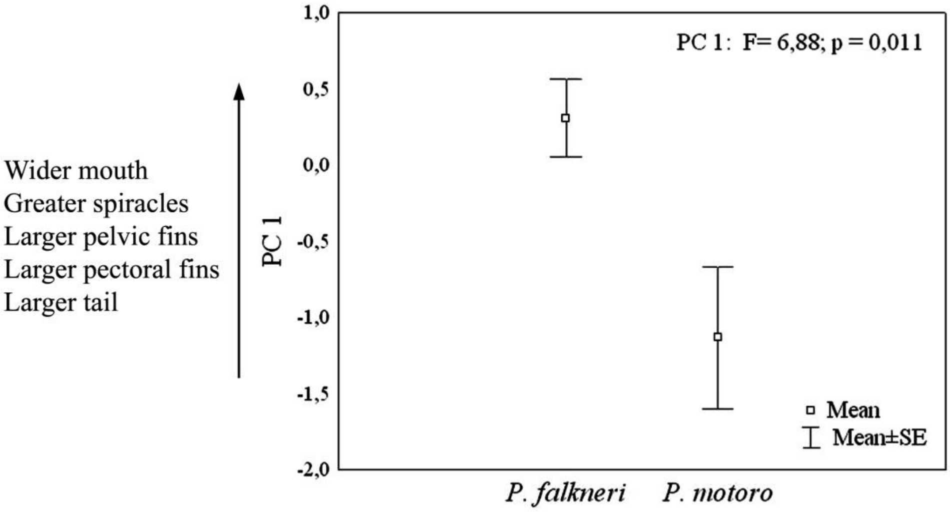

**Figure 3.** Mean and standard error of the scores of the individuals of *P. falkneri* and *P. motoro* in the first principal component of the PCA (PC1), calculated on the correlation matrix of five ecomorphological indices.

The five ecomorphological indices were positively correlated with PC 1. Their contributions were: relative width of the mouth (RWMo = 0.51), relative opening of the spiracle (ROSp = 0.49), relative length of the pelvic fin (RLPel = 0.48), relative length of the pectoral fin (RLPec = 0.47) and relative length of the tail (RLTa = 0.16). *Potamotrygon motoro* was more related to the negative scores of the PC1 and its distribution differed significantly from *P. falkneri* (Figure 3). The great variation around the mean, in relation to the scores of *P. motoro*, indicates great intraspecific morphological variation.

The PCA indicated that the individuals of *P. falkneri* presented wider mouths, which shows the potential as regards prey size, i.e. the efficient consumption of relatively larger prey. The relatively greater spiracles may help process taking of food and increase respiratory capacity. In addition, the larger pelvic and pectoral fins may indicate their greater swimming potential in the execution of certain swimming strategies (e.g. rapid movements in short distance to capture prey). Therefore, this group of characteristics may promote better efficiency in the exploitation of food resources.

Pearson correlation values (r) ($p < 0.01$) from the canonical variables (residuals standardized from the linear morphometric measurements) with the first canonical axis of the CDA indicate the spiracles (SpW = 0.70) and mouth width (MoW = 0.63) as the measurements that most contributed to the segregation between the two species, following SpL= 0.53 and PelL= 0.37.

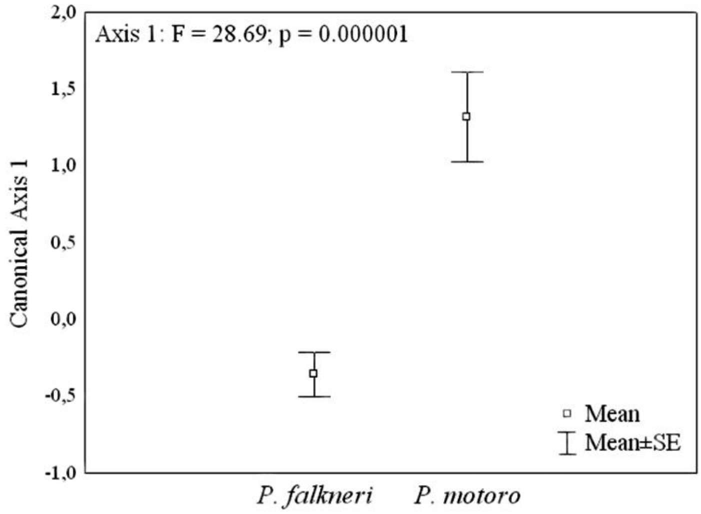

**Figure 4.** Mean and standard error of the scores of the first canonical axis of the CDA calculated on the correlation matrix of the standardized residuals from the linear morphological measurements by disk width.

The results of CDA (Fig. 4) indicating significant differences in the species take into account the linear measurements. Despite the inverted order of the parameters that most contributed to the formation of the axes in the two multivariate analyses (measurements related to the mouth and the spiracle), the results of the CDA corroborate those observed in the PCA.

According to the CDA (Table III), there was a 93.75% correct classification of *P. falkneri*, while *P. motoro* revealed a low percentage of correct classification (38.46%). This is probably due to the great intraspecific ecomorphological variability observed for *P. motoro* in the PCA and CDA.

The Mantel test revealed that there is a significant correlation (Z = 0.27; p = 0.0002) between the ecomorphological distance matrix (Euclidian distance between the partial CDAs scores) and the trophic model matrix, which indicates that the feeding habits of the species depend on the body shape of the stingrays

**Table III**. Classification matrix predicted by CDA model for the species *P. falkneri* and *P. motoro* in the upper Paraná river.

| | | Predict Groups | | | |
|---|---|---|---|---|---|
| | | *P. falkneri* | *P. motoro* | Observed Total | Correct Classification (%) |
| Observed groups | *P. falkneri* | 45 | 3 | 48 | 93.75 |
| | *P. motoro* | 8 | 5 | 13 | 38.46 |
| | Predict Total | 53 | 8 | 61 | 81.96 |

## Discussion

In this study, the null hypothesis of absence of ecomorphological variation between *P. falkneri* and *P. motoro* was rejected indicating interspecific ecomorphological structuration, which may directly interfere in the efficiency of the natural resource exploitation by these species. The morphological characteristics that most differentiated the two species were width of the spiracles and mouth, followed by the length pelvic and pectoral fins.

The spiracles consist of the first modified gill slit (Rand 1907). These dorsal openings of the oropharyngeal cavity are widely variable characteristics in elasmobranchs. Many families of shark have lost them completely; others possess them, but not have valves to close them. Other groups still possess large spiracles with valves, which are important to the respiratory flow (Summers & Ferry-Graham 2001).

Among the various forms of water flow for respiration, the stingrays employ the two most common: (i) the water enters only through the spiracle when they are buried on the bottom or; (ii) the water enters through the mouth and through the spiracle simultaneously when these fishes swim actively during foraging and migration (Summers & Ferry-Graham 2001). Low oxygen concentration on the bottom is common in the region of study, mainly in the lentic environments. Among the specimens analyzed, *P. falkneri* presented larger spiracles in relation to *P. motoro*, which may indicate a modification in response to hypoxia or better relative respiratory performance. This may be related to the fact that this species has successfully colonized lotic and lentic environments of the upper Paraná River floodplain. More efficient respiratory performance also promotes better physiological conditions that are reflected in the exploitation of food resources, taking into account the communication of the spiracles with the oropharyngeal cavity.

Stingrays present the mouth located ventrally and, as in teleosts, their size is directly related to the potential amplitude of prey size (Gatz Jr. 1979, Balon *et al.* 1986, Winemiller 1991). Prey capture in Elasmobranchii is a process that involves various mechanisms: (i) blowing/suction to reposition the prey; (ii) crushing; (iii) removal of pieces; (iv) biting, which can be employed with movements of the head to reduce prey size (Wilga *et al.* 2007).

The musculature that controls the anatomic system, responsible for feeding is highly conservative in the Chondrichthyes and relatively simple when compared to the Actinopterygii (Wilga *et al.* 2007). Some stingrays protract their jaws during the expansive phase of feeding. This because of the greater mechanical connection that they possess in their jaws and the loss of skull-palate articulation that occurs in function of the dorso-ventral flattening of the body (Rand 1907). Thus, protrusion in elasmobranchs is important because it allows the rapid closing of the jaws, combined with the tearing and swallowing of small pieces of prey or even entire prey (Wilga *et al.* 2001).

Most species of sharks and stingrays are feeders that use suction and can separate and remove material through the manipulation in the oral cavity and reingestion of the food, although stingrays possess more precise control of the lower jaw due to the large number of muscular insertions (Dean *et al.* 2005).

Functional anatomy analyses carried out with *P. motoro* revealed that this species presents spiracular muscles and hypertrophied hyomandibular depressor muscles, which reinforces the use of the suction mechanism in feeding and, in this way, the consumption of benthic invertebrates (Pantano-Neto & Souza 2002). When *Dasyatis americana*, a marine stingray, feeds in sandy bottoms using suction, which consists in the contraction and expansion of the oropharyngeal canal, a jet of sand is frequently observed coming out of the spiracles during the sequence of movements (Aguiar 2005).

The pelvic fins in Chondrichthyes generally offer stability, and brake movements (Harder 1975). In addition, benthic species like stingrays use pelvic fins to create friction and to help stabilize themselves in the substrate (Bond 1979). Their contribution to locomotion was considered minimal (Lindsey 1978), and in males are modified with the presence of copulatory organs.

The pectoral fins are very developed and promote propulsion and direction in swimming (Compagno 1990, Rosenberg & Westneat 1999) and are therefore considered the main structures responsible for locomotion (Alexander 1967, Lagler *et al.* 1977, Compagno 1990, Dorit *et al.* 1991, Breda *et al.* 2005).

The type of swimming used by these fishes is the so-called undulatory locomotion and consists of waves that are produced in the pectoral fins from the anterior part to the posterior. Even the most of the stingrays with spines (Dasyatidae) present this type of locomotion (Rosenberg & Westneat 1999).

The undulation of the pectoral fins allows smooth forward or backward movements (helping in rapid inversion in the direction), making the exploitation of structured habitats possible (e.g. vegetation or rock crevices). Location of the environment occurs using an electro-sensory system (Lindsey 1978).

The greater relative length of the pectoral fins of *P. falkneri* (piscivorous) may indicate greater propulsion potential during rapid moviments in short distances, when high acceleration is used at the beginning of the movement (interfering directly in the capture of prey). On the other hand, *P. motoro* (considered an insectivorous species in this ecosystem; Lonardoni *et al.* 2006), presents mouth, spiracles and pectoral fins smaller in relation to *P. falkneri*. These morphological characteristics are compatible with its feeding behavior, potentially favoring the efficient consumption of prey with little evasive capacity (e.g. aquatic insects). In addition, the large variation around the mean verified in the analyses suggests greater intraspecific ecomorphological variation, which explains the questionable taxonomic fit of these individuals, with some researchers believing in the existence of a complex of *P. motoro* species, like found by Toffoli (2006) in the Amazon basin collections.

There is a tendency for competitive pressures to cause ecological segregation between species, mainly in those philogenetically related or morphologically similar. This argument has been presented as a natural alternative to the principle of competitive exclusion proposed by Georgii Gause in “The struggle for existence” (Gause 1934). Simultaneously, over evolutionary history, competition tends to stimulate selective adaptations that make possible the coexistence of a diversity of organisms in a given area, promoting specializations in narrower niches (Pianka 2000). Such specializations in the use of resources (especially food) may be expressed by the ecomorphological diversifications presented by *P. falkneri* and *P. motoro* in this study.

Ours results suggest that the significant ecomorphological differences detected between these two species probably allows distinct functional performances of the morphological structures, indicating differential use of resources. The coexistence between these two species in the Paraná river reinforces the thesis that phylogenetically close species can exploit the natural resources in simpatry, because of the differentiated exploitation of the food resources in the environment.

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# Hábitos alimentares da raia *Atlantoraja platana* (Günther, 1880) (Elasmobranchii, Rajidae) no litoral norte de Santa Catarina, Brasil

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**Resumo.** Após longos períodos de altas capturas de camarão pela frota de arrasto de fundo em Santa Catarina a produção do mesmo declinou e a pescaria começou a atuar sobre espécies da fauna acompanhante, como as raias da família Rajidae. Este trabalho teve como objetivo determinar a dieta da raia *Atlantoraja platana*, componente da captura incidental da pesca de arrasto duplo na costa norte do Estado de Santa Catarina, Brasil. As amostras foram provenientes de oito cruzeiros realizados pelo NP Soloncy Moura, na área situada no litoral norte de Santa Catarina (25°-27°S), Brazil. Foram analisados o conteúdo de 119 estômagos, sendo calculado a frequência de ocorrência, porcentagem numérica e em peso, e o Índice de Importância Relativa (IRI) de cada item alimentar. Os resultados mostram que a dieta desta espécie é composta por Decapoda (IRI= 10317), que se mantêm como principal presa ao longo das estações do ano, classes de comprimento e diferentes profundidades. A maior diversidade de presas foi observada no verão e inverno, em regiões mais afastadas da costa.

**Palavras chave:** Dieta, raia, pesca de arrasto.

**Abstract. Food habits of the skate *Atlantoraja platana* (Günther, 1880) (Elasmobranchii, Rajidae) on the north coast of Santa Catarina, Brazil.** After long periods of high catches of the fleet of shrimp trawls in Santa Catarina its production declined and the fishery began to act on companion animal species, such as the skate of the family Rajidae. This study aimed to determine the diet of the skate *Atlantoraja platana* component of the incidental capture of two trawlers on the northern coast of Santa Catarina, Brazil. The samples were collected from eight cruises conducted by NP Soloncy Moura, in the area is located on the north coast of Santa Catarina (25°-27°S). The contents of 119 stomachs were analyzed, which established the frequency of occurrence, percentage number and weight, and the Index of Relative Importance (IRI) of each food item. The results show that the diet of this species is composed of Decapoda (IRI= 10317), which remain as the principal prey over the seasons, size classes and depths. The greatest diversity of prey can be seen in summer and winter, in areas further from shore.

**Key words:** Diet, skate, double rig trawl.

## Introdução

No Brasil, a pescaria de arrasto de fundo era inicialmente praticada por pescadores artesanais, sendo que no final da década de 1940 passou a ser realizada pela frota industrial, direcionada a diferentes espécies de camarões (Perez & Pezzuto 1998, Pezzuto 2001, Perez *et al.* 2003). Desde então, esta atividade sofreu com a diminuição da abundância deste recurso, fazendo com que as espécies acessórias, tais como os elasmobrânquios (tubarões e raias), fossem alvo da atividade pesqueira (Vooren 1998, D'Incao *et al.* 2002). Esta recente mudança na pescaria, aliada ao fato de que os estudos sobre os impactos pesqueiros concentram-se principalmente nas espécies-alvo, se traduz na falta de conhecimento sobre as outras espécies, de menor interesse econômico, capturadas incidentalmente.

A atividade pesqueira realizada sobre os tubarões e as raias é preocupante uma vez que se tratam de animais com ciclo de vida caracterizado por maturação sexual tardia, baixa fecundidade e baixa taxa de crescimento (Hoening & Gruber 1990, Jennings *et al.* 1998, Martins & Schwingel 2003, Mazzoleni 2006) e, portanto, sensíveis a pressão pesqueira. Um exemplo da pesca desordenada foi relatado por Brander (1981) para a espécie *Dipturus batis* (como *Raja batis*) da região da Irlanda, onde após períodos de altas capturas, não foi mais observada nas pescarias de arrasto de fundo onde era tradicionalmente capturada.

Segundo Marçal (2003) a espécie de raia *Atlantoraja platana* é encontrada até os 231 metros de profundidade do litoral de São Paulo à Argentina. Em um estudo realizado por Martins (2007), na região sul do Brasil, pode-se observar que a amplitude de comprimento desta espécie varia entre 14 e 81 cm de comprimento total. A relação macho/fêmea observada é de 1:1,65 em favor das fêmeas, sendo que a partir dos 73 cm estas já se encontram maturas e os machos a partir dos 70 cm. As fêmeas ovadas são mais frequentes no final do verão com a maior captura de fêmeas imaturas observada na primavera e inicio do verão, enquanto que os machos maturos são observados na primavera e verão.

Em função do escasso conhecimento de aspectos alimentares de raias costeiras no sul do Brasil e sua importância na cadeia alimentar como predadores de topo, o presente trabalho tem como principal objetivo conhecer a dieta da raia demersal *Atlantoraja platana*, componente da captura incidental da pesca de arrasto de camarão no litoral norte de Santa Catarina, Brasil. Tais dados devem servir como base para futuros estudos sobre relações tróficas de elasmobrânquios na região sul.

## Materiais e Métodos

As amostras de *Atlantoraja platana* foram provenientes do projeto "Levantamento e avaliação das populações de *Litopenaeus schimitti*, *Farfantepenaeus paulensi*s e *F. brasiliensis* (CAMBA)" realizado pelo CEPSUL (Centro de Estudo e Gestão Pesqueira do Sudeste e Sul do Brasil) - IBAMA (Instituto Brasileiro do Meio Ambiente). As coletas foram realizadas pelo NP Solancy Moura, adaptado com uma rede de arrasto de fundo de 22 m de comprimento, com abertura superior e inferior da boca de 15 m e 18 m, respectivamente, e malha do saco de 10 mm. A área de estudo compreende o litoral norte do Estado de Santa Catarina, Brasil, sobre a plataforma continental entre as latitudes 25º30'S - 27º00'S (Fig. 1).

As estações de coleta foram distribuídas da seguinte forma: quatro na zona costeira em profundidades menores que 20 metros; e 15 estações dispostas em três perfis perpendiculares a costa, nas isóbatas de 20, 40, 60, 80 e 100 m. Um total de oito cruzeiros de coleta foram realizados, a saber: junho e agosto de 2004; janeiro, março e outubro/novembro de 2005; março, abril/maio e julho de 2006. Em cada uma das 19 estações de coleta, foram realizados dois arrastos, um diurno e outro noturno, com duração média de 30 minutos cada.

Os indivíduos capturados foram pesados (kg), sexados e registradas as medidas de largura do disco - LD (cm) e comprimento total - CT (cm), sendo os estômagos retirados e conservados em formol 4%. Para a análise do conteúdo estomacal, cada presa foi identificada até o menor táxon possível de acordo com Shultz (1969), Figueiredo & Menezes (1978; 1980), Amaral & Nonato (1996) e Melo (1996; 1999). A alimentação foi analisada a partir dos dados de frequência de ocorrência do item alimentar no conteúdo estomacal (FO); número de indivíduos de cada item alimentar (N), representando a abundância; e peso (precisão de 0,01g) dos indivíduos de cada item alimentar na dieta (P), representando a biomassa. Esses parâmetros foram analisados para diferentes cruzeiros de pesca, classes de comprimento e profundidades de captura, sendo FO, N e P apresentados em porcentagens. O Índice de Importância Relativa (IRI) foi calculado para estabelecer a ordem de importância dos itens alimentares (Schwingel & Castelo, 1994), representado pela fórmula:

$$IRI = (\%P + \%N) \times \%FO$$

As presas foram classificadas como: maior importância (*IRI* > 1000), importância intermediária (*IRI* entre 50 e 1000), menor importância (*IRI* < 50). Na análise da diversidade de espécies foram utilizados os índices de Shannon-Wiener (H') representado pela fórmula:

$$H' = -\sum_{i=1}^{S} (pi) \ln (pi)$$

onde *pi* é igual à proporção (em peso) de cada taxa na dieta e *S* é o peso de todos os taxas encontrados (Ludwig & Reynolds, 1988).

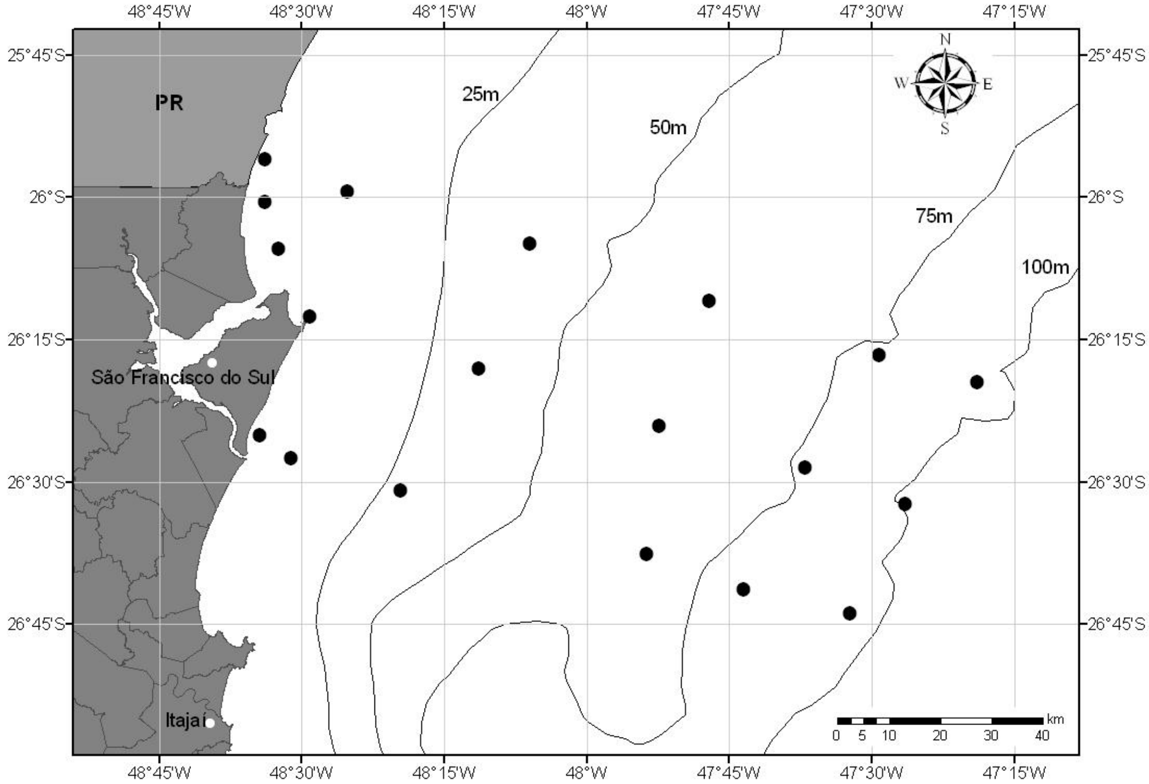

**Figura 1.** Localização dos pontos amostrais do projeto CAMBA, onde foram coletados exemplares de *Atlantoraja platana*, no litoral norte do Estado de Santa Catarina, Brasil.

## Resultados e Discussão

Um total de 119 exemplares de *Atlantoraja platana* foram capturados, sendo este também o número total de estômagos analisados. No outono-inverno de 2004 foi capturado o menor número de indivíduos (n= 6) e o maior no início do verão de 2005 (n= 27), sugerindo um padrão sazonal na sua abundância na região (Fig. 2). Um predomínio de fêmeas nas classes de indivíduos maiores de 72 cm foi observada (Fig. 3).

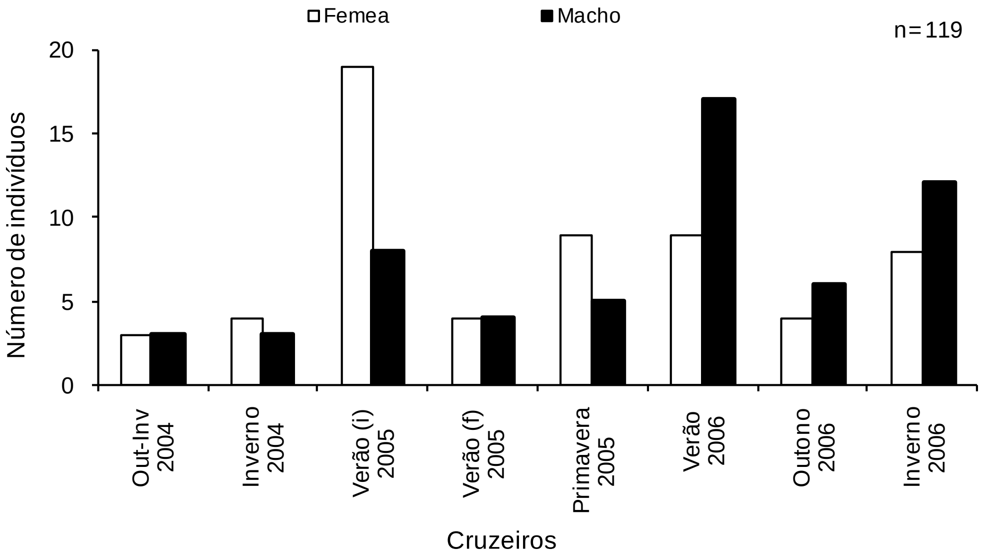

**Figura 2.** Número de indivíduos de *Atlantoraja platana* capturados entre 2004 e 2006 no litoral norte de Santa Catarina, Brasil. (Nota: i=início; f=final).

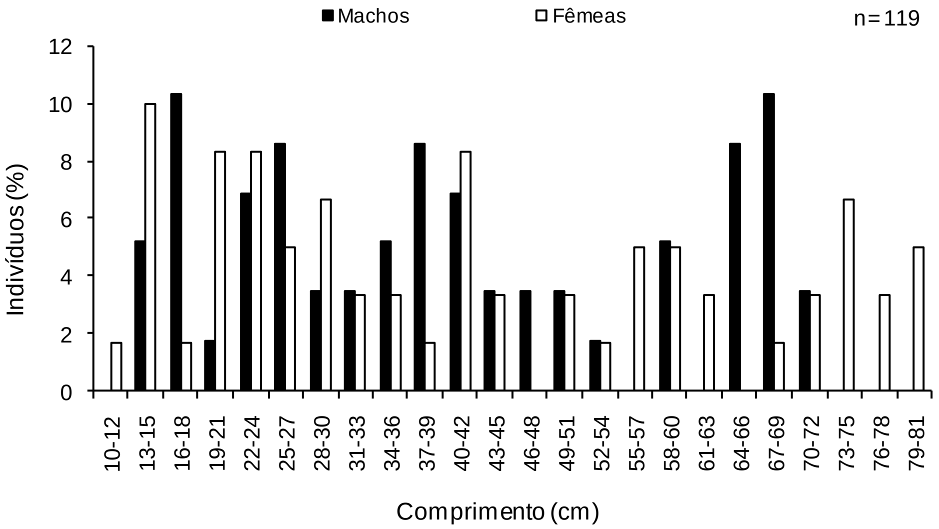

**Figura 3.** Porcentagem de indivíduos capturados por classe de comprimento de *Atlantoraja platana* capturados entre 2004 e 2006 no litoral norte de Santa Catarina, Brasil.

O índice de repleção mostra que, ao longo dos cruzeiros, os estômagos apresentavam-se vazios ou com 25% de alimento em seu interior (Fig. 4). O espectro alimentar de *Atlantoraja platana* foi composto por um total de 27 itens alimentares (Tabela I), dentre os quais, a ordem com maior representatividade foi Decapoda, sendo este o item alimentar de maior importância de acordo com o IRI (Fig. 5, Tabela II). Pode-se observar também que existem outros dois grupos de presas na dieta de *A. platana*, um composto por itens alimentares de importância intermediária (i.e. Anguiliformes, Batrachoidiformes, Teuthida e Stomatopoda) e outro por presas de menor importância (i.e. Scorpaeniformes, Octopoda e Clupeiformes).

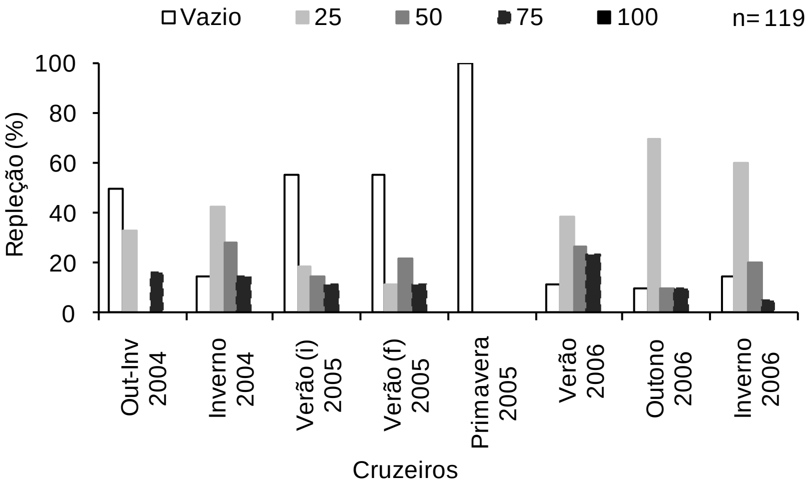

**Figura 4.** Repleção estomacal de *Atlantoraja platana* capturadas entre 2004 e 2006 no litoral norte de Santa Catarina, Brasil. (Nota: vazio= estômago sem conteúdo, 100= estômago 100% cheio, i=início; f=final).

Estudos sobre alimentação de raias da família Rajidae revelam uma dieta bastante variada. Caridea, Penaeidea e Teleostei são a base da alimentação de *Rioraja agassisi*, enquanto Caridea, Brachyura, Amphipoda e Gammaridea, compõem a dieta de *Psammobatis extenta* na costa sudeste do Brasil e norte da Argentina (Muto *et al.* 2001, Braccini & Perez 2005). Ruocco *et al.* (2007), estudando a espécie *Bathyraja albomaculata* na costa sul da Argentina, encontraram um total de 14 *taxa* de presas no conteúdo estomacal, sendo que as principais foram Polychaeta, Amphipoda e Isopoda. Lucifora *et al.* (2000) observaram que a dieta da raia *Dipturus chilensis* na costa da Argentina era composta basicamente por Teleostei (*Patagonotothen ramsay*), Cephalopoda (*Illex argentinus*) e outras presas de menor importância. Por outro lado, o presente trabalho identifica uma dieta baseada em organismos pertencentes a ordem Decapoda para *A. platana*. Esta diferença na alimentação das raias da mesma família pode estar relacionada ao tamanho que cada espécie atinge, sendo que as menores se alimentam de itens menores, *e.g. B. albomaculata* em relação a *A. platana*.

A variação sazonal da alimentação de *A. platana* mostra que Decapoda é uma presa constante no conteúdo estomacal, enquanto que os outros itens tiveram ocorrências pontuais na dieta (e.g. Anguiliformes, Batrachoidiformes, Teuthida, Stomatopoda, Scorpaeniformes e Octopoda), não apresentando um padrão sazonal definido (Fig. 6). Para as diferentes classes de comprimento de *A. platana*, o item Decapoda é observado constantemente na alimentação de indivíduos maiores que 19 cm. Batrachoidiformes, Teuthida e Scorpaeniformes são característicos de classes de comprimento maiores que 60 cm, enquanto Anguiliformes, Stomatopoda e Octopoda são componentes ocasionais na dieta, associados a distintas classes de comprimento (Fig. 7). Ruocco *et al.* (2007), estudando *B. albomaculata*, observou que haviam diferenças na alimentação de acordo com o tamanho das raias, sendo que as menores se alimentavam preferencialmente de Amphipoda e as maiores de Polychaeta. Isso, segundo o mesmo autor, acontece em consequencia do tamanho da boca dos indivíduos. Lucifora *et al.* (2000) também encontrou variações ontogenéticas na raia *D. chilensis* uma vez que indivíduos maiores desta raia se alimentavam preferencialmente de peixes.

Foi observado um padrão de variação batimétrica (espacial) da participação das principais presas da dieta de *A. platana* na região estudada. Os itens Decapoda, Batrachoidiformes, Scorpaeniformes e Octopoda aumentam sua participação em profundidades maiores. No entanto, outras presas encontradas, tais como Teuthida e Stomatopoda, foram considerados presas ocasionais na alimentação desta espécie (Fig. 8).

**Tabela I.** Lista taxonômica dos itens alimentares encontrados nos estômagos de *Atlantoraja platana* capturadas entre 2004 e 2006 no litoral norte de Santa Catarina, Brasil.

Filo Chordata
Subfilo Cephalochordata
Ordem Amphioxiformes
Família Branchiostomatidae
*Branchiostoma* sp.
Subfilo Vertebrata
Classe Actinopterygii
Subclasse Teleostei
Ordem Scorpaeniformes
Família Dactylopteridae
*Dactylopterus volitans* (Linnaeus, 1758)

Ordem Clupeiformes
Família Engraulidae

Ordem Anguiliformes

Ordem Batrachoidiformes
Família Batrachoididae
*Porichthys pososissimus* (Cuvier, 1829)

Filo Nemerteia

Filo Nematoda

Filo Mollusca
Classe Cephalopoda
Ordem Teuthida
Família Loliginidae
*Lolligungula brevis* (Blainville, 1823)

Ordem Octopoda
Família Octopodidae
Subfamília Eledonidae

Filo Arthropoda
Classe Malacostraca
Ordem Stomatopoda
Família Squillidae
*Cloridopsis dubia* (Edwards, 1837)

Ordem Decapoda
Infraordem Brachyura
Família Portunidae
*Portunus spinicarpus* (Stimpson, 1871)
Família Stenopodidae
Subordem Dendrobranchiata
Família Penaeidae
Família Calappidae
*Acanthocarpus alexandri* (Stimpson, 1871)
Infraordem Caridea
Infraordem Astacidea
Família Nephropidae
*Metanephrops rubellus* (Moreira, 1903)

Ordem Amphipoda
Subordem Gammaridea

Ordem Isopoda

Filo Annelida
Classe Polychaeta
Ordem Scolecida
Família Opheliidae
*Armandia* sp.
Ordem Aciculata
Família Onuphidae

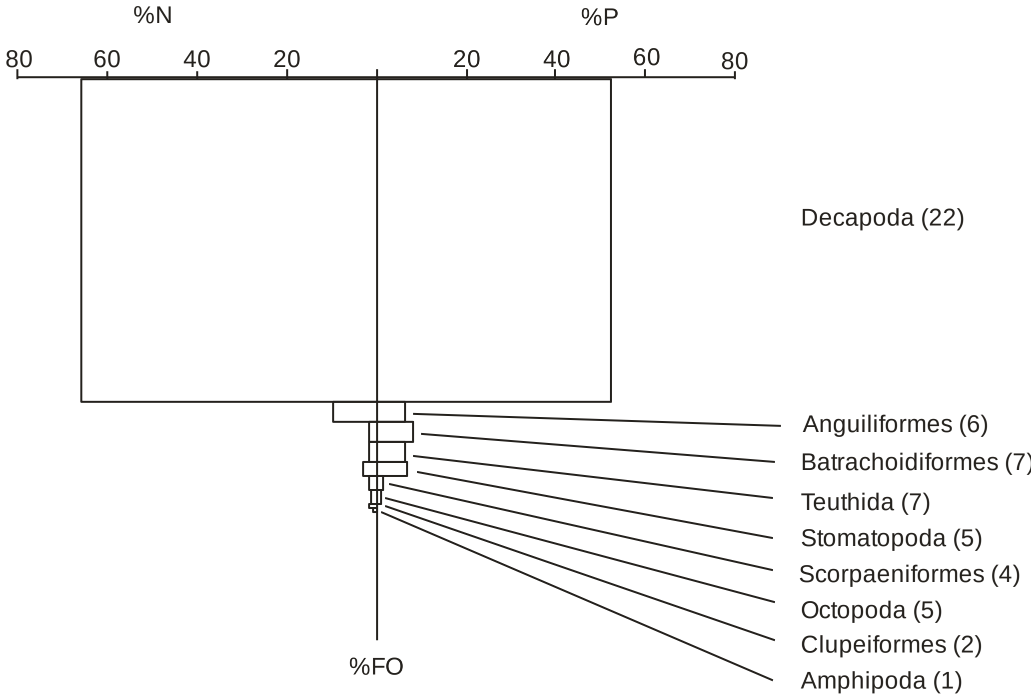

**Figura 5.** Índice de Importância Relativa (IRI) para as principais presas, agrupadas por ordem, encontradas nos estômagos (n= 119) de *Atlantoraja platana* capturadas entre 2004 e 2006 no litoral norte de Santa Catarina, Brasil. Entre parênteses as suas respectivas frequências de ocorrência.

**Tabela II.** Itens alimentares, agrupados por ordem, observados nos estômagos (n= 119) de *Atlantoraja platana* e as suas respectivas médias de frequências de ocorrência (%FO); porcentagem numérica (%N); porcentagem em peso (%P); e Índice de Importância Relativa (IRI) e erro padrão.

| | F.O. | Erro (+/-) | % N | Erro (+/-) | % P | Erro (+/-) | IRI |
|---|---|---|---|---|---|---|---|
| Decapoda | 88,63 | 13,03 | 65,46 | 10,47 | 50,95 | 13,29 | 10317,60 |
| Anguiliformes | 5,56 | 4,39 | 10,57 | 10,40 | 8,34 | 7,59 | 105,05 |
| Batrachoidiformes | 6,55 | 4,49 | 1,70 | 1,12 | 11,53 | 11,05 | 86,59 |
| Teuthida | 7,34 | 4,38 | 1,85 | 1,10 | 8,37 | 8,34 | 75,05 |
| Stomatopoda | 4,76 | 4,45 | 4,17 | 4,17 | 8,60 | 8,60 | 60,78 |
| Scorpaeniformes | 3,63 | 2,21 | 2,40 | 1,62 | 2,49 | 1,94 | 17,75 |
| Octopoda | 4,76 | 4,45 | 0,96 | 0,96 | 0,44 | 0,44 | 6,67 |
| Clupeiformes | 1,59 | 1,48 | 0,93 | 0,93 | 0,38 | 0,38 | 2,07 |

A variação sazonal da diversidade de presas na alimentação de *A. platana* mostra que nos períodos de inverno e verão ocorrem os maiores valores do índice de Shannon-Weaver (Fig. 9a), quando a dieta é composta por Decapoda, Anguiliformes, Batrachoidiformes, Teuthida, Stomatopoda, Scorpaeniformes e Octopoda (Fig. 6). O índice de Shannon-Wiener para diferentes classes de comprimento mostra uma variação ontogenética na diversidade das presas onde indivíduos maiores que 58 cm apresentam diversidade alimentar maior (Fig. 8b), fato que está associado à participação de Decapoda, Batrachoidiformes, Teuthida e Scorpaenifomes nesta classe de comprimento (Fig. 7). Nas regiões mais afastadas da costa a diversidade observada foi maior (Fig. 9c), onde aumenta a participação na dieta de presas como Decapoda, Anguiliformes, Batrachoidiformes, Scorpaeniformes e Octopoda (Fig. 8).

Considerando o tamanho de primeira maturação para *A. platana* em 62 e 71,5 cm de comprimento total para machos e fêmeas, respectivamente (Oddone *et al.*, 2008), fica evidenciado que mudanças no comportamento alimentar não estão associadas a maturação e sim ao crescimento do indivíduo (Fig. 6). Ruocco *et al.* (2007) observaram variações na dieta de *B. albomaculata* em função do tamanho dos indivíduos, da área de distribuição e de características morfológicas do aparato bucal. Essas observações mostram similaridade com o observado para *A. platana* no presente estudo, onde também foram verificadas variações na dieta de acordo com o crescimento e a área (profundidade) ocupada pelos indivíduos. Este comportamento pode estar relacionado com a disponibilidade do alimento nas diferentes profundidades ou ainda com a forma e o tamanho da boca destas raias.

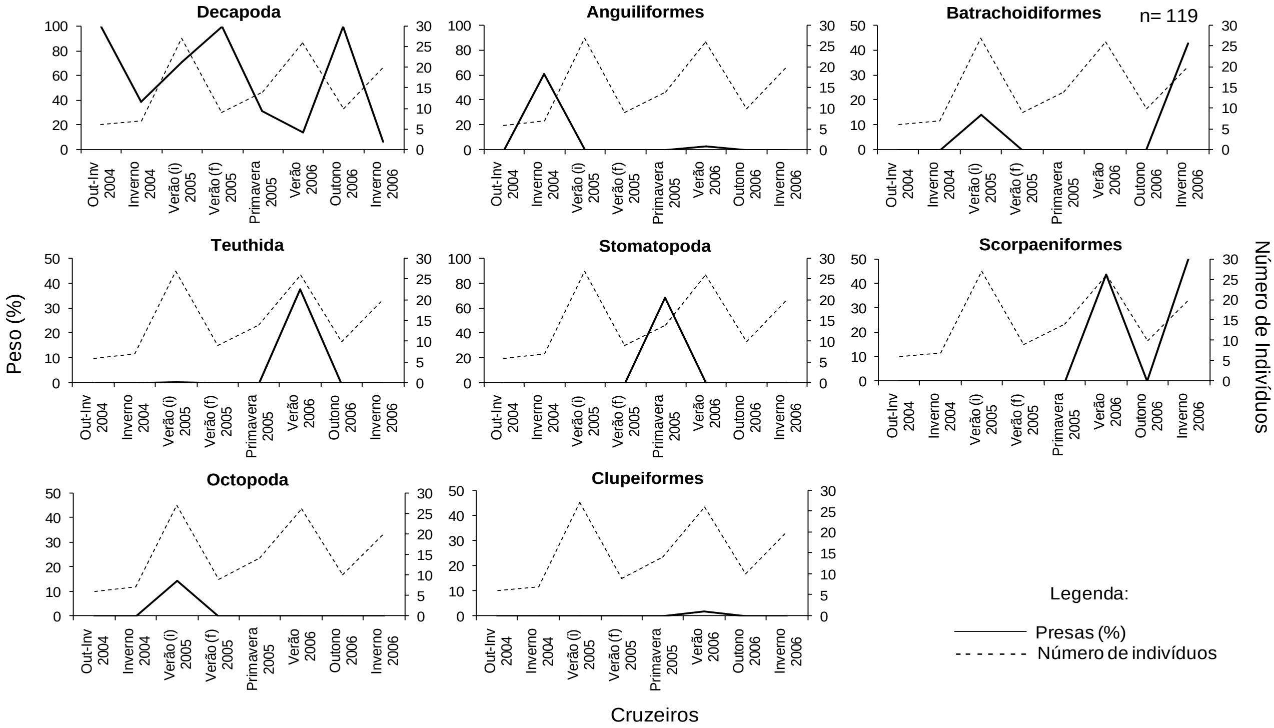

**Figura 6.** Variação sazonal dos itens alimentares, agrupados por ordem, observados nos 119 estômagos de *Atlantoraja platana* capturadas entre 2004 e 2006 no litoral norte de Santa Catarina, Brasil. (Nota: i=início; f=final).

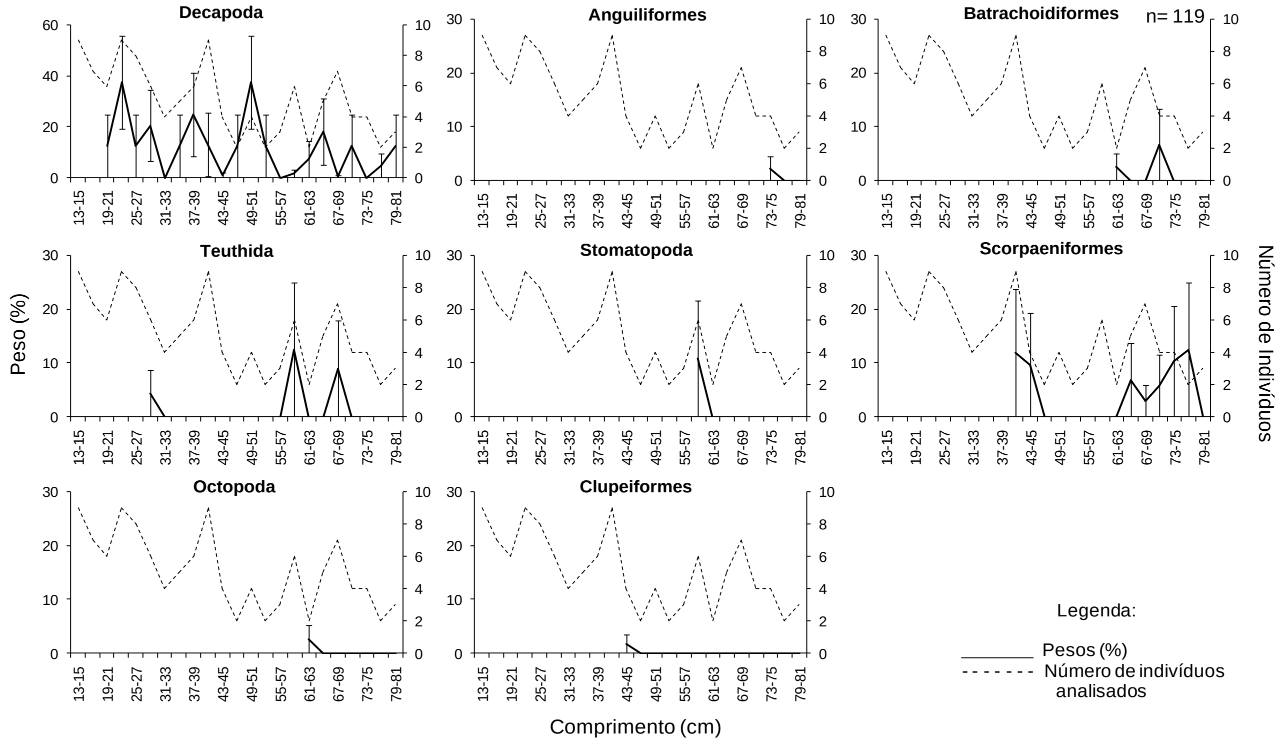

**Figura 7.** Variação ontogenética dos itens alimentares, agrupados por ordem, em relação aos comprimentos de 119 *Atlantoraja platana* capturadas entre 2004 e 2006 no litoral norte de Santa Catarina, Brasil (barras= erro padrão).

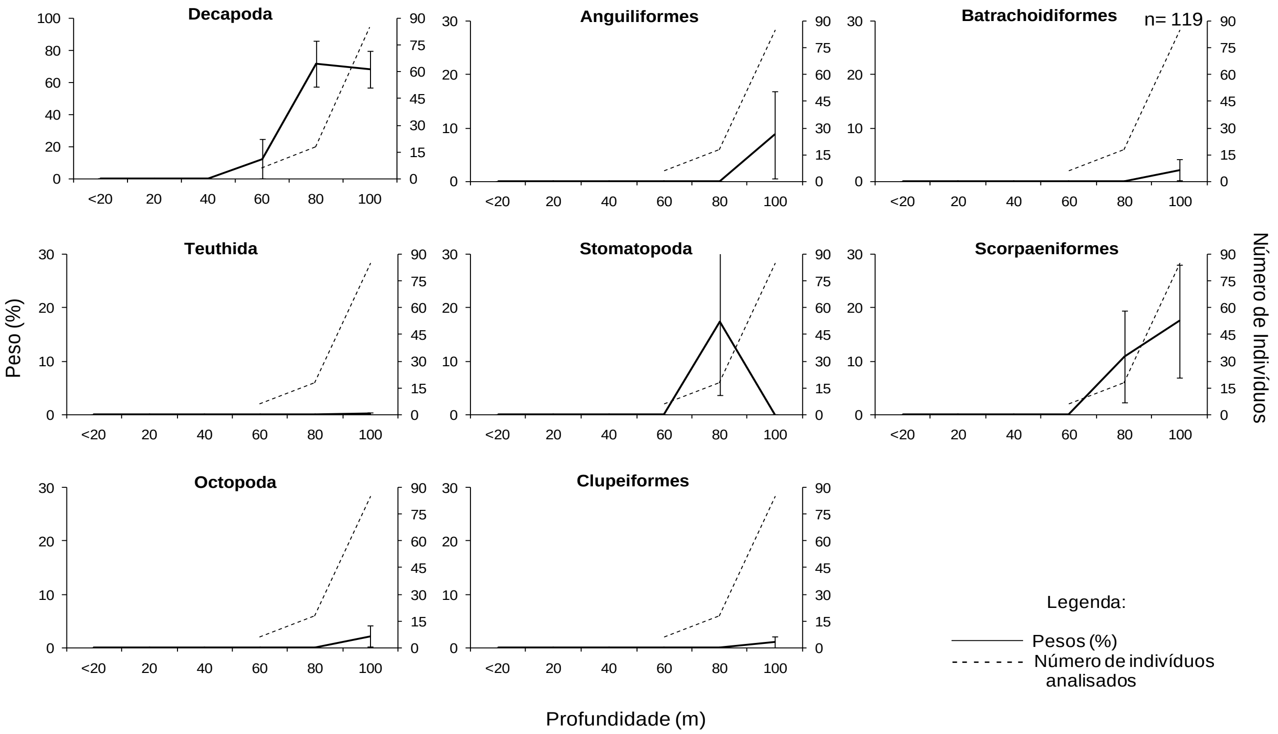

**Figura 8.** Variação batimétrica dos itens alimentares, agrupados por ordem, observados em 119 estômagos de *Atlantoraja platana* capturadas entre 2004 e 2006 no litoral norte de Santa Catarina, Brasil (barras= erro padrão).

Muto *et al.* (2001) observaram que as raias da família Rajidae possuem mecanismos de sucção oral que permitem o consumo de invertebrados bentônicos. Por outro lado, Pedersen (1995) verificou que a espécie *Raja radiata* usa uma estratégia alimentar oportunista sobre camarões e peixes (espécies-alvo da pesca a qual estavam associadas). Comportamentos similares podem ser observados também para *A. platana*, incluindo a ocorrência de espécies-alvo da pescaria na composição de sua dieta (*e.g.* Decapoda). Esse fato pode caracterizar um aumento da vulnerabilidade desta espécie frente a pesca de arrasto duplo na costa sudeste e sul do Brasil (Martins, 2007). Segundo Marçal (2003), uma diminuição da população, devido a pesca intensiva, pode levar a substituição por outras espécies ali existentes, especialmente espécies de menor porte que habitam uma faixa similar de profundidade e encontram um aumento da disponibilidade de alimento.

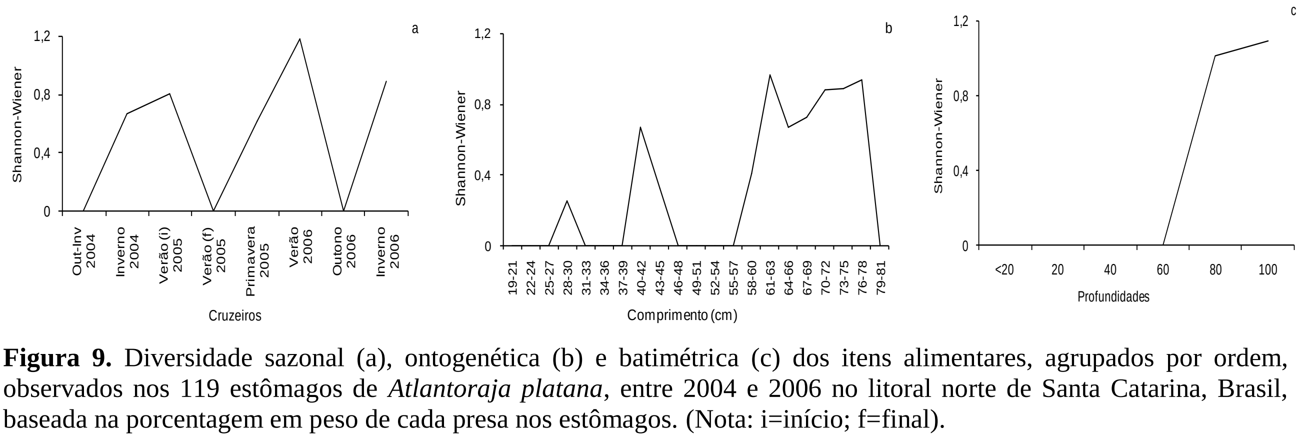

**Figura 9.** Diversidade sazonal (a), ontogenética (b) e batimétrica (c) dos itens alimentares, agrupados por ordem, observados nos 119 estômagos de *Atlantoraja platana*, entre 2004 e 2006 no litoral norte de Santa Catarina, Brasil, baseada na porcentagem em peso de cada presa nos estômagos. (Nota: i=início; f=final).

## Conclusão

A alimentação de *Atlantoraja platana* foi composta principalmente pelo item Decapoda, sendo este o grupo de presas mais importante para diferentes épocas do ano e classes de comprimento. Com o aumento da profundidade outras presas se destacaram na participação da dieta, tais como Anguiliformes, Batrachoidiformes, Scorpaeniformes e Octopoda.

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# Fishery and morphometric relationships of the banded guitarfish, *Zapteryx exasperata* (Elasmobranchii, Rhinobatidae), from the Gulf of California, Mexico

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**Abstract.** The banded guitarfish (*Zapteryx exasperata*) is a commercially-important species in the Northwest artisanal ray fishery of Mexico. However, very little information about its fisheries characteristics and catch abundance is available. Seasonal sampling was conducted between 1998─2000 and 2004─2005 in five fishery camps in the Gulf of California. *Z. exasperata* is a secondary resource in ground fisheries, and is caught using gill nets with mesh sizes between 15─20 cm from small fiberglass boats called "pangas," fishing between 4─54 m depth. Catches were composed of individuals between 41.3─90 cm TL with an average weight of 2.18 ± 1.13 kg. The sex ratio of the catches was 1:1. Females reached larger sizes and weights than males; therefore, the morphometric relationships were different between sexes. CPUE reached its highest values during spring (3.4 ind/trip), and was lowest during summer. CPUE was also higher in fishing sites with depths between 100─200 m (5.5 ind/trip). *Z. exasperata* fishery characteristics are similar to those reported for elasmobranchs in other regions of Mexico. In particular, the seasonality of the catches was similar to that reported for other ray species in the Gulf of California, with a peak during spring and summer.

**Key words:** Artisanal fisheries, CPUE, elasmobranch, catch composition

**Resumen. Pesquería y relaciones morfométricas de el pez guitarra rayada, *Zapteryx exasperata* (Elasmobranchii, Rhinobatidae), en el Golfo de California, México.** El pez guitarra rayada es una especie de importancia comercial en el noroeste de México, en donde es componente importante de las capturas de la pesquería artesanal de rayas, sin embargo no existe actualmente información sobre las características y abundancias de su pesquería en esta región del país. Se llevaron a cabo muestreos estacionales entre 1998─2000 y 2004─2005, en cinco campos pesqueros del Golfo de California. *Z. exasperata* es un recurso secundario en pesquerías de fondo, es capturada con redes de enmalle de 15 a 20 cm de abertura de malla, utilizando lanchas de fibra de vidrio denominadas "pangas" y a profundidades entre 4─54 m. Las capturas estuvieron compuestas por machos y hembras en una proporción 1:1 con LT entre 41.3 y 90 cm y con un peso promedio de 2.18 ± 1.13 kg. La talla y peso de las hembras fue mayor que en los machos por lo que las relaciones morfométricas fueron diferentes entre sexos. La CPUE presentó su mayor valor durante la primavera (3.4 inv/viaje) y el más bajo durante el verano, así mismo en los caladeros que presentaron profundidades entre los 100 y 200 m la CPUE fue la más alta (5.5 indv/viaje). Las características de la pesquería de *Z. exasperata* concuerda con la de la pesquería de elasmobranquios en otras regiones de México y la estacionalidad de las capturas en el golfo de California es similar a la de otras especies de rayas que se caracterizan por ser abundantes durante la primavera y el verano.

**Palabras clave:** Pesquería artesanal, CPUE, elasmobranquios, composición de las capturas

## Introduction

The ray fishery in the Mexican Pacific was developed with the introduction of bottom gillnets in the Upper Gulf of California. Between 1990 and 2000, the ray landings from the Mexican Pacific coast showed a relatively stable trend with an average of 5,514 tons/year . The Gulf of California (GC) represented 93% of the Pacific coast total ray production during the same period (CONAPESCA 2002). The ray fishery extends throughout the Gulf of California, decreasing from north to south, and is largely represented by small-scale artisanal fishermen (Márquez-Farías 2002, Bizzarro *et al.* 2007, Bizzarro *et al.* 2009). Rays dominate artisanal chondrichthyans landed in Sonora, representing 63.4% of the total catch (Bizzarro *et al.* 2009). At least 18 ray species are caught in the GC, and the composition varies according to season, fishery area, and the nets employed for capture (Márquez-Farías & Blanco-Parra 2006, Bizzarro *et al.* 2009). The principal ray families captured in this fishery are: Rhinobatidae, Urolophidae and Mobulidae, representing more than 90% of the total rays captured in the GC (Márquez-Farías & Blanco-Parra 2006, Bizzarro *et al.* 2009).

Similar to sharks, batoids can also be extremely vulnerable to overfishing due to shared life history characteristics (late maturity, long life span, slow growth and low fecundity) that result in slow population growth (Stevens *et al.* 2000, Dulvy & Reynolds 2002). The most abundant ray family in the Gulf of California catches, the Rhinobatidae, accounts for 52% of the total number of individuals, with the main species consisting of *Rhinobatos productus*, *Rhinobatos glaucostigma* and *Zapteryx exasperata* (Márquez-Farías & Blanco-Parra 2006). Catches are seasonal, with 75% occurring from March to June, with a peak in April when gravid females migrate to shallower waters and become vulnerable to the bottom gillnets commonly used in the artisanal fishery (Villavicencio-Garayzar 1995, Márquez-Farías 2007). The limited distribution of most of the rhinobatid species, the lack of available biological information, and the exploitation by directed and undirected fisheries around the world all contribute to their risk of overexploitation.

The family Rhinobatidae represents one of the most ancient batoid lineages and contains approximately 42 species (Compagno 2005). The genus *Zapteryx* is comprised of three poorly-known species that are distributed only in the waters of the American continent. Two of the three species, *Z. exasperata* (Jordan & Gilbert 1880), and *Zapteryx xyster* (Jordan & Everman 1896), occur in the Eastern Pacific, and little is known of the distribution limits (Ebert 2003) and biology of these rays.

The banded guitarfish, *Z. exasperata*, is a bottom-living elasmobranch found on the Northeast Pacific coast from southern California (USA) to Mazatlán, including the Gulf of California, and inhabits rocky reefs from the intertidal zone to a depth of 69 m (Ebert 2003). The presence of this species south of Mazatlán (Gulf of California) is unknown due to possible misidentification with *Z. xyster*, a more tropically distributed species. *Zapteryx exasperata* is a commercially-important species in the northwest of Mexico, where it is one of the most important species caught in the artisanal ray fishery (Villavicencio-Garayzar 1995, Márquez-Farías & Blanco-Parra 2006), and is caught as bycatch by shrimp trawlers (Pérez-Mellado & Findley 1985). Despite the development of this fishery, there is no information available about its characteristics. Therefore, the aim of this study was to describe the basic characteristics of the *Z. exasperata* fishery, as well as their abundance and morphometric relationships, in the Gulf of California.

## Materials and Methods

Seasonal surveys of artisanal fishing sites were conducted from March 1998 to May 2000, and from November 2004 to July 2005 at artisanal fishery landings in Sonora, along the northern Gulf of California (Fig. 1). During the first year, the aim of the surveys was to determine the location and activities of all active artisanal fishing sites. During 1999 and 2000, the primary elasmobranch fishing camps were visited to collect data on fishing effort, fishery targets, fishing operation, fishing location, gear type, catch composition and biological information.

*Zapteryx exasperata* individuals were sexed and total length (TL, to the nearest cm) and weight (W) (to the nearest 0.1 kg) were measured. Other morphological measurements were also taken: disc width (DW, linear distance across the widest portion of the disc), body length (BL, linear distance from the tip of the snout to the distal edge of the pelvic fin) and disc length (DL, linear distance from the tip of the snout to the distal edge of the pectoral fins). Sexual maturity was estimated in males by considering the degree of calcification and capacity of rotation of the claspers, and in females by macroscopic inspection of the ovaries and uterus (Blanco-Parra *et al.* in press). Juvenile (sexually immature organisms) and adult (sexually mature organisms) ontogenetic categories were assigned.

Fishing site locations were located on maps using the fishermen’s reports and were grouped in five zones based on the utilization of these sites by the fishermen from each fishing camp (Fig. 1). Zone one is the coast surrounding Tiburón Island, San Esteban Island and the Infiernillo channel; this zone includes nine fishing sites used by fishermen from Bahía de Kino. The second zone is the coast from Bahía de Kino to San Nicolas, which includes 15 fishing sites used by fishermen from Bahía de Kino, El Sahuimaro and El Choyudo. The third zone is the coast in front El Cardonal to el Sahuimaro, and includes five fishing sites used by fishermen from El Sahuimaro and El Choyudo. Zone four is the coast from Estero Tastiota to El Choyudo, and includes 12 fishing sites used by fishermen from El Choyudo. The fifth zone is the surrounding area from San Pedro Martir Island which is used by fishermen from Bahía de Kino.

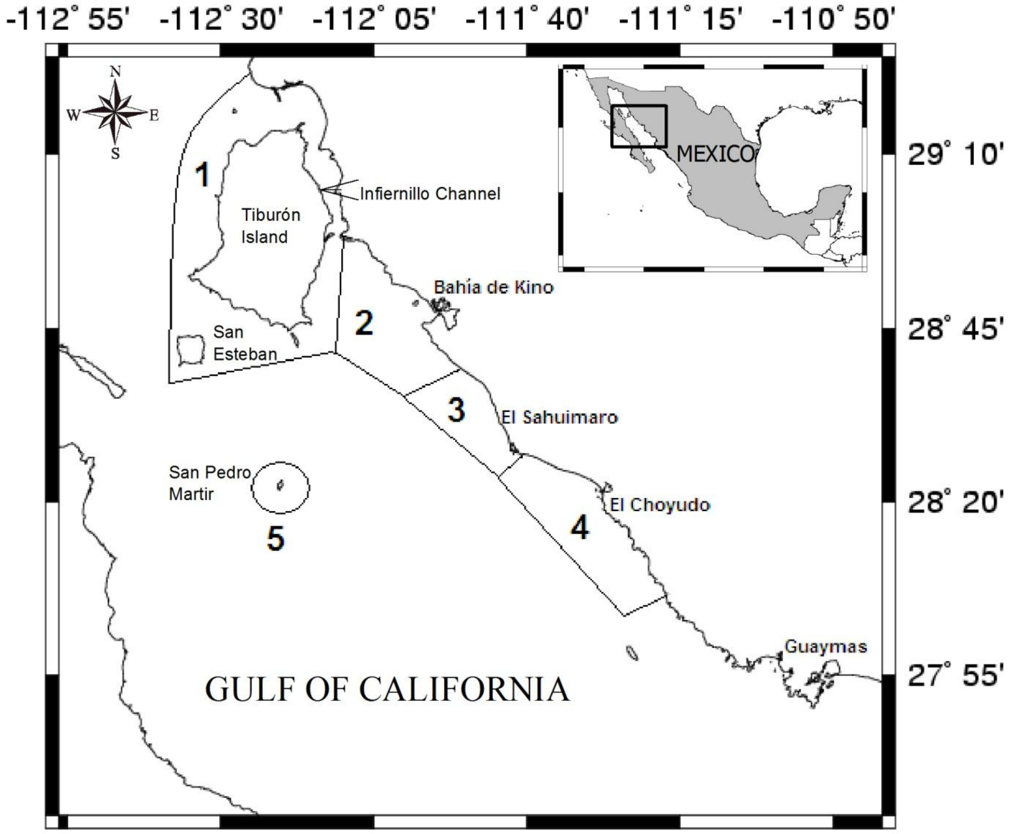

**Figure 1.** Study area showing de fishery camps sampled and the fishing areas into de Gulf of California

Catch per unit effort (CPUE), defined as number of individuals/vessel trip was determined for *Z. exasperata* from landings in each location.

Male and female size composition was tested for normality (Kolmogorov-Smirnov-Lilliefors test). Potential differences in mean size were then evaluated using parametric or non parametric statistics, as appropriate. Sex ratios were tested using a $X^2$ test with Yates correction for continuity (Zar 1996). The relationship between weight (W) and length (TL) was estimated for combined sexes and for males and females separately, adjusting the data to the following model:

$$W= a*TL^b$$

where $W$ is the total weight (kg), $TL$ is the total length (cm), and $a$ and $b$ are the fitting constants. In order to determine the type of growth shown by this species (isometric $b$=3 or alometric $b \neq 3$), the t-Student test (one sample) was used (Zar 1996).

The relationships of DW, BL, DL to TL, were calculated using linear regression. Analysis of covariance (ANCOVA) was employed to determine potential differences between sexes in all relationships.

## Results

*Fishery description. Zapteryx exasperata* is caught in a multispecific artisanal fishery in the northern Gulf of California using nylon bottomset gillnets (nylon diameter 0.4−0.55 mm) with mesh sizes between 9 to 33 cm (commonly 15−20 cm), and a length of 200 to 2400 m. Fiberglass boats regionally called “Panga”, typically 6−9 m long, with outboard engines of 115 HP, were used for the fishing operations. During winter, gillnets are typically soaked for 48 hours due to the low water temperature, but during summer a maximum period of 24 hours was employed. During winter months the main target species were flatfish, and *Z. exasperata* and other rays species were just secondary target species. However, during spring and summer months rays became the principal component of the catches (Fig. 2).

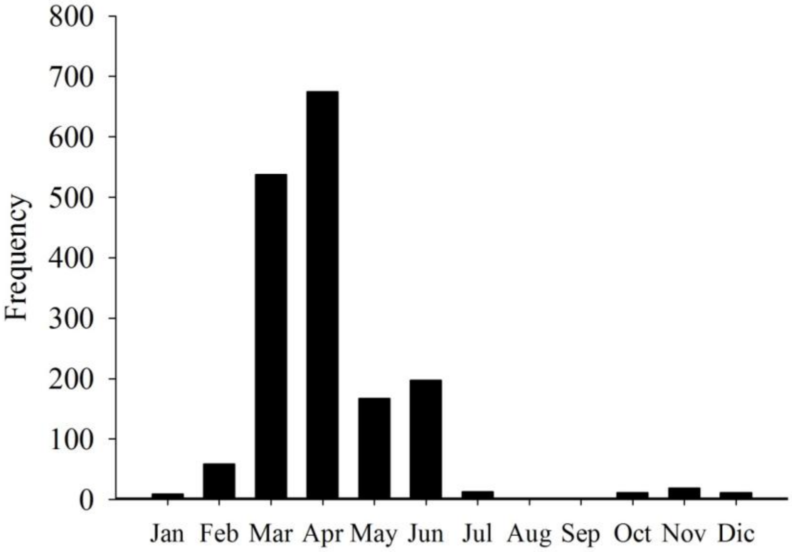

**Figure 2.** *Z. exasperata* catches distribution during 1998−1999 in the artisanal fishery from the Gulf of California.

The ray fishery in Sonora used 45 sites from Tiburon Island to Guaymas. The fishing depth usually ranged from 4 to 54 m. The fishermen that participate in this activity are local people. Some of them belong to fishery cooperatives, whereas others work by themselves only during the time that the shrimp fishery is closed. There are two kinds of fishing camps: permanent ones (Choyudo and Bahía de Kino) that comprise societies with well-organized infrastructure, and isolated camps with poor infrastructure, where fishermen move looking for better fishery areas. *Z. exasperata* is locally known with many names at each camp. Some of the common names include: *guitarrón*, *huesuda*, *bandolón*, and *chalaman*. This species is commercialized as fillets, and is sold under the name "payaso", and "cazón" mixed with other species of sharks and rays.

A total of 1688 individuals of *Z. exasperata* were caught in Sonora during the sampling period. Spring was the season where the catches were highest (65.52%.) and individuals were caught in waters between 9−22 m deep, whereas during winter and autumn, individuals where caught in deeper areas (54−92 m) and in lower amounts (5.13%). During August and September, no *Z. exasperata* were found in the catch.

*Size composition and morphometric relationships.* Banded guitarfish caught during the sampling period had a mean total length of 70.01 ± 9.91 cm (ranging from 41.3 to 93 cm) and a mean weight of 2.18 ± 1.13 kg (ranging from 0.3 to 6.97 kg). Size composition of the overall catch shows that the majority of the specimens ranged from 65 to 80 cm TL, with only females occupying size classes >85 cm (Fig. 3). Significant differences were found in the mean size and weight of females (73.46 ± 10.42 cm; ranging from 41.3 to 93 cm; mean weight 2.51 ± 1.13 kg) and males (66.06 ± 7.57 cm, ranging from 41.90 to 81.00; mean weight 1.49 ± 0.51 kg) [Kolmogorov-Smirnov; p<0.001]. The sex ratio was 1:1 ($X^2$ = 1.91, p = 0.16), and was constant throughout the sampling period.

The largest female was 82 cm TL and weighed 6.97 kg, whereas the largest male was 75 cm TL and weighed 4.33 kg. The model that provided the best fit for the W-TL relationship was, for females: $W_{(kg)} = 1\times10^{-6}TL^{3.4226}, r^2 = 0.97$; males $W_{(kg)} = 9\times10^{-6}TL^{2.8578}, r^2 = 0.95$ (Fig. 4), these relationships were significantly different between sexes (ANCOVA p<0.01). The slope (*b*) of the W-TL model differed from three for females and males (t-student, p<0.01).

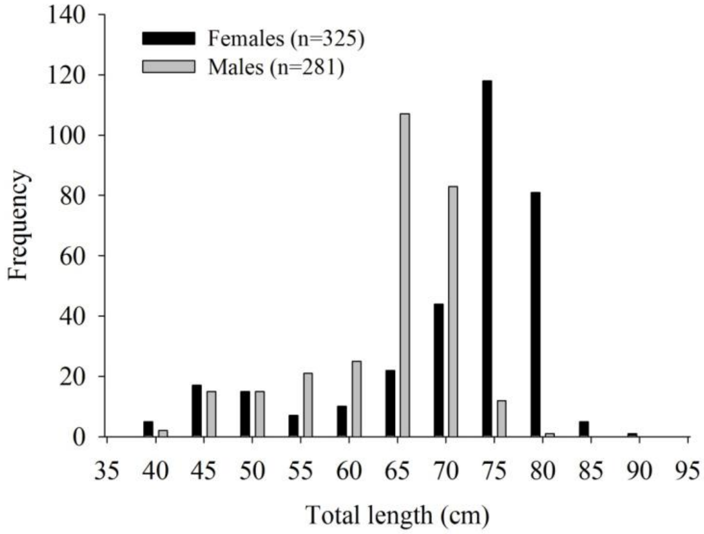

**Figure 3.** Size composition of *Z. exasperata* males and females sampled from the artisanal fishery landings in the Gulf of California

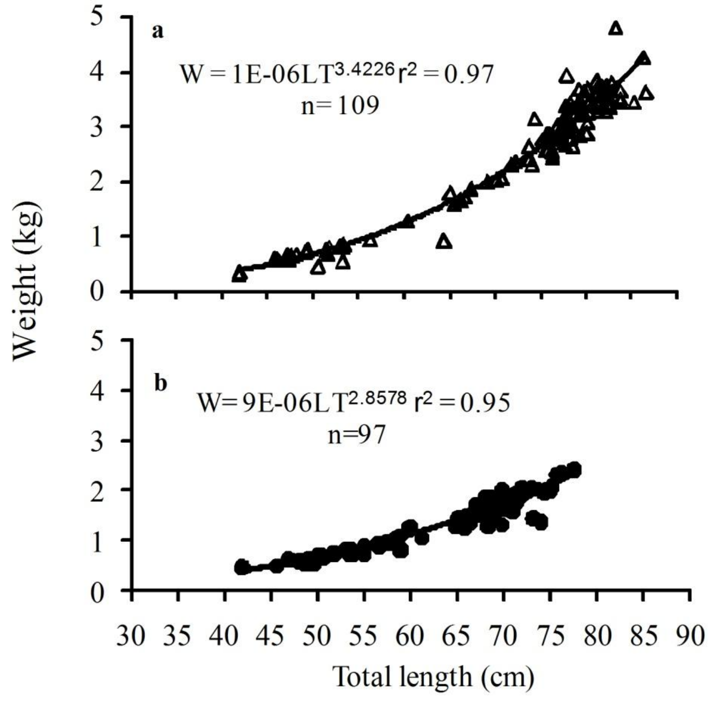

**Figure 4.** Weight-total length relationship for females (a) and males (b) of *Z. exasperata*

Sex-specific differences in all morphometric relationships were observed (ANCOVA, $p<0.01$) and were represented by the following linear equations:

Females

TL= 1.73BL+ 2.89 $r^2$= 0.95, (n=194);
TL= 2.41DL - 4.26, $r^2$ = 0.97 (n=164);
TL = 2.09DW - 3.04, $r^2$= 0.97, (n=199);

Males

TL= 1.87BL - 0.96, $r^2$= 0.97, (n=199);
TL = 2.67DL - 8.90, $r^2$ = 0.93, (n=170),
TL = 2.52AD - 12.02, $r^2$ = 0.9291, (n=199).

*Catch per unit effort (CPUE).* During the sampling period, 1688 individuals of *Z. exasperata* were registered in the catches. March and April were the months with the highest values (Table I). Spring was the season with the highest CPUE value (3.4), whereas winter showed the lowest value (1.0).

**Table I.** Individuals of *Z. exasperata* sampled in the catches of the artisanal fishery from the fishery camps sampled during 1998−1999.

| | Choyudo | Kino | Sahuimaro | Tastiota | Lobos | Desemboque | TOTAL |
|---|---|---|---|---|---|---|---|
| **January** | 1 | 8 | | | | | 9 |
| **February** | 38 | 21 | | | | | 59 |
| **March** | 167 | 226 | 116 | | | | 538 |
| **April** | 455 | 206 | 8 | 6 | | | 675 |
| **May** | 91 | 76 | | | | | 167 |
| **June** | 168 | 29 | | | | | 197 |
| **July** | 11 | | | | 2 | | 13 |
| **October** | 2 | 2 | 1 | | | 6 | 11 |
| **November** | | 19 | | | | | 19 |
| **TOTAL** | 933 | 587 | 125 | 6 | 2 | 6 | 1688 |

We did not register catches of *Z. exasperata* during August and September; however, in October the CPUE increased (1) until November (2.7) (Fig. 5).

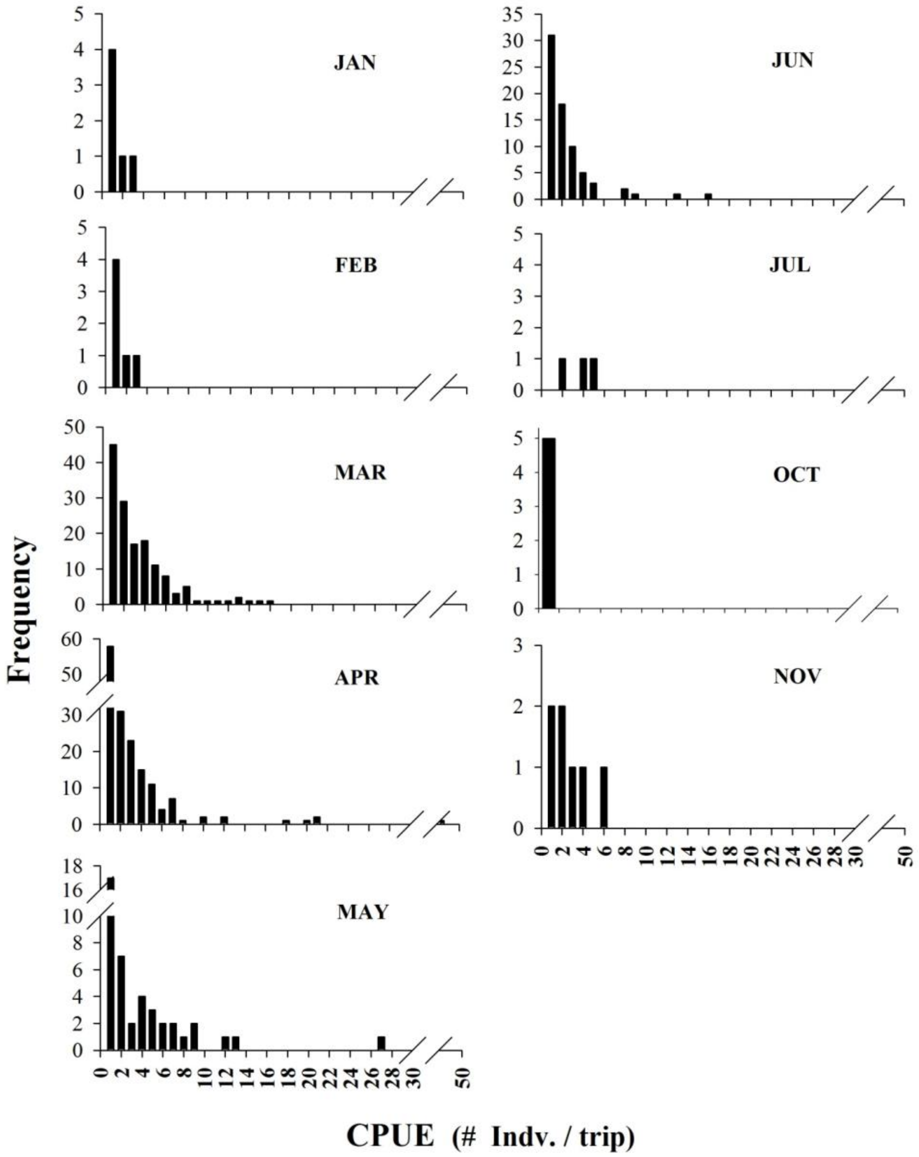

**Figure 5.** *Z. exasperata* CPUE per month in the Gulf of California.

The CPUE had similar values in all fishing zones, ranging from 2 (zone 5) to 3.5 (zone 3) (Fig. 6). El Sahuimaro was the fishing camp in which CPUE was highest (5.2), followed by El Choyudo (3.3). The mesh sizes with the highest CPUE values were 20, 21.5 and 33 cm, whereas the lowest value was for 9 cm mesh.

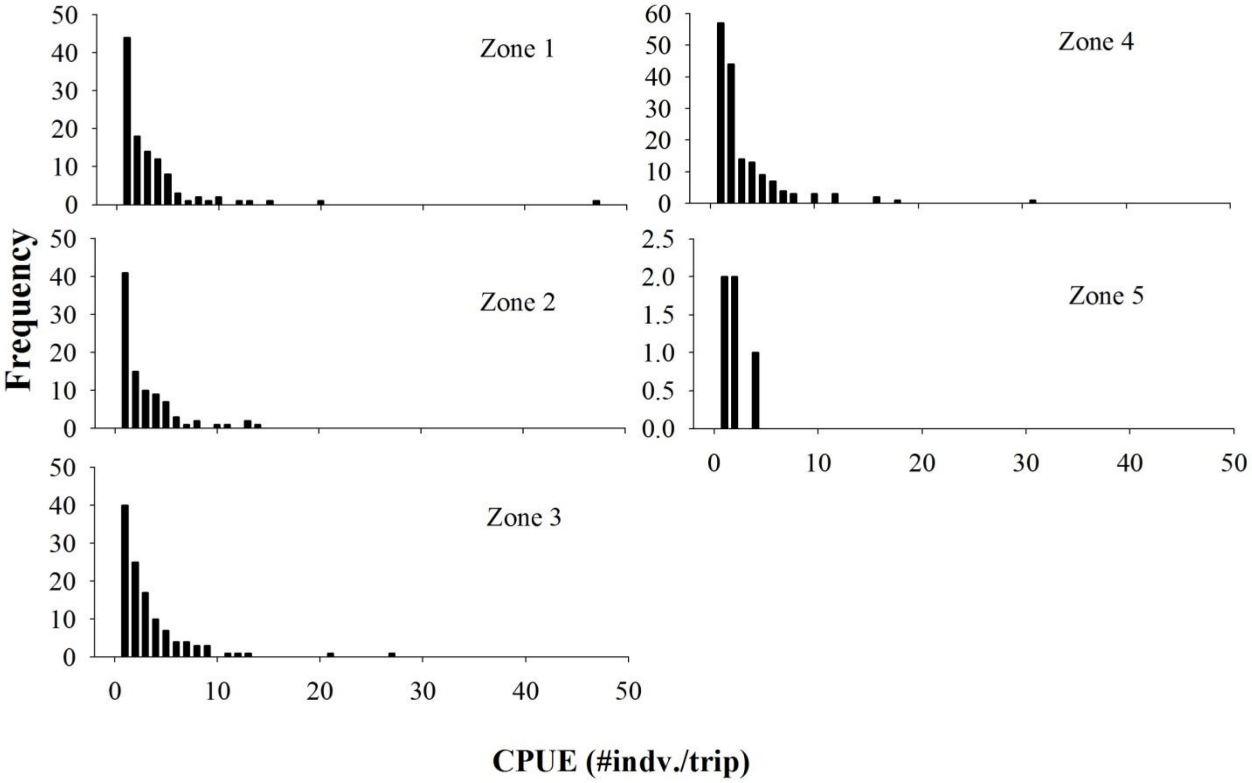

**Figure 6.** Z. exasperata CPUE per fishing zone in the Gulf of California.

## Discussion

Most of the elasmobranch fishery in Mexico is a multiespecific artisanal activity (Castillo-Géniz 1992). In the Gulf of Mexico as well as in the Gulf of California this fishery depends on the seasonal abundance of elasmobranchs, as well as other resources such as teleosts and crustaceans (Castillo-Géniz *et al.* 1998, Márquez-Farías & Blanco-Parra 2006). In the Gulf of California the family Rhinobatidae is the most important component of the catches (Bizzarro *et al.* 2009). Our results confirm the importance of *Zapteryx exasperata* as target species in the artisanal elasmobranch fishery in the Gulf of California. The characteristics of the fishery remain similar to those described before in this region (Márquez-Farías 2002, Bizzarro *et al.* 2009). Villavicencio-Garayzar (1995) previously reported that *Z. exasperata* was caught only occasionally in the commercial fishery of rays in Bahía Almejas on the west coast of the Baja California Peninsula, in contrast to our results on the Sonora coast where this species was a common component in the catches. As in other regions of the Pacific coast of Mexico (Villavicencio-Garayzar 1995, Márquez-Farías & Blanco-Parra 2006), the *Z. exasperata* fishery in Sonora operates in coastal areas using small boats (pangas).

In the Gulf of California different gear types and set locations are used by the elasmobranch fishery (Bizzarro *et al.* 2009), and some ray species are caught with more than one gear type (Bizzarro *et al.* 2007). However, *Z. exasperata* was caught only with bottomset gillnets on the Sonora coast. These findings are consistent with previous reports on the west coast of the Baja California Peninsula, where this species was caught with bottomset gillnets (Villavicencio-Garayzar 1995).

Size-at-birth of *Z. exasperata* ranges between 15 and 22 cm TL, and the maximum reported size is 91 cm (Fisher *et al.* 1995). In the present study, landings of this species were composed of individuals in almost all its reported size range. Villavicencio-Garayzar (1995) report landings of individuals of *Z. exasperata* between 55.5 and 97 cm TL in the artisanal fishery from Bahía Almejas. Considering that in both areas fishermen use similar fishing gear, the occurrence of smaller organisms in Sonora catches could be associated with nursery areas in this region.

*Zapetryx exasperata* is commonly segregated by sex, and males and females are only found together during mating seasons (Ebert 2003). On the western coast of Baja California Peninsula, landings were dominated by females (Villavicencio-Garayzar 1995). The presence of males and females in the same proportion in the landings of this study area provides evidence of the importance of the Sonora coast as a reproductive area for *Z. exasperata*. Recent studies confirmed the importance of the Sonora coast as a reproductive area for *Z. exasperata* (Blanco-Parra *et al.* in press) and other batoids such as the shovelnose guitarfish, *Rhinobatos productus* (Marquez-Farías 2007), and the golden cownose ray, *Rhinoptera steindachneri* (Bizzarro *et al.* 2007).

Sexual dimorphism in elasmobranchs can be seen in the teeth structures (Kajiura & Tricas 1996), head (Kajiura *et al.* 2005), or differences in length of both sexes (Bizzarro *et al.* 2007, Powter & Gladstone 2008). Female *Z. exasperata* were 11% bigger than males and all morphometric relationships were different by sex. Sexual dimorphism has been reported before for other rhinobatids, in which females were bigger than males (Capapé & Zaouali 1994, Villavicencio-Garayzar 1995, Ismen *et al.* 2007, Márquez-Farías 2007).

Differential growth by sex was observed for *Z. exasperata* based on the differences in the W-TL relationships found between sexes. In other rhinobatids, similar findings have been reported with females reaching larger weight and size than males (Ismen *et al.* 2007, Márquez-Farías 2007). Female *Z. exasperata* exhibit alometric growth with a value of $b>3$ (Wooton 1990), indicating a faster growth in weight than in size, probably as a result of the fast increase in weight during gestation period. Male *Z. exasperata* also had alometric growth, but with a value of $b<3$, indicating a faster increase in size. These differences have been reported in *Rhinobatos rhinobatos*, where males have isometric growth, and females had alometric growth (Ismen *et al.* 2007).

During spring and summer landings of the elasmobranch fisheries from the Gulf of California are dominated by ray species (Márquez-Farías & Blanco-Parra 2006, Bizzarro *et al.* 2007, Bizzarro *et al.* 2009). *Zapteryx exasperata* landings peaked during spring in the Sonora coast, whereas during late summer, autumn and winter, this species was rarely landed. Spring was also reported as the main season for *Z. exasperata* landings in Bahía Almejas (Villavicencio-Garayzar 1995). The low number of *Z. exasperata* individuals during summer could be associated with a migration of the species to deeper waters out of the fishing areas of the elasmobranch fishery. This behavior has been reported for other rays in the Gulf of California (Márquez-Farías & Blanco-Parra 2006).

The CPUE also showed seasonal changes, with high values during spring months (March, April and May). These results could be associated with the reproductive migration of males and females to shallower areas where they are vulnerable to bottom gillnets used in the artisanal fishery from Sonora. For *R. productus* from the Gulf of California, this kind of migration to and from shallow coastal areas during reproductive periods has been associated with changes in water temperature (Soto-Mardones *et al.* 1999, Márquez-Farías & Blanco-Parra 2006).

It has been reported that rocky reef is the most abundant habitat around Isla Tiburón and Infiernillo Channel, as well as the coast between El Sahuimaro and El Choyudo (Thomson *et al.* 2000). The CPUE values were very similar between zones; however in zones three (El Sahuimaro) and one (Isla tiburón and Infiernillo channel) they reached the highest values. These results could be explained by the preference of *Z. exasperata* for rocky reef habitats (Ebert 2003). Fishing sites with depths >100 m showed the highest CPUE values for *Z. exasperata.* These findings agree with previous reports for California, in which *Z. exasperata* was found commonly associated to areas with depths between 100 and 200 m (Allen *et al.* 2006).

A recent study on the reproductive biology of *Z. exasperata* from the Sonora coast has reported that the main reproductive season for this species takes place during spring and summer in the coastal areas (Blanco-Parra *et al.* in press). Therefore, our results showed that the reproductive portion of this population is directly affected by the artisanal elasmobranch fishery in the Gulf of California. Fishery regulations should thus be developed for the elasmobranch fishery from the Gulf of California in order to prevent the overexploitation of this and other ray species.

## Acknowledgements

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# Analysis of stomach contents of freshwater stingrays (Elasmobranchii, Potamotrygonidae) from the middle Negro River, Amazonas, Brazil

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**Abstract.** Potamotrygonid stingrays are restricted to Neotropical rivers and information on their diet remains scarce. Thus, the prey composition of four freshwater stingray species from the middle Negro River was studied using stomach contents analysis: *Potamotrygon motoro* (n=40), *Potamotrygon orbignyi* (n=27), *Potamotrygon* sp. “cururu” (n=26), and *Paratrygon aiereba* (n=34). Prey items were identified up to the lowest taxonomic level possible and analyzed with the Index of Relative Importance (%IRI). Teleosteans, crustaceans and insect larvae were consumed by all species in distinct proportions. *Potamotrygon motoro* fed mainly on palaemonid shrimps (33.8%) and trichodactylid crabs (48.7%). Stomach contents of *Potamotrygon orbignyi* were composed principally by insects (96.4%), with predominance of gomphid dragonfly larvae. *Potamotrygon* sp. “cururu” fed on crustaceans (shrimps and crabs: 49.4%) and insect larvae (30.2%). *Paratrygon aiereba* consumed mainly teleosteans (94.8%), which were composed by a wide variety of species. These results suggest a food partitioning among the four freshwater stingray species, based on the use of different microhabitats and foraging substrates. Different mechanisms of prey detection and capture may also contribute to the differences of prey composition in the stomach contents of these stingray species.

**Key words:** feeding, potamotrygonids, aquatic communities, diet

**Resumo. Análise dos conteúdos estomacais de espécies de raias de água doce (Elasmobranchii, Potamotrygonidae) do médio rio Negro, Amazonas, Brasil.** As raias Potamotrygonidae são restritas aos rios neotropicais e pouco se conhece sobre a alimentação dessas espécies. Com base nisso, a composição de presas foi estudada para quatro espécies de raias do médio rio Negro: *Potamotrygon motoro* (n=40), *Potamotrygon orbignyi* (n=27), *Potamotrygon* sp. “cururu” (n=26) e *Paratrygon aiereba* (n=34), por meio de análise de conteúdos estomacais. Os itens alimentares foram identificados até o menor nível taxonômico possível, e os resultados foram analisados utilizando o Índice de Importância Relativa (%IRI). As quatro espécies alimentaram-se de peixes, crustáceos e insetos, porém em proporções diferenciadas. Os exemplares de *P. motoro* consumiram principalmente camarões Palaemonidae (33,8%) e caranguejos Trichodactylidae (48,7%). Os conteúdos estomacais de *Potamotrygon orbignyi* foram compostos majoritariamente por insetos (96,4%), com predomínio de larvas de libélula Gomphidae, enquanto *Potamotrygon* sp. “cururu” consumiu crustáceos (camarões e caranguejos: 49,4%) e larvas de insetos (30,2%). *Paratrygon aiereba* ingeriu predominantemente peixes (94,8%). Estes resultados indicam uma possível partilha de recursos alimentares entre essas quatro espécies de raias, baseada no uso de diversos microhabitats e substratos de forrageamento. Mecanismos diferenciados de detecção e captura de presas também podem contribuir para as diferenças observadas na alimentação dessas raias de água doce.

**Palavras-chave:** alimentação, potamotrigonídeos, comunidade aquática, dieta

## Introduction

Elasmobranchs occur in all aquatic ecosystems and are dominant predators of communities where they live (Camhi *et al.* 1998, Wetherbee & Cortés 2004). This group presents complex sense organs and a variety of feeding mechanisms and mechanics that make them highly competitive with marine tetrapods and teleosteans (Compagno 1990, Maruska 2001, Motta 2004).

While increasing attention has been given to the diet and feeding behavior of sharks, batoids have generally been overlooked (Lowe *et al.* 1996, Heithaus 2001, Kyne & Bennett 2002, Ebert & Cowley 2003). Detailed information about the feeding habits of elasmobranchs will provide a better understanding of their natural history, their role in aquatic ecosystems, and the position of each species in the trophic levels within their particular environments (Cortés 1999, Wetherbee & Cortés 2004).

Only few species of skates and rays occupy the apex of the food chain in marine environments and most of them are predators of benthic communities (Kyne & Bennett 2002, Gilliam & Sullivan 1993), consuming primarily mollusks, crustaceans and teleosteans. There are exceptions to this generalization, however, due to the plasticity of their feeding habits, ontogenetic variations of their diets, and the geographic distribution or availability of different types of prey (Compagno 1990, Wetherbee & Cortés 2004).

Few studies have been undertaken to examine the diets and feeding habits of potamotrygonid rays, as is also true with several other groups of marine rays. Achenbach & Achenbach (1976) were the first to determine the diet of stingrays from that family, and these authors reported ontogenetic changes in terms of the prey consumed.

Rosa *et al.* (1987) described the stomach contents of specimens of *Plesiotrygon iwamae* from the Solimões and Napo Rivers in Brazil, and reported finding teleosteans, insects and decapods. This analysis was based on only three individuals, which did not allow them to determination the importance of each prey category. Lasso *et al.* (1996) analyzed the diets of *Potamotrygon orbignyi* and *Paratrygon aiereba* from the Apure River, Venezuela, and identified insectivorous and piscivorous habits respectively.

Pantano-Neto (2001) examined the diet and anatomy of the orobranchial muscles of two *Potamotrygon* species from Brazil and observed that *P. motoro* fed mainly on insects while *P. henlei* fed especially on gastropods. This author also demonstrated a strong relationship between the feeding habits and the oral muscles of these species, with *P. motoro* having a higher relative biomass of muscles responsible for suction (*e.g. depressor hyomandibulae*), while *P. henlei* had stronger adductor muscles (*e.g. adductor mandibulae*) that aid in breaking its prey apart.

Rincon-Filho (2006) found a high predominance of Ephemeroptera in the diet of *P. orbignyi* in the upper Tocantins River, Brazil. The same author also reported teleosteans, mollusks and crustaceans as the main prey items in the diets of three other potamotrygonid species (*Paratrygon aiereba*, *Potamotrygon henlei* and *P.* sp “n”) from the same sampling site, although these findings were based on very few individuals. Lonardoni *et al.* (2006) found that *P. falkneri* and *P. motoro* fed mainly on teleosteans and insects, respectively, in the upper Paraná River, Brazil. These authors observed seasonal fluctuations of the dominant prey items for the two species, and both consumed mollusks during the flooding season. Overall, studies of batoids have shown that marine and freshwater species both consume the same broad prey categories (teleosteans, crustaceans and mollusks). The greatest difference between them is the considerable importance of insect larvae in the diets of freshwater stingrays (as insects are essentially absent in marine environments).

Comparisons of the dietary compositions recorded in different studies have been complicated by the use of various different indices. Cortés (1997) proposed the use of an Index of Relative Importance (IRI) for interpreting dietary data in elasmobranchs. However, earlier diet analyses carried out by Cortés (1997) as well as some later studies by Pantano-Neto (2001) and Lonardoni *et al.* (2006), for example, use only direct counts, such as frequency of occurrence, volume and/or numbers. This lack of standardization has resulted in incomplete interpretations, however, as they are based solely on the frequency of occurrence of the prey items.

Feeding ecology involves food partitioning and different levels of competition among species, especially in environments with high biodiversity. Despite the similarities between the anatomical features of potamotrygonid species and their co-occurrence in the Negro River, each population has its own distinct microhabitats and feeding habits. According to Araújo (1998), juveniles of *Potamotrygon motoro* occur in tributaries on both margins of the Negro River, whereas juveniles of *Paratrygon aiereba* occur at the mouths of these tributaries as well as on nearby sand beaches; adults of both species occur in the main river channel.

Juveniles and adults of *P. orbignyi* have been associated with sandy beaches, and *Potamotrygon* sp. (locally known as “cururu”) is frequently observed in flooded forests (“igapós”). These findings suggest that sympatric potamotrygonid species may exploit different feeding grounds and prey types, which may lessen competitive interactions.

The present study analyzes the prey composition in the stomachs of the co-occurring stingrays *Potamotrygon motoro*, *P. orbignyi*, *Potamotrygon* sp. “cururu” and *Paratrygon aiereba* in the middle course of the Negro River during the dry season, using Cortés’ methodology (Cortés 1997).

## Material and Methods

The present study was undertaken from December 2001 to March 2007 by a team from the Project Freshwater Stingrays Monitoring Plan (FAPEAM, Amazonas Funding Agency). Sampling was carried out during the low (dry season) to rising (rainy season) hydrological periods, from September to March (Fig. 1). Stingray sampling is seasonal, with an inverse relationship being observed between capture vulnerability and the water level in the river (see Araújo 1998).

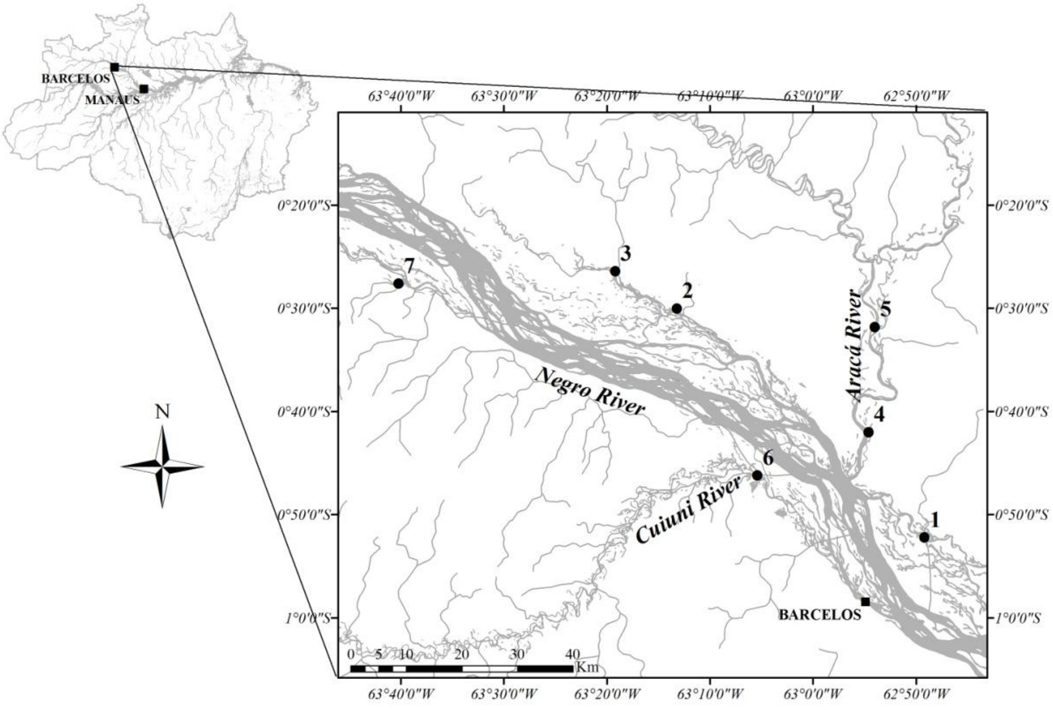

**Figure 1.** Sampling sites of *Potamotrygon motoro*, *P. orbignyi*, *Potamotrygon* sp. “cururu” and *Paratrygon aiereba*, in the middle Negro River, Barcelos, Amazonas State, Brazil. 1. Zamula Stream; 2 – Daraquá Stream; 3 – Itu River; 4 – Maqui Lake; 5 – Demeni River; 6 – Cuiuni River; 7 – Arirahá River.

Neonates and juveniles of *P. motoro*, *P. orbignyi* and *Paratrygon aiereba* as well as juveniles and adults of *Potamotrygon* sp. “cururu” were collected using a dip net. Adults of *P. motoro* and *Paratrygon aiereba* were collected using bottom longlines, while *P. orbignyi* adults were collected by gillnets. All specimens were collected by local fishermen during the night and in different habitats (sandy and muddy beaches, river channels, lakes and streams).

Stingrays were euthanized with clove oil (Eugenol), and their stomachs were immediately removed and injected with a 10% formalin solution to halt digestion. After a few days of immersion in formalin, the stomachs were gently washed and conserved in 70% ethanol. All stingray specimens were identified according to Rosa (1985) and maintained in 10% formalin. Total length (TL), disc width (DW), total weight (TW) and sex were recorded for each individual.

Stomach contents were analyzed with the aid of a stereoscopic microscope. Prey items were sorted, weighted (g), identified to the lowest taxonomic level possible and subsequently counted and maintained in 70% ethanol. Prey items were identified using specific identification keys (*e.g.*

Géry 1977, Burgess 1989, Keith *et al*. 2000, Melo 2003) and were also compared with specimens from the Zoological Collections of the National Institute for Amazonian Research – INPA, with the assistance of specialists for each taxonomic category.

The percentages of frequency of occurrence (%F.O.), numbers (%N), and weight (%W) were calculated for each prey category according to the following equations (Hyslop 1980):

%F.O. = 100 x Fi/n, where: **Fi** is number of stomachs containing a particular prey taxon; **n** is total number of stomachs with any prey.

%N = 100 x Ni/n, where: **Ni** is total number of prey of a particular taxon; **n** is the total number of all prey identified.

%W = 100 x Wi/n, where: **Wi** is the total weight of prey of a particular taxon; **n** is the total weight of all prey in the stomachs.

The Index of Relative Importance (IRI) was calculated combining %F.O., %N, and %W (Pinkas *et al.* 1971), replacing volumetric percentage for weight percentage: IRI = (%P + %N) x %F.O. The IRI was transformed into a percentage (%IRI; *cf.* Cortés 1997), for comparisons among the studies. Empty stomachs and those presenting only amorphous substances (unidentified digested contents) were not considered in the IRI calculation. The results of %W, %N and %F.O. were used to prepare three-dimensional graphics to aid in interpreting the contributions of each prey item categories to the stingrays' diets (Cortés 1997).

## Results

Forty specimens of *Potamotrygon motoro*, with disc widths (DW) ranging from 17.0 to 56.0 cm, 27 specimens of *P. orbignyi* (DW: 17.0 – 48.2 cm), 26 *Potamotrygon* sp. "cururu" (DW: 14.9 – 31.0 cm), and 34 *Paratrygon aiereba* (DW: 18.4 – 67.0 cm) were analyzed. The numbers of empty stomachs, those with only amorphous substances, and those presenting at least one prey item for each stingray species are summarized in Table I.

Prey items that were found in all four species included insect larvae, mollusks, crustaceans and teleosteans. Palaemonid shrimps and dragonfly larvae (Odonata: Gomphidae) were present in distinct proportions in the stomachs of all of the species analyzed; mollusks were observed in the stomachs of only one specimen of *P. motoro*. A total of 18 taxonomic groups were found in all species. The results of percentages of number, weight and frequency of occurrence and the Index of Relative Importance (IRI) of prey items are shown in Table I.

The relative importance of prey categories (%IRI) indicated differences among the stingray species. *Potamotrygon motoro* had decapods as its dominant prey (70.0%), followed by teleosteans (26.5%). Insects and mollusks had minor importance for this species, with %IRI values of 3.4% and 0.1% respectively. *Potamotrygon orbignyi* fed mainly on insects (96.4%), with a low participation of teleosteans (2.7%) and crustaceans (0.9%). *Potamotrygon* sp. "cururu" had the largest %IRI for crustaceans (49.4%), followed by insects (30.2%) and teleosteans (20.4%). *Paratrygon aiereba* consumed primarily teleosteans (94.8%), while crustaceans and aquatic insects (both with 2.6%) had lower participations in its diet.

Palaemonid shrimps had high importance for *P. motoro* (33.8%), in contrast for the other three species. Dragonfly larvae were the dominant item in the diet of *P. orbignyi*, having a 73.9% importance level, while this prey item presented only 23.7% IRI for *P.* sp. "cururu". Crustaceans represented almost 50% IRI for *P.* sp. "cururu"; they were not the dominant prey item in this species' diet because the percentages of frequency of occurrence of insect larvae and crustaceans were similar but the low contribution of the weight of crustaceans made them the second most important item for *P.* sp. "cururu".

The three-dimensional graphic representations of the %F.O., %N and %W values illustrate the relative importance of the different prey categories to each stingray species (Fig. 2). *Potamotrygon motoro* (Fig. 2a), *P. orbignyi* (Fig. 2b) and *Paratrygon aiereba* (Fig 2c) had up to two dominant prey items in their diets, while *P.* sp. "cururu" (Fig. 2d) showed a more homogeneous participation of various prey taxa. Crustaceans were dominant in the diet of *Potamotrygon motoro*, although teleosteans were also significant; mollusks were a rare item in the diet of this species. Insects were the dominant prey of *P. orbignyi*. Insects were also consumed by *Potamotrygon* sp. "cururu", but in similar proportions to both crustaceans and teleosteans. *Paratrygon aiereba* had teleosteans as its dominant prey, while invertebrates were rare in its diet.

## Discussion

Similar general food categories were consumed by *Potamotrygon motoro*, *P. orbignyi*, *P.* sp. "cururu" and *Paratrygon aiereba*; however, each species had different predominant prey items. In the current study, crustaceans (especially trichodactylid crabs) were the main prey item for *Potamotrygon motoro*. Pantano-Neto (2001) reported that *P. motoro* from the Cristalino River, a tributary of the Araguaia River, in Mato Grosso State, Brazil, consumed large amounts of insect larvae (99%), although this author used a different method for calculating the feeding index (Kawakami & Vazzoler 1980). Rincon-Filho (2006), however, noted that the specimens examined by Pantano-Neto (2001) were actually chromatic variants of *P. orbignyi*, which would explain the observed differences in their diets. Individuals of *P. motoro* from the upper Paraná River had insect larvae as their dominant prey item, as well as some mollusks and teleosteans (Lonardoni *et al.* 2006, Silva & Uieda 2007). The present study found a similar percentage of teleosteans and crustaceans, although teleosteans numbers and weight percentages indicated a lower contribution to the diet of *P. motoro* as compared to crustaceans (%N, %W and %F.O. values higher than 50%).

**Table I.** Prey items found in the stomachs of *Potamotrygon motoro*, *P. orbignyi*, *P.* sp. "cururu" and *Paratrygon aiereba*, from Negro River basin, expressed in percentages of number (%N), weight (%W) and frequency of occurrence (%F.O.), Index of Relative Importance (%IRI). Number of stomachs with contents (C), stomachs with amorphous substance (A) and empty stomachs (E) are presented for each potamotrygonid species.

| | ***P. motoro*** | | | | ***P. orbignyi*** | | | | ***Potamotrygon* sp. "cururu"** | | | | ***Paratrygon aiereba*** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (C=32; A=5; E=3) | | | | (C=12; A=5; E=10) | | | | (C=17; A=1; E=8) | | | | (C=15; A=6; E=13) | | | |
| Items | %N | %W | %F.O. | %IRI | %N | %W | %F.O. | %IRI | %N | %W | %F.O | %IRI | %N | %W | %F.O. | %IRI |
| **FISHES** | **29.8** | **33.2** | **53.2** | **26.5** | **3.6** | **32.7** | **9.1** | **2.7** | **12.7** | **55.0** | **29.4** | **20.4** | **77.8** | **99.8** | **50.0** | **94.8** |
| **Characiformes** | | | | | | | | | | | | | | | | |
| Characidae | | | | | 3.6 | 32.7 | 9.1 | 5.1 | 1.8 | 38.9 | 5.9 | 7.8 | 2.8 | <0.1 | 5.6 | 0.8 |
| Curimatidae | 0.7 | 0.4 | 3.1 | <0.1 | | | | | 3.6 | 13.1 | 5.9 | 3.2 | | | | |
| **Clupeiformes** | | | | | | | | | | | | | | | | |
| Engraulididae | | | | | | | | | | | | | 30.6 | 1.1 | 5.6 | 9.6 |
| **Gymnotiformes** | | | | | | | | | | | | | | | | |
| Unidentified | | | | | | | | | | | | | 2.8 | 0.1 | 5.6 | 0.9 |
| **Perciformes** | | | | | | | | | | | | | | | | |
| Cichlidae | 20.4 | 20.2 | 9.4 | 6.9 | | | | | | | | | 2.8 | 42.3 | 5.6 | 13.6 |
| **Siluriformes** | | | | | | | | | | | | | | | | |
| Callichthyidae | | | | | | | | | | | | | 2.8 | 0.4 | 5.6 | 0.9 |
| Cetopsidae | | | | | | | | | | | | | 2.8 | 54.4 | 5.6 | 17.3 |
| Doradidae | 1.8 | 2.3 | 9.4 | 0.7 | | | | | 1.8 | 0.5 | 5.9 | 0.4 | 8.3 | 1.0 | 11.1 | 5.5 |
| Loricariinae | 0.7 | 1.0 | 6.3 | 0.2 | | | | | | | | | 2.8 | 0.3 | 5.6 | 0.9 |
| **Synbranchiformes** | | | | | | | | | | | | | | | | |
| Synbranchidae | 2.2 | 4.1 | 9.4 | 1.1 | | | | | | | | | | | | |
| Unidentified | 4.0 | 5.2 | 34.4 | 5.7 | | | | | 5.5 | 2.5 | 17.6 | 4.6 | 22.1 | 0.2 | 27.8 | 33.6 |
| **MOLLUSKS** | **1.1** | **0.8** | **3.1** | **0.1** | | | | | | | | | | | | |
| Caenogastropoda | | | | | | | | | | | | | | | | |
| *Pomacea* sp. | 1.1 | 0.8 | 3.1 | 0.1 | | | | | | | | | | | | |
| **CRUSTACEANS** | **54.9** | **62.9** | **75.0** | **70.0** | **3.6** | **1.6** | **18.2** | **0.9** | **47.3** | **34.7** | **58.8** | **49.4** | **11.1** | **0.1** | **22.2** | **2.6** |
| **Decapoda** | | | | | | | | | | | | | | | | |
| Euryrhynchidae | | | | | | | | | 34.5 | 7.9 | 17.6 | 24.2 | 2.8 | 0.1 | 5.6 | 0.8 |
| Palaemonidae | 42.5 | 3.5 | 40.6 | 33.8 | 3.6 | 1.6 | 18.2 | 1.4 | 5.5 | 0.8 | 17.6 | 3.6 | 8.3 | <0.1 | 16.7 | 7.6 |
| Trichodactylidae | 12.4 | 59.4 | 37.5 | 48.7 | | | | | 7.3 | 26.0 | 23.5 | 25.4 | | | | |
| **INSECTS** | **14.2** | **3.1** | **25.0** | **3.4** | **92.8** | **65.7** | **72.7** | **96.4** | **40.0** | **10.3** | **58.8** | **30.2** | **11.1** | **0.1** | **22.2** | **2.6** |
| **Odonata** | | | | | | | | | | | | | | | | |
| Cordulidae | 5.8 | 2.4 | 9.4 | 1.4 | | | | | | | | | | | | |
| Gomphidae | 3.3 | 0.5 | 9.4 | 0.6 | 25.5 | 62.9 | 54.5 | 73.9 | 14.5 | 6.2 | 35.3 | 23.7 | 2.8 | <0.1 | 5.6 | 0.8 |
| Libellulidae | 2.2 | 0.2 | 9.4 | 0.4 | | | | | 14.5 | 3.2 | 5.9 | 3.4 | | | | |
| **Ephemeroptera** | | | | | | | | | | | | | | | | |
| Leptophlebiidae | 0.7 | <0.1 | 3.1 | 0.1 | 67.3 | 2.8 | 18.2 | 19.6 | 7.3 | 0.7 | 11.8 | 3.0 | | | | |
| **Unidentified** | 2.2 | <0.1 | 6.2 | 0.2 | | | | | 3.7 | 0.2 | 5.9 | 0.7 | 8.3 | <0.1 | 16.7 | 7.5 |

*Potamotrygon orbignyi* had insectivorous feeding habits, mainly consuming dragonfly larvae. Similar results were reported by Lasso *et al.* (1996) and Rincon-Filho (2006) for individuals from the Apure and Tocantins river basins respectively, and both studies encountered mainly Ephemeroptera (the second most important group of insects for *P. orbignyi* from Negro River basin). The predominance of insects in the diet of *P. orbignyi* is possibly related to its small mouth, which makes capturing large prey such as crabs and teleosteans more difficult. Additionally, this stingray species lives near sandy beaches where insect larvae are abundant. Bragança *et al.* (2004) investigated the feeding biology of *P. orbignyi*, *P. scobina* and *Plesiotrygon iwamae* and found considerable quantities of crustaceans and insects (Diptera) in their stomachs.

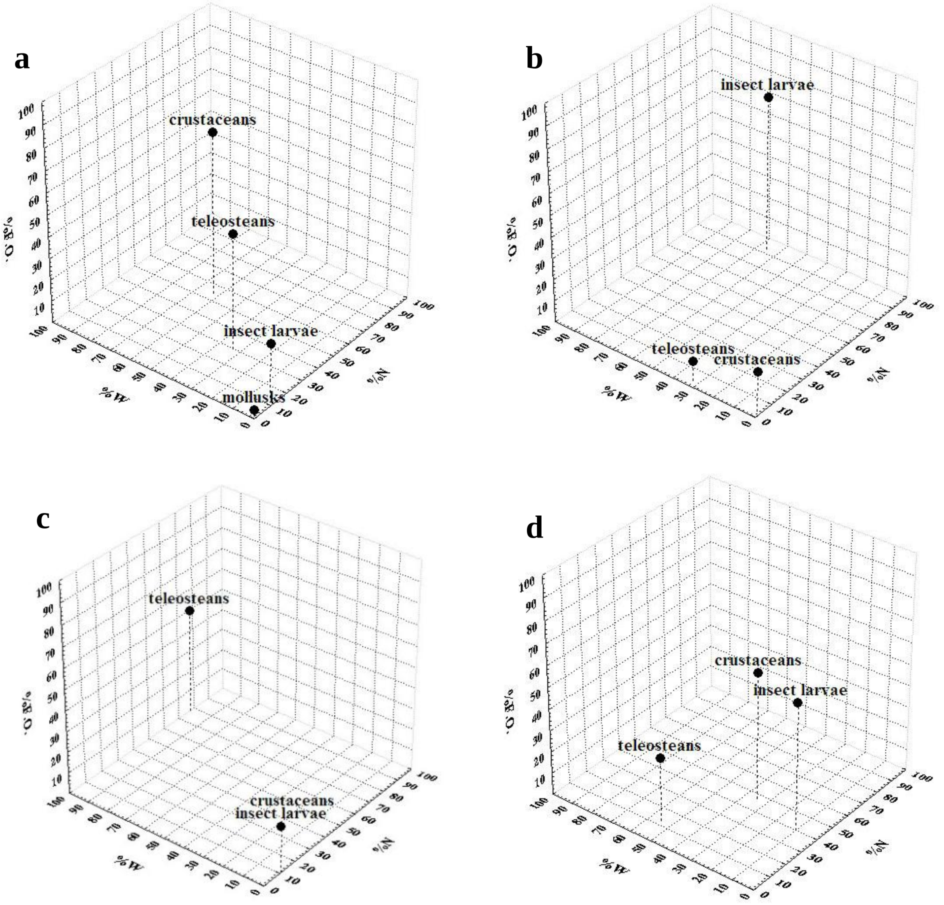

**Figure 2.** Graphic representation of the diet of *Potamotrygon motoro* (a), *P. orbignyi* (b), *Paratrygon aiereba* (c), and *Potamotrygon* sp. “cururu” (d), using percentages of weight (%W), number (%N) and frequency of occurrence (%F.O.).

The diet of *Potamotrygon* sp. “cururu”, which had never been previously examined, indicated generalist feeding habits based on the consumption of trichodactylid crabs, euryrhynchid shrimps and gomphid dragonflies. Teleosteans remains were encountered, but this prey item apparently contributed very little to the diet of this stingray species. According to Araújo (1998), “cururu” stingrays occur in flooded forests (“igapós”) where its main prey are common and abundant (Melo 2003, Fidelis *et al.* 2008). There is no information available about this species during the dry season when there are no flooded forest sites; these stingrays may change their diets or simply reduce their feeding activities during this period, which remains to be investigated.

*Paratrygon aiereba* demonstrated strongly piscivorous habits, consuming a wide variety of teleosteans commonly found in the river channel (*e.g.* Cetopsidae and Doradidae) and near sandy beaches (*e.g.* Engraulididae and Loricariinae), where adults and juveniles of *P. aiereba* are common, respectively. Lasso *et al.* (1996) and Rincon-Filho (2006) reported similar results for stingray specimens from the Apure River (Venezuela) and Tocantins River (Brazil), although they did not identify the prey fish to species level.

The varied consumption patterns of a given stingray species at different locations may be a consequence of particular habitat features at each site, as observed for *P. motoro* (Lonardoni *et al.* 2006) and *P. orbignyi* (Bragança *et al.* 2004, Rincon-Filho 2006), and indicates that at least some stingrays are able to adapt to different environments and different prey availabilities. This same situation was not observed for *Paratrygon aiereba*, however, as it consistently exhibited a strongly piscivorous diet, differing only in terms of the fish taxa consumed.

More than 50% of the specimens of *P. orbignyi* and *Paratrygon aiereba* had empty stomachs or stomachs containing only amorphous substances (see Table I). Simpfendorfer (1998) and Barry (2002) considered empty stomachs or those containing only amorphous substances as indicating regurgitation due to excessively distended stomach walls. The empty stomachs observed with *P. orbignyi* and *Paratrygon aiereba*, however, may also have been caused by capture stress (*q.v.* Wetherbee & Cortés 2004), as being hooked for long periods of time may well cause regurgitation of their stomach contents. The high occurrence of empty stomachs and prey in advanced degrees of digestion may also suggest that the specimens analyzed were not feeding frequently, for prey items in different stages of digestion would otherwise have been expected (Wetherbee & Cortés 2004).

Bethea *et al.* (2007) reported that plants were frequently found in the stomach contents of bonnethead shark *Sphyrna tiburo* and were considered a prey item for this species - even though its presence may only be the result of their feeding behavior, as undigested plants were rarely found in the spiral valve of sharks. Some authors (*e.g.* Bragança *et al.* 2004, Lonardoni *et al.* 2006) consider plants as making up at least part of the diets of potamotrygonid species. In the current study, plants were rare among the stomach contents of the potamotrygonid species analyzed, and were not considered a prey category. These discrepancies in interpreting the role of plant material in the diet of freshwater stingrays clearly indicate the need for more detailed studies on its nutritional contribution.

The IRI interpretation proposed by Cortés (1997) has been employed in many studies of the diet and feeding habits of elasmobranchs (*e.g.* Ebert & Cowley 2003, Rincon-Filho 2006, Collins *et al.* 2007). There had been a lack of standardization of feeding analyses before Cortés's study due to the use of various methods proposed by a number of different authors - making comparative studies more difficult (see Hyslop 1980, Kawakami & Vazzoler 1980 and Costello 1990).

Some studies carried out after Cortés' review (1997) (such as Pantano-Neto 2001 and Lonardoni *et al.* 2006) did not adopt %IRI, but rather used percentage of frequency of occurrence (%F.O.). Their findings showed a high participation of insect larvae (more than 90%F.O.) in the diet of *P. motoro*, whereas the current study observed 71.9% teleosteans, 78.1% crustaceans, and a low occurrence of insect larvae (37.5%) for the same stingray species.

Mollusks (*Pomacea* sp.) were found in the stomach contents of only one specimen of *P. motoro*. Low conductivity, an acid pH, and low levels of calcium and phosphorus in the waters of the Negro River are supposed to limit the occurrence of mollusks (Sioli 1953, Goulding *et al.* 1988, Volkmer-Ribeiro *et al.* 1998), which may explain the rarity of this prey item in the diet of freshwater stingrays. However, more than 50% of the diet of potamotrygonid species (*e.g. Potamotrygon henlei*) from clear waters rivers (Cristalino and Paraná Rivers) has been reported to be composed of gastropods and bivalves (Pantano-Neto 2001, Lonardoni *et al.* 2006).

Dragonfly larvae were present in the diets of all of the stingrays species analyzed, and with particularly high participation in the diets of *Potamotrygon* sp. "cururu" (23.7%) and *P. orbignyi* (73.9%). The high %IRI of this prey type for *P. orbignyi* reflects its habitat of sandy beach areas along the Negro River where insect larvae are commonly found buried in the sand (Fidelis *et al.* 2008). The consumption of large amounts of gomphid dragonfly larvae also provides us with indirect information about the foraging tactics of this stingray species, which digs up prey buried in the sand.

A temporal investigation of the diets of *P. motoro* and *P. falkneri* from Upper Paraná River was undertaken by Lonardoni *et al.* (2006) and demonstrated differences in their diets during the dry and flooding seasons. The largespot stingray (*P. falkneri*) had piscivorous feeding habits in the dry season but malacophagous habits in the flooding season. The ocellate river stingray (*P. motoro*) fed mainly on aquatic insects in both seasons, but also consumed mollusks during the flooding season. The present study have shown that the four stingray species that co-occur in the Negro River consumed similar prey items, although with distinct individual %IRI values that presumably reflect differences between the habitats where each species is found. Seasonal, ontogenetic and sex variations on their diet may also exist and should be considered in future studies.

The present results corroborated observations from previous studies that the diets of the same species of Potamotrygonidae from distinct locations cannot be generalized. The abundance and availability of prey items in the environment where these stingrays live strongly influence their diets, which would at least partially explain the differences encountered in the published data on the subject. These differences may be particularly important in short term studies, and the results presented here must be considered carefully in light of its restriction to the dry and rising seasons. Information concerning changes in prey consumption linked to seasonal variations is essential for a better understanding of the role of locally available prey items and the specific habitats used by potamotrygonid species during the annual hydrological cycles of Amazonian rivers.

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# Estimativas de mortalidade e tabelas de vida do tubarão-azul, *Prionace glauca* (Carcharhinidae), no sul do Brasil e águas internacionais adjacentes

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**Resumo.** Tabelas de vida do tubarão-azul *Prionace glauca* incorporando os dados mais recentes sobre idade e crescimento, idade de maturação sexual, ciclo reprodutivo e fecundidade idade-específica no sul do Brasil foram desenvolvidas. A taxa instantânea de mortalidade total teve valores de 0,589 para os machos e 0,601 para as fêmeas, o que reflete sobrevivência entorno de 55% para ambos os sexos após a idade de recrutamento pesqueiro, estimada em 4 anos para os machos e 6 anos para as fêmeas. No caso hipotético de ausência da pesca, e considerando 65,9% de sobrevivência ao 1º ano de vida, a população cresceria aproximadamente 24,2% ao ano. Na situação real, considerando a mortalidade por pesca atual, observou-se que com sobrevivência inicial inferior a 27,4% a população se encontraria diminuindo. No cenário mais otimista e plausível, considerando sobrevivência inicial entorno de 40% e taxa de mortalidade por pesca atual, a população apresentaria crescimento populacional positivo de 5,4% ao ano. O valor positivo de crescimento populacional é evidência de que *P. glauca* se encontra tentando recuperar seu estado de equilíbrio num ambiente cujos recursos são cada vez mais limitados. A taxa positiva de crescimento não é necessariamente sinal de saúde populacional, podendo constituir um flagrante de alerta à tomada de medidas preventivas. *P. glauca* é uma espécie produtiva e resiliente, mas à luz das substanciais incertezas associadas às estimativas das taxas de mortalidade e aos modelos associados, recomenda-se cautela no nível de explotação da espécie.

**Palavras-chave:** história de vida, dinâmica populacional, taxas de explotação, avaliação de estoques.

**Abstract. Mortality estimates and life tables of the blue shark, *Prionace glauca* (Carcharhinidae), off southern Brazil and adjacent international waters.** Life tables of the blue shark *Prionace glauca* incorporating the most recent data on age and growth, age at maturity, reproductive cycle and age-specific fecundity were performed. The instantaneous rate of total mortality had values of 0.589 for males and 0.601 for females, reflecting around 55% of survival for both sexes after the age at fisheries recruitment, estimated at 4 years for males and 6 years for females. In the hypothetical case of absence of fishing, and with 65.9% surviving the 1st year of life, the population could increase at approximately 24.2% per year. In the real situation, considering the current fishing mortality and initial survival lower than 27.4%, the population will be decreasing. In the most optimistic and plausible scenario, considering initial survival around 40% and the actual fishing mortality, the population will show positive population growth of 5.4% per year. This positive value of population growth is evidence that *P. glauca* is trying to recover its state of equilibrium in an environment where resources are increasingly limited. The positive rate of growth is no sign of population health, by contrast, is a stark warning to take preventive measures. *P. glauca* is a resilient and productive species, but given the substantial uncertainties associated with estimates of mortality rates and the associated models, caution is recommended in the level of exploitation of the species.

**Keywords:** life history, population dynamics, exploitation rates, stock assessment.

## Introdução

O tubarão-azul, *Prionace glauca* (Linnaeus 1758), é a espécie mais capturada nas pescarias oceânicas em nível mundial (Camhi *et al*. 1998). O efeito desta explotação contínua nos processos populacionais de *P. glauca* é matéria de debate. No Atlântico Norte, alguns autores observaram declínio nas taxas de captura de *P. glauca* (Simpfendorfer *et al*. 2002, Baum *et al*. 2003, Campana *et al*. 2006, Cortés 2008, Aires-da-Silva *et al*. 2008), enquanto que a frota de espinhel japonesa não têm sido observadas mudanças, com taxas de captura aproximadamente constantes no período de 1971 a 2003 (Nakano & Clarke 2005).

No Atlântico Sudoeste *P. glauca* vem sendo capturada desde meados do século XX, quando se iniciou a pesca com espinhel pelágico no Brasil e no Uruguai (Hazin *et al*. 1990, Amorim *et al*. 1998, Domingo *et al*. 2002). Na frota brasileira as taxas de captura padronizadas anuais se mantiveram estáveis de 1978 a 2006 (Mourato *et al*. 2007, Hazin *et al*. 2008). Já na frota uruguaia as taxas de captura padronizadas anuais nos anos de 1999 a 2006 foram 44% da média dos anos de 1992 a 1998 (Pons & Domingo 2008).

Apesar dos indícios de declínio das taxas de captura de *P. glauca* no Oceano Atlântico acima mencionados, a Comissão Internacional para a Conservação dos Tunídeos do Atlântico - ICCAT, avaliou em 2008 que os estoques de tubarão-azul em todo o oceano Atlântico encontravam-se próximos do nível da biomassa virgem e que as taxas de mortalidade por pesca eram inferiores àquelas necessárias para alcançar o rendimento máximo sustentável (Anônimo 2008). As divergências entre as avaliações publicadas sobre o estado dos estoques de *P. glauca* no oceano Atlântico justificam a necessidade de estudos adicionais sobre a mortalidade e demografia desses estoques.

Dada a relação direta entre a fecundidade e o número inicial da coorte nos peixes elasmobrânquios, a análise demográfica através da elaboração de tabelas de vida é uma metodologia apropriada para avaliar o estado populacional dessas espécies (Cortés 2004). Com o uso dessa metodologia, o objetivo do presente estudo foi avaliar a capacidade de crescimento populacional de *P. glauca* no sul do Brasil sob condições variadas de mortalidade natural e por pesca.

## Materiais e Métodos

A demografia de *P. glauca* no Atlântico Sudoeste foi estudada através da confecção de tabelas de vida onde foram combinadas estimativas de reprodução e mortalidade (Tabela I) sob diferentes cenários, para estimar a taxa intrínseca de crescimento populacional segundo o modelo de Lotka (1907 *apud* Krebs 1989). Nesse modelo a taxa de crescimento populacional é uma função dos parâmetros $l_x$ (proporção de fêmeas sobreviventes da coorte na idade $x$), e $m_x$ (fertilidade em número de fêmeas *per capita*, na idade $x$), segundo as expressões:

$$R_0 = \sum l_x m_x$$

$$G = \frac{\left(\sum l_x m_x x\right)}{R_0}$$

$$r = \frac{\left(\ln R_0\right)}{G}$$

onde, $R_0$ é a taxa líquida reprodutiva, $G$ é o tempo de geração e $r$ é a taxa instantânea de crescimento populacional. A taxa anual de crescimento populacional é dada por $e^r$. Os valores de $R_0$ e $r$ indicam se a população está aumentando ou diminuindo. Quando $R_0 = 1$ e $r = 0$, a população substitui a si mesma geração a geração; quando são maiores do que estes valores, a população está crescendo, e quando menores, a população está decrescendo (Odum 1986, Krebs 1989).

*Mortalidade e Sobrevivência.* No estudo da mortalidade e sobrevivência foi usado o modelo tradicional da biologia pesqueira apresentado por Ricker (1975), onde $M$, $F$ e $Z$ são os coeficientes instantâneos de mortalidade natural, por pesca e total, respectivamente e $S$ é a taxa anual de sobrevivência.

Dado que a mortalidade varia muito com a idade, nas tabelas de vida foram incorporadas mortalidades no primeiro ano de vida ($M_0$), na fase juvenil ou não completamente recrutada à pesca ($Z_{juv}$) e na fase plenamente recrutada ($Z_{rp}$).

O coeficiente instantâneo de mortalidade natural ($M$) não tem sido estimado de forma direta para *P. glauca*. Estimativas de $M$ em tubarões são obtidas através de métodos indiretos, utilizando modelos que relacionam parâmetros populacionais, fatores ambientais e mortalidade em peixes (Cortés 1995, 1998, Simpfendorfer 1999). Entretanto, no primeiro ano de vida a mortalidade natural é maior (Odum 1986). Heupel & Simpfendorer (2002) e Manire & Gruber (1993 *apud* Cortés 1995) estimaram taxas de mortalidade anual de 40 – 60% no 1° ano em *Carcharhinus limbatus* e *Negaprion brevirostris*, respectivamente. Essas são as únicas estimativas diretas disponíveis da taxa de mortalidade no 1° ano de vida em tubarões. Heupel & Simpfendorfer (2002) constataram ainda que as referidas taxas de mortalidade no primeiro ano de vida foram maiores que aquelas obtidas com o método usado por diversos autores (Cailliet 1992, Cortés & Parsons 1996, Sminkey & Musick 1996, Simpfendorfer 1999) de multiplicar por dois ou três a estimativa indireta de $M$ para o 1º na de vida. Por esse motivo, taxas anuais de sobrevivência natural de 40 – 60% durante o 1º ano de vida, foram usadas na presente análise demográfica de *P. glauca*. Ainda, com a finalidade de avaliar o efeito da mortalidade dos neonatos sobre o crescimento populacional, foram também usados valores de sobrevivência de 10 – 40%.

Para as taxas de mortalidade natural nas idades superiores ao primeiro ano de vida foram usadas as estimativas indiretas de $M$, através do ajuste de oito modelos que assumem mortalidade constante ao longo da vida (Rikhter & Efanov 1976 *apud* Sparre & Venema 1995, Pauly 1980, Hoenig 1983, Jensen 1996) (Tabela I). Também foi utilizado o método idade-específica de Peterson e Wroblewski (1984) (Tabela I). Esse método requer estimativas do peso total seco em gramas na idade $x$ ($W_x$), que foram obtidas através das relações peso-comprimento e idade-comprimento, estimadas para a região (Montealegre-Quijano & Vooren, 2010). Cortés (2002 *apud* Simpfendorfer 2004) sugere que em tubarões pode ser usado um fator de conversão de um quinto para obter o peso seco, critério que foi incorporado na presente análise. Considerando que durante um ano de vida os indivíduos crescem em peso desde $W_x$ até $W_{x+1}$, o coeficiente instantâneo de mortalidade natural durante o $x$-ésimo ano de vida ($M_t$) foi estimado como $M_t = (M_x + M_{x+1})/2$.

O coeficiente instantâneo de mortalidade total ($Z$), após a idade de pleno recrutamento pesqueiro, foi calculado mediante ajuste da curva de captura *sensu* Ricker (1975) à composição etária da população, estimada através da chave idade-comprimento, a partir de amostras coletadas em sete cruzeiros de pesca comercial com espinhel, no Atlântico sudoeste, no período de 2004 a 2006 (Montealegre-Quijano 2007, Montealegre-Quijano & Vooren 2010).

*Parâmetros Reprodutivos.* A função logística que descreve a proporção de fêmeas grávidas por classes de comprimento furcal (CF) e a curva de crescimento de von Bertalanffy ajustada para as fêmeas (Montealegre-Quijano 2007), foram utilizadas para estimar a proporção de fêmeas grávidas por classe etária ($g_x$). Para cada classe etária $x$ se estimou o CF, que foi inserido no modelo logístico. As equações utilizadas foram:

$$CF_x = 245{,}6\left[1 - e^{-0{,}16(x+1{,}549)}\right]$$

$$g_x = \frac{1}{1 + e^{15{,}588-(0{,}081CF_x)}}$$

*P. glauca* tem ciclo reprodutivo anual e gera ninhadas com proporção sexual 1:1. O número de filhotes do sexo feminino na ninhada ($f_x$) aumenta com o CF da fêmea grávida (Montealegre-Quijano 2007), segundo a expressão:

$$f_x = \frac{0{,}0000249CF^{2{,}643}}{2}$$

A fertilidade em número de fêmeas *per capita* ($m_x$) na idade $x$ foi obtida do produto entre $g_x$ e $f_x$.

*Tabelas de vida.* A seqüência de cenários nas tabelas de vida seguiu dois objetivos principais:

1. Diagnosticar se a população sob o nível atual de pesca está ou não em equilíbrio. Para tanto, determinou-se o valor da taxa de crescimento sob os valores de $m_x$ e $l_x$ em vigor em 2004-2006, com os valores de $Z_{rp}$ constatados, e com as melhores estimativas disponíveis de $M_0$ e $Z_{juv}$.
2. Avaliar a eficácia de um aumento na idade de recrutamento pesqueiro ($t_{rp}$) como instrumento de manejo sustentável da pesca intensiva. Determinou-se o efeito (sobre $r$) de mudanças da $t_{rp}$ sob diferentes valores de mortalidade por pesca ($F$).

## Resultados

*Mortalidade e Sobrevivência.* Os coeficientes instantâneos de mortalidade natural $M$, estimados pelos métodos indiretos baseados nas características da história de vida e que assumem mortalidade constante, foram semelhantes entre os modelos e entre os sexos, com taxas de sobrevivência de 70 a 80% (Tabela I). O valor médio dessas estimativas anuais de mortalidade natural foi de 0,256 para as fêmeas e 0,243 para os machos, que correspondem a taxas anuais de sobrevivência de 77,5 e 78,5%, respectivamente (Tabela I).

A taxa instantânea de mortalidade natural idade-específica das fêmeas, estimada pelo método de Peterson & Wroblewski (1984), diminuiu com o aumento da idade, de 0,417 no primeiro ano de vida para a 0,173 no 12º ano de vida (idade máxima observada), e 0,164 no 22º ano (idade da longevidade) (Fig. 1). Essas estimativas indicam que durante o 1º ano de vida 65,9% das fêmeas de *P. glauca* sobrevivem às causas naturais de mortalidade, taxa que aumenta de forma acelerada e contínua até o 6º ano de vida, a partir do qual a sobrevivência tende a se estabilizar em torno de 83 a 85% ao ano (Fig. 1).

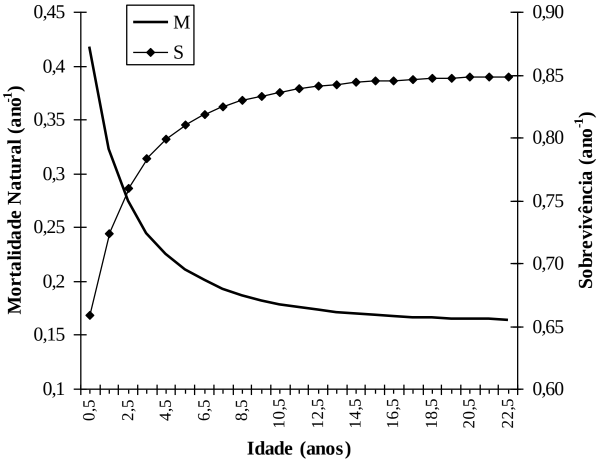

**Figura 1.** Curvas de mortalidade natural e sobrevivência de *P. glauca* no Atlântico Sudoeste, estimadas a partir do método de Peterson & Wroblewski (1984) e as informações reprodutivas de maturidade sexual e fecundidade no Atlântico Sudoeste.

A média dos métodos indiretos de mortalidade constante (0,256) foi semelhante à média da mortalidade entre o 1º e 6º ano de vida (0,246), mas subestima a capacidade de sobrevivência na fase adulta. Nessa fase da vida o método idade-específica de Peterson & Wroblewski (1984) rendeu uma média de mortalidade natural de 0,182, mais próxima das estimativas obtidas pelos métodos de Hoenig (1983), considerando a idade de longevidade (Tabela I).

A composição por idades nos cruzeiros individuais refletiu idades de pleno recrutamento pesqueiro variando de 4 a 6 anos para os machos, enquanto que para as fêmeas foi constante em 6 anos (Tabela II; Fig. 2). Com os cruzeiros agrupados, constatou-se que os machos estão completamente recrutados à pesca aos 5 anos e as fêmeas aos 6 anos de vida (Tabela II; Fig. 3).

**Tabela I.** Coeficientes instantâneos de mortalidade natural (M) estimados por métodos indiretos e características de história de vida de *P. glauca* no Atlântico Sudoeste. S = taxa de sobrevivência; Z = taxa de mortalidade total.

| Autor | Modelo | | M♀ | S♀ | M♂ | S♂ |
|---|---|---|---|---|---|---|
| Rikhter e Efanov (1976) | $M = 1{,}521 / (t_{mat}^{0{,}720}) - 0{,}155$ | | 0,220 | 0,803 | 0,264 | 0,768 |
| Pauly (1980) | $\log M = -0{,}0066 - 0{,}279 \log(L_\infty) + 0{,}6543 \log(k) + 0{,}4634 \log(T°)$ | | 0,256 | 0,774 | 0,242 | 0,785 |
| Hoenig (1983) - (Peixes) | $\ln Z = 1{,}46 - 1{,}01 \ln t_{max}$ | | 0,350 | 0,705 | 0,323 | 0,724 |
| | $\ln Z = 1{,}46 - 1{,}01 \ln t_\infty$ | | 0,199 | 0,820 | 0,181 | 0,834 |
| Hoenig (1983) - (Cetáceos) | $\ln Z = 0{,}941 - 0{,}873 \ln t_{max}$ | | 0,293 | 0,746 | 0,273 | 0,761 |
| | $\ln Z = 0{,}941 - 0{,}873 \ln t_\infty$ | | 0,180 | 0,836 | 0,166 | 0,847 |
| Jensen (1996) | $M = 1{,}65 / t_{mat}$ | | 0,236 | 0,790 | 0,275 | 0,760 |
| Jensen (1996) | $M = 1{,}6\ k$ | | 0,293 | 0,746 | 0,238 | 0,788 |
| Jensen (1996) | $M = 1{,}5\ k$ | | 0,275 | 0,760 | 0,224 | 0,800 |
| Peterson e Wroblewski (1984) | $M_t = 1{,}92\ W_t^{-25}$ | | | | | |
| | | Média: | 0,256 | 0,775 | 0,243 | 0,785 |
| **Parâmetros:** | | | ♀ | | ♂ | |
| | Idade de Maturação (anos) | $t_{Mat} =$ | 7 | | 6 | |
| | Idade Máxima Observada (anos) | $t_{max} =$ | 12 | | 13 | |
| | Longevidade Fabens (1964) (anos) | $t_\infty =$ | 21 | | 23 | |
| | Comprimento máximo teórico (cm) | $L_\infty =$ | 242,4 | | 256,8 | |
| | Constante de crescimento (ano$^{-1}$) | k = | 0,183 | | 0,149 | |
| | Peso total na idade *t* (kg) | | $W_t = 1 \times 10^{-6} CF^{3{,}3504}$ | | $W_t = 2 \times 10^{-6} CF^{3{,}1931}$ | |
| | Temperatura média do ambiente (ºC) | Tº = | 20 | | 20 | |

A taxa instantânea de mortalidade total (*Z*), estimada pela curva de captura ajustada aos dados da composição etária de cada cruzeiro (Fig.2; Tabela II), teve variação semelhante entre os sexos, com

0,432 a 0,669 para os machos e 0,461 a 0,693 para as fêmeas. Devido às diferenças na composição etária de cada cruzeiro essas taxas mínimas e máximas não foram obtidas nos mesmos cruzeiros. Os valores de Z estimados com base na curva de captura ajustada aos dados da composição etária dos cruzeiros agrupados foram de 0,589 para os machos e 0,601 para as fêmeas (Fig. 3; Tabela II). Segundo os valores de *Z* para os cruzeiros agrupados, a sobrevivência para ambos os sexos foi em torno de 55%.

Considerando a média das estimativas de *M* obtidas pelos métodos indiretos por sexo, como sendo a taxa de mortalidade natural a partir da idade de recrutamento pesqueiro, e as taxas de mortalidade total obtidas para os cruzeiros agrupados, constatou-se que a taxa de explotação (*E*) é entorno de 58% para ambos os sexos (Tabela II).

**Tabela II.** Estimativas dos coeficientes instantâneos de mortalidade total (*Z*) e por pesca (F), e das taxas de sobrevivência (S) e de explotação (E), a partir das curvas de captura estabelecidas por sexo para cada cruzeiro, considerando as classes etárias superiores à idade de pleno recrutamento à arte de pesca ($t_{rp}$), e o valor médio dos coeficientes instantâneos de mortalidade natural obtidos pelos métodos indiretos. s.d.= sem dados suficientes

| | | **FÊMEAS** | | | | | **MACHOS** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $t_{rp}$ | *Z* | *F* | *S* | *E* | $t_{rp}$ | *Z* | *F* | *S* | *E* |
| Fevereiro | 2004 | 6 | s.d. | s.d. | s.d. | s.d. | 5 | 0,448 | 0,205 | 0,639 | 0,458 |
| Junho | 2004 | 6 | 0,461 | 0,205 | 0,631 | 0,445 | 5 | 0,641 | 0,398 | 0,527 | 0,621 |
| Setembro | 2004 | 6 | 0,478 | 0,222 | 0,620 | 0,464 | 4 | 0,669 | 0,426 | 0,512 | 0,637 |
| Março | 2005 | 6 | 0,693 | 0,437 | 0,500 | 0,631 | 6 | 0,432 | 0,189 | 0,649 | 0,438 |
| Julho | 2005 | 6 | s.d. | s.d. | s.d. | s.d. | 5 | 0,482 | 0,239 | 0,618 | 0,496 |
| Dezembro | 2005 | 6 | 0,596 | 0,34 | 0,551 | 0,570 | 4 | 0,572 | 0,329 | 0,564 | 0,575 |
| Agosto | 2006 | 6 | 0,481 | 0,225 | 0,618 | 0,468 | 5 | 0,610 | 0,367 | 0,543 | 0,602 |
| **Amostras Agrupadas** | | 6 | 0,601 | 0,345 | 0,548 | 0,574 | 5 | 0,589 | 0,346 | 0,555 | 0,587 |

*Tabelas de vida.* As tabelas de vida construídas para a população de *P. glauca* amostrada na região sudoeste do Oceano Atlântico, no caso hipotético de ausência da pesca, mostraram a capacidade de crescimento populacional da espécie. Num primeiro cenário, com as estimativas de mortalidade natural idade-específica, obtidas pelo método de Peterson & Wroblewski (1984), a população cresceria aproximadamente 24,2% ao ano, com uma taxa líquida reprodutiva ($R_0$) de 6,9 e um tempo médio de geração de (G) 8,9 anos (Tabela III).

Dada a incerteza do nível de sobrevivência durante o 1º ano de vida, os cenários em que se avaliaram taxas de sobrevivência inicial variando de 5 a 60%, permitiram constatar que sob condições naturais, sem pesca, a população de *P. glauca* suportaria uma perda de até 90% dos neonatos, condição na qual estaria próxima do equilíbrio (Tabela IV). O equilíbrio perfeito sob condições de mortalidade natural foi obtido com taxas de sobrevivência de 9,54% durante o 1º ano de vida e a partir do 2º ano de acordo com as estimativas obtidas pelo método de Peterson & Wroblewski (1984) (Tabela IV, Cenário H).

Na situação real, considerando a mortalidade por pesca atual, o coeficiente instantâneo de mortalidade total (*Z*) considerado foi de 0,693. Isso se justificou por ser o valor estimado pela curva de captura das fêmeas no cruzeiro de março de 2005, quando se observou a maior abundância de todas as classes etárias a partir de 6 anos, que foi a idade do recrutamento pesqueiro. Incluindo essa taxa de mortalidade a partir da idade de recrutamento pesqueiro, junto com taxas de sobrevivência inicial variando de 10 a 60%, e desconsiderando as mortes por pesca na fase não completamente recrutada, observou-se que, caso a sobrevivência inicial seja inferior a 27,4%, a população se encontraria diminuindo (Tabela V, Cenários J – M). Se a sobrevivência no 1º ano de vida for de 10% como observado na condição de equilíbrio nos cenários naturais, a população de *P. glauca* estaria diminuindo em torno de 13% ao ano (Tabela V, Cenário N). Considerando idades de recrutamento de 5 e 7 anos, as taxas de mortalidade inicial na qual a população encontra o equilíbrio foram estimadas em 40,3 e 20,0%, respectivamente (Tabela V, Cenário O – V). No cenário mais otimista e plausível, considerando sobrevivência inicial entorno de 40% e taxa de mortalidade por pesca atual, a população não está em equilíbrio, com crescimento populacional positivo de 5,4% (Tabela V, Cenário K). Sob estas condições, o equilíbrio seria obtido caso a sobrevivência inicial fosse de apenas 27,4% (Tabela V, Cenário M).

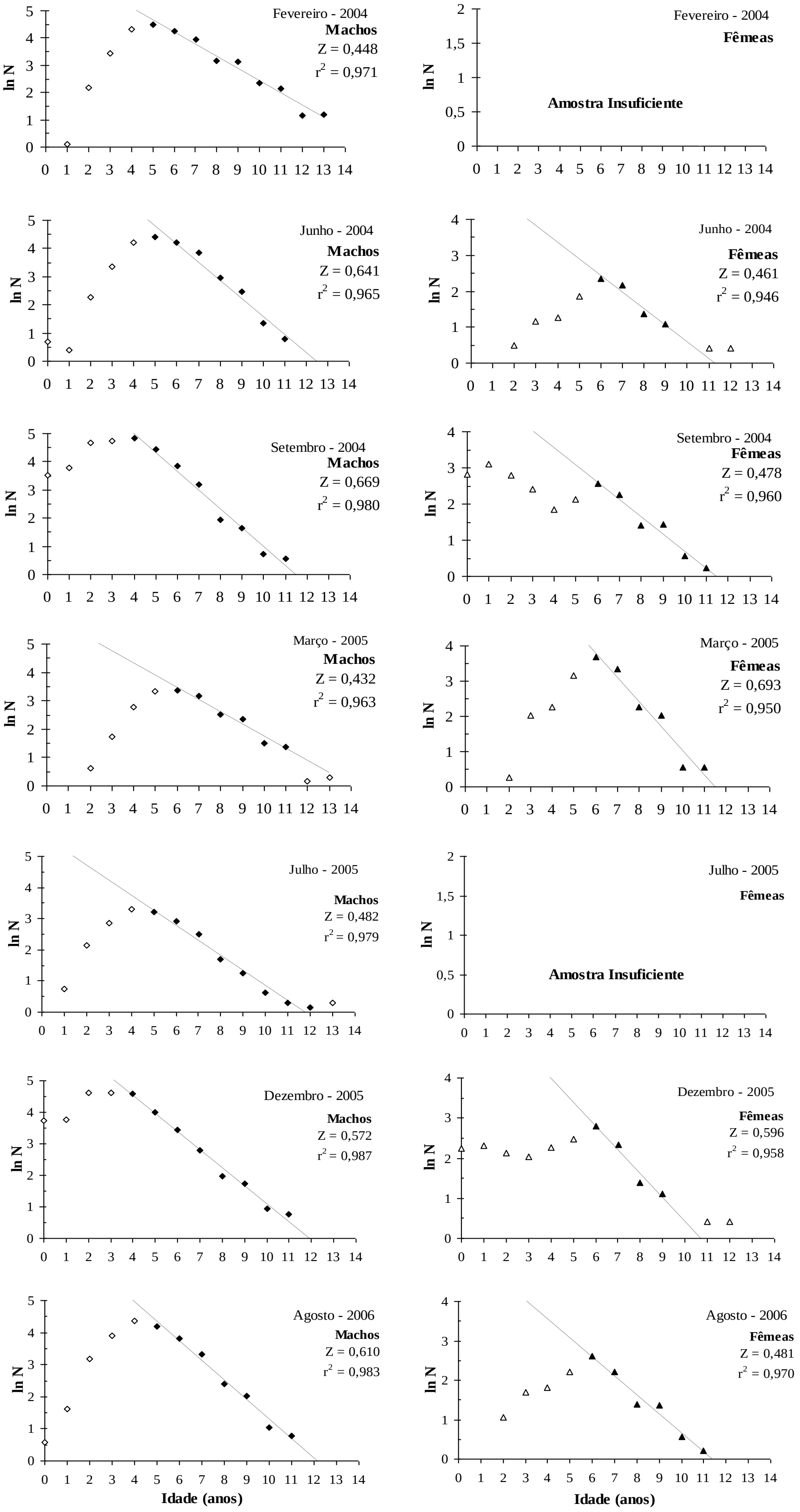

**Figura 2.** Estimativas de mortalidade total (*Z*) por sexo a partir da curva de captura ajustada às composições etárias de cada um dos sete cruzeiros de pesca comercial no Atlântico Sudoeste (Montealegre-Quijano & Vooren 2010). N = número de indivíduos.

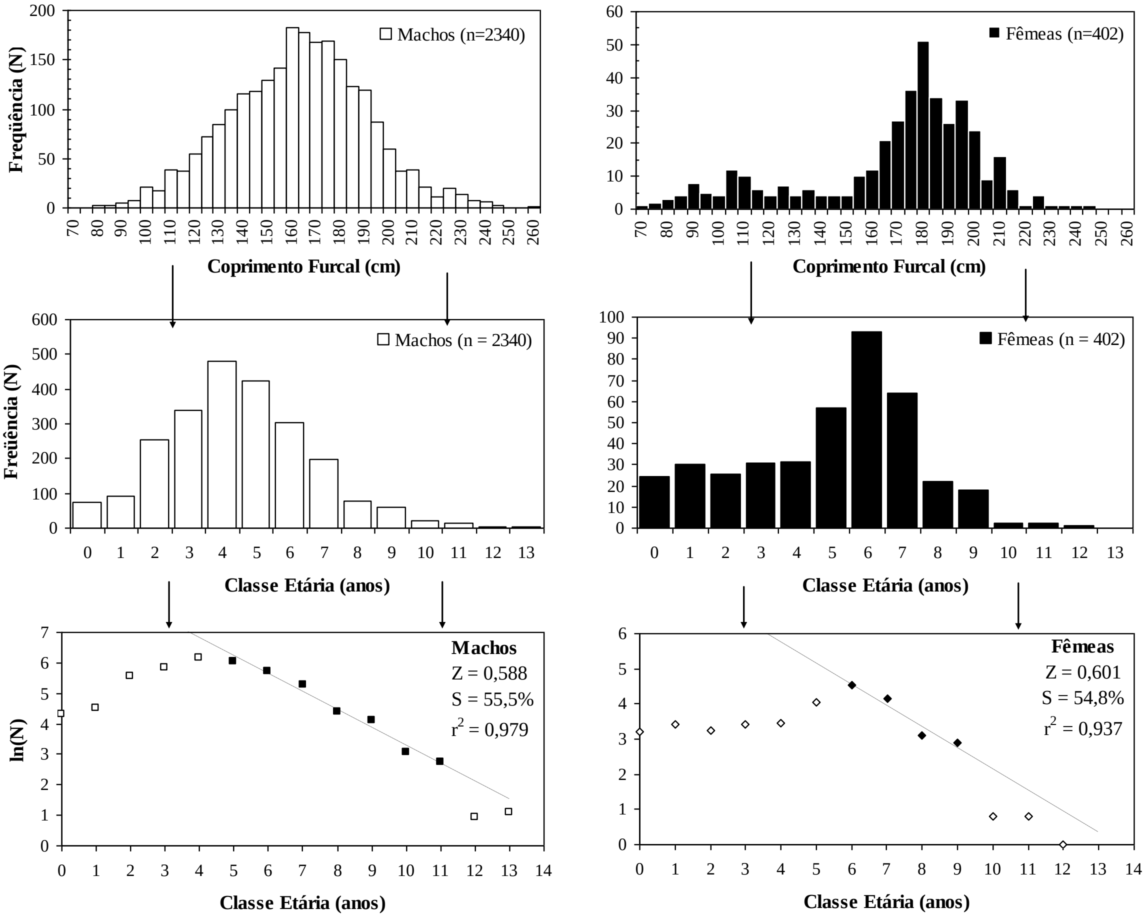

**Figura 3.** Estimativa da taxa instantânea de mortalidade total (Z) por sexo, usando curvas de captura geradas a partir da estrutura etária da população no Atlântico Sudoeste, obtida com base no total de tubarões medidos em sete cruzeiros de pesca comercial e a chave idade-comprimento (Montealegre-Quijano 2007; Montealegre-Quijano & Vooren 2010).

**Tabela III.** Tabela de vida de Prionace glauca no Atlântico Sudoeste na situação hipotética de ausência da pesca, com taxas de mortalidade natural idade-específica estimadas pelo método de Peterson & Wroblewski (1984). x = idade; gx = proporção de fêmeas grávidas; fx= número de filhotes de sexo feminino por fêmea grávida; mx= fertilidade em número de fêmeas per capita; M= taxa de mortalidade natural durante o ano; lx= taxa de sobrevivência; R0 = taxa líquida reprodutiva; G = tempo de geração; r = taxa de crescimento populacional; er= taxa finita de crescimento populacional.

| $x$ | $g_x$ | $f_x$ | $m_x$ | $M$ | $l_x$ | $l_x m_x$ | $l_x m_x x$ | $R_0$ | $G$ | $r$ | $e^r$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | 0 | 0 | 0 | 0,417 | 1,000 | 0 | 0 | 6,903 | 8,93 | 0,216 | 1,242 |
| **1** | 0 | 0 | 0 | 0,323 | 0,659 | 0 | 0 | | | | |
| **2** | 0 | 0 | 0 | 0,274 | 0,477 | 0 | 0 | | | | |
| **3** | 0 | 0 | 0 | 0,245 | 0,363 | 0 | 0 | | | | |
| **4** | 0,1 | 6,447 | 0,365 | 0,225 | 0,284 | 0,104 | 0,415 | | | | |
| **5** | 0,2 | 8,092 | 1,287 | 0,211 | 0,227 | 0,292 | 1,459 | | | | |
| **6** | 0,3 | 9,643 | 3,177 | 0,201 | 0,184 | 0,584 | 3,502 | | | | |
| **7** | 0,5 | 11,066 | 5,768 | 0,193 | 0,150 | 0,867 | 6,069 | | | | |
| **8** | 0,7 | 12,346 | 8,378 | 0,187 | 0,124 | 1,038 | 8,307 | | | | |
| **9** | 0,8 | 13,478 | 10,590 | 0,182 | 0,103 | 1,089 | 9,798 | | | | |
| **10** | 0,9 | 14,469 | 12,343 | 0,179 | 0,086 | 1,057 | 10,575 | | | | |
| **11** | 1 | 15,328 | 13,716 | 0,176 | 0,072 | 0,983 | 10,812 | | | | |
| **12** | 1 | 16,067 | 14,802 | 0,173 | 0,060 | 0,890 | 10,678 | | | | |

**Tabela IV.** Resultados das tabelas de vida avaliando a capacidade de crescimento populacional do tubarão-azul *Prionace glauca* no Atlântico Sudoeste sob condições de ausência da pesca e com diferentes taxas de sobrevivência durante o 1º ano de vida ($S_0$). $Z_0$= mortalidade inicial; $Z_{juv}$= mortalidade durante as idades não recrutadas; $Z_{rp}$= mortalidade a partir do recrutamento pesqueiro; $R_0$ = taxa líquida reprodutiva; $G$ = tempo de geração; $r$ = taxa de crescimento populacional; $e^r$= taxa finita de incremento populacional. P&W = taxas de mortalidade natural idade-específica, estimadas pelo método de Peterson & Wroblewski (1984).

| Cenário | $S_0$ (%) | $Z_0$ | $Z_{juv}$ | $Z_{rp}$ | $R_0$ | $G$ | $r$ | $e^r$ |
|---|---|---|---|---|---|---|---|---|
| A | 66,0 | P&W | P&W | P&W | 6,903 | 8,925 | 0,216 | 1,242 |
| B | 60,0 | 0,511 | P&W | P&W | 6,287 | 8,925 | 0,206 | 1,229 |
| C | 50,0 | 0,693 | P&W | P&W | 5,240 | 8,925 | 0,186 | 1,204 |
| D | 40,0 | 0,916 | P&W | P&W | 4,192 | 8,925 | 0,161 | 1,174 |
| E | 30,0 | 1,204 | P&W | P&W | 3,144 | 8,925 | 0,128 | 1,137 |
| F | 25,0 | 1,386 | P&W | P&W | 2,620 | 8,925 | 0,108 | 1,114 |
| G | 10,0 | 2,303 | P&W | P&W | 1,048 | 8,925 | 0,005 | 1,005 |
| H | **9,5** | **2,350** | P&W | P&W | **1,000** | 8,925 | **0,000** | 1,000 |
| I | 5,0 | 2,996 | P&W | P&W | 0,524 | 8,925 | -0,072 | 0,930 |

**Tabela V.** Tabelas de vida para a população do tubarão-azul *Prionace glauca* no Atlântico Sudoeste sob diferentes cenários de mortalidade, sobrevivência, e idades de recrutamento pesqueiro ($t_{rp}$). $S_0$=sobrevivência no primeiro ano de vida; $Z_0$= mortalidade inicial; $Z_{juv}$= mortalidade dos jovens; $Z_{rp}$= mortalidade a partir do recrutamento pesqueiro; $R_0$ = taxa líquida reprodutiva; $G$ = tempo de geração; $r$ = taxa de crescimento populacional; $e^r$= taxa finita de incremento populacional.

| Cenário | $t_{rp}$ | $S_0$ (%) | $Z_0$ | $Z_{juv}$ | $Z_{rp}$ | $R_0$ | $G$ | $r$ | $e^r$ |
|---|---|---|---|---|---|---|---|---|---|
| J | 6 | 66,0 | P&W | P&W | 0,693 | 2,400 | 7,144 | 0,123 | 1,130 |
| K | 6 | 40,0 | 0,916 | P&W | 0,693 | 1,457 | 7,144 | 0,053 | 1,054 |
| L | 6 | 30,0 | 1,204 | P&W | 0,693 | 1,093 | 7,144 | 0,012 | 1,013 |
| M | 6 | **27,4** | **1,293** | P&W | 0,693 | **1,000** | 7,144 | **0,000** | 1,000 |
| N | 6 | 10,0 | 2,303 | P&W | 0,693 | 0,365 | 7,144 | -0,141 | 0,868 |
| O | 5 | 66,0 | P&W | P&W | 0,693 | 1,633 | 6,921 | 0,071 | 1,073 |
| P | 5 | **40,3** | **0,908** | P&W | 0,693 | **1,000** | 6,921 | **0,000** | 1,000 |
| Q | 5 | 30,0 | 1,204 | P&W | 0,693 | 0,744 | 6,921 | -0,043 | 0,958 |
| R | 5 | 10,0 | 2,303 | P&W | 0,693 | 0,248 | 6,921 | -0,202 | 0,817 |
| S | 7 | 66,0 | P&W | P&W | 0,693 | 3,304 | 7,456 | 0,160 | 1,174 |
| T | 7 | 40,0 | 0,916 | P&W | 0,693 | 2,006 | 7,456 | 0,093 | 1,098 |
| U | 7 | **20,0** | **1,609** | P&W | 0,693 | **1,004** | 7,456 | **0,000** | 1,000 |
| V | 7 | 10,0 | 2,303 | P&W | 0,693 | 0,502 | 7,456 | -0,093 | 0,912 |

O efeito de variações na idade de recrutamento pesqueiro ocasiona uma acentuada queda na sobrevivência e no potencial reprodutivo a partir da respectiva idade de recrutamento. A proporção de indivíduos maduros por classe de idade aumenta de 20% na idade 4 a 100% na idade 11 (Montealegre-Quijano 2007). No cenário com sobrevivência inicial de 40% e ausência de mortalidade por pesca, o potencial reprodutivo conseguiria compensar a mortalidade natural, continuando a aumentar entre as idades de 5 e 8 anos, mas a partir dos 9 anos, o potencial reprodutivo não consegue alcançar ao nível anterior, devido ao menor número de sobreviventes, e começa a diminuir lentamente (Fig. 4; Tabela IV, Cenário D). Na idade de 11 anos, com 100% dos indivíduos maduros, não há possibilidade de aumento do potencial reprodutivo e este diminui aceleradamente em função das perdas por mortalidade natural (Fig. 4). Na situação real, com mortalidade por pesca e variação da idade de recrutamento pesqueiro ($t_{rp}$) entre 5 e 7 anos, o nível máximo do potencial reprodutivo é alcançado na idade de 6 anos, quando ainda menos da metade dos indivíduos da classe estão maduros. O aumento na proporção de indivíduos maduros nas idades seguintes não permite aumento do potencial reprodutivo. Nesse cenário real a população não se encontra em equilíbrio, com taxa positiva de crescimento de 5,4% ao ano (Fig. 5, Tabela V, Cenário K). Sob essas condições, se diminuída a idade de recrutamento pesqueiro para 5 anos, o potencial reprodutivo alcança o máximo também na idade de seis anos, mas a capacidade de crescimento da população seria prejudicada ainda mais. Se por outro lado, a idade de recrutamento pesqueiro é aumentada para 7 anos, o máximo potencial reprodutivo é alcançado aos sete anos e a população estaria com capacidade de crescimento populacional de 10% (Fig. 5, Tabela V, Cenários T e P).

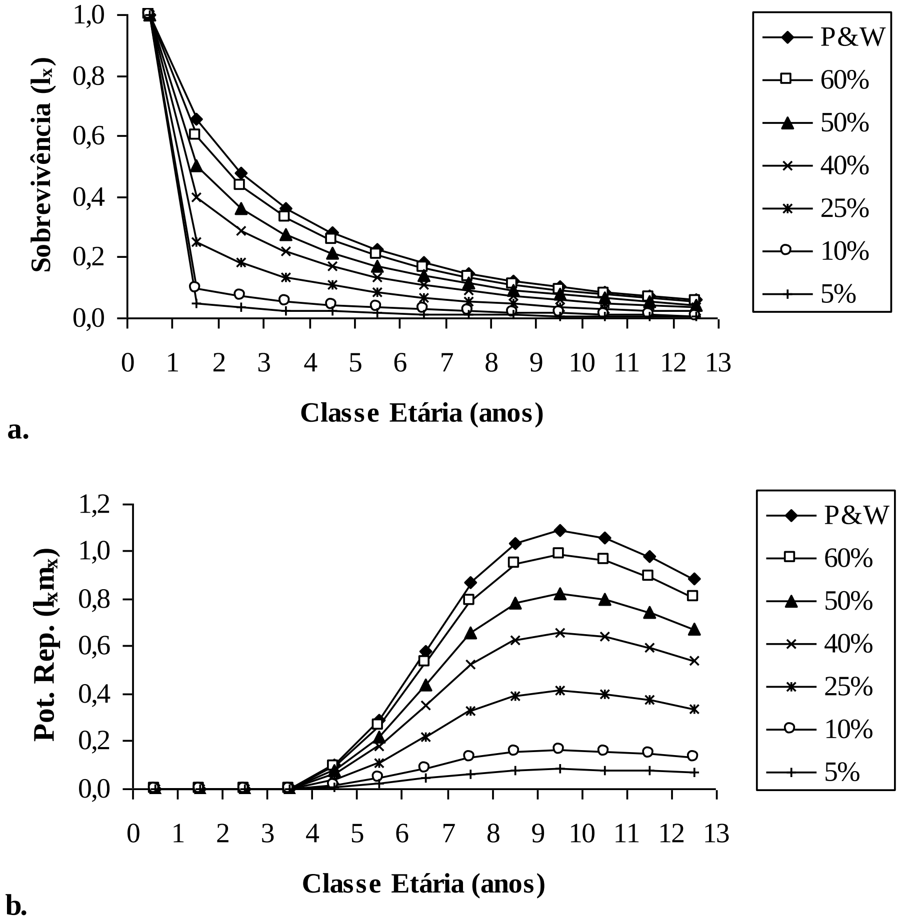

**Figura 4.** Curvas de sobrevivência (a.) e de potencial reprodutivo (b.) de *P. glauca* no Atlântico sudoeste, sob condições de ausência da pesca, para diferentes taxas de mortalidade durante o 1º ano de vida. P&W= Mortalidade natural obtida pelo método de Peterson & Wroblewski (1984). (Cenários A – D, F, G & I).

## Discussão

Segundo o modelo de Lotka (1922 *apud* Krebs 1989), populações com taxas constantes de natalidade e mortalidade, gradualmente se aproximam de uma estrutura etária estável fixa, qualquer que tenha sido a estrutura etária inicial. No Atlântico Sul as fêmeas imaturas não sofrem mortalidade por pesca, as fêmeas adultas permanecem na área de atuação das pescarias e as taxas de captura de *P. glauca* entre 1978 e 2006 permaneceram constantes (Hazin *et al.* 1990, 1994, Castro & Mejuto 1995, Lessa *et al.* 2004, Hazin & Lessa 2005, Mejuto & García-Cortés 2005, Mourato *et al.* 2007, Anônimo 2008, Hazin *et al.* 2008, Pons & Domingo 2008, Montealegre-Quijano & Vooren 2010). Portanto, pode-se assumir que a estrutura etária das fêmeas adultas, a partir da qual foram estimados os parâmetros demográficos, representa uma visão estática real dessa parcela da população. Portanto, as taxas de mortalidade e natalidade podem ser consideradas estáveis ao menos durante a última década.

Taxas de mortalidade natural no primeiro ano de vida de 40 a 60%, como as observadas por Heupel & Simpfendorfer (2002) para *Carcharhinus limbatus*, parecem boas estimativas preliminares para *P. glauca* devido à similaridade de algumas das características de história de vida entre as espécies. Ambas as espécies são tubarões pelágicos vivíparos de grande porte da família Carcharhinidae, que atingem mais de 250 cm de comprimento furcal, com crescimento relativamente rápido e maturação sexual relativamente precoce quando comparadas a outras espécies da família Carcharhinidae (Branstetter 1990, Cortés 2000). Manire & Gruber (1993 *apud* Cortés 1995) também observaram taxas de mortalidade inicial similares para *Negaprion brevirostris*, outra espécie de grande porte da mesma família. Portanto, taxas de sobrevivência durante o primeiro ano de vida de 40 a 60% podem ser boas aproximações para grandes tubarões pelágicos dessa família.

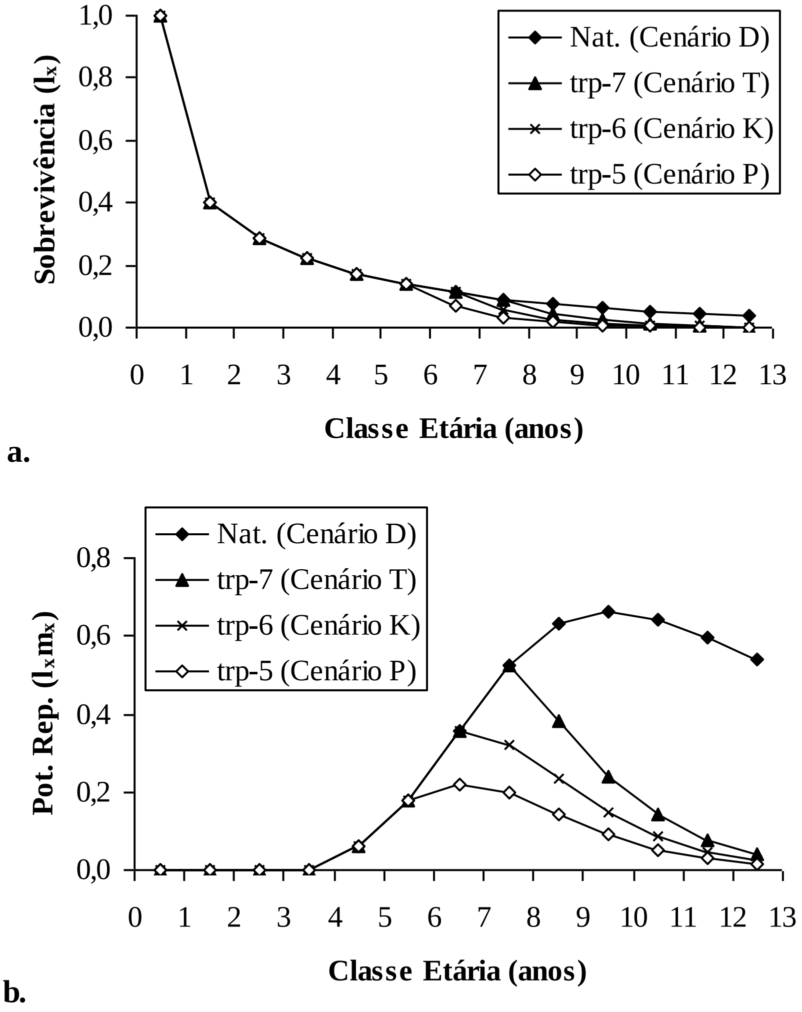

**Figura 5.** Curvas de sobrevivência e potencial reprodutivo, sob diferentes idades de recrutamento pesqueiro ($t_{rp}$), de *P. glauca* no Atlântico sudoeste, com taxa de sobrevivência durante o 1° ano de vida de 40%, mortalidade natural segundo método de Peterson & Wroblewski (1984), e mortalidade total atual de 0,693.

Contudo, em alguns aspectos das características de história de vida, *P. glauca* difere notoriamente das outras espécies de tubarões pelágicos. Especificamente em relação às duas espécies mencionadas, *C. limbatus* e *N. brevirostris* geram neonatos com comprimento superior a 20% do tamanho máximo da espécie (Branstetter 1990), que são paridos em locais costeiros protegidos que servem como áreas de berçário, onde os filhotes permanecem durante o 1° ano de vida (Gruber *et al.* 1988 *apud* Simpfendorfer & Heupel, 2004, Heupel & Simpfendorfer 2002); enquanto que *P. glauca* gera descendência com comprimento de nascimento inferior a 20% do tamanho máximo da espécie (Branstetter 1990), e procura áreas de convergência oceânicas (Nakano 1994, Montealegre-Quijano 2007) onde a disponibilidade de alimento é alta e, portanto também os predadores (Lalli & Parsons 1993). Embora não existam registros de *P. glauca* no conteúdo estomacal de outras espécies, a alta fecundidade, o relativo pequeno tamanho de nascimento, e a taxa de crescimento relativamente rápida, são indícios de uma elevada mortalidade natural durante o 1º ano de vida (Branstetter 1990, Cortés 2000). Por esse motivo, a estimativa obtida pelo método de Peterson & Wroblewski (1984), de 66% de sobrevivência no 1º ano de vida, parece sobreestimada, enquanto que as mortalidades obtidas para os anos seguintes, são mais razoáveis (Fig. 1; Tabela III). Essas taxas de sobrevivência foram similares às obtidas pelos métodos indiretos de mortalidade constante, e dado que incorporam a variabilidade idade-específica, justificou-se sua escolha como mortalidade natural após o 1º ano de vida.

A mortalidade natural, especialmente durante o 1º ano de vida, é determinante para as estimativas obtidas pelo modelo de análise demográfica. Existe um contínuo debate em relação ao melhor método para estimar a taxa de mortalidade natural, e a forma como esse coeficiente se relaciona com a idade. Dada a escassez de estimativas diretas, a prática comum é o uso dos métodos indiretos baseados nas características de história de vida (Cortés 2007), que no presente estudo renderam resultados similares aos obtidos para *P. glauca* em outras regiões (Campana *et al.* 2005, Chen & Yuan 2006).

Sob condições de ausência da pesca, variações nas taxas de sobrevivência inicial demonstraram a plasticidade ecológica de *P. glauca*. Com taxas de sobrevivência inicial diminuindo de 66 a 25%, a taxa de crescimento populacional é positiva com valores de 24,2 e 11,4% ao ano, respectivamente. A mortalidade de 90% dos neonatos rendeu a situação de equilíbrio, sendo a população substituída geração a geração.

De acordo com a teoria do modelo logístico de crescimento populacional (Odum 1986), aproximadamente 60 anos atrás a população de *P. glauca* no Atlântico Sul, livre de mortalidades por pesca, teria alcançado um estado de equilíbrio, de tal forma que o número de nascimentos compensaria exatamente o número de mortes, e o número de indivíduos permaneceria constante. Mas, o desenvolvimento da pesca oceânica constituiu um evento catastrófico para a população que teve reduzida a sua população de forma repentina. Segundo a teoria, esperar-se-ia que a espécie possuísse algum mecanismo para que a população se recuperasse, caso contrário, sucessivos eventos catastróficos levariam a espécie à extinção. Com a população diminuída, em teoria há uma maior disponibilidade de recursos para cada individuo. Com mais energia disponível, os organismos deveriam ser capazes de alocar maior esforço para o crescimento e a reprodução, e com isso a população voltaria a atingir seu estado de equilíbrio (Odum 1986).

Com base no anterior, significa então que esses valores positivos de 11 a 24% de crescimento populacional, são possivelmente evidências de que *P. glauca* se encontra tentando recuperar seu estado de equilíbrio, mas na situação real, a disponibilidade de recursos não é ilimitada, muito pelo contrario, os recursos vivos no ambiente oceânico são cada vez menores (Helfman *et al.* 1997). Na atualidade a população de *P. glauca* não se encontra em equilíbrio, e contrário ao diagnostico comumente utilizado quando constatadas taxas de crescimento positivas como sendo um sinal de saúde populacional, na verdade, essas taxas constituem flagrantes de alerta à tomada de medidas preventivas.

Os resultados do presente estudo são consistentes com as observações de alguns autores que apontam *P. glauca* como sendo uma espécie produtiva e resiliente quando comparada a outras espécies de tubarões (Smith *et al.* 1998, Frisk *et al.* 2000, Cortés 2000, Campana *et al.* 2005, Chen & Yuan, 2006). Isto pode explicar porque a espécie tem sido lenta na sua diminuição perante o que aparenta ser uma elevada explotação pesqueira.

No Atlântico Norte, estudos de marcação e recaptura demonstraram a ampla capacidade migratória de *P. glauca*, com circuito transoceânico, que evidenciou a existência de uma única população (Stevens 1990, Kohler *et al.* 1998). No Atlântico Sul ainda não foi realizado um programa de marcação e recaptura de peixes oceânicos, mas dado que vários dos parâmetros populacionais de reprodução, crescimento e mortalidade estimados para *P. glauca* não diferem entre as bacias oceânicas (Nakano & Seki 2003), e dada a sincronia de eventos e processos do ciclo reprodutivo entre as regiões equatorial e subtropical (Hazin & Lessa 2005, Montealegre-Quijano & Vooren, 2010), é provável que também no Atlântico Sul a espécie constitua uma única população e, portanto, uma única unidade de manejo. Com isso, a taxa instantânea de mortalidade total (Z) e a taxa de crescimento populacional (*r*), estimadas no presente estudo, podem ser consideradas parâmetros da população. São necessários ainda dados de taxas de captura por estagio de vida e sexo, classificadas por áreas geográficas, no intuito de contribuir para um melhor conhecimento da biologia populacional de *P. glauca* em todo o Atlântico Sul.

O nível atual de mortalidade por pesca tem causado uma diminuição nos tamanhos e idades máximos de *P. glauca*, o que constitui um indício de declínio populacional. No cenário mais real (Tabela V, Cenário K), a população estaria ainda crescendo em uma taxa de 5,4% ao ano. Contudo, à luz das substanciais incertezas associadas às estimativas dos parâmetros de mortalidade e crescimento e aos modelos associados, recomenda-se cautela no nível de explotação da espécie. Medidas de manejo e conservação tais como a estabelecimento de áreas e/ou épocas de exclusão da pesca, e a proibição de captura de fêmeas grávidas e de pequenos juvenis, podem ser medidas mitigatórias válidas, para garantir uma explotação sustentável. Análises que avaliem a probabilidade das incertezas e o uso de outros modelos de diagnóstico do estado populacional são necessárias, no intuito de reforçar ou contestar os resultados da presente análise demográfica.

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# Distribution and size of the shortfin mako (*Isurus oxyrinchus*) in the Mexican Pacific Ocean

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**Abstract.** The shortfin mako, *Isurus oxyrinchus*, is a highly migratory species with wide distribution. It is caught directly both as target and bycatch in pelagic fisheries. Detailed knowledge of the biology and nursery grounds of shortfin mako in Eastern Pacific Ocean is limited. Hence, insights on this issue will help understand the structure of the population for further assessment. In the present study we analyze the catch and biological data collected by scientific observers aboard longline vessels during fishing periods from 1986 to 2003. The examined sharks ranged from 55 to 264 cm in fork length (FL) (63-276 cm total length, TL) and from 7 to 72 kg in weight. No sex-specific differences were observed between the weight-length relationship. Shortfin makos are caught in Northwest Mexico, especially along the southwest Baja California Peninsula, in the vicinity of the Marias and Revillagigedo Islands. In the same area, young makos of 55 to 88 cm FL (63-100 cm TL) were found from January to August. Presumably, these juveniles inhabit the corridor from the Southern California Bight to an oceanic polygon that includes the Marias and Revillagigedo Islands, suggesting a nursery for this species.

**Key words**: Elasmobranchs, Lamniformes, Nursery area, bycatch, longline pelagic fishery

**Resumen. Distribución y tamaño del tiburón mako (*Isurus oxyrinchus*) en el Océano Pacífico Mexicano.** El Tiburón mako, *Isurus oxyrinchus*, es una especie altamente migratoria de amplia distribución. Es una especie valiosa capturada directa e incidentalmente en pesquerías pelágicas. El conocimiento detallado de su biología y áreas de crianza del mako en el Océano Pacífico Oriental es limitado. Contribuciones al respecto permitirán entender la estructura de la población para evaluaciones a futuro. En el presente estudio, se analizaron la captura y datos biológicos colectados por observadores científicos abordo de embarcaciones palangreras durante los periodos de pesca de 1986 a 2003. Los tiburones examinados oscilaron de 55 a 264 cm de longitud furcal (LF) (63-276 cm longitud total, LT) y de 7 a 72 kg de peso entero. No se observaron diferencias significativas en la relación peso-longitud entre sexos. Los makos son capturados en el noroeste de México, especialmente a lo largo de la costa suroeste de la Península de Baja California, en la vecindad de las Islas Marías e Islas Revillagigedo. En la misma área, se encontraron los juveniles de 55 a 88 cm LF (63-100 cm TL) de enero a agosto ocupando el área que va del sur de la Bahía de California a un polígono oceánico que incluye las Islas Marías e I. Revillagigedo sugiriendo esta área de crianza.

**Palabras clave**: Elasmobranquios, Lamniformes, Área de crianza, captura incidental, pesquería pelágica palangrera.

## Introduction.

The shortfin mako *Isurus oxyrinchus* (Rafinesque 1810) is one of the two shark species of the genus *Isurus* and is circumglobal distributed in temperate and tropical waters. Shortfin mako is common in epipelagic zone vertically ranging from 0 to 500 m depth. The preferred water temperature ranges from 17 to 22ºC (Compagno 2001). In the eastern Pacific Ocean shortfin mako occurs in almost all coastal areas North and South America from 50º N to 40ºS (Strasburg 1958).

The characteristic mobility of this species renders the study of its life history rather difficult. The biology of makos in the eastern Pacific Ocean is still poorly understood. Previous reports are mainly based on individuals of large size captured in US waters (Strasburg 1958, Cailliet *et al*. 1983; Cailliet & Bedford 1983, Hanan *et al*. 1993). Mollet *et al*. (2000) gathered worldwide information on the mako shark and provided an overview of the reproductive biology focusing on the size at maturity. These authors concluded that size at maturity of the shortfin mako is 270 cm to 300 cm TL for females and 200 to 220 cm TL for males; fecundity is 4 to 25 embryos that feed on uterine capsules. Shortfin makos are born with 70 cm TL and their gestation period lasts 15 to18 months (Mollet *et al*. 2000). The diet consists of a variety of demersal and pelagic species of teleost fishes, cephalopods and elasmobranchs (Compagno 2001). Except for an age and growth study from specimens captured in the northwest of Mexican Pacific (Ribot−Carballal *et al*. 2005) data on distribution, abundance, catch composition and fishery biology of the shortfin mako occurring in Economic Exclusive Zone (EEZ) of Mexico are limited.

Longline fishing industry along the Economic Exclusive Zone (EEZ) of Mexico includes both domestic and joint venture Japanese vessels, the later targeting highly valuable sailfish (*Istiophorus platypterus*), striped marlin (*Tetrapturus audax*), swordfish (*Xhiphias gladius*) and tunas (*Tunnus albacares*) (Squire & Au 1990). The operation of such fleets generated invaluable research data sets for targeted species (Squire & Suzuki 1990) whereas information brought about for pelagic sharks captured by Japanese longliners was rather limited (Sosa–Nishizaki 1998).

Analyzed data in the present study come from longline fleet based in Manzanillo, Colima, operating in the EEZ of the Mexican Pacific Ocean since the 1980's targeting billfishes and sharks. Billfishes and sharks were proportionally equivalent in the catches of these vessels. The pelagic thresher shark *Alopias pelagicus*, and silky shark *Carharhinus falciformis* typically dominated the catches. A shift of the fleet to the west coast off Baja California Peninsula has lead to a notable change in species composition of catches with the blue shark *Prionace glauca*, becoming the dominant species. The shortfin mako represented only a small proportion of the bycatch in such vessels (Vélez–Marín *et al*. 2000).

Onboard monitoring of longliners based in Manzanillo allows data on biology and occurrence of the shortfin mako to be collected. Here we report information on distribution, morphometrics, and catch composition collected from 1986 to 2003 by observers of the Instituto Nacional de Pesca of Mexico. We also report on the occurrence and distribution of neonates and juveniles and provide evidence on potential nursery areas for shortfin mako. Recent assessment suggest that pelagic sharks cannot sustain current levels of fishing pressures, consequently shorfin mako and other lamnid sharks are listed as globally Vulnerable in the IUCN Red List (Camhi 2008). Given the lack of knowledge on natural history of large pelagic sharks, this information will contribute to the understanding of a shared stock within US and Mexican waters.

## Materials and Methods

*Vessels and fishing gear.* Operations of longline fleet started in 1986 with four vessels based in Manzanillo, Colima. Since 1992 only one vessel operates targeting billfish, tuna, sharks and other large pelagic species. Sampling was carried out from 1986–2003 by observers of Instituto Nacional de Pesca (INAPESCA). Technological characteristics of such vessels and fishing strategy that might contribute to differences in fishing power remained mostly the same since the first surveys. However, sometimes, sets for testing provoked amplitude of ranges. The vessels are Japanese longliners of 44 m length with 120 ton of storage capacity. Average time of the submerged gear was 8 h and line-hauling ranged from 6–11 h depending on the catch. Length of the main line ranged between 25,200– 75,000 m and the number of hooks from 500 to 1,500. The material of the main line is 4 mm diameter polyamide. Branch lines and buoys lines measured from 9–22 m and 11–12 m, respectively. The branch lines were attached to the main line every 50 m. Acrylic buoys of 30 cm diameter were placed every 5 hooks. Hooks commonly used were Japanese-tuna No. 3.8 of 65 mm length, 30 mm width and 4 mm in diameter. Operating depth of hooks ranged from 61.4 m to 87.4 m. The bait used included small white mullet (*Mugil curema*) and chub mackerel (*Scomber japonicus*) (Santana-Hernandez *et al*. 1998).

*Data collection.* Observers onboard identified and quantified all catch species. Routinely, oceanic and atmospheric information were recorded, as well as the fishing strategy (i.e setting the fishing gear in zig-zag). Shorfin mako specimens were measured and sexed, and only a randomly selected subsample was weighed. Measurements were done in straight line including total length (TL) and fork length (FL) in centimeters, and total weight (W) in kg. For comparison with other studies, linear regressions were performed between sizes (TL–FL).

*Data analysis.* Lengths (TL= total length and FL= furcal length) and weights (W) were tested for sex-specific differences. The relationship of W (kg) and FL (cm), described by the equation $W = a(FL)^b$ was calculated through power regression in Minitab (Ver. 14.2, Minitab Inc), and sex-specific differences between these relationships were tested using analysis of covariance (ANCOVA). Sizes (LT) were converted to age using the inverse equation of von Bertalanffy with the parameters: $L_\infty$= 411 cm, $k$= 0.05 $y^{-1}$, $to$= -4.7 years estimated for shortfin mako from the Northwest of Mexican Pacific (Ribot-Carballal *et al*. 2005). Age 0 and 1 were plotted to show the distribution of early juveniles.

Maps of effort distribution and catch (number) per set by the fleet from 1986 to 2003 were built at 1x1 degree. Also, for comparison purposes, average catch per unit of effort (CPUE) was calculated as number of sharks per 1000-hooks. The overall sets with positive catch (> 0) of shortfin makos were plotted by quarter. To infer on the location of nursery areas, distribution maps were built to identify the occurrence of age-0 and age-1 shortfin makos.

## Results

*Catches and spatial/temporal distribution.* Catches of shortfin mako were low compared to other sharks and other large pelagic species as billfishes. Numerically shortfin mako represents only 0.05% of total catch of all species and 1.19% of sharks. A total of 784 (47.3% female, 44.7% male) shortfin makos were caught in the analyzed period. From the total catch of shortfin mako during 1986 to 2003, 31.1% were caught in the first quarter of the year, followed by the second and third quarter with, 26.7% and 24.8%, respectively. The remaining 17.2% of the total makos were caught in the fourth quarter of the year. Despite the fleet operation all over Mexican EEZ, historical data collected by observers show that shortfin mako was mainly captured in the northwest Mexican Pacific in particular along the west coast of Baja California to Islas Revillagigedo and in the vicinity of Islas Marías. Catch per set of shortfin makos yielded higher values in southwest Cabo San Lucas and Islas Marías than in the remaining areas of occurrence. In terms of catch per unit of effort (CPUE), average yield of shortfin mako was 0.04 (± 0.031) individual per 1000 hooks during the period 1986-2003. Catch per set for the entire period is dominated by a large proportion of sets with one individual (95%), followed by set with two (3%) and three organisms (1.3%). Set with four shorfin makos represent only 0.8%. Notably no catches were recorded in the area of the center of Mexican Pacific (Fig. 1).

Maps of catches by quarter pooling all years show that makos occurred in deep waters off Baja California Peninsula west coast of the continental shelf. From January to March (first quarter) makos seem to be closer to Baja California Peninsula and were recorded in the mouth of the Gulf of California (Fig. 2a). A wide dispersion of makos was observed during April to June and July to September, when isolated individuals occurred in southern areas of the Gulf of Tehuantepec (Fig. 2b-c). With exception of the quarter of July to September mako sharks were always caught at the Revillagigedo islands. In quarter of October to December makos were distributed in all the northwest of the Mexican Pacific (Fig. 2d).

*Length composition.* From the total (784) shortfin makos captured, 722 were biologically examined. The mean size of males was 142 cm FL ranging from 55 to 220 cm FL (sd = 23.2 cm; n = 351). Mean size of female was 143 cm FL ranging from 69 to 264 cm FL (sd = 24.5 cm; n = 371). The length frequency distribution shows small individuals of both sexes of 70 cm FL. Both sexes are represented by a modal size of 150 cm FL (Fig. 3), whereas females show also a mode at 120 cm FL. There was no significant difference in the average length (FL) for males and females (ANOVA, $F$ = 0.81, $P$ = 0.367, df = 721).

Average total weight of males was 32.5 kg with a range of 10-70 kg (sd = 12.9 kg; n = 138), and females average weight was 34.5 kg with a range of 7-72 kg (sd = 12.6 kg; n = 124). No significant sex-specific differences in average weight was found (ANOVA, $F$ = 1.55, $P$ = 0.214, df = 260).

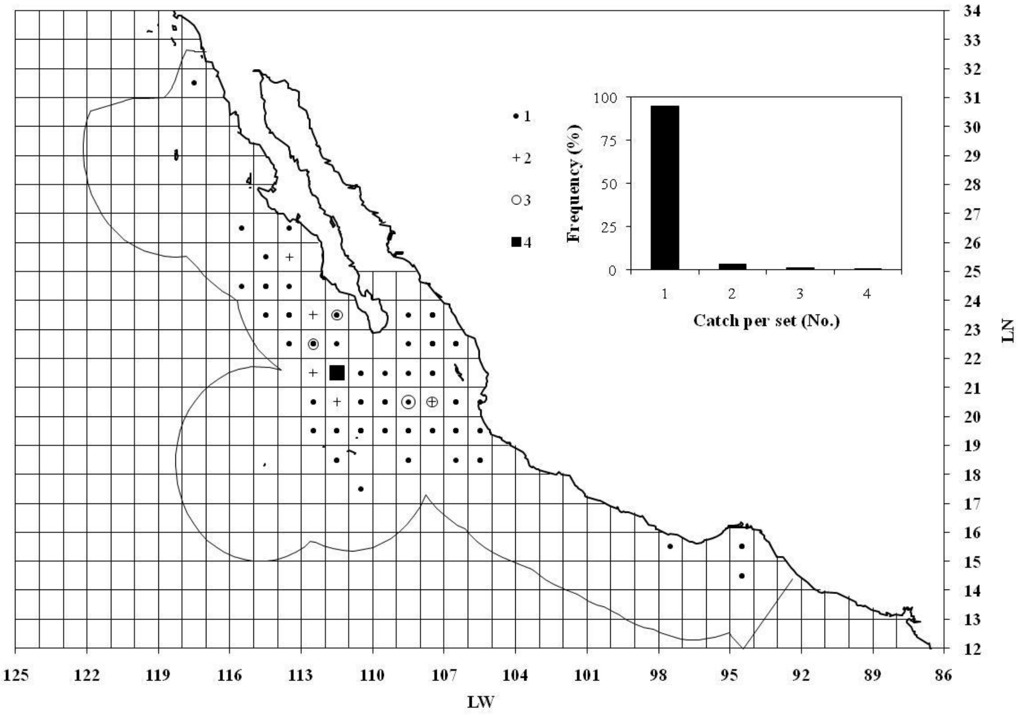

**Figure 1.** Distribution of the catch per set and frequency of catch per set (bars).

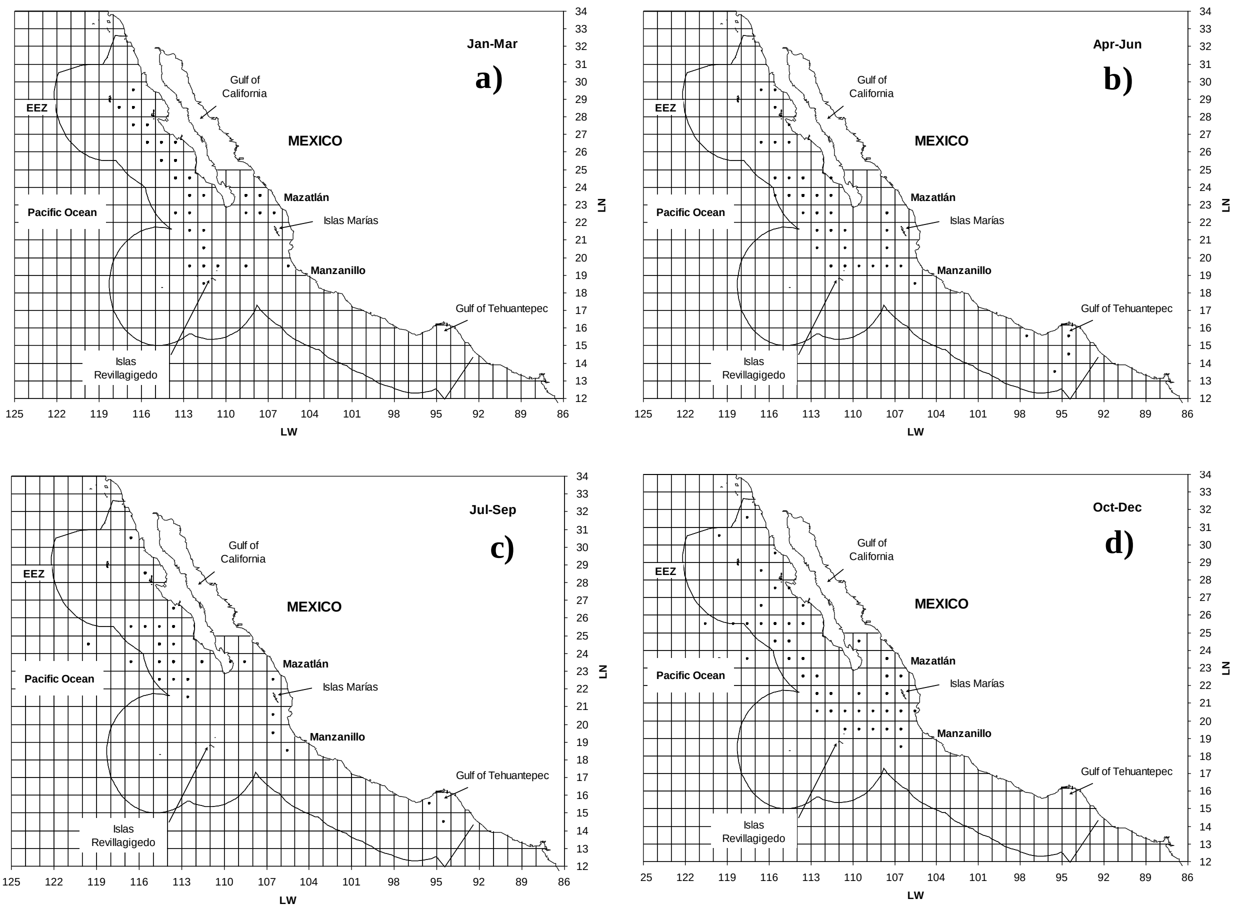

**Figure 2.** Distribution of the shortfin mako catches by quarter.

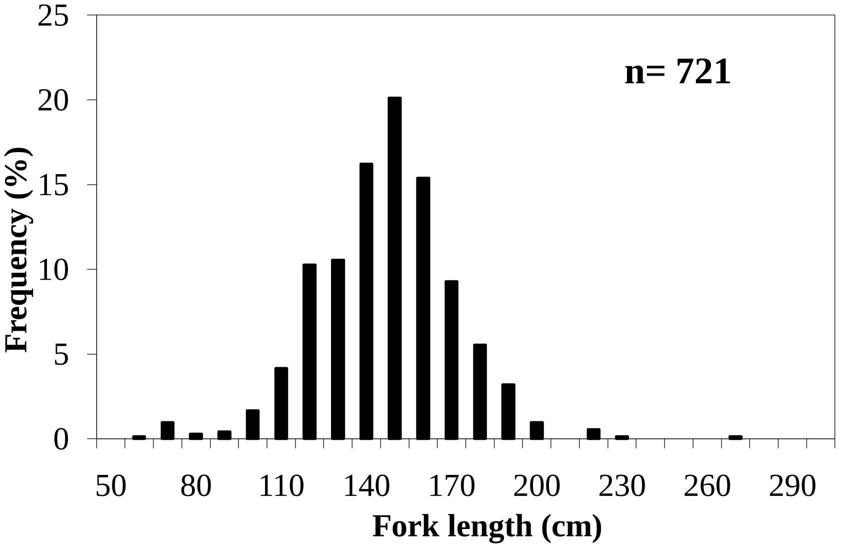

**Figure 3.** Length frequency distribution shortfin mako taken from the Pacific Ocean of Mexico (n= 722).

*Morphometrics.* No statistical differences between FL (cm) -TL (cm) relationship were observed by sex (ANCOVA, $F= 0.31$, $P = 0.579$), therefore linear regression was calculated together with the following parameters estimates: TL = 8.159+1.039(LF) ($r^2 = 0.98$, n = 408). Also, there were no statistical differences between sexes in the relationship between W (kg) and FL (cm) (ANCOVA, $F= 2.6$, $P > 0.05$). Thus, data were also pooled and the value of the parameters of best fit were: $W = 6.8E\text{-}5(FL)^{2.627}$ ($r^2 = 0.82$; n = 260) (Fig. 4).

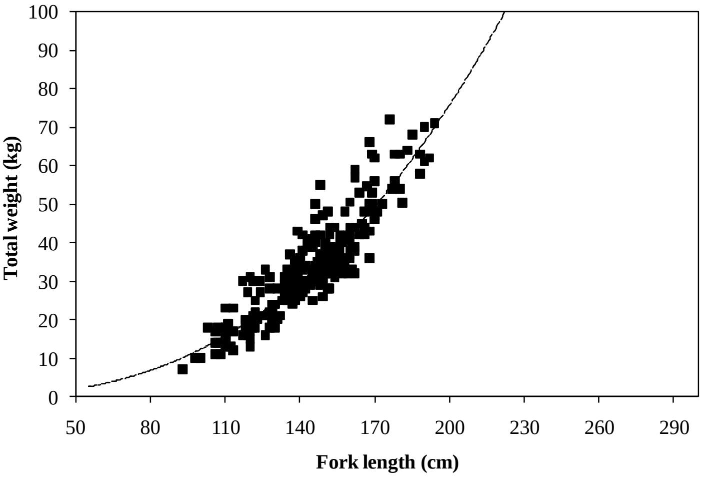

**Figure 4.** Weight-length relationship for the shortfin mako from the Pacific Ocean of Mexico.

Accounting all the period it was found that shortfin makos age-0 averaged 72.5 cm FL (83.5 cm TL) with a size range from 55 to 88 cm FL (63-100 cm TL) were captured in the west of Baja California Sur in January, April and May with SST of 24.5°C, 19.3°C, and 19°C, respectively. Sets of shortfin makos age-0 had an average sea surf temperature (SST) of 22°C ranging from 18.5-27°C. Age-1 shortfin makos averaged 100 cm FL (110.4 cm TL) having a size range from 92 to108 cm FL (103-116 cm TL) were present offshore waters of Baja California Peninsula, between Islas Marías and the Gulf of California mouth, and in the Revillagigedo archipelago (Fig. 5) with an average SST of 22°C ranging from 18.5-27°C. Isolated catches of age-1 shorfin mako occurred in Cabo Corrientes, South Islas Marias. Information related to the catch of individuals of age-0 and age-1 is given in Table I. The smallest mako of 55 cm FL weighted 3.0 kg and was captured in January 27, 2002 in Revillagigedo at SST = 24.5ºC (Fig 5).

**Table I.** Data of shortfin makos captured by the longliners. FL= Fork length (cm), TL= Total length (cm), Temperature in Celcius degrees, Sex (f= female, m= male), position (LN, Latitude North, LW= Longitud West), and dates.

| Month | Day | Year | T°C | LN | LW | FL | TL | Age | Sex |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 27 | 2002 | 24.5 | 19.6 | 112 | 55 | 63 | 0 | m |
| May | 20 | 1998 | 19.5 | 23.3 | 113 | 68 | 78 | 0 | m |
| May | 21 | 1998 | 19.6 | 23.3 | 113 | 68 | 78 | 0 | m |
| Apr | 19 | 1998 | 19.0 | 23.3 | 114 | 69 | 76 | 0 | m |
| May | 4 | 1998 | 19.0 | 26.6 | 116 | 69 | 80 | 0 | f |
| Apr | 29 | 1998 | 22.5 | - | - | 70 | 82 | 0 | f |
| May | 5 | 1998 | 22.5 | 24.2 | 114 | 70 | 83 | 0 | f |
| Aug | 6 | 2000 | 26.1 | 28.0 | 115 | 70 | 84 | 0 | f |
| May | 6 | 2000 | 21.0 | 23.0 | 114 | 73 | 85 | 0 | m |
| Jan | 25 | 1998 | 22.0 | 25.2 | 114 | 74 | 86 | 0 | f |
| Jul | 26 | 2000 | 21.7 | 25.4 | 114 | 83 | 95 | 0 | m |
| Jan | 20 | 1998 | 22.0 | 26.0 | 114 | 85 | 96 | 0 | f |
| Jan | 27 | 1998 | 21.0 | 26.2 | 114 | 88 | 100 | 0 | m |
| Jan | 28 | 1998 | 21.0 | 26.0 | 115 | 92 | 106 | 1 | f |
| Mar | 23 | 1998 | 20.0 | 23.0 | 112 | 92 | 103 | 1 | m |
| Mar | 16 | 1996 | 23.0 | 22.0 | 107 | 93 | 104 | 1 | f |
| Feb | 24 | 1998 | 21.0 | 24.0 | 113 | 94 | 106 | 1 | m |
| Jul | 5 | 1999 | 27.0 | 23.0 | 108 | 94 | 107 | 1 | m |
| Jan | 30 | 1998 | 18.5 | 28.0 | 117 | 95 | 108 | 1 | m |
| Oct | 5 | 1989 | 27.0 | 20.0 | 106 | 96 | 103 | 1 | f |
| Dec | 20 | 1986 | 24.0 | 23.0 | 107 | 98 | 110 | 1 | f |
| Jun | 8 | 2002 | 21.0 | 23.0 | 113 | 100 | 110 | 1 | m |
| Jan | 30 | 1998 | 18.5 | 28.0 | 117 | 100 | 110 | 1 | m |
| Aug | 7 | 2000 | 23.4 | 25.0 | 113 | 100 | 112 | 1 | m |
| Oct | 5 | 2000 | 23.1 | 25.0 | 115 | 100 | 115 | 1 | f |
| Jan | 30 | 2002 | 24.8 | 20.0 | 111 | 101 | 111 | 1 | f |
| Jan | 30 | 1998 | 18.5 | 28.0 | 117 | 101 | 112 | 1 | f |
| Mar | 13 | 1987 | 23.0 | 23.0 | 108 | 103 | 113 | 1 | f |
| Jan | 30 | 1998 | 18.5 | 28.0 | 117 | 104 | 115 | 1 | f |
| Jan | 31 | 1998 | 18.5 | 29.0 | 116 | 105 | 115 | 1 | f |
| Oct | 24 | 2001 | 26.0 | 21.0 | 112 | 106 | 116 | 1 | m |
| Mar | 17 | 2002 | 22.8 | 22.0 | 112 | 106 | 114 | 1 | m |
| Jun | 6 | 2002 | 20.5 | 23.0 | 113 | 106 | 115 | 1 | m |
| Jun | 8 | 2002 | 21.0 | 23.0 | 113 | 106 | 116 | 1 | m |
| Jun | 6 | 2002 | 20.5 | 23.0 | 113 | 108 | 114 | 1 | f |
| | age-0, mean (s.d.) | | | | | 72.5(8.7) | 83.5(9.7) | | |
| | age-1, mean (s.d.) | | | | | 100(5.10) | 110.7(4.30) | | |

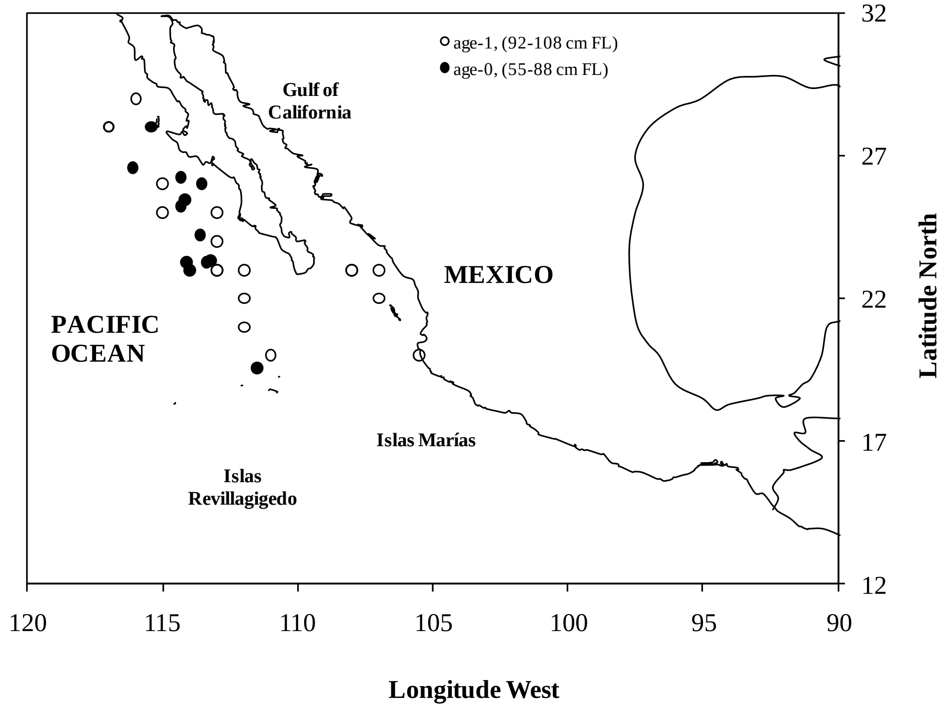

**Figure 5.** Distribution of the small shortfin mako occurring in the catches of the longliners.

## Discussion

The present study shows that the shortfin mako may occur in almost all the EEZ of the Mexican Pacific. Despite the long period of data set analyzed, limited catch of shortfin mako make inference of any pattern of abundance impossible, in this case, occurrence of mako shark can be interpreted by presence-absence criteria. During the development of the Mexican oceanic fishery in the eighties and nineties, dominant shark species in the catch were the pelagic thresher shark, *Alopias pelagicus*, and the silky shark, *Carcharhinus falciformis* which were mistakenly reported as *A. vulpinus* and *C. limbatus*, respectively (Mendizabal–Oriza *et al*. 2001). The shift of fleet to new fishing areas in the vicinity of Baja California Peninsula led to changes in catch composition, with prevalence of species that tolerate water mixtures of lower temperatures such as blue shark, *Prionace glauca* (Strasburg 1958; Cailliet *et al*. 1983). Despite of the fleet operation in the EEZ, shortfin mako catches were sporadic and almost insignificant compared to US pelagic fishery (Holts 1988). Occurrence of makos in the Gulf of Tehuantepec (GOT) is highly interesting because it is considered as a dynamic zone influenced by the Costa Rican current, characterized by seasonal upwelling (Stumpf 1975) and with similar dynamic oceanographic conditions, as the west coast of Baja California Sur, where mako sharks occur. In South America, information on shortfin makos is limited and restricted to their occurrence. Martínez (1999) described the shark fishery in Ecuador with evidence of juvenile mako sharks.

The west coast of Baja California has been recognized as a Biological Activity Center (BAC) of strong upwelling activity where the mixture of currents from California and Costa Rica characterizes its oceanographic conditions (Lluch–Belda *et al*. 2000). The great level of biomass produced in the area is based on large fisheries for small pelagics. Thus, the occurrence of mako sharks and other highly migratory top predators (i.e: sharks, tunas and billfish) in the area coincides with the presence of important small pelagic foraging species (Squire & Au 1990). Therefore, occurrence of small shortfin makos in the west coast of Baja California, in the lower Gulf of California and in the vicinity of Islas Marías may be due to preferred environmental factors (De La Lanza–Espino 1991) and food supply suggesting closeness of a nursery. Based on length frequency distribution analysis, Hanan *et al*. (1993) suggest that the southern California area may be encompassed by the nursery area for makos. Off the west coast of United States, juvenile makos inhabit the coastal waters of California during spring-summer in temperatures ranging from 18º to 22ºC. Even though the mako shark can tolerate extreme temperatures owing its ability to balance heat turnover (Bernal *et al*. 2001), it is frequently found where cold and tropical waters mix such as those off Baja California shore. Although, in this study no data on pregnant females is available to contrast full term or full term embryos *vs* the size of small swimming makos, we believe that the west coast of Baja California and surrounding areas of Islas Revillagigedo and Islas Marías gather the environmental conditions for a nursery for shortfin makos representing an extension of the nursery from Southern California Bight in US waters (Taylor & Bedford 2001). Nurseries for shortfin mako were reported at similar latitudes (LN 20:00-LN 30:00) in the western Pacific (Shoou–Jeng & Hua–Hsun, 2005). Criteria to infer on nurseries for sharks were recently reviewed by Heupel *et al*. (2007) arguing that the seminal concept of nursery area proposed by Springer (1967) and Bass (1978) and its derivations (Branstetter 1990, Castro 1993) should be redefined. In particular, we consider that the review by Heupel *et al*. (2007) is a hybrid of the previous concepts of nursery areas that is more adequate for sharks associated to coastal systems. Little was discussed for sharks inhabiting oceanic environment such as shortfin mako, *I. oxyrinchus*, oceanic white tip, *Carcharhinus longimanus*, silky shark, *C. falciformis*, among others. However, the definition proposed by these authors offers a working framework for either testing or differentiating between nurseries, juvenile areas or birth place.

In Mexico a formal assessment of the status of pelagic sharks has not been carried out despite a long exploitation. However, regulation of the elasmobranch fisheries started in May, 2007 detailing gear and area restrictions. Regulation is accompanied by initiatives of monitoring fishing effort and catches of large vessels trough a Vessel Monitoring System (VMS) that will be mandatory of all the fleet. The status of shortfin makos in the waters of California is uncertain. Holts *et al*. (1998) report a small decrease in average size across the period 1981-1994, although it is unclear whether the effect is caused by historical changes in the mesh-size used on fishing vessels or by overexploitation.

Although the shortfin mako has a worldwide distribution and is considered a species of only intermediate productivity (Smith *et al*. 1998 and 2008), further investigation is needed on biological aspects of this species for determining if differences exist in the pattern of development (maturity, size) in its area of distribution. For instance, lengths of shortfin makos historically reported from California indicated that they are larger than those captured in Mexican waters (Hanan *et al*. 1993), however, as was said before, we caution that such results may be influenced by highly size-selective fishing such as gillnets used in the US fishery. Whether or not there are size structure differences in the catches of makos along California and Baja California, a global study combining the available information on mako sharks and other oceanic shark species will provide a better understanding of temporal and spatial distribution patterns by size and sex, information required for fisheries management.

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# Fishery biology of the Caribbean reef sharks, *Carcharhinus perezi* (Poey, 1876), in a Caribbean insular platform: Los Roques Archipelago National Park, Venezuela

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**Abstract.** Catches of *Carcharhinus perezi* by the artisanal shark fishery in the Los Roques Archipelago during 2001 and 2002 were analyzed in terms of spatial distribution, abundance, diet composition, population structure and growth. The species accounted for 37.7% of the total shark catch. The 303 *C. perezi* specimens examined measured between 67 and 270 cm TL. Mean size estimates of mature males and females were 180.8 and 182.6 cm TL, respectively. Neonates and juveniles were caught mainly in shallow waters (< 20 m depth) along coral reefs bordering the islands. Annual mean CPUE were 1.7 and 1.9 sharks 100-hooks$^{-1}$ in 2001 and 2002, respectively. Stomach contents were mainly teleost fishes (99.5 %IRI), with the most important prey group being Carangidae (10.0 %IRI). Analysis of the length-frequency distribution allowed separation of five age groups (from 0 to 4 years old). The estimated growth rate fell from 31.6 to 17.4 cm year$^{-1}$ during the first four years of life. The von Bertalanffy growth model predicted similar estimates of the parameter K for males (0.16 year$^{-1}$) and females (0.15 year$^{-1}$). Of the *C. perezi* caught by the local shark fishery in Los Roques, 88.6% were immature; hence, a conservation strategy for this species must be included in the management of this national park.

**Keywords:** conservation, elasmobranchs, fishery, management, nursery area.

**Resumen. Biología pesquera del tiburón coralino, *Carcharhinus perezi* (Poey, 1876), en una plataforma insular del Caribe: Parque Nacional Archipiélago Los Roques, Venezuela.** Se analizó la distribución espacial, abundancia, composición de dieta, estructura poblacional y crecimiento de la especie *Carcharhinus perezi* en el Archipiélago Los Roques. Durante el periodo de estudio, el 37,7% de la captura total de tiburones estuvo constituida por la especie *C. perezi*. Los 303 ejemplares examinados midieron entre 67 y 270 cm LT y la talla media de los individuos sexualmente maduros fue 180,8 cm LT en los machos y 182,6 cm LT en las hembras. Los recién nacidos y juveniles fueron capturados principalmente en aguas poco profundas (< 20 m) en áreas que bordean las islas. Las medias anuales de la CPUE fueron 1,7 y 1,9 individuos 100-anzuelos$^{-1}$ en los años 2001 y 2002, respectivamente. La dieta estuvo dominada por peces teleósteos (99,5 %IRI), siendo el ítem Carangidae (10,0 %IRI) el más importante. El análisis de la distribución de frecuencias de talla resultó en la separación de cinco grupos de edad (0-4 años). A su vez, la tasa de crecimiento durante los primeros cuatro años de vida decreció desde 31,6 hasta 17,4 cm año$^{-1}$. El ajuste del modelo de von Bertalanffy resultó en valores del parámetro K similares en los machos (0,16 año$^{-1}$) y hembras (0,15 año$^{-1}$). El 88,6% de las capturas de *C. perezi* estuvieron constituidas por individuos inmaduros, por consiguiente medidas de conservación dirigidas a esta especie deberían ser incluidas en los actuales planes de manejo del parque nacional.

**Palabras-Clave:** conservación, elasmobranquios, pesquería, planes de manejo, área de criadero.

## Introduction

The Caribbean reef shark, *Carcharhinus perezi*, is a bottom-dwelling species of continental and insular shelves, and is commonly associated with tropical coral ecosystems. It is distributed along the western Atlantic seaboard, from the southeastern coast of Florida to southern Brazil, including the Gulf of Mexico, the chain of greater and lesser Caribbean islands and the northern coast of South America (Compagno 2002). In the Caribbean Sea, *C. perezi* is one of the species most frequently caught by many diverse fisheries targeting sharks (Bonfil 1997, Castro *et al*. 1999). Monitoring of medium-scale longline fleets has indicated that shark catches are largely dominated by *C. perezi* off several oceanic islands of the southern Caribbean Sea (Tavares 2005, Ballesteros & Castro 2006). Moreover, this species has acquired economic importance for the diving industry as a living resource in eco-tourism and shark-feeding activities (Compagno 2002). In spite of the economic and ecological value of *C. perezi*, the conservation status is unknown throughout its distribution range. The species has been poorly studied in the Caribbean Sea and there is little information concerning its contribution to catches, its abundance and its biology.

Los Roques Archipelago is recognized in the Caribbean Sea for its high diversity and abundance in marine resources, and also by the high standard of conservation of the coral reef ecosystems (Baamonde 2003). Although the archipelago has the status of national park, and commercial exploitation of its marine resources is controlled, the current conservation and management measures do not include regulation of fishing for sharks. Previous studies have shown the importance of Los Roques Archipelago as habitat for several species of sharks, including *C. perezi* (Tavares 2001, 2005). Those earlier studies provided information regarding the catch contribution and relative abundance of *C. perezi* on the basis of shark fishery data. *Carcharhinus perezi* has been studied also by Chapman *et al*. (2005) and Pikitch *et al*. (2005) in the Glover's Reef Atoll (Belize) and by Garla *et al*. (2006a, 2006b) in the Fernando de Noronha Archipelago and Atol das Rocas (Brazil). Those authors employed a combination of tag-recapture and acoustic telemetry techniques to describe the population structure, movement patterns and habitat use of this species, with particular emphasis on juvenile populations.

In several areas of the world, scientific evidence indicates that sharks are particularly vulnerable to overexploitation (FAO 2005). Two main factors have contributed to the collapse of several shark populations: the large numbers of immature individuals caught by the fisheries, and the degradation of areas inhabited by neonates and juveniles (Camhi *et al*. 1998). Both actions directly interfere with recruitment processes; affecting the rate of population increase. Shark nursery habitats are geographically discrete areas where parturition occurs and neonates spend their first weeks, months, or years (Castro 1993). These areas can be easily identified by the capture of neonates or juveniles, or of females at advanced stages of pregnancy. Because sharks have a low reproductive potential and do not support high levels of fishing mortality (Stevens *et al*. 2000), the identification and protection of shark nurseries could constitute an important conservation measure for heavily exploited species. With the purpose of obtaining basic information required for future management plans in the Los Roques Archipelago, the present study aimed to examine the horizontal and vertical distribution, parturition season, abundance, diet composition, population structure and growth of *C. perezi* on the basis of individuals caught by artisanal shark fishing.

## Materials and Methods

The Los Roques Archipelago National Park is situated in the southern Caribbean Sea, approximately 160 km directly north of the mainland central coast of Venezuela (11º 43'- 11º 58' N/66º 35'- 6º 57' W; Figure 1). The archipelago consists of one main island (Gran Roque) and about 40 small low keys grouped around a central lagoon. Water temperature varies between 25 ºC (February) and 30 ºC (August). Mean annual rainfall is ~256 mm, in contrast to the 1841 mm mean annual evaporation (source: Hydrography and

Navigation Dept, Cagigal Naval Observatory). Los Roques contains diverse coral forms, such as dense and diffuse patch reefs, fringing reefs, and two major barrier reefs 24 and 30 km in length that are respectively located along the southern and eastern edges of the archipelago (Baamonde 2003).

The samples analyzed in the present study were obtained from the local shark fishery operating in the Los Roques Archipelago during the years 2001 and 2002. This fishery uses artisanal bottom longlines of either mono- or multi-filament with 100 to 400 hooks (J-type, size # 3-5). The fishing vessels are mainly small wooden boats between 6 m and 8 m in length and equipped with one or two outboard motors, commonly 40 to 48 hp. Bait is usually composed of grunts (Haemulidae), parrots (Scaridae), porgies (Sparidae), snappers (Lutjanidae) and moray eels (Muraenidae). Fishing zones comprise both internal shallow waters (< 20 m) and bordering deep zones (20-80 m) of the archipelago (Figure 1).

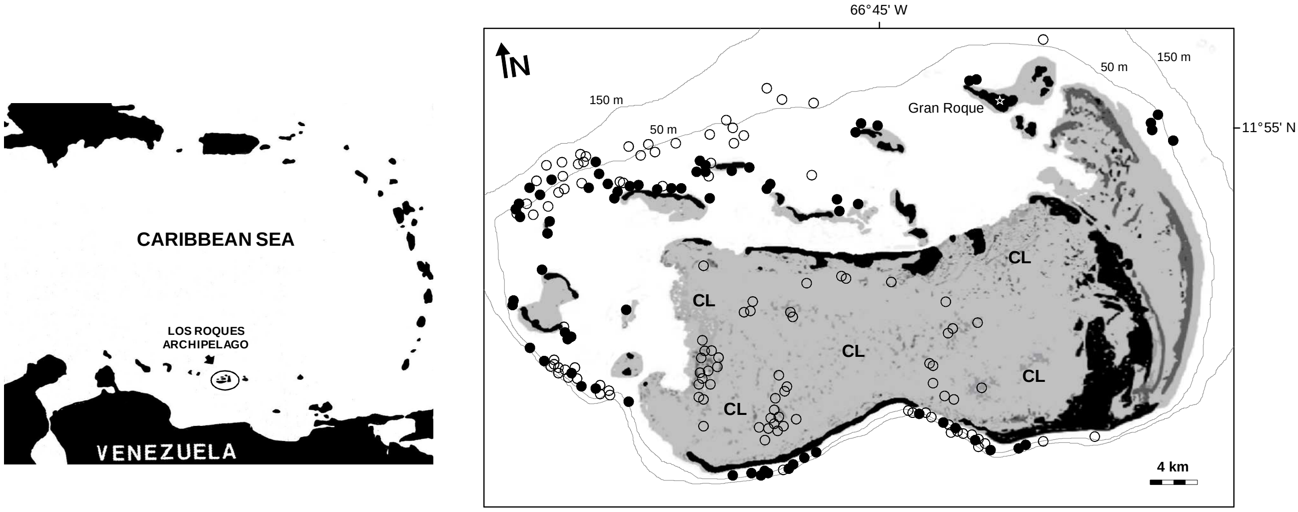

**Figure1. .** Location of the Los Roques Archipelago National Park, showing the catch distribution of sharks registered during fishing monitoring in 2001 and 2002. Map colors: black = islands or keys, dark gray = eastern coral reef barriers, light gray = shallow-water zones maximum depth 8 m. Symbols: ● = catches positive for *Carcharhinus perezi*, ○ = catches of other shark species, CL = central lagoon.

*Carcharhinus perezi* specimens were measured, weighed, sexed and examined for reproductive status and stomach contents. The size measures used were the total length (TL) and fork length (FL) in cm, and the total weight (TW) was measured in kg. Sexual maturity was determined on the basis of the general development and characteristics of the reproductive organs in both sexes. Males were considered mature if they had calcified claspers and developed testis; and females when they showed developed ovaries or pregnancy. Neonates were easily identified by the presence of an open or only partially closed umbilical scar. Fishing locations were recorded by using a manual GPS (Global Positioning System) and fishing depths were obtained with the assistance of the local fishermen.

The population structure of *C. perezi* was characterized in the study area on the basis of the size composition by sex of the artisanal fishing catches. Variation in sex ratios for each year and trimester (years combined) was evaluated by employing a chi-square ($\chi^2$) test. In order to determine if length data (sexes combined) were normally distributed, a quantile-quantile plot of total length was done to compare the observed and normal distributions of this variable. The goodness of fit between the two distributions was measured with a

Kolmogorov-Smirnov statistic. Because length data violated the assumption of normal distribution, the non-parametric Kruskal-Wallis test was employed to compare variability between sexes. Regression techniques were applied between the most important biometric variables (FL vs. TL and TL vs. TW), in order to obtain conversion equations. Subsequently, differences between line regressions by sex were tested by analysis of covariance (ANCOVA).

The abundance levels of *C. perezi* were investigated by calculating the index of catch per unit effort (CPUE; sharks 100-hooks$^{-1}$); where the fishing sets with no captures of this species corresponded to cero CPUE. The fishing operations within the central lagoon of the archipelago were excluded from this analysis because the species *C. perezi* is absent from this area (Tavares 2008). Mean CPUE and confidence limits (CL 95%) by year and by trimester were calculated by computing Monte-Carlo simulations with 2000 estimates of CPUE, randomly generated from a standard normal distribution (mean and sd from observed data; Grunkemeier & Wu 2004). Then, differences between years and between trimesters (years combined) were tested with a one-way analysis of variance (ANOVA I) and Tukey's pairwise comparison (TPC). Additionally, the vertical distribution of the relative abundance was explored by plotting CPUE values against catch depths; the level of correlation between these two variables was measured with the Pearson coefficient (r). The diet was analyzed quantitatively by applying the prey importance indices by number (%N), by occurrence (%O) and by weight (%W). The index of relative importance (%IRI), which incorporates the previous three indices and facilitates comparisons among the contributions of different prey, was estimated (Cortés 1997).

The indirect growth assessment was carried out by using the Bhattacharya (1967) method based on the statistical analysis of the modal groups observed in the length-frequency distribution (FAO-ICLARM, Fish Stock Assessment Tools II); this assumes that each normal component represents one age group or cohort. The separation index (SI) was used to measure the goodness of the modal separation: $SI = |L'_{i+1} - L'_i| / |(s_{i+1} + s_i)/2|$, where $L'_i$ is the mean length of the distribution i, $L'_{i+1}$ is the mean length of distribution i+1, and s is standard deviation of the distributions. Only those values of SI >2 were considered as successfully separated by definition. Annual growth rates (cm year$^{-1}$) were estimated from the difference between successive mean lengths corresponding to identified age groups. The length and age groups generated from modal analysis were used to fit the von Bertalanffy growth function (VBGF): $L_t = L_\infty |1 - e^{-K(t-to)}|$, where $L_t$ is the predicted length at time t, $L_\infty$ is the mean asymptotic length, K is the growth rate parameter, and $t_0$ is the theoretical age at which length is zero. For the study area, the maximum lengths reported for *C. perezi* are 289 cm TL in males and 305 cm TL in females (Tavares 2005) and hence these sizes were used as $L_\infty$ values in the VBGF. Growth was modeled by fixing the asymptotic length ($L_\infty$) to estimate the parameters K and $t_0$. The regression procedure was carried out by employing a Gauss-Newton algorithm of the Systat package that provides confidence limits (95% CL) of the parameters and the r-squared statistic ($r^2$). An F-test assessed differences in growth curves between sexes. Once growth parameters had been obtained, the individual age was derived for each male and female by applying the inverse VBGF: $t = |t_0 - 1/K| \times \log|1 - L_t/L_\infty|$. The statistical methods (significant if $p \leq 0.05$) used in the present study (without cited references) are fully described by Zar (1998).

## Results

In total, 194 fishing sets (32,728 deployed hooks) were registered as fishing effort during monitoring of local shark fishing in 2001 and 2002. Catch data were lacking during some months of the study period (May, Nov and Dec 2001; Jan, May, Jun, Oct and Dec 2002) owing to the absence of either monitoring activities or shark fishing. The 803 sharks caught represented 13 species in 5 families, with the most important group being Carcharhinidae (93.3%). The contribution of *C. perezi* to annual shark catches represented 38.2% in 2001 and

35.8% in 2002. The spatial distribution of shark catches showed that *C. perezi* was primarily caught in areas close to the islands and bordering the archipelago, in waters between 3 m and 60 m in depth (Figure 1).

On the basis of specimens examined in this study, total length and total weight could be estimated by using the following conversion equations: $TL = 3.087 + |1.198 \times FL|$ ($n = 116$, $r^2 = 0.99$); $TW = |0.000002 \times TL|^{3.21}$ ($n = 244$; $r^2 = 0.97$). There were not significant differences between sexes for FL vs. TL or TL vs. TW (ANCOVA, $p > 0.05$). The annual and seasonal sex ratio of the *C. perezi* did not vary significantly from the expected proportion of 1:1 (Table I).

**Table I.** Catch numbers by sex (including results of $\chi^2$-test) of *Carcharhinus perezi* caught by the artisanal fishery in the Los Roques Archipelago National Park.

| **Sampled Periods** | **Catch** | | **$\chi^2$-test** | |
|---|---|---|---|---|
| | Males | Females | $\chi^2$ value | p value |
| Years | | | | |
| 2001 | 120 | 124 | 0.03 | 0.87 |
| 2002 | 25 | 34 | 1.41 | 0.24 |
| Years Combined | | | | |
| Trimester 1 | 36 | 39 | 0.16 | 0.69 |
| Trimester 2 | 21 | 18 | 0.59 | 0.44 |
| Trimester 3 | 81 | 96 | 0.72 | 0.40 |
| Trimester 4 | 7 | 5 | 2.78 | 0.10 |

Overall, 145 males (47.9%) and 158 females (52.1%) were caught during the study period. Analysis showed that length data were not normally distributed (Figure 2; Kolmogorov-Smirnov test, $p<0.05$). Subsequent comparison of length composition between sexes showed no significant difference (Kruskal-Wallis test, $p > 0.05$). Males measured between 67 and 216 cm TL and females measured between 72 and 270 cm TL. In males, the smallest adult measured 149 cm TL, and the estimated mean length of the mature individuals was 180.8 cm TL ($n = 18$). In females, the smallest adult measured 154 cm TL, and the estimated mean length of the mature specimens was 182.6 cm TL ($n = 38$). In total, 17 neonates with sizes between 74 and 86 cm TL (mean: 80.7 ± 3.2 sd) were observed during August and September months. Another 17 individuals (67-87 cm TL) had a recently closed umbilical scar and these were captured during the same months. Two gravid females (210 and 229 cm TL) were caught in April 2002, and these carried three (62-66 cm TL) and four (59-62 cm TL) embryos at an advanced stage of development, respectively. Assessment of the reproductive condition indicated that 88.6% of the *C. perezi* caught were immature. The body size were positively correlated to the depth of the waters in which the sharks were caught ($r = 0.77$; Figure 3). The capture of small juvenile *C. perezi* (< 100 cm TL) was primarily observed in depths < 20 m.

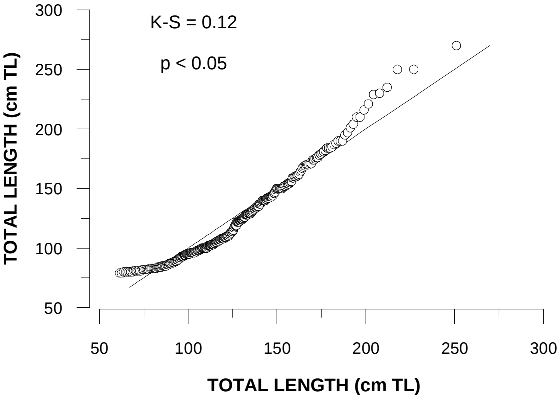

**Figure 2.** Normal quantile-quantile plot of the total length (TL cm) of *Carcharhinus perezi* caught by the artisanal longline fishery in the Los Roques Archipelago National Park. The Kolmogorov-Smirnov test indicated a significant difference ($p < 0.05$) from normality.

Monte-Carlo estimates of annual mean CPUE were 1.7 and 1.9 sharks 100-hooks$^{-1}$ in 2001 and 2002, respectively (Figure 4). Statistical analysis to test for differences in mean CPUE estimates was not significant for years (ANOVA, $p > 0.05$). In relation to the seasonal estimates by trimester, mean CPUE varied from a low of 1.1 sharks 100-hooks$^{-1}$ (trimester 2) to a high of 2.1 sharks 100-hooks$^{-1}$ (trimester 3). The only significant estimate (ANOVA, $p < 0.05$) was the CPUE in trimester 3 that was greater than the estimates observed in trimesters 1, 2 and 4. The vertical distribution of CPUE values estimated from the individual fishing sets showed that the abundance of *C.*

*perezi* appeared to be negatively correlated with depth (r = – 0.61, Figure 3). The highest CPUE values (> 5 sharks 100-hooks$^{-1}$) were observed in zones with depths < 20 m.

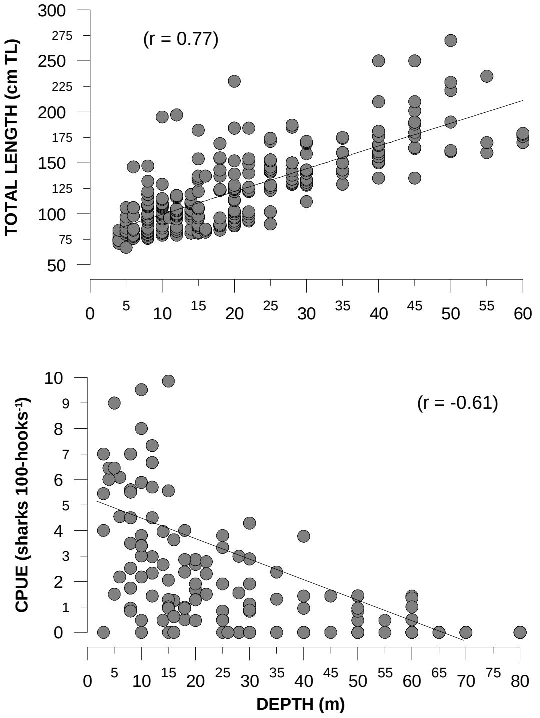

**Figure 3.** Individual lengths and relative abundance estimates (CPUE) in relation to depth of water column for *Carcharhinus perezi* caught by the artisanal longline fishery in the Los Roques Archipelago National Park.

Of 139 individuals (67-270 cm TL) examined for diet analyses, 77.7% had empty stomachs and 22.3% contained food items. A total of 10 families and 12 species of prey could be positively identified (Table II). Teleost fishes were the main prey group observed in stomachs (99.5% IRI), followed by cephalopods (0.5% IRI). However, a high proportion of teleost prey (70.1 %IRI) remained unidentified because of their advanced stage of digestion. Among teleosts, the more important components of the diet were members of the families Carangidae (*Caranx hippos* and *Caranx* spp.; 10.0% IRI), Lutjanidae (*Ocyurus chrysurus* and *Lutjanus* spp.; 6.9% IRI) and Belonidae (*Hemiramphus brasiliensis* and *Ablennes hians*; 5.4% IRI). The analysis also indicated that Carangidae also contributed the highest proportion by weight (32.7% W).

Analysis of the length-frequency distribution by sex (years combined) resulted in the successful separation of five modal components or cohorts, from 0 to 4 years of age (Table III, Figure 5). When data for the two sexes were combined, the mean lengths ranged from 79.6 cm TL (group of age 0) to 178.7 cm TL (group of age 4), and growth rates varied from 31.6 to 17.4 cm year$^{-1}$ during the first four years of life (Table III, Figure 5). The von Bertalanffy growth model predicted similar estimates of the parameter K for males (0.16 year$^{-1}$) and females (0.15 year$^{-1}$) (Table IV). The estimated age groups for *C. perezi* catches ranged from 0 to 7 years for males and from 0 to 14 years for females (Figure 6). Statistical analysis indicated that growth curves did not differ significantly between males and females (F-test, p > 0.05).

**Table II.** Diet composition of *Carcharhinus perezi* in the Los Roques Archipelago National Park, expressed as percentage of prey items by numbers (%N), frequency of occurrence (%O), percent weight (%W) and percentage of relative importance (%IRI).

| Prey item | Quantitative method | | | |
|---|---|---|---|---|
| | %N | %O | %W | %IRI |
| Teleosts | | | | |
| Carangidae | | | | |
| *Caranx* spp. | 8.1 | 9.7 | 15.8 | 7.9 |
| *Caranx hippos* | 2.7 | 3.2 | 16.8 | 2.1 |
| Lutjanidae | | | | |
| *Ocyurus chrysurus* | 8.1 | 9.7 | 10.6 | 6.1 |
| *Lutjanus* spp. | 2.7 | 3.2 | 3.8 | 0.7 |
| Belonidae | | | | |
| *Hemiramphus brasiliensis* | 8.1 | 9.7 | 6.7 | 4.9 |
| *Ablennes hians* | 2.7 | 3.2 | 2.6 | 0.6 |
| Haemulidae | | | | |
| *Haemulon sciurus* | 5.4 | 6.5 | 5.1 | 2.3 |
| Scaridae | | | | |
| *Scarus* spp. | 2.7 | 3.2 | 0.8 | 0.4 |
| *Scarus guacamaia* | 2.7 | 3.2 | 7.3 | 1.1 |
| Pomacentridae | | | | |
| *Abudefduf saxtatilis* | 2.7 | 3.2 | 3.0 | 0.6 |
| Mullidae | | | | |
| *Mulloidichthyes martinicus* | 2.7 | 3.2 | 5.0 | 0.8 |
| Aulostomidae | | | | |
| *Aulostomus maculatus* | 2.7 | 3.2 | 2.0 | 0.5 |
| Sphyraenidae | | | | |
| *Sphyraena barracuda* | 2.7 | 3.2 | 8.3 | 1.2 |
| Teleosts non-identified | 43.2 | 38.7 | 10.0 | 70.1 |
| Cephalopods | | | | |
| Octopidae | | | | |
| *Octopus vulgaris* | 2.7 | 3.2 | 2.0 | 0.5 |

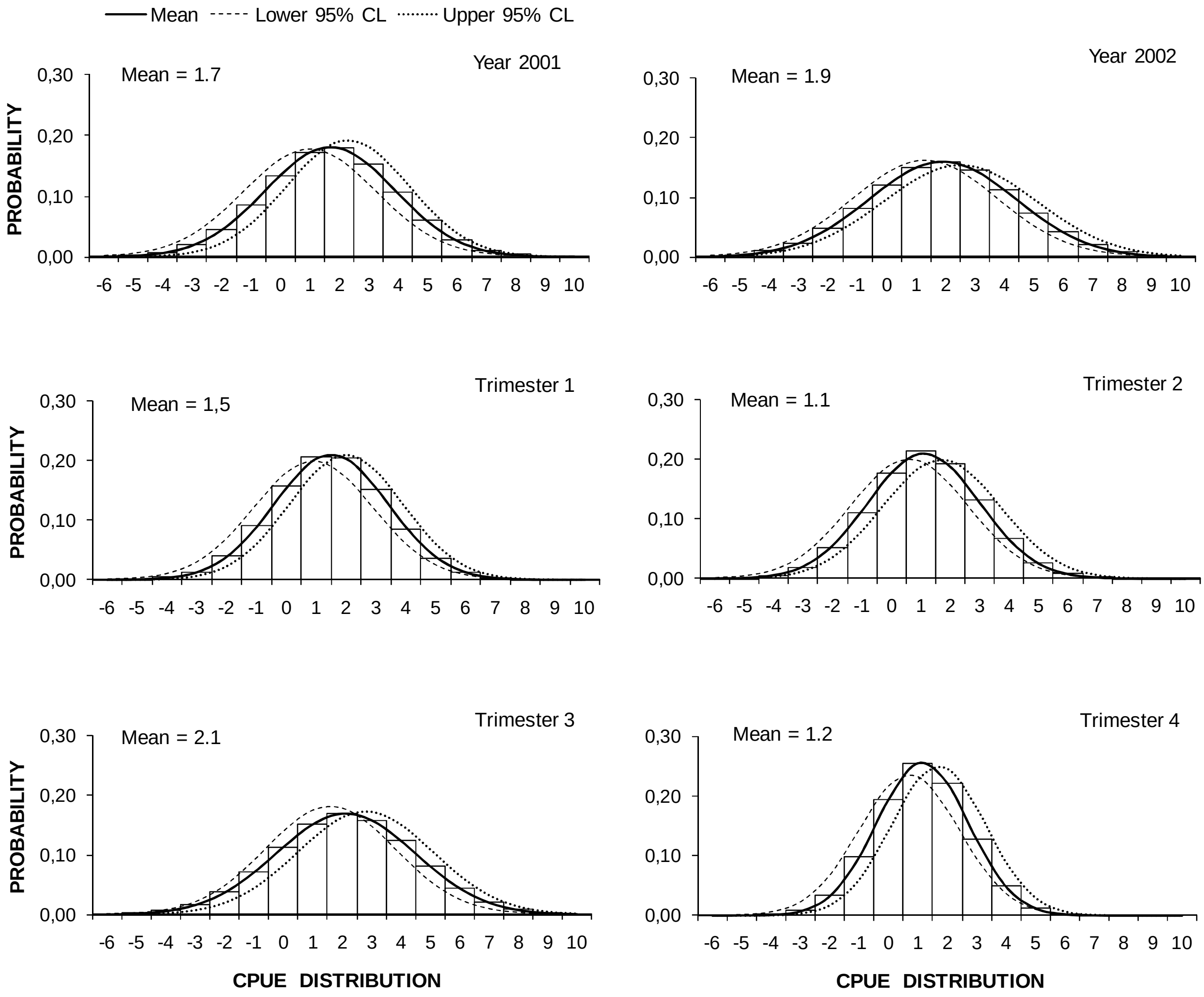

**Figure 4.** CPUE (sharks 100-hooks$^{-1}$) distributions by year and by trimester (years combined) estimated for *Carcharhinus perezi* caught by the artisanal longline fishery in the Los Roques Archipelago National Park. Also indicated are Monte-Carlo means of CPUE and 95% confidence limits (CL).

**Table III.** Results obtained from the Bhattacharya (1967) modal analysis applied to the length frequency distribution of *Carcharhinus perezi* caught by the artisanal longline fishery in the Los Roques Archipelago National Park. (sd = standard deviation, SI = separation index).

| Bhattacharya Modal Analysis | | | | | | |
|---|---|---|---|---|---|---|
| Sample | Age Group | Mean Length (cm TL) | sd | SI | Growth Rate | |
| | | | | | Year | cm year$^{-1}$ |
| Sexes combined | 0 | 79.6 | 5.5 | n.a | n.a | n.a |
| | 1 | 111.2 | 8.2 | 4.6 | 1 | 31.6 |
| | 2 | 140.7 | 7.3 | 3.8 | 2 | 29.6 |
| | 3 | 161.3 | 3.6 | 3.8 | 3 | 20.6 |
| | 4 | 178.7 | 5.4 | 3.9 | 4 | 17.4 |
| Males | 0 | 78.0 | 4.3 | n.a | n.a | n.a |
| | 1 | 114.2 | 9.3 | 5.3 | 1 | 36.2 |
| | 2 | 140.0 | 9.7 | 2.7 | 2 | 25.8 |
| | 3 | 162.9 | 5.2 | 3.1 | 3 | 22.9 |
| | 4 | 181.2 | 4.2 | 3.9 | 4 | 18.3 |
| Females | 0 | 83.0 | 5.1 | n.a | n.a | n.a |
| | 1 | 108.8 | 9.2 | 3.6 | 1 | 25.8 |
| | 2 | 141.2 | 7.0 | 4.0 | 2 | 32.4 |
| | 3 | 159.7 | 3.1 | 3.6 | 3 | 18.5 |
| | 4 | 176.3 | 4.9 | 4.1 | 4 | 16.7 |

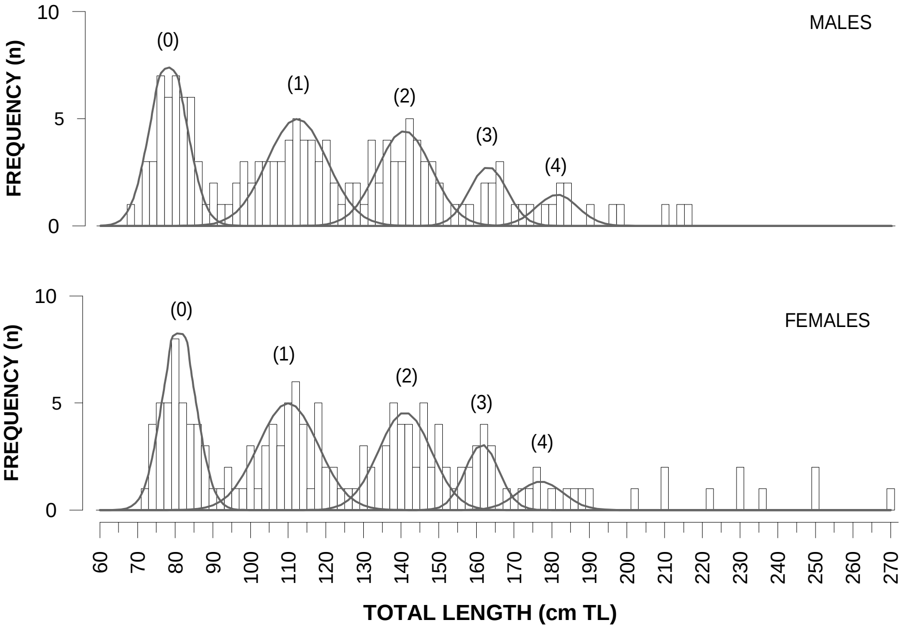

**Figure 5.** Length and age groups identified from the modal progression analysis of the length-frequency distribution of *Carcharhinus perezi* caught by the artisanal longline fishery in the Los Roques Archipelago National Park. Age groups from 0 to 4 years old are indicated.

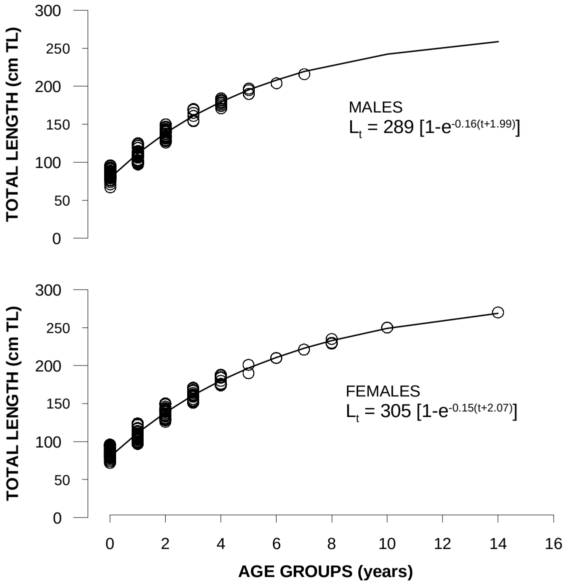

**Figure 6.** Von Bertalanffy growth curve fitted to length and age group data of *Carcharhinus perezi* caught by the artisanal longline fishery in the Los Roques Archipelago National Park.

**Table IV.** von Bertalanffy growth parameters estimated for *Carcharhinus perezi* caught by the artisanal longline fishery in the Los Roques Archipelago National Park. (95% CL = confidence limits of the parameters, $r^2$ = r-squared statistic).

| von Bertalanffy Growth Function | | | |
|---|---|---|---|
| Parameter | Value | 95% CL | $r^2$ |
| Males | | | |
| $L_\infty$ | 289 | fixed value | 0.95 |
| K | 0.16 | 0.15 - 0.17 | |
| $-t_0$ | 1.99 | 2.10 - 1.68 | |
| Females | | | |
| $L_\infty$ | 305 | fixed value | 0.95 |
| K | 0.15 | 0.14 - 0.16 | |
| $-t_0$ | 2.07 | 2.41 - 1.69 | |

## Discussion

The results showed that *C. perezi* is a shark species frequently caught in the Los Roques Archipelago and its presence and abundance could keep relation with the presence of large expanses of coral reef structures. On the basis of personal observations, *C. perezi* is seldom if ever observed in the main artisanal fisheries conducted along the continental shelf of Venezuela, and the occurrence of this species is limited to some areas characterized by their low to moderate human impact. In the Caribbean Sea, other studies have revealed that *C. perezi* is common on several oceanic insular platforms, such as Glover's Reef Atoll, Belize (Pikitch *et al*. 2005), Las Aves Archipelago and La Blanquilla island, Venezuela (Tavares 2005), and San Andres, Providencia and Santa Catalina islands, Colombia (Ballesteros & Castro 2006). In the southwestern Atlantic Ocean, *C. perezi* has been also reported as one of the most important shark species occurring around the oceanic Brazilian islands of Fernando de Noronha Archipelago and Atol das Rocas (Garla *et al*. 2006a). All those study areas have two main characteristics in common: the existence of important coral reef formations; and their remoteness from the anthropogenic influence of the continental mainland coast. Considering that sharks are the top predators in the oceans and thus play an important role in marine ecosystems (Wetherbee & Cortés 2004), *C. perezi* must be a key species for the ecological maintenance of the oceanic insular areas in the Caribbean Sea.

In the present study area, catches of *C perezi* were composed of a wide range of lengths, from neonates to large adults in both sexes. However, the sizes of adult males were below the maximum lengths reported for this species in Los Roques. Results also indicated that body sizes tend to increase with depth and hence these findings indicate that large adults usually inhabit or spend more time in deep zones (> 60 m). This conclusion is consistent with previous information obtained for the same study area, which showed that large adults of this species were commonly captured at depths of as much as 200 m (Tavares 2005). On the other hand, the capture of neonates and small juveniles *C. perezi* was restricted to zones of shallow water (3-20 m depth), indicating the importance of these areas close to shore as habitat for the early life-stages of this species. The studies conducted by Pikitch *et al*. (2005) and by Garla *et al*. (2006a) provided similar results in relation to the distribution of *C. perezi* according to ontogenetic development. Changes in habitat type with increasing length or age have been widely documented in sharks (Simpfendorfer & Heupel 2004). On the basis of the findings from all the above-mentioned studies of *C. perezi* (including the present work), a common distribution pattern appears to be followed by this species. This pattern can be described as follows: neonates and small juveniles (< 130 cm TL) are primarily distributed along shallow fringing reefs close to islands (< 30 m depth); and large juveniles and adults commonly occur in deeper zones along ocean reefs bordering the insular shelves, although they can also make incursions into shallow areas, probably for feeding purposes during night hours. In the study area, the observed sex ratio (~1:1) and the length structure of *C. perezi* catches suggest the presence of a localized population in the Los Roques Archipelago. This conclusion is consistent with tag-recapture and telemetry data that have also suggested a non-migratory behavior in this species (Kohler *et al*. 1998, Chapman *et al*. 2005, Garla *et al*. 2006b).

Owing to the structure of the CPUE data (typically log-normal distribution), the use of Monte-Carlo simulations can be an alternative procedure to normalize the data. The CPUE analysis showed that abundance of *C. perezi* did not change significantly between sampled years. The higher mean CPUE observed during the third trimester was related to the birth period, which occurred during August and September. Previous seasonal CPUE estimates for *C. perezi* in the Los Roques Archipelago were highly variable (Tavares 2005), fact attributed to differences in the sources of fishing data. The information analyzed in that previous study came from the monitoring of fishing by medium-scale longline fleets operating around Venezuelan insular platforms and hence catch data were restricted to depth zones. Catches obtained in the present study can be considered a good representation of the population structure of *C. perezi*, since local shark fisheries exploit areas ranging from internal shallow waters to zones as deep as 80 m. The analysis revealed that higher CPUE values were also concentrated in the shallow zones (< 20 m) inhabited by the early life-stages. These nearshore reef zones sustain an abundant and diverse marine fauna, which makes them highly productive habitats (i.e. shark nursery areas) for the development of juvenile *C. perezi*. The species *C. limbatus* and *Negaprion brevirostris* also have nursery grounds in the Los Roques Archipelago;

however, the habitats used by the early life-stages of these two species are discretely partitioned within the insular area (Tavares 2008, 2009). The selection of a specific nursery habitat by sharks of each species helps to reduce the levels of competition and predation, and thereby leads to ecological benefits for the juvenile populations. The most recent insights regarding the complex process of shark nursery selection and habitat use are extensively discussed by Heithaus (2007) and Heupel *et al.* (2007).

The stomach contents were dominated by teleost remains, with members of the Carangidae, Lutjanidae and Belonidae being the ones most often identified. Although all teleost species that could be identified are common inhabitants of the reef zones of the Los Roques Archipelago, *C. perezi* appeared to prey mainly on those three specific groups of fishes. This pattern appears to be common in carcharhinids and the factors influencing shark feeding behavior were fully reviewed by Wetherbee & Cortés (2004). Those authors suggested that the presence of a specific prey in the diet of a particular predator might be related to the abundance of those prey species in distinct geographic areas or habitat types. However, it is necessary to take into account that prey that are easily captured could also dominate the diet of a particular shark species. Moreover, the use of separate habitats by different shark species (particularly by juvenile individuals) will avoid competition for food. Other studies conducted in Los Roques Archipelago showed that *C. limbatus* preyed primarily on Gerreidae fishes but also on clupeids when these were present in the area (Tavares & Provenzano 2000, Tavares 2008). The spatial distribution and diet composition of *C. limbatus* and *C. perezi* within the same insular area constitute a good example of habitat and dietary partitioning. The high percentage of empty stomachs observed in the present study, combined with the frequent occurrence of prey items in advanced stages of digestion, was probably a consequence of the fishing method used. Wetherbee & Cortés (2004) concluded that sharks attracted with bait (e.g. linehooks) generally had relatively empty stomachs. Consequently, stomachs obtained from individuals caught by non-baited fishing methods (such as gillnets) would be most appropriate for diet analysis in sharks.

In the present study, the length frequency analysis appeared to provide a reasonable approximation of the annual growth rates of *C. perezi* during the first life stages, owing to the clear separation of the modal groups. Mean size estimates of mature males (180.8 cm TL) and females (182.6 cm TL) corresponded to age group of 4 years in both sexes. The information compiled by Cailliet & Goldman (2004) on the age and growth of elasmobranchs shows that, on average, the age at maturity is 9 years among sharks of the genus *Carcharhinus*. Also in Los Roques Archipelago, the species *C. limbatus* exhibits a rapid juvenile growth when compared with populations of the same species from other geographic areas (Tavares 2008). The factors that could be influencing this rapid growth observed in the study area are: (1) the constant and elevated temperature of the sea water, typical of the tropical regions; (2) the availability of prey and consequent food abundance; (3) the well conserved state of the marine ecosystems; and (4) the apparently low rate of competition as a result of the partitioning of nursery areas. In regard to the von Bertalanffy growth modeling, the K values obtained in this study (males: 0.16 $year^{-1}$; females: 0.15 $year^{-1}$) were within the range of faster-growing species ($K > 0.1$) given by Branstetter (1990). However, growth parameters estimated for *C. perezi* will have to be re-examined and verified through the use of other techniques such as tag-recapture or vertebral analysis, since stock evaluation requires precise and accurate age information in order to avoid inappropriate management decisions.

This study has demonstrated that a large proportion of the *C. perezi* individuals caught by the local shark fishery (88.6%) are immature; these are captured mainly in zones of shallow water (< 30 m depth) along the coral reefs bordering the islands or keys. These findings have led to recognition of the areas occupied by neonates and juveniles of this species in Los Roques Archipelago. The delineation and protection of shark nursery areas, as a conservation measure, has received increased attention in recent years; this measure would be of significant benefit for the maintenance or recovery of the exploited shark populations. Nevertheless, Kinney & Simpfendorfer (2008) recently suggested that, for management purposes, protection of adult sharks beyond nurseries may be more important than protection of juvenile individuals within the nursery areas. In the case of the Los Roques Archipelago, the adult population of *C. perezi* appears not to be significantly affected by the artisanal fishery conducted in the area. Research must continue in order to increase biological knowledge of the most important species of sharks captured in the study area. However, considering the status of the Los Roques Archipelago as a national park, a closed season for shark fishing should be established in this area.

## Acknowledgments

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# The seasonal importance of small coastal sharks and rays in the artisanal elasmobranch fishery of Sinaloa, Mexico

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**Abstract.** Seasonal surveys were conducted during 1998–1999 in Sinaloa, Mexico to determine the extent and activities of the artisanal elasmobranch fishery operating in the southeastern Gulf of California. Twenty–eight fishing sites were documented, the majority of which (78.6%) targeted elasmobranchs during some part of the year. Sharks numerically dominated sampled landings (65.0%, $n$ = 2390), and catch rates exceeded those of rays during autumn–spring. The scalloped hammerhead, *Sphyrna lewini*, was the primary fishery target during these seasons, with most landings composed of early life stages. During summer, rays, especially *Rhinoptera steindachneri*, were numerically dominant (87.7%). Large sharks were of comparably minor importance in the artisanal fishery during all seasons. Catch composition was similar between spring and winter ($SIM_{obs}$ = 0.393, $SIM_{exp}$ = 0.415; $P$ = 0.25), largely because the fishery mainly targeted "cazón" (sharks $\leq$ 1.5 m total length) during this period (e.g., *S. lewini*, *Rhizoprionodon longurio*). Small size classes of large sharks and a wide size range of coastal sharks and rays were primarily observed. In addition, size composition of *S. lewini* and to a lesser extent, *R. longurio* decreased significantly between historic and contemporary landings. Local populations of these species should therefore be closely monitored.

**Keywords:** catch composition, CPUE, Gulf of California, size composition, sex ratio

**Resumen. Importancia estacional de los cazón y rayas en la pesquería artesanal de elasmobranquios de Sinaloa, México.** Se realizaron prospecciones estacionales durante 1998–1999 en Sinaloa, México para determinar la magnitud y las actividades de la pesquería artesanal de elasmobranquios del sureste del Golfo de California. Se documentaron veintiocho localidades pesqueras, la mayoría (78.6%) pescaron elasmobranquios en alguna época del año. Los tiburones dominaron numéricamente los desembarques (65.0%, $n$ = 2390), sus tasas de captura excedieron a las de rayas en otoño–invierno. El tiburón martillo, *Sphyrna lewini*, fue la principal especie objetivo con la mayoría de los desembarques compuestos por juveniles. En verano, las rayas, especialmente, *Rhinoptera steindachneri*, fueron numéricamente dominantes (87.7%). Los tiburones grandes fueron de menor importancia en todas las temporadas. La composición de las capturas fue similar en primavera e invierno ($SIM_{obs}$ = 0.393, $SIM_{exp}$ = 0.415; $P$ = 0.25), debido a que la pesquería pesca "cazón" (tiburones de $\leq$ 1.5 m) durante este periodo (ej., *S. lewini*, *Rhizoprionodon longurio*). De tiburones grandes se observaron tallas pequeñas, mientras que de tiburones costeros y rayas un mayor intervalo de tallas. Además, las tallas de *S. lewini* y *R. longurio* disminuyeron significativamente entre los desembarques históricos y los actuales. Por lo tanto, las poblaciones locales de estas especies deberían ser monitoreadas cuidadosamente.

**Palabras clave:** composición de la captura, composición por talla, CPUE, Golfo de California, razón sexual

## Introduction

Mexico has historically been among the global leaders in shark and ray fishery production (Stevens *et al.* 2000, FAO 2007). Increasing concern regarding the status and sustainability of elasmobranch populations in Mexican waters, however, has prompted the development of a federal management plan and underscored the need for fundamental information on targeted species (DOF 2007). Improved management of Mexican elasmobranch fisheries has been hampered, in part, by a lack of detailed quantitative information on the location and activities of artisanal fishing sites, species composition of landings, and basic life history information of targeted species (Castillo–Géniz *et al.* 1998, Márquez–Farías 2002). The Gulf of California is one of Mexico's most important regions in terms of overall and elasmobranch fisheries production (CONAPESCA 2006). Contemporary and historic data indicate that the state of Sinaloa, which bounds the southeastern Gulf of California, has been consistently among the national leaders in elasmobranch landings (CONAPESCA 2006).

Elasmobranchs landings ranged from 1924–5883 t and averaged 1.6% of total fishery production in Sinaloa during 1996–2006, the most recent available time series (CONAPESCA 2006). Elasmobranch landings from Sinaloa comprised 16.5% of national elasmobranch production during 2006, the greatest of all Mexican states, and averaged 8.0% of national production during 1996–2006. Sharks, especially "tiburón" (sharks > 1.5 m total length), constituted the great majority of reported landings, with rays contributing an average of 9.4% by weight during 1996–2006 (CONAPESCA 2006). However, rays and small sharks ($\leq$ 1.5 m total length), or "cazón," have been reported to constitute a considerable portion of artisanal landings in other regions of the Gulf of California (Bizzarro *et al.* 2009a, Smith *et al.* 2009a) and have supported historic artisanal fisheries in Sinaloa (Saucedo–Barrón *et al.* 1982, Righetty–Rojo & Castro–Morales 1990, Castillo–Géniz 1990).

To improve the understanding, conservation, and management of exploited shark and ray populations in the Gulf of California (GOC), a two–year study was undertaken during 1998–1999 to describe the extent and activities of the artisanal elasmobranch fisheries in each state bordering on the GOC. Manuscripts providing detailed elasmobranch fishery information for Sonora (Bizzarro *et al.*, 2009a), Baja California (Smith *et al.*, 2009a), and Baja California Sur (Bizzarro *et al.*, 2009b) have been recently published. This complementary work on the artisanal elasmobranch fishery of Sinaloa therefore completes the series. Specific objectives were to: 1) determine the locations and activities of elasmobranch fishing sites in Sinaloa; 2) determine seasonal species composition of elasmobranchs from these sites, and 3) provide biological information (size composition, sex ratios) for the primary species in landings. Limited, supplemental information was collected during 2005–2009 and used for comparative purposes with the historic data presented from 1998–1999.

*Study Site Information.* Bordered by the GOC to the west, mainland Sinaloa contains 640 km of coastline (INEGI 2007). The continental shelf off Sinaloa is relatively wide, with the shelf break typically occurring > 50 km offshore. The shelf is widest off the southern portion of the state, where it may occur > 100 km from shore, and narrowest (~ 20 km) off Isla Altamura (Dauphin & Ness 1991) (Fig. 1). Coastal regions are composed largely of sandy substrates. Lagoons, estuaries, and other insular waters occur extensively throughout Sinaloa.

Sinaloa is one of Mexico's most important states in terms of fishery production, accounting for 17.3% of landings and 20.7% of revenues during 2006 (CONAPESCA 2006). These totals ranked second among Mexican states in both categories. The most important fishery resources in Sinaloa were, in order of descending landings during 1996–2006: tunas, sardines, and shrimps. Shrimp production is the greatest source of revenue among Mexican fishery resources, and Sinaloa landed more shrimp than any other Mexican state during 1996–2006 (CONAPESCA 2006). The main fishery port in Sinaloa is Mazatlán (Fig. 1).

## Materials and Methods

Sinaloa was surveyed in spring and autumn of 1998 and during all seasons of 1999. Data were collected specifically during March 2–8, October 1–7, 1998, and January 10–February 17, March 2–16, June 3–17, and November 11–13, 1999. Seasons were defined as follows: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). Camp locations and general fisheries information were collected exclusively during 1998. Camps that directly targeted elasmobranchs were revisited seasonally during 1999 to sample landings and collect biological data. Contemporary observations of the Sinaloa artisanal elasmobranch fishery were made during 2005–2009 from opportunistic field surveys, with all size frequency data collected during 2007–2008.

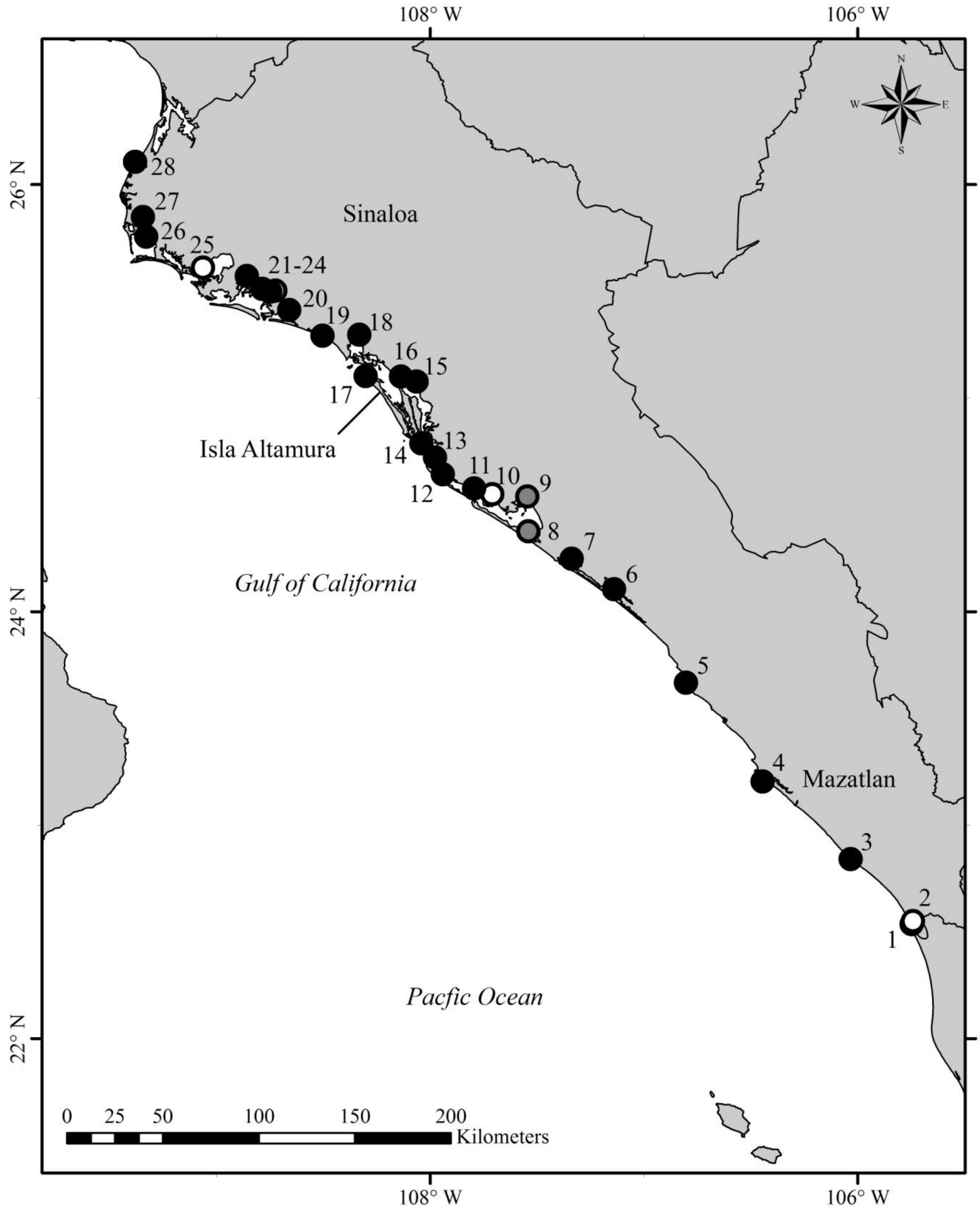

**Figure 1.** Locations of artisanal fishing sites (*n* = 28) documented in Sinaloa during 1998–1999. Designations are as follows: black dots = elasmobranchs targeted, white dots = elasmobranchs not targeted, gray dots = fishery targets unknown.

Locations of fishing sites were determined from maps, local knowledge of fishing activity, and exploration. Once located, the exact position of each site was determined with a handheld Global Positioning System (GPS) unit. At each site, artisanal fishing vessels ("pangas"), typically 5.5–7.6 m long, open–hulled fiberglass boats with outboard motors of 55–115 hp, were sampled and fishermen were interviewed to determine fishery targets, elasmobranch species composition, fishing locations, and gear types. All references to mesh size of gillnets indicate stretched mesh size (the distance between knots when the mesh is pulled taut). Type of fishing site (A = little to no infrastructure, remote sites with no electricity or running water and small shelters located along the beach; B = moderate infrastructure, sites associated with small towns with limited electricity and/or running water and occasionally permanent dwellings; C = significant infrastructure, sites associated with cities with consistent electricity and running water and permanent dwellings), permanence (1 = permanent, 2 = seasonal), period of activity, and number of active pangas were recorded for each site.

Elasmobranch landings were identified to lowest possible taxonomic level, enumerated, sexed, and measured whenever possible. Gymnurid (i.e., *Gymnura crebripunctata*, *G. marmorata*) and narcinid (i.e., *Narcine entemedor*, *N. vermiculatus*, *Diplobatis ommata*, and a possible undescribed species in this region) rays were grouped into species complexes (i.e., *Gymnura* spp., Narcinidae) because of taxonomic confusion within these genera during the time of surveys. Taxonomic uncertainty involving eastern Pacific gymnurids has since been resolved (Smith *et al.* 2009b). Standard measurements (e.g., stretched total length, disc width) were consistently recorded on linear axes to the nearest 1.0 cm for sampled sharks and rays.

Elasmobranch landings were summed by season and by year to determine species composition. Only landings from vessels targeting elasmobranchs were sampled. Catch per unit effort (CPUE), defined as number of individuals/vessel/trip, was calculated for each season.

All measured specimens were utilized to determine size composition and sex ratio of landings. For all species with $\geq$ 50 measured individuals, potential differences in the size composition of landed females and males were examined using parametric and non–parametric approaches, as appropriate. Raw size data were first evaluated for normality and equality of variances using Shapiro–Wilk and two–tailed variance ratio *(F)* tests, respectively (Zar 1999). When data were determined to be normally distributed and of equal variance, two–tailed *t*–tests were applied to test the hypothesis that mean sizes of females and males did not significantly differ ($\alpha = 0.05$) among landings. Size data that did not meet the assumptions of normality or homoscedasticity were transformed (log, square root) in an attempt to correct for deviations from these assumptions and re–examined with Shapiro Wilk and two–tailed *F*–tests. If transformations were unsuccessful, size data were evaluated using two–tailed non–parametric Mann–Whitney *U* tests (Zar 1999). Additionally, the assumption of equal sex ratios (1:1) within the landings was tested using chi–square analysis with Yates correction for continuity (Zar 1999).

Reproductive status was assessed opportunistically and specimens were assigned to one of the following categories: neonate, juvenile, adult, or gravid. Males with fully calcified claspers that could be easily rotated, coiled epididymides, and differentiated testes were considered mature (Pratt 1979, Ebert 2005). Female maturity was determined by macroscopic inspection of the ovaries and uteri (Martin & Cailliet 1988, Ebert 2005). Mature females had oviducal glands that were well–differentiated from the uteri, and vitellogenic follicles >1.0 cm diameter and/or egg capsules in utero. Neonates of placentally viviparous species could be identified based on the presence of an umbilical scar. A qualitative comparison of observed size to known size at birth was used to distinguish neonates of oviparous or aplacentally viviparous species. Any female containing an embryo or fertilized ova was considered gravid.

Sample size–sufficiency of temporal catch composition estimates was investigated using cumulative taxon curves (Gotelli & Colwell 2001). To determine if landings from a sufficient number of vessels had been sampled to adequately describe catch composition for a time period, the mean cumulative number of elasmobranch taxa present in each vessel was plotted against the randomly pooled number of vessels (Ferry & Cailliet 1996). Catch composition of 5000 randomly selected vessels was resampled using Matlab (ver. 2007b, The MathWorks, Inc., Natick, MA) to calculate a mean and standard deviation estimate for each sample. Using 5000 iterations insured that estimates were precise and increased consistently with increasing sample size. Linear regression of the raw data generated for the last four vessel samples was used to determine if the curve reached an asymptote, signifying an adequate number of samples (Bizzarro *et al.* 2007, 2009a). In a slight modification of this technique, the slope of the regression line (*b*) was used to evaluate samples size sufficiency instead of the *P*–value of the regression. This modified technique was used because the *P*–value associated with *b* is influenced by the precision of curve estimates and the number of iterations (i.e., amount of input data), and may indicate a significant increasing trend even at slopes close to zero. Since $b = 1.00$ signifies perfect agreement and $b = 0.00$ signifies no agreement (Zar 1999), sufficient sample size was achieved at $b < 0.05$.

If a sufficient number of samples was

collected, temporal comparisons of bottom–set longline composition were conducted using randomization tests (Manly 2007). The presence of singletons (vessel landings comprised of only one individual) precluded the use of Morisita's original index (Morisita 1959). Horn's index was therefore applied to proportional species–specific (including species complexes) data to determine similarity of landings among vessels, as recommended by Krebs (1999), The mean similarity value observed between temporal groupings ($SIM_{obs}$) was determined from similarity values calculated for all possible pair–wise comparisons. A null distribution was then created using catch composition of 1000 vessels bootstrapped from each group to equalize sample size. Resulting pooled data were then resampled back to original sample sizes and similarity values were generated from all possible pair–wise comparisons of catch composition between resampled groups. This process was repeated 1000 times to generate a null distribution of expected mean similarity values ($SIM_{exp}$). $SIM_{obs}$ was compared to null distribution values to determine if catch composition differed significantly.

## Results

*Camp characteristics.* During 53 survey days in 1998 and 1999, 28 artisanal fishing sites, broadly termed "camps," were identified in Sinaloa (Table I, Fig. 1). Directed fisheries for elasmobranchs were documented at 78.6% (*n* = 22) of these locations. Three sites, SIN–02, SIN–10, and SIN–25, were not found to support active fisheries for elasmobranchs and the occurrence of elasmobranch fisheries could not be verified at three additional sites. Most fishing camps were active throughout the year (96.4%; *n* = 27). Fishing camps were typically well–developed, containing either moderate (*n* = 20) or significant (*n* = 5) infrastructure. The number of pangas actively involved in fishing operations at the time of the surveys ranged from 10 at SIN–18 and SIN–19 to approximately 500 operating from SIN–15. Seasonal variability in the number of active pangas was notable at several camps (e.g., SIN–01, SIN–12, SIN–28). The onset of the shrimp fishing season in September dramatically altered fishing operations and shifted effort among locations.

No systematic surveys of artisanal fishing camps have been conducted in Sinaloa since 1998–1999. However, based on reports from other monitoring programs of the Instituto Nacional de Pesca, some fishing camps are still operational, including: Teacapán (SIN–01), Playa Sur (SIN–04), Barras de Piaxtla (SIN–05), Cospita (SIN–06), Altata (SIN–12), and La Reforma (SIN–15). Most were found to have characteristics that were generally similar to those noted during 1998–99.

*Fishery characteristics.* All of the 96 vessels sampled during the winter used bottom set longlines. Fishing depths were infrequently recorded, but were reported to occur as shallow as 5–6 m and at depths of $\geq$ 45 m. Soak times and gear lengths were largely undocumented. Fishermen reported traveling 5–30 km to set gear.

Gear use during the spring fishery consisted primarily of longlines (96.9%) among 64 sampled vessels, with only two boats observed using gillnets. All gear was fished on the bottom, with the exception of one longline set that was fished in the water column. More than one longline or net was typically deployed from each vessel. Fishing depths ranged from 4–90 m. Soak times of longlines were often brief (< 2 hours), but were occasionally fished for $\leq$ 24 hours. Gillnets were most often soaked for 12–24 hours before retrieval. Mesh sizes of gillnets ranged from 7.6–20.3 cm.

Among 23 combined vessels for which gear use was known from summer (*n* = 21) and autumn (*n* = 2), bottom set gillnets were determined to be most widely used in the summer (85.7%) and longlines set in the water column were exclusively sampled during autumn. Bottom set longlines comprised the remaining 14.3% of the gear recorded during the summer. Bottom set gillnets and longlines were typically fished at ~11–30 m. Gillnet soak times varied from 15–24 hours. Mesh sizes measured 7.6–40.6 cm, with larger mesh sizes (e.g., 21.6 cm, 40.6 cm) most commonly observed.

Seasonal catch composition in Sinaloa was assessed from 3676 total specimens (Table II). Sharks comprised the majority of overall landings (65.0%), with rays contributing 35.0%. Skates and chimaeras were not documented from artisanal landings. The scalloped hammerhead (*Sphyrna lewini*) was the most frequently observed species and was consistently represented in landings during all seasons, comprising 43.1% of the total recorded catch.

The great majority of 1089 specimens recorded from winter landings in Sinaloa were sharks (89.1%) (Table II). Included among these specimens was the only observed pelagic thresher shark, *Alopias pelagicus*. Elasmobranch landings were dominated by two species, *S. lewini* (54.4%) and the Pacific sharpnose shark, *Rhizoprionodon longurio* (27.4%), which accounted for more than 81% of the season's total catch. The smooth hammerhead, *Sphyrna zygaena*, represented an additional 6.4% of winter landings. Catches of rays were primarily composed of diamond stingrays, *Dasyatis dipterura* (8.2%), and speckled guitarfish, *Rhinobatos glaucostigma* (1.8%). A sufficient number of vessels was sampled during winter 1999 to adequately characterize species composition of landings ($r^2$ = 0.720; *b* = 0.013).

**Table I.** Descriptive information for all artisanal fishing camps documented in Sinaloa (SIN) during 1998-1999. Type = A (little to no infrastructure), B (moderate infrastructure), and C (significant infrastructure); Perm. (Permanence) = 1 (permanent) and 2 (seasonal); Active = period of fishing activity; #Pangas = number or range of operational artisanal fishing vessels at the time of survey(s); Elasmo. (elasmobranchs targeted) = Yes (elasmobranchs were targeted during the year) and No (there was no directed fishery for elasmobranchs). Zero values listed for #Pangas indicate that the camp was temporarily inactive (because of weather, holidays, etc.) or seasonally abandoned at the time of survey. In all instances, U = unknown.

| Camp Code | Camp Name | Latitude | Longitude | Type | Perm. | Active | #Pangas | Elasmo. |
|---|---|---|---|---|---|---|---|---|
| SIN-01 | Teacapan | 22.536 | -105.747 | C | 1 | Year-Round | 42-80 | Yes |
| SIN-02 | La Brecha | 22.551 | -105.741 | B | 1 | Year-Round | 27 | No |
| SIN-03 | Majahual | 22.841 | -106.033 | B | 1 | Year-Round | 22 | Yes |
| SIN-04 | Playa Sur | 23.204 | -106.444 | C | 1 | Year-Round | 29 | Yes |
| SIN-05 | Barras de Piaxtla | 23.667 | -106.804 | B | 1 | Year-Round | 18-49 | Yes |
| SIN-06 | Cospita | 24.104 | -107.140 | B | 1 | Year-Round | 22-35 | Yes |
| SIN-07 | El Conchal | 24.247 | -107.338 | B | 1 | Year-Round | 14 | Yes |
| SIN-08 | Las Arenitas | 24.376 | -107.541 | B | 1 | Year-Round | U | U |
| SIN-09 | Las Puentes | 24.539 | -107.546 | B | 1 | Year-Round | 50 | U |
| SIN-10 | El Castillo | 24.550 | -107.710 | B | 1 | Year-Round | U | No |
| SIN-11 | Las Aguamitas | 24.577 | -107.795 | B | 1 | Year-Round | 50 | Yes |
| SIN-12 | Altata | 24.643 | -107.941 | C | 1 | Year-Round | 90-200 | Yes |
| SIN-13 | Dautillos | 24.721 | -107.978 | B | 1 | Year-Round | 250 | Yes |
| SIN-14 | Yameto | 24.788 | -108.042 | A | 1 | Year-Round | U | Yes |
| SIN-15 | La Reforma | 25.077 | -108.064 | C | 1 | Year-Round | 500 | Yes |
| SIN-16 | Costa Azul | 25.101 | -108.137 | B | 1 | Year-Round | 50 | Yes |
| SIN-17 | La Riscion - Isla de Altamura | 25.103 | -108.302 | A | 2 | Dec-Apr | 0-15 | Yes |
| SIN-18 | Playa Colorada | 25.297 | -108.332 | B | 1 | Year-Round | 10 | Yes |
| SIN-19 | Boca del Rio | 25.292 | -108.504 | B | 1 | Year-Round | 10 | Yes |
| SIN-20 | El Tortugo | 25.412 | -108.660 | B | 1 | Year-Round | 30 | Yes |
| SIN-21 | El Coloradito | 25.503 | -108.725 | B | 1 | Year-Round | 20 | U |
| SIN-22 | El Caracol | 25.498 | -108.749 | B | 1 | Year-Round | 50 | Yes |
| SIN-23 | Huitussi | 25.511 | -108.787 | B | 1 | Year-Round | 50 | Yes |
| SIN-24 | Cerro el Cabézon | 25.572 | -108.858 | B | 1 | Year-Round | 50-60 | Yes |
| SIN-25 | Topolobampo | 25.610 | -109.063 | C | 1 | Year-Round | 20 | No |
| SIN-26 | El Colorado | 25.756 | -109.330 | B | 1 | Year-Round | 15 | Yes |
| SIN-27 | Las Grullas Margen Izquierdo | 25.848 | -109.345 | A | 1 | Year-Round | 23-51 | Yes |
| SIN-28 | Las Lajitas | 26.107 | -109.381 | B | 1 | Year-Round | 50-100 | Yes |

Spring landings were dominated by small sharks and to a lesser extent, rays (Table II). The most common species among landings were *S. lewini* (45.4%), *R. glaucostigma* (22.6%), *R. longurio* (16.0%), and *D. dipterura* (10.1%). The only blue shark (*Prionace glauca*) reported from Sinaloa was observed during spring 1999. An insufficient number of vessels was sampled to adequately characterize species composition of landings during spring 1999 when data from all vessels were used ($r^2$ = 0.947 *b* = 0.058). However, when data were limited to vessels using bottom–set longline gear and species (or species–complex) identifications (*n* = 62), estimates were precise ($r^2$ = 0.876; *b* = 0.021).

**Table II.** Seasonal, annual, and total catch composition of shark and ray landings sampled from artisanal vessels targeting elasmobranch in Sinaloa during 1999. *n* = number of individuals, % = percentage of elasmobranch landings

| | | Winter | | Spring | | Summer | | Autumn | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Higher Taxon | Lowest Possible Taxon | n | % | n | % | n | % | n | % | n | % |
| Sharks | *Alopias pelagicus* | 1 | 0.1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.0 |
| | *Carcharhinus altimus* | 1 | 0.1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.0 |
| | *Carcharhinus leucas* | 0 | 0.0 | 0 | 0.0 | 2 | 0.4 | 0 | 0.0 | 2 | 0.1 |
| | *Carcharhinus limbatus* | 4 | 0.4 | 10 | 0.5 | 19 | 4.1 | 0 | 0.0 | 33 | 0.9 |
| | *Carcharhinus obscurus* | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 18.2 | 2 | 0.1 |
| | *Carcharhinus* spp. | 0 | 0.0 | 0 | 0.0 | 2 | 0.4 | 0 | 0.0 | 2 | 0.1 |
| | *Nasolamia velox* | 4 | 0.4 | 4 | 0.2 | 0 | 0.0 | 0 | 0.0 | 8 | 0.2 |
| | *Prionace glauca* | 0 | 0.0 | 1 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.0 |
| | *Rhizoprionodon longurio* | 298 | 27.4 | 338 | 16 | 7 | 1.5 | 1 | 9.1 | 644 | 17.5 |
| | *Sphyrna lewini* | 592 | 54.4 | 959 | 45.4 | 25 | 5.4 | 8 | 72.3 | 1584 | 43.1 |
| | *Sphyrna zygaena* | 70 | 6.4 | 40 | 1.9 | 2 | 0.4 | 0 | 0.0 | 112 | 3.0 |
| | **Subtotal** | **970** | **89.1** | **1352** | **64.0** | **57** | **12.3** | **11** | **100.0** | **2390** | **65.0** |
| Rays | *Aetobatus narinari* | 0 | 0.0 | 0 | 0.0 | 3 | 0.6 | 0 | 0.0 | 3 | 0.1 |
| | *Dasyatis dipterura* | 89 | 8.2 | 214 | 10.1 | 26 | 5.6 | 0 | 0.0 | 329 | 8.9 |
| | *Dasyatis longa* | 4 | 0.4 | 15 | 0.7 | 1 | 0.2 | 0 | 0.0 | 20 | 0.5 |
| | *Dasyatis* spp. | 0 | 0.0 | 8 | 0.4 | 0 | 0.0 | 0 | 0.0 | 8 | 0.2 |
| | *Gymnura* spp. | 3 | 0.3 | 8 | 0.4 | 66 | 14.2 | 0 | 0.0 | 77 | 2.1 |
| | *Mobula munkiana* | 0 | 0.0 | 0 | 0.0 | 5 | 1.1 | 0 | 0.0 | 5 | 0.1 |
| | *Mobula* sp. | 0 | 0.0 | 0 | 0.0 | 1 | 0.2 | 0 | 0.0 | 1 | 0.0 |
| | *Narcinidae* | 0 | 0.0 | 1 | 0.0 | 19 | 4.1 | 0 | 0.0 | 20 | 0.5 |
| | *Rhinobatos glaucostigma* | 20 | 1.8 | 477 | 22.6 | 54 | 11.6 | 0 | 0.0 | 551 | 15.0 |
| | *Rhinobatos* spp. | 0 | 0.0 | 32 | 1.5 | 0 | 0.0 | 0 | 0.0 | 32 | 0.9 |
| | *Rhinoptera steindachneri* | 3 | 0.3 | 3 | 0.1 | 233 | 50.1 | 0 | 0.0 | 239 | 6.5 |
| | *Zapteryx exasperata* | 0 | 0.0 | 1 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.0 |
| | **Subtotal** | **119** | **10.9** | **759** | **36.0** | **408** | **87.7** | **0** | 0.0 | **1286** | **35.0** |
| | **Total** | **1089** | **100.0** | **2111** | **100.0** | **465** | **100.0** | **11** | **100.0** | **3676** | **100.0** |

Summer landings were dominated by rays (87.7%) (Table II). Six ray species and three taxa were recorded. The most frequently occurring species were the golden cownose ray, *Rhinoptera steindachneri* (50.1%) and *R. glaucostigma* (11.6%). Butterfly rays, *Gymnura* spp., accounted for 14.2% of all recorded elasmobranchs during the summer. The pygmy devil ray (*Mobula munkiana*) and spotted eagle ray (*Aetobatus narinari*) were observed exclusively during this season. *Sphyrna lewini* was the only shark species to comprise > 5.0% of summer landings (5.4%). The only bull sharks ($n$ = 2), *Carcharhinus leucas*, documented from Sinaloa surveys were reported from summer landings. Too few vessels were sampled for precise estimates of species composition ($r^2 = 0.994$; $b = 0.097$).

Autumn catch composition was described from only 11 specimens landed by two vessels (Table II). Most of these individuals were *S. lewini* (72.7%). No rays were reported during this sampling period.

Variability was evident in vessel–specific catch composition within, but not between temporal sampling periods. Vessel–specific composition of demersal gillnet landings during winter did not differ significantly from that during spring ($SIM_{obs} = 0.393$, $SIM_{exp} = 0.415$; $P = 0.25$). During both seasons, landings were composed primarily of sharks, especially *S. lewini* and to a lesser extent, *R. longurio*. Although ray landings (e.g., *R. glaucostigma*, *D. dipterura*) comprised a substantially greater proportion of vessel–specific landings during spring, most landings were contributed by relatively few vessels. Considerable intraseasonal variability in catch composition was evident during winter ($SIM_{winter} = 0.503 \pm 0.429$) and spring ($SIM_{spring} = 0.358 \pm 0.463$).

Overall CPUE in Sinaloa was greatest during spring (32.0) and at a minimum (5.5) in autumn (Table III). CPUE estimates for sharks were greater than those of rays during all seasons except summer. CPUE exceeded 1.0 for only two species in the winter, *S. lewini* (mean ± SE; 6.1 ± 1.0) and *R. longurio* (3.1 ± 0.5). The greatest catch rates observed in the spring fishery were associated with *S. lewini* (14.5 ± 2.6). This rate represents the greatest species–specific seasonal CPUE among Sinaloa landings. Catch per unit effort values exceeding 1.0 were obtained for three additional species during spring: *R. glaucostigma* (7.2 ± 4.1), *R. longurio* (5.1 ± 1.4), and *D. dipterura* (3.2 ± 1.0). Three taxa, *R. steindachneri*, *Gymnura* spp., and *R. glaucostigma* largely accounted for the elevated CPUE of rays in the summer. Among these, the catch rate was greatest for *R. steindachneri* (11.1 ± 3.5). CPUE exceeded 1.0 for only one shark species, *R. longurio* (1.2 ± 0.7), during summer months. No rays were observed among the landings of two vessels sampled during autumn. CPUE for *S. lewini* (4.0 ± 4.0) was the greatest observed for a species in this season.

Artisanal fishing effort was often opportunistic and directed toward multiple species. Groupers and sea basses (Serranidae), as well as snappers (Lutjanidae), were frequently taken in combination with elasmobranchs in Sinaloan longline fisheries. Croakers (Sciaenidae) and catfishes (Ariidae) were often captured in association with sharks and rays in the bottom set gillnet fishery. Invertebrates landed incidentally by pangas targeting elasmobranchs included shrimps (Penaeidae) and lobsters (Palinuridae).

Contemporary fishery characteristics and those documented during 1998–1999 were generally similar. The scalloped hammerhead, *S. lewini*, remains a commonly landed species from Teacapan to Cospita (SIN–01 to SIN–06), especially during the pupping season (August–November). As a result, small, early life stages are almost exclusively targeted. *R. longurio* is also still commonly landed in Sinaloa, especially during seasonal migrations (winter–spring). Contemporary landings of this species are composed of a mixture of juveniles and adults, including pregnant females. Rays, especially *D. dipterura*, the longtail singray, *D. longa*, *R. glaucostigma*, and *R. steindachneri*, still constitute a considerable proportion of artisanal elasmobranch landings, especially in northern camps. Large sharks such as the shortfin mako shark, *Isurus oxyrinchus*, thresher sharks, *Alopias* spp., and carcharhinids are harvested by industrial longliners and gillnetters that operate in offshore waters. Catch of these species is rare in the contemporary artisanal fishery.

*Biological characteristics.* Species–specific size and sex composition were available for a subset of the total elasmobranchs recorded in the Sinaloa artisanal fishery (Table IV). Specimens were occasionally dressed prior to offload and overall sampling time was limited to minimize interference with general fishing operations. Size composition of landings varied greatly by species, but small size classes of large sharks and a wide size range of coastal sharks and rays were primarily observed.

**Table III.** Seasonal catch per unit effort (CPUE = #individuals/vessel/trip) and standard error (SE) of shark, skate, and ray landings sampled in Sinaloa during 1999. Sample size (number of vessels examined) is indicated for each season in parentheses. 0.0 = Values < 0.05.

| Higher Taxon | Lowest Possible Taxon | Winter (n = 97) | | Spring (n = 66) | | Summer (n = 21) | | Autumn (n = 2) | |
|---|---|---|---|---|---|---|---|---|---|
| | | CPUE | SE | CPUE | SE | CPUE | SE | CPUE | SE |
| Shark | *Alopias pelagicus* | 0.0 | 0.0 | | | | | | |
| | *Carcharhinus altimus* | 0.0 | 0.0 | | | | | | |
| | *Carcharhinus leucas* | | | | | 0.1 | 0.1 | | |
| | *Carcharhinus limbatus* | 0.0 | 0.0 | 0.2 | 0.1 | 0.9 | 0.7 | | |
| | *Carcharhinus obscurus* | | | | | | | 1.0 | 1.0 |
| | *Carcharhinus* spp. | | | | | 0.1 | 0.1 | | |
| | *Nasolamia velox* | 0.0 | 0.0 | 0.1 | 0.0 | | | | |
| | *Prionace glauca* | | | 0.0 | 0.0 | | | | |
| | *Rhizoprionodon longurio* | 3.1 | 0.5 | 5.1 | 1.4 | 0.3 | 0.2 | 0.5 | 0.5 |
| | *Sphyrna lewini* | 6.1 | 1.0 | 14.5 | 2.6 | 1.2 | 0.7 | 4.0 | 4.0 |
| | *Sphyrna zygaena* | 0.7 | 0.1 | 0.6 | 0.3 | 0.1 | 0.1 | | |
| | **Subtotal** | **10.0** | **1.1** | **20.5** | **3.5** | **2.7** | **1.3** | **5.5** | **2.5** |
| Ray | *Aetobatus narinari* | | | | | 0.1 | 0.1 | | |
| | *Dasyatis dipterura* | 0.9 | 0.5 | 3.2 | 1.0 | 1.2 | 0.5 | | |
| | *Dasyatis longa* | 0.0 | 0.0 | 0.2 | 0.1 | 0.1 | 0.1 | | |
| | *Dasyatis* spp. | | | 0.1 | 0.1 | | | | |
| | *Gymnura* spp. | 0.0 | 0.0 | 0.1 | 0.1 | 3.1 | 1.5 | | |
| | *Mobula munkiana* | | | | | 0.2 | 0.2 | | |
| | *Mobula* sp. | | | | | 0.1 | 0.1 | | |
| | Narcinidae | | | 0.0 | 0.0 | 0.9 | 0.5 | | |
| | *Rhinobatos glaucostigma* | 0.2 | 0.1 | 7.2 | 4.1 | 2.6 | 1.7 | | |
| | Rhinobatos spp. | | | 0.5 | 0.5 | | | | |
| | *Rhinoptera steindachneri* | 0.0 | 0.0 | 0.0 | 0.0 | 11.1 | 3.5 | | |
| | *Zapteryx exasperata* | | | 0.0 | 0.0 | | | | |
| | **Subtotal** | **1.2** | **0.6** | **11.5** | **6.3** | **19.4** | **4.4** | **0.0** | **0.0** |

More female ($n = 324$) than male ($n = 266$) *R. longurio* were examined from 1999 fishery landings, indicating a significant difference from an expected sex ratio of 1:1 ($\chi^2_{0.05,1} = 5.507$, $P = 0.021$). The observed size composition was bimodal, with peaks occurring from 65.0–74.9 cm and 85.0–99.9 cm stretched total length, STL (Fig. 2a). The smallest and largest specimens measured 30 cm and 125 cm STL, respectively (Table IV). Average female size was (mean ± SD) 91.6 ± 17.2 cm STL. Mean male length was slightly smaller (89.4 ± 14.5 cm STL). Observed differences in STL were determined to differ significantly between sexes ($U = 47{,}452.50$, $P = 0.034$).

The majority of *R. longurio* specimens inspected during winter (70.0%, $n = 180$) and approximately half of those inspected during spring (48.7%, $n = 57$) were juveniles. Gravid *R. longurio* were encountered during winter (10.5%, $n = 27$) and early spring (16.2%, $n = 19$). The remaining observed specimens were non–gravid adults (winter = 19.5%, $n = 50$; spring = 35.0%, $n = 41$).

Size composition and sex ratio of 2007–2008 *R. longurio* landings differed considerably from those of 1999. Significantly more male ($n = 298$) than female ($n = 231$) specimens were observed during 2007–2008 ($\chi^2_{0.05,1} = 4.005$, $P = 0.045$). Size composition of landings was bimodal, with a primary peak occurring from 60.0–74.9 cm STL and a secondary peak from 80.0–104.9 cm STL. Females (80.4 ± 13.7 cm STL) were significantly larger than males (75.9 ± 11.8; $U =$

41,833.50, *P* < 0.001) (Fig. 2b). When compared with 1999 landings, overall size composition of 2007–2008 landings was significantly smaller (*U* = 80,322.00, *P* < 0.001).

**Table IV.** Size composition (minimum, maximum, and mean size) of elasmobranchs sampled from artisanal fishery landings in Sinaloa during 1998-1999. Only specimens identified to species are included. DW = disc width; PCL = precaudal length; STL= stretched total length, TL = total length.

| Group | Species | Sex | n | Measurement | Min (cm) | Max (cm) | Mean (cm) | ±1 SD |
|---|---|---|---|---|---|---|---|---|
| Shark | *Carcharhinus altimus* | F | 1 | STL | 119 | 119 | | |
| | *Carcharhinus leucas* | F | 1 | STL | 123 | 123 | | |
| | | M | 1 | STL | 182 | 182 | | |
| | *Carcharhinus limbatus* | F | 12 | STL | 67 | 146 | 90.2 | 29.2 |
| | | M | 23 | STL | 57 | 233 | 114.1 | 66.0 |
| | *Carcharhinus obscurus* | M | 2 | STL | 248 | 268 | 258.0 | 14.1 |
| | *Mustelus henlei* | M | 3 | STL | 57 | 67 | 62.7 | 5.1 |
| | *Nasolamia velox* | F | 6 | STL | 97 | 100 | 99.2 | 1.3 |
| | | M | 2 | STL | 93 | 94 | 93.3 | 0.4 |
| | *Prionace glauca* | F | 1 | PCL | 69 | 69 | | |
| | *Rhizoprionodon longurio* | F | 324 | STL | 30 | 125 | 91.6 | 17.2 |
| | | M | 266 | STL | 32 | 124 | 89.4 | 14.5 |
| | *Sphyrna lewini* | F | 832 | STL | 35 | 245 | 85.9 | 12.0 |
| | | M | 683 | STL | 36 | 242 | 86.8 | 12.9 |
| | *Sphyrna zygaena* | F | 46 | STL | 86 | 143 | 115.7 | 12.3 |
| | | M | 39 | STL | 100 | 155 | 114.3 | 13.6 |
| | *Squatina californica* | F | 1 | STL | 77 | 77 | | |
| | | M | 5 | STL | 70 | 79 | 75.4 | 3.5 |
| Batoid | *Aetobatus narinari* | M | 1 | DW | 80 | 80 | | |
| | *Dasyatis dipterura* | F | 97 | DW | 34 | 76 | 54.5 | 9.1 |
| | | M | 81 | DW | 37 | 63 | 48.0 | 4.6 |
| | *Dasyatis longa* | F | 13 | DW | 39 | 124 | 61.5 | 22.1 |
| | | M | 3 | DW | 49 | 81 | 60.1 | 17.7 |
| | *Mobula munkiana* | F | 12 | DW | 66 | 89 | 75.2 | 7.3 |
| | | M | 3 | DW | 107 | 108 | 107.7 | 0.6 |
| | *Rhinobatos glaucostigma* | F | 418 | TL | 47 | 89 | 72.2 | 7.3 |
| | | M | 73 | TL | 48 | 88 | 57.4 | 7.2 |
| | *Rhinoptera steindachneri* | F | 26 | DW | 58 | 85 | 72.3 | 7.6 |
| | | M | 105 | DW | 54 | 89 | 72.1 | 9.7 |
| | *Zapteryx exasperata* | F | 1 | TL | 59 | 59 | | |

The great majority of *S. lewini* examined from fishery landings in 1999 measured < 100 cm STL, and only four specimens > 200 cm STL were documented among 1515 measured specimens (Fig. 3a). Female *S. lewini* comprised the largest and smallest individuals recorded for this species, ranging from 35–245 cm STL (Table IV). Females and males averaged 85.9 ± 12.0 cm STL and 86.8 ± 12.9 cm STL, respectively. Size of landed females was significantly smaller than that of males (*U* = 257,789.00, *P* = 0.002). The observed proportion of females and males differed significantly from a 1:1 ratio ($\chi^2_{0.05,1}$= 14.458, *P* < 0.001), with females much more commonly observed.

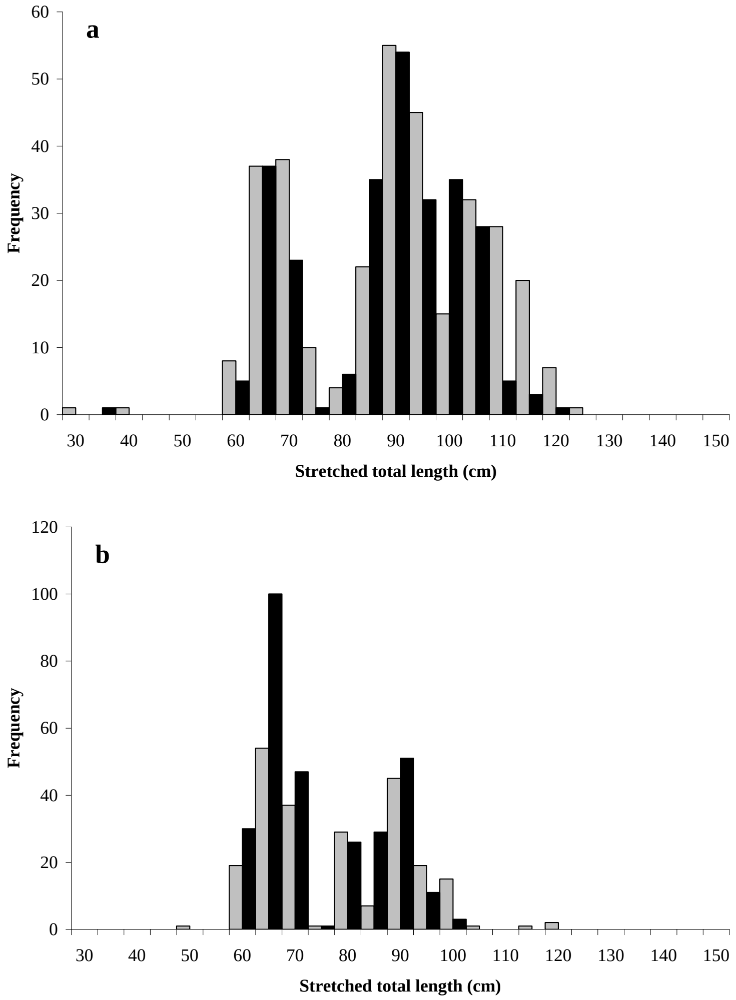

**Figure 2.** Size compositions of (**a**) female (*n* = 324) and male (*n* = 266) Pacific sharpnose sharks, *Rhizoprionodon longurio*, sampled from artisanal fishery landings in Sinaloa during 1999 and (**b**) female (*n* = 231) and male (*n* = 298) *R. longurio* sampled during 2007–2008. Females are depicted in gray, males in black. Minimum and maximum values along the x–axis generally reflect size at birth and maximum reported size for each species.

The great majority of inspected *S. lewini* individuals were juveniles. During autumn (*n* = 8) and winter (*n* = 571) no other life stages were documented among landings. During March, the inspected catch consisted almost exclusively of juveniles (99.3%, *n* = 303), with one neonate and one gravid individual observed. By contrast, among a limited number of individuals inspected during June, most were neonates (70.6%, *n* = 12). In addition, two juveniles, two adults, and one gravid individual were sampled during this time period.

Contemporary *S. lewini* landings were skewed towards small size ranges, with no specimens > 96.5 cm STL observed (Fig. 3b). No mature specimens were documented and neonates comprised 14.7% of the catch (*n* = 59). Size composition of females (65.9 ± 10.6 cm STL) and males (65.1 ± 11.3 cm STL) did not differ significantly (*t* = 0.727, *P* = 0.468). In addition, *S. lewini* individuals landed during 2007–2008 were significantly smaller than those landed during 1999 (*U* = 39,892.00, *P* < 0.001). The ratio of females (*n* = 190) to males (*n* = 211) sampled during 2007–2008 did not differ significantly ($\chi^2_{0.05,1} = 0.450$, *P* = 0.500).

Female and male *S. zygaena* landed during 1999 ranged from 86–155 cm STL (Table IV). The majority of the 85 specimens sampled, however, measured 100–120 cm STL (Fig. 3c). No significant difference was found between mean sizes of females and males (*t* = 0.484, *P* = 0.630). The proportion of females and males within landings also did not deviate significantly from a 1:1 ratio ($\chi^2_{0.05,1}$= 0.424, *P* = 0.522). All inspected specimens were juveniles (n = 75).

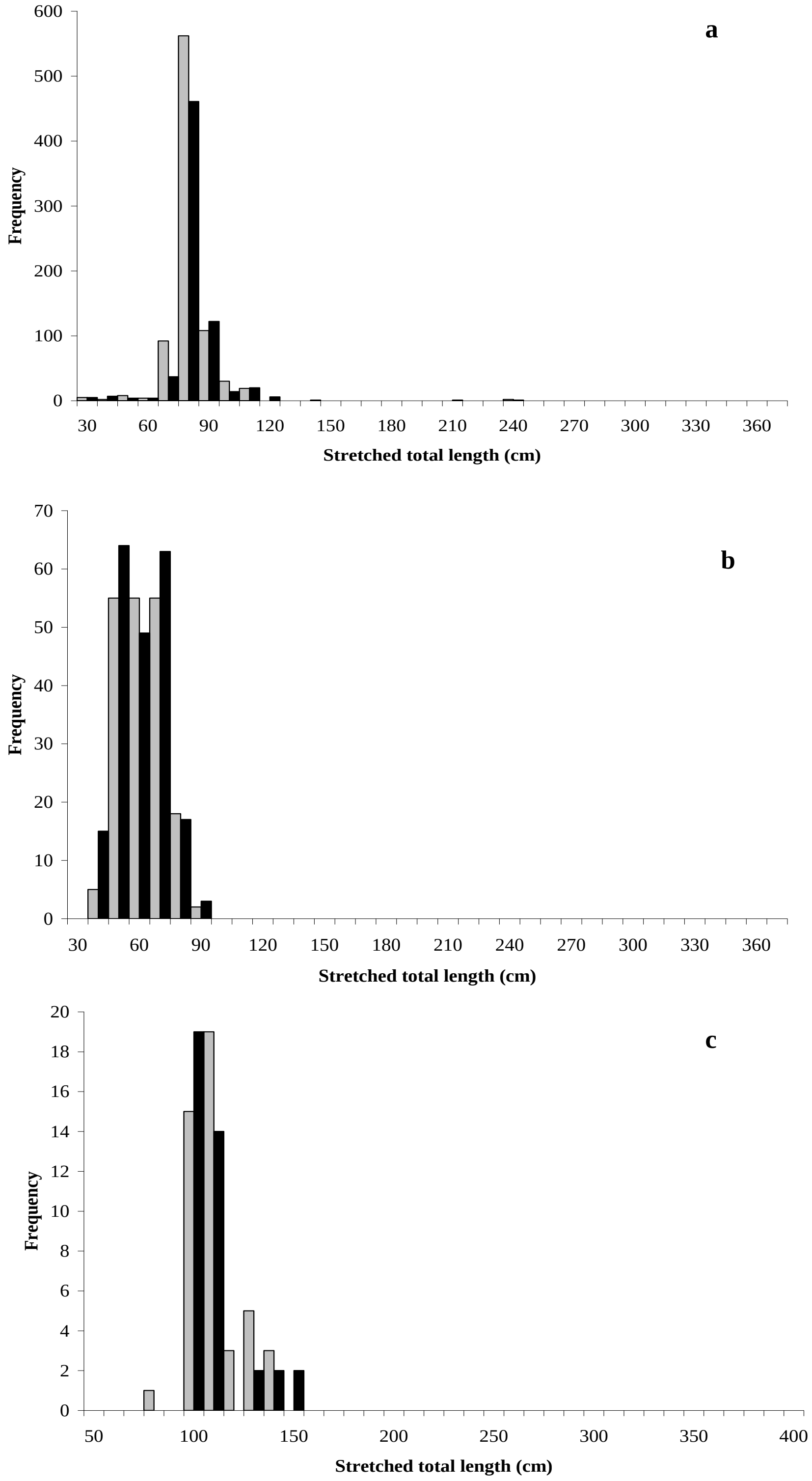

**Figure 3.** Size compositions of (**a**) female (*n* = 832) and male (*n* = 683) scalloped hammerheads, *Sphyrna lewini*, sampled from artisanal fishery landings in Sinaloa during 1999, (**b**) female (*n* = 190) and male (*n* = 211) *S. lewini* sampled during 2007–2008, and (**c**) female (*n* = 46) and male (*n* =39) smooth hammerheads, *S. zygaena*, sampled during 1999. Females are depicted in gray, males in black. Minimum and maximum values along the x–axis generally reflect size at birth and maximum reported size for each species.

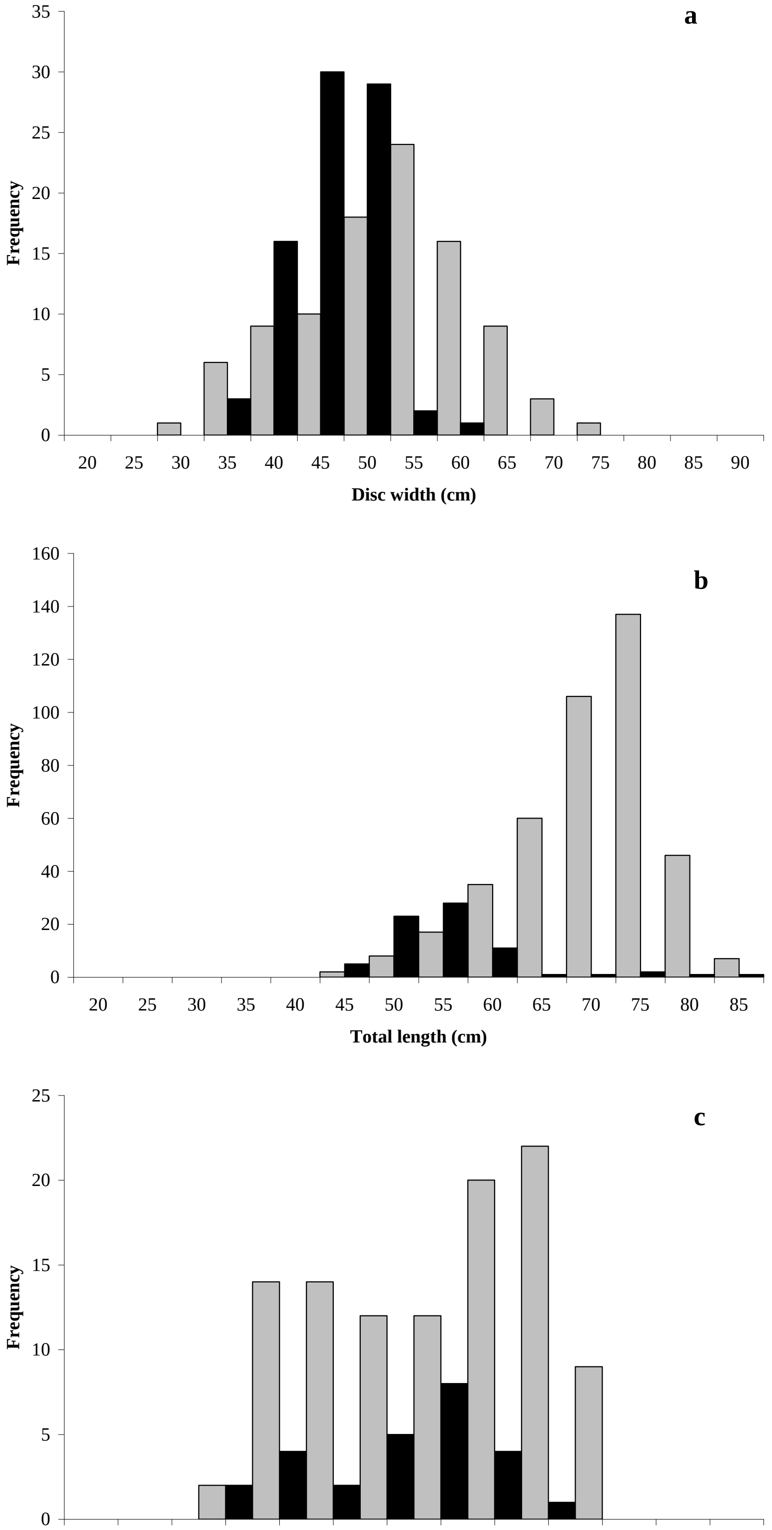

**Figure 4.** Size compositions of rays sampled from artisanal fishery landings in Sinaloa during 1998–1999. Only species with ≥ 50 specimens measured were included: (**a**) female (*n* = 97) and male (*n* = 81) diamond stingrays, *Dasyatis dipterura*, (**b**) female (*n* = 418) and male (*n* = 73) speckled guitarfish, *Rhinobatos glaucostigma*, and (**c**) female (*n* = 26) and male (*n* = 105) male golden cownose rays, *Rhinoptera steindachneri*. Females are depicted in gray, males in black. Minimum and maximum values along the x–axis generally reflect size at birth and maximum reported size for each species.

A total of 178 *D. dipterura* was directly examined from 1999 Sinaloa artisanal fishery landings. These specimens ranged from 34–76 cm DW (Table IV), with individuals > 55 cm DW consisting almost exclusively of females and males dominating smaller size classes (Fig. 4a). Females averaged 54.5 ± 9.1 cm DW, whereas males averaged 48.0 ± 4.6 cm DW. These differences in size were found to be statistically significant ($U = 5909.00$, $P < 0.001$). The number of females ($n = 97$) and males ($n = 81$) did not differ significantly from a predicted sex ratio of 1:1 ($\chi^2_{0.05,1} = 1.264$, $P = 0.267$).

The great majority of *D. dipterura* sampled during the winter were adults (76.7%, $n = 66$), and two gravid specimens were observed (2.3%). The remaining inspected specimens in winter were juveniles ($n = 18$, 20.9%). Insufficient data were available for other seasons to facilitate comparisons.

Female *R. glaucostigma* were considerably larger than males in 1999 artisanal fishery landings (Table IV, Fig. 4b). Mean DW of males was 57.4 ± 7.2 cm, whereas female DW averaged 72.2 ± 7.3 cm. Females were much more prevalent among sampled landings, comprising 418 of the 491 specimens measured. A significant difference was found in mean STL between sexes ($t = 1.965$, $P < 0.001$). The observed (5.7:1.0) and expected (1.0:1.0) ratio of females to males also differed significantly ($\chi^2_{0.05,1} = 241.010$, $P < 0.001$). Most inspected *R. glaucostigma* were juveniles ($n = 17$, 77.3%), but two gravid specimens were observed during June.

More male ($n = 105$) than female ($n = 26$) *R. steindachneri* were reported from fishery landings sampled during 1999, resulting in a sex ratio that differed significantly from 1:1 ($\chi^2_{0.05,1} = 46.443$, $P < 0.001$). However, observed mean sizes were similar between the sexes, with females averaging 72.3 ± 7.6 cm DW and males averaging 72.1 ± 9.7 cm DW ($t = 1.978$, $P = 0.896$) (Fig. 4c). Individuals of combined sexes ranged from 54–89 cm DW (Table IV). All specimens inspected during summer 1999 were adults ($n = 12$).

## Discussion

Most fishing camps in Sinaloa were associated with urban or suburban centers and active throughout the year. Coincidentally, fishing effort was considerable at most sites, especially when compared to camps on the Baja California Peninsula (Smith *et al.* 2009a, Bizzarro *et al.* 2009b). Most fishing sites were concentrated in the northern part of the state, with considerably fewer camps and less effort in southern Sinaloa. Among the primary state–wide fisheries during 1998–1999, an extensive artisanal shrimp fishery was noted during autumn. However, artisanal landings of tunas and sardines were not observed (CONAPESCA 2006).

In addition to being direct artisanal fishery targets in Sinaloa, elasmobranchs are commonly caught incidentally in industrial teleost fisheries and often retained for sale. Large pelagic sharks are typical bycatch of a pure–seine fishery for yellowfin tuna (*Thunnus albacares*) that operates off Sinaloa (Mendizábal & Oriza *et al.* 2000, CONAPESCA 2006). Large coastal and pelagic sharks were also observed as incidental landings of drift gillnet and drift longline fisheries for tunas and billfishes during the course of this study.

Incidental capture in shrimp fisheries represents a considerable source of mortality for coastal elasmobranchs in tropical and subtropical regions (Ruffino & Castello 1993, Stobutzki *et al.* 2002; Zhou & Griffiths 2008), including Sinaloa. The shrimp fishery of Sinaloa, centered in Mazatlan, is most productive in Mexico (CONAPESCA 2006, Meltzer & Chang 2006). Both industrial and artisanal shrimp fisheries are active, with an average yearly production of 37,104 t since 1996 (CONAPESCA 2006). Rays (e.g., *N. vermiculatus*, *Urobatis halleri*, *Urotrygon chilensis*, *Urotrygon nana*) and to a lesser extent, small sharks are captured incidentally in these fisheries (Flores *et al.* 1995, Garcia–Caudillo *et al.* 2000), with mortality levels possibly exceeding those from directed fisheries (Márquez–Farías 2002). Shrimp trawling in Sinaloa often occurs on nursery areas for rays and sharks, and may therefore represent a considerable source of mortality for early life stages. Given its long history and magnitude, mortality due to the Sinaloa shrimp fishery has almost certainly impacted the structure and relative abundance of exploited elasmobranch populations. Detailed catch records of elasmobranchs in Mexican shrimp fisheries are necessary to determine the composition and magnitude of the incidental catch but are currently unavailable. Any effective management plan to sustain or rebuild populations of rays and small sharks in Sinaloa and the broader GOC must mitigate the impact of shrimp trawling on exploited populations, especially on nursery and breeding grounds.

Although catch composition of landings could not be precisely determined for all seasons, sampling was adequate to formulate reliable inferences about the faunal characteristics of Sinaloa during winter and spring. Tropically and subtropically distributed species dominated landings of sharks and rays, with no species of primarily temperate distributions observed (Love *et al.* 2005). Catch composition from this region was comparable to that of Baja California Sur during the same time period (Bizzarro *et al.* 2009b), but differed considerably from that of Baja California (Smith *et al.* 2009a) and Sonora (Bizzarro *et al.* 2009a). Temperature and current patterns are highly variable between the southern and northern Gulf of California (García–Silva & Marinone 1997, Soto–Mardones *et al.* 1999), resulting in a more tropically derived fish fauna in the lower Gulf and a more temperate fauna in the northern Gulf (Thomson *et al.* 2000). Regional patterns in catch composition probably reflect these faunal differences and exemplify the opportunistic nature of the regional artisanal elasmobranch fishery.

Rays were of variable seasonal importance in the Sinaloa artisanal elasmobranch fishery, with their greatest contributions occurring during summer and to a lesser extent, spring. During spring, *R. glaucostigma* was the second most important species in the fishery, whereas landings of the most abundant ray species during the winter (*D. dipterura*) constituted only 8.2% of the catch. During these seasons, ray landings were composed largely of these two species, with little overall diversity evident. As observed in Sonora for *R. productus* (Bizzarro *et al.* 2009a), massive vessel–specific landings of *R. glaucostigma* (≤ 257 individuals/vessel) were documented during spring in association with emigrations of gravid females to nearshore and inshore waters. In contrast to spring and winter fishery characteristics, summer landing of rays far exceeded those of sharks, with *R. steindachneri* comprising more than half of the total catch, and *Gymnura* spp. and *R. glaucostigma* also contributing substantially. During this time, *R. steindachneri* was directly targeted at La Reforma (SIN–15) for use as bait in a portunid crab fishery. Although a summer trend of increased ray landings and catch rates was also documented in Sonora (Bizzarro *et al.* 2009a) and Baja California (Smith *et al.* 2009a), low sample size precludes definitive conclusions from Sinaloa.

Landings from SIN–04 (Playa Sur) comprised the majority of the sampled catch during winter and a substantial portion of the catch during spring. An active winter and spring cazón fishery primarily targeting *S. lewini* and *R. longurio* has been previously documented at Playa Sur (Saucedo–Barrón *et al.* 1982, Rodríguez–García 1986, Castillo–Géniz 1990, Righetty–Rojo & Castro–Morales 1990). The primary targets of this fishery remained consistent, but a greater proportion of *S. lewini* was noted during this study than was generally observed from prior studies. In addition, triakids were absent from observed landings in this study but comprised a minor component of historic landings (Rodriguez–García 1986, Righetty–Rojo & Castro–Morales 1990). The observed species composition of cazón in Sinaloa differed greatly to that of Sonora, where *Mustelus* spp. were the primary targets and *R. longurio* and *S. lewini* contributed a trivial relative proportion of landings. In addition, although catch rates of cazón were the greatest reported for any elasmobranch group, they were considerably less than those reported for cazón in Sonora and Baja California *Mustelus* fisheries (Bizzarro *et al.* 2009a, Smith *et al.* 2009a).

Although species composition of contemporary and historic cazón landings was generally similar, the fishery appears to be landing considerably smaller individuals. Landings of small *S. lewini* and a broad size range of *R. longurio* have been previously documented at Playa Sur (Saucedo–Barrón *et al.* 1982, Rodríguez–García 1986, Castillo–Géniz 1990, Righetty–Rojo & Castro–Morales 1990). The targeted size class of *S. lewini* was substantially smaller during 1999, whereas that of *R. longurio* was comparable (Saucedo–Barrón *et al.* 1982). Contemporary landings of both species reflect a considerable reduction in size composition when compared to those of 1999. Since gear type and sampling location were generally consistent between sampling periods, this trend suggests that the size composition of the local *S. lewini* population may have been truncated. The apparent absence of large *R. longurio* (> 100 cm STL) from recent landings is problematic if reflective of the true population at large and warrants further attention In addition, the current fishery appears to be targeting early life stages on their nursery grounds. In order to sustain or rebuild exploited stocks, *S. lewini* and *R. longurio* populations in the southeastern Gulf of California should be closely monitored and cautiously managed.

Large sharks (tiburón) comprised a very small proportion of overall landings from Sinaloa, with only 12 individuals > 1.5 m documented among 2248 measured sharks. Although large sharks were never a primary component of the artisanal elasmobranch fishery, fishery effort dedicated to tiburón was considerably reduced during summer months of this study when compared to the historic situation. A similar trend has been observed throughout the Gulf of California, where the historic immigration of fishermen from the southern state of Chiapas has been almost entirely curtailed (J.L. Castillo–Géniz & J.F. Márquez–Farías, pers. obs.). Several previously documented shark species (e.g., *C. falciformis*, *G. cuvier*, *I. oxyrinchus*, *S. mokarran*) were not observed among artisanal landings during 1998–1999 and only one individual of *A. pelagicus*, a common commercial species off Mazatlán during 1986–1987 (Mendizábal & Oriza 1995), was reported.

Although it appears likely that populations of some large shark species have declined, results of this study may not be entirely representative of the contribution of large sharks to the artisanal fishery. A lack of temporal replication and the limited number of camps surveyed may have resulted in underestimates of large shark landings and diversity. Even so, the sizeable reported contribution of tiburón to statewide elasmobranch production (> 70%, CONAPESCA 2006), if accurate, is most likely a consequence of the industrialized, offshore fishery and not a sizeable artisanal fishery.

Fisheries for small coastal sharks may be sustainable (Walker 1998), but the targeting of large shark species is not typically advisable (Smith *et al.* 1998). Fisheries for *Rhizoprionodon* spp. have been well documented (e.g., Castillo–Géniz 1990, Castillo–Géniz *et al.* 1998, Henderson *et al.* 2007), and yet all species with sufficient data for assessment are considered to be "widespread and abundant" by the IUCN (IUCN 2009). Accordingly, *R. longurio* is considered among the most resilient of eastern North Pacific sharks to fishing pressure as a result of its high fecundity and relatively early age at maturity (Smith *et al.* 1998). After a long period of heavy exploitation in southern Sinaloa, *R. longurio* still exhibits a size composition that is generally suggestive of a healthy population. However, because contemporary landings indicate a shift towards smaller specimens and a distinct lack of large specimens (> 100 cm STL), targeted populations should be closely monitored for possible changes in population structure. Hammerhead sharks, although fecund, attain large sizes and have relatively late ages at maturity (PSRC 2004). Large species, such as *S. lewini* and *S. zygaena*, may therefore be susceptible to population declines due to overfishing (Smith *et al.* 1998). Such declines have been speculated to occur for *S. lewini* (Klimley *et al.* 2005) and *S. mokarran* (Bizzarro *et al.* 2009a) populations in the Gulf of California, and *Sphyrna lewini* was recently declared globally endangered (Dulvy *et al.* 2008), although supporting data are somewhat lacking. The Sinaloa artisanal fishery targets early life stages of sharks, reducing the productivity, resilience, and sustainability of targeted populations (Kokko *et al.* 2001). Populations of both sphyrnids should therefore be carefully monitored and more rigorously assessed.

Elasmobranch landings from the Sinaloa fishery were composed of medium and large size classes of most cazón and ray species. Size composition of *R. longurio* landings indicated a bimodal distribution consisting primarily of medium and large specimens. In contrast, landings of *S. lewini* and *S. zygaena* were composed of size classes corresponding to early life stages (Compagno *et al.* 1995, Anislado–Tolentino & Robinson–Mendoza 2001). Among rays, *D. dipterura* landings consisted primarily of medium and large specimens. Landings of *R. steindachneri* were similarly distributed, but contained a greater proportion of relatively large individuals. Most *R. glaucostigma* were large females and the previously reported maximum size (85 cm total length; Amezcua–Linares 1996) was exceeded (89 cm TL).

The results of this study have provided the first detailed, quantitative information on the artisanal elasmobranch fisheries of Sinaloa, one of Mexico's most productive states in terms of elasmobranch landings. Landings of small sharks were substantial during the survey years and probably represent a significant source of mortality for exploited populations. Although catch rates of some ray species were elevated during spring and summer (e.g., *R. glaucostigma*, *R. steindachneri*), the local shrimp fishery is probably the main source of mortality for this group and should be considered in any management plan. Large sharks did not contribute substantially to artisanal fishery landings and many species that were once common have likely been overfished. Using the results of this study as a baseline, it is important that additional research is conducted off Sinaloa to determine any changes in catch rates, species composition, and size composition that may have occurred in the artisanal elasmobranch fishery since 1998–1999. The historic information presented in this manuscript should also be useful for comparison with similar studies conducted in other subtropical and tropical regions of the world.

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# Age and growth of the Brazilian sharpnose shark, *Rhizoprionodon lalandii* and Caribbean sharpnose shark, *R. porosus* (Elasmobranchii, Carcharhinidae) on the northern coast of Brazil (Maranhão)

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**Abstract.** Age and growth of *R. lalandii* and *R. porosus* were estimated from vertebrae age bands off northern Brazil. Marginal increment values were estimated in order to identify a tendency toward annual band formation, with this pattern assumed for both species. There was no significant difference in growth between sexes and the estimated parameters were: $L_\infty$ = 78.10 cm; $k$ = 0.301; $t_0$ = -1.463 years for *R. lalandii* and $L_\infty$ = 112.99 cm; $k$ = 0.171; $t_0$ = -1.751 years for *R. porosus*. Age ranged from one to six years for *R. lalandii*, with an age at first maturity ($t_{mat}$) of 2.6 years; the majority of the sample was formed by adult individuals (61.9%). For *R. porosus*, age ranged from less than one year ($0^+$) to five years, with $t_{mat}$ = 3.3 years; the majority of the sample was made up of juveniles (72.4%). Contrary to what was found for *R. lalandii*, the estimated $L_\infty$ for *R. porosus* was much greater than the maximum length in this sample (85.5 cm). This is attributed to the selectivity of the gillnet, which is gear that catches *R. lalandii* individuals in all age classes and *R. porosus* individuals up to five years of age.

**Keywords:** Vertebrae, Age structure, Age at first maturity, Maximum age

**Resumo. Idade e crescimento do tubarão figuinho, *Rhizoprionodon lalandii* e do tubarão rabo seco, *R. porosus* (Elasmobranchii, Carcharhinidae) na costa norte do Brasil (Maranhão).** A idade e o crescimento de *R. lalandii* e *R. porosus* foram estimados à partir da contagem de anéis etários presentes nas vértebras. Valores de incremento marginal estimados mostraram uma tendência de formação anual do anel, para ambas as espécies. Não houve diferença significativa no crescimento entre os sexos, e os parâmetros estimados foram: $L_\infty$ = 78,10 cm; $k$ = 0,301; $t_0$ = -1,463 anos para *R. lalandii* e $L_\infty$ = 112,99 cm; $k$ = 0,171; $t_0$ = -1,751 anos para *R. porosus*. As idades variaram entre 1 e 6 anos para *R. lalandii*, com uma idade de primeira maturação ($t_{mat}$) de 2,6 anos, e a maioria da amostra formada por indivíduos adultos (61,9%). Já para *R. porosus*, foram amostrados indivíduos com menos de um ano ($0^+$) até 5 anos de idade, e $t_{mat}$ = 3,3 anos, e a maior parte da amostra formada por indivíduos jovens (72,4%). O $L_\infty$ estimado para *R. porosus* foi muito superior ao comprimento máximo da espécie na amostra (85,5 cm). Tal fato parece estar vinculado à seletividade da rede de emalhar, onde esta rede captura indivíduos em todas as classes de idade para *R. lalandii* e até os 5 anos de idade para *R. porosus*.

**Palavras-chave:** Vértebra, Estrutura etária, Idade de primeira maturação, Idade máxima

## Introduction

Several elasmobranch populations throughout the world have been depleted due to overexploitation (Baum *et al.* 2003). Despite the low number of fisheries that effectively target sharks and rays, they have been heavily exploited in the world as bycatch (Stride *et al.* 1992, Yokota & Lessa 2006). The high fishing effort exerted over elasmobranch populations, along with their biological and ecological characteristics (high longevity, low fecundity and late age at first maturity), makes them vulnerable to excessive mortality due to fisheries (Holden 1974). For this reason, population assessments on elasmobranches are need for determining both the risks brought about by exploitation and how to circumvent these risks through management measures (Walker 2007). Information on age is the basis for growth rate, mortality and productivity estimates, composing input data for age-based stock assessment methods (Campana 2001), which are especially needed for exploited populations.

Among the seven shark species of the genus *Rhizoprionodon* spread throughout the world, two are recorded for Brazil: The Brazilian sharpnose shark (*R. lalandii*) and the Caribbean sharpnose shark (*R. porosus*). Both species are only found in the western Atlantic from Central America to Uruguay, including the entire Brazilian coast (Compagno 1984). Despite sharing the same habitats, the abundance of each species varies according to region. Along the southeastern and southern coast of Brazil, *R. lalandii* is more abundant than *R. porosus* (Ferreira 1988, Motta *et al.* 2005), whereas the opposite pattern is recorded throughout the northern and northeastern regions (Lessa 1986, Lessa 1988a, Menni & Lessa 1998; Yokota & Lessa 2006).

Along the coast of the state of Maranhão (northeastern Brazil) (1º35'S/46º W to 3º S/42W), these two species are incidentally caught using gillnets that target the Brazilian Spanish mackerel (*Scomberomorus brasiliensis*) and acoupa weakfish (*Cynoscion acoupa*) (Stride *et al.* 1992, Menni & Lessa 1998), operating in coastal waters to depths of 40 m. In landings between 1990 and 2000, *R. porosus* ranked the second most frequent elasmobranch species, making up 20.5% of total catches, whereas *R. lalandii* ranked the fifth, corresponding to 5% of the total number of elasmobranches caught (Lessa 1986, Lessa & Menni 1994).

Studies on *R. lalandii* and *R. porosus* have focused on diet (Silva & Almeida 2001), genetics (Mendonça *et al.* 2009, Pinhal *et al.* 2009), occurrence, length frequency (Motta *et al.* 2005) and reproductive biology (Menni & Lessa 1998, Ferreira 1988, Lessa 1988b, Machado *et al.* 2000, Mattos *et al.* 2001, Motta *et al.* 2007, Andrade *et al.* 2008). Although extensively studied due to the wide range of distribution, age and growth aspects have not yet been investigated for either species.

The Brazilian sharpnose shark is included on the IUCN red list as "data deficient" (Rosa *et al.* 2004), whereas the Caribbean sharpnose shark is listed in the "least concern" category (Lessa *et al.* 2006). In Brazil, neither species has yet been included on the National List of Endangered or Overexploited Species (Brasil 2004). Nonetheless, as subsidizing policies that foster exploitation have brought about an overall decrease in CPUE for sharks in coastal areas of Brazil, age and growth information is required in order to appropriately assess the status of these species using age-based methods. Thus, the specific aims of the present study were to provide growth parameters derived from vertebral analyses for both species, with the aim of contributing toward the management of these species in northern/northeastern Brazil.

## Materials and methods

From 1984 to 1989, specimens of both species were collected on fishing operations targeting the Brazilian Spanish mackerel (*Scomberomorus brasiliensis*) using sailing boats equipped with gillnets measuring up to 900 m in length, 7.5 m in height and mesh size of 8.0 cm mesh size. In 1998, motorized boats used a 1200 m net with similar a mesh size. Fishing operations were carried out in areas with depths ranging from 6 to 40 m on four to seven-day trips along the coast of the state of Maranhão (1º35'S/46º W to 3º S/42' W) between Tubarão and Turiaçú bays (Fig. 1).

The natural total length (TL) and sex were recorded for each individual and a block of approximately 5 vertebrae was removed from the region just below the first dorsal fin. The vertebrae were cleaned of excess conjunctive tissue, fixed in 4% formaldehyde for 24 h and preserved in 70% alcohol. The vertebrae were embedded in polyester resin, labeled and cut with the aid of a low-speed metallographic saw and diamond cutting disk. Two to three longitudinal cuts were performed on each vertebra in order to reach section that passed precisely through the nucleus of the vertebra. Each vertebral body was sectioned on the frontal plane, as suggested by Cailliet *et al.* (1983), at a thickness of approximately 0.3 mm. The growth rings, made up of translucent (narrow) and opaque (wide) bands (Casselman 1983), were observed and measured on each cut using a stereomicroscope at a magnification of 10 x and the aid of a micrometric ocular, which enabled measuring the distances necessary for the estimation of the marginal increment (MI) and back-calculated lengths.

The linear relation between the radius of the hard structure (distance form the nucleus to the edge of the structure) and the length of the individuals from each species were estimated. The difference between sexes was compared using analysis of covariance (ANCOVA). To estimate the accuracy of the ring counts, two readings were performed on different occasions, with no knowledge regarding the length of the individuals. The index of average percentage error (IAPE) was estimated for each age class, following the method described by Campana (2001).

$$IAPE = 100\% \times \frac{1}{R} \times \sum_{i=1}^{R} \frac{\left| X_{ij} - \overline{X_j} \right|}{\overline{X_j}}$$

in which $N$ = number of vertebrae; $R$ = number of readings performed on individual $j$; $X_{ij}$ = age $i$ determined for individual $j$; $X_j$ = mean age calculated for individual $j$.

MI values were calculated for each individual and mean monthly values were estimated using the following formula:

$$MI = \frac{VR - R_n}{R_n - R_{n-1}}$$

in which $VR$ = distance between the nucleus and edge of the hard structure; $R_n$ = distance between the nucleus and last ring; $R_{n-1}$ = distance between the nucleus and penultimate ring.

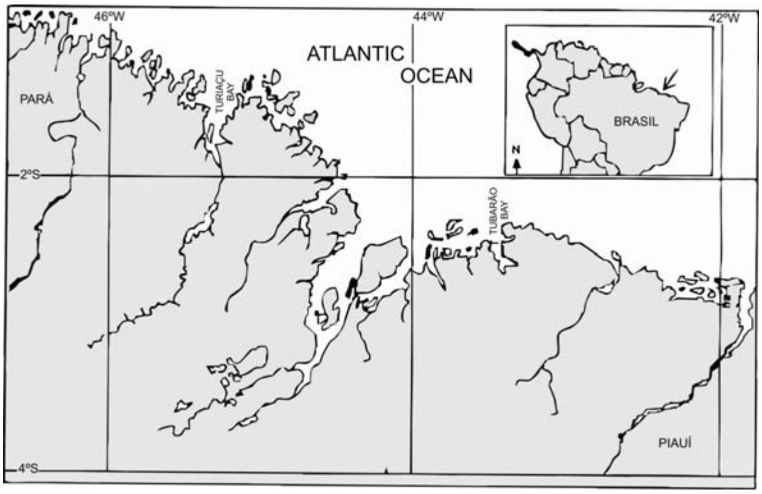

**Figure 1.** Location of the sampling area for the Brazilian sharpnose shark (*Rhizoprionodon lalandii*) and Caribbean sharpnose shark (*R. porosus*) collected off Maranhão state.

The lengths of the individuals at previous ages were back-calculated from measurements between the nucleus and each ring in the structure, following the method described by Fraser-Lee, which assumes a linear relation in the proportionality between the two variables (Francis 1990):

$$L_t = \left( \frac{R_t}{VR} \right) \times \left( L_c - a \right) + a$$

in which $L_t$ = is the back-calculated length corresponding to age $t$; $R_t$ = distance between the nucleus and each ring at age t; $VR$ = radius of the structure; $L_c$ = length at the time of capture; $a$ = interception of the regression between VR and $L_c$.

Five models were adjusted to the age and length data (observed and back-calculated): The von Bertalanffy growth function (VBGF) (von Bertalanffy 1938) (g1); the generalized VBGF (g2) and the logistic model (g3) described by Katsanevakis (2006); and the Gompertz (g4) and Richards (g5) models described by Schnute (1981):

$$\text{g1}: L_t = L_\infty \times \left[ 1 - e^{-k \times (t - t_0)} \right]$$

$$\text{g2}: L_t = L_\infty \times \left[ 1 - e^{-k \times (t - t_0)} \right]^p$$

$$\text{g3}: L_t = L_\infty \times \left[ 1 + e^{-k \times (t - t_0)} \right]^{-1}$$

$$\text{g4}: L_t = L_\infty \times e^{\left[ -a \times e^{(-k \times t)} \right]}$$

$$\text{g5}: L_t = \frac{L_\infty}{\left[ 1 + e^{(-k \times t + b)} \right]^m}$$

in which $L_t$ is predicted length at age t; $L_\infty$ is the mean asymptotic total length; $k$ is the growth coefficient; $t_0$ is the age when length is theoretically zero, and $p$, $a$, $b$ and $m$ are constants of the models.

The parameters of these models were estimated using the Solver function on the Excel program. The likelihood tools and bootstrap iteration functions of the PopTools program (Hood 2006) were used to generate confidence intervals for each parameter based on minimum likelihood. The modified von Bertalanffy model was also used, which allows estimating the size at birth of the species studied ($L_0$) (Semba *et al.* 2009):

$$L_t = L_0 + (L_\infty - L_0) \times \left[ 1 - e^{-k \times t} \right]$$

Model selection was carried out using the

Akaike information criterion (AIC), which reveals a better adjusted curve for the model with the lowest AIC (Katsanevakis, 2006):

$$AIC = -2 \times \log(\ell(\theta / data)) + 2K$$

in which $\log(\ell(\theta / data))$ is the numerical value of the log-likelihood at the minimal point; $\theta$ is the vector of the estimated parameters of the model; and $K$ is the number of estimated parameters. Comparisons of growth curves by sex were based on the likelihood test for the curve with the best AIC (Cerrato, 1990).

## Results

Eighty-four specimens of *R. lalandii* were collected, with lengths ranging from 48 to 76.5 cm and a modal length of 56 cm (Figure 2a). There was no significant difference in length between genders (Kolmogorov-Smirnov two-sample test, P > 0.05) (Figure 2a). The *R. porosus* sample (134 specimens) was composed of 101 males (75.4%), ranging in length from 37.6 to 85.5 cm (mean = 59.2 cm), with a bimodal frequency distribution (modal classes = 50 and 66 m); and 33 females, with lengths ranging from 37.9 to 80.5 cm (mean = 52.5 cm). There was a significant difference in length between sexes (Kolmogorov-Smirnov two-sample test, P < 0.05) (Fig. 2b).

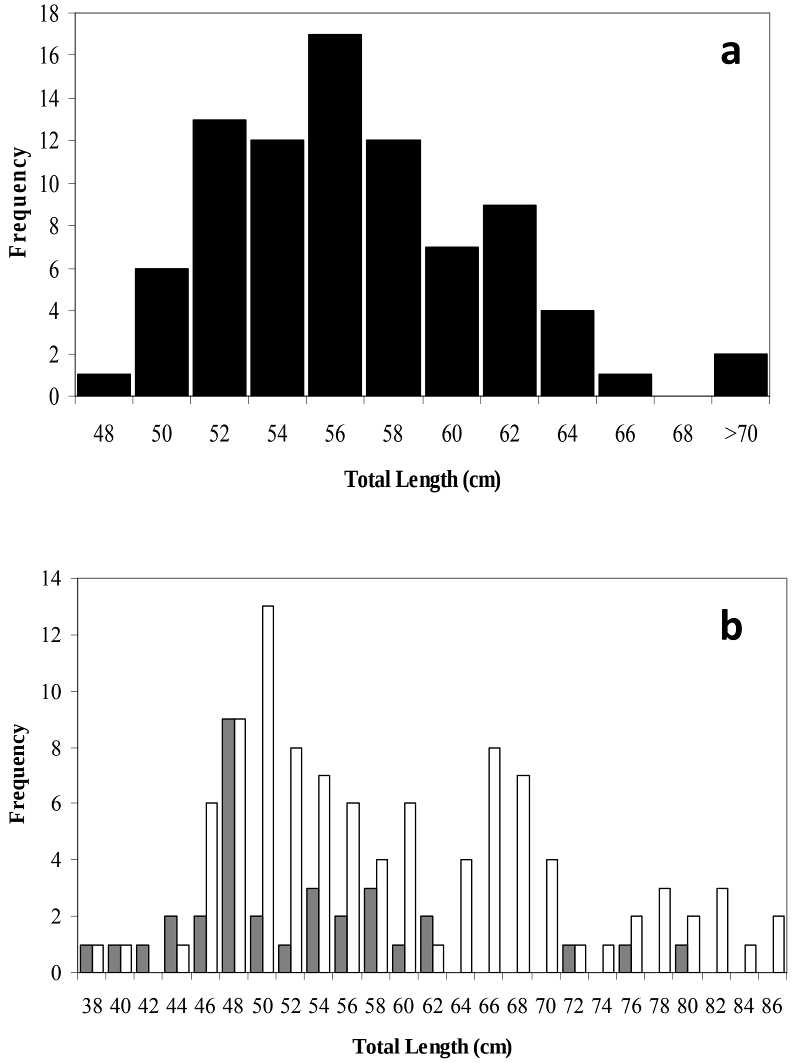

**Figure 2.** Length-frequency distributions for the Brazilian sharpnose shark, *Rhizoprionodon lalandii* (a) and Caribbean sharpnose shark, *R. porosus* (b) caught off Maranhão state (black bars=sex together, white bars = males; grey bars = females).

There were no significant differences between sexes regarding the relation of the vertebral radius and total length (ANCOVA, P > 0.05) for either species. The regression for both sexes combined resulted in the equation $TL = 8.463 \times VR + 25.735$ ($r^2$ = 0.912) for *R. lalandii* and the equation $TL = 10.952 \times VR + 18.670$ ($r^2$ = 0.899) for *R. porosus*. The IAPE value for *R. lalandii* ranged from 4.4% for the four-ring class (n = 18) to 6.3% for the two-ring class (n = 17), with a mean error of 4.6% for the overall sample between the two readings. For *R. porosus*, the two-ring class had the highest IAPE value (7.2%, n = 51) and the six-ring class had the lowest (2.7%, n = 3); the IAPE for the overall sample was 3.4%.

The *R. lalandii* individuals were not caught between March and May, but there was a tendency toward an increase in MI at February and June, with a drop between July and November (Fig. 3a). The *R. porosus* specimens were only caught between April and September, which does not allow accuracy in the determination of an annual growth ring. The lowest monthly MI was estimated in April and the highest in September, which allows reflecting on the hypothesis of the formation of an annual ring in the months prior to and close to April (Fig. 3b). For both species, the data do not allow an accurate identification of the period of new ring formation and it was therefore assumed that each ring is formed annually.

Back-calculated length for the time of birth corresponded to 26.95 cm for *R. lalandii* and 29.02 for *R. porosus*. Both species exhibited a similar pattern of annual growth (observed from the back-calculated lengths) of around 12 cm in the first year and, in the last year, 4.5 cm for *R. lalandii* and 6.6 cm and *R. porosus* (Table I).

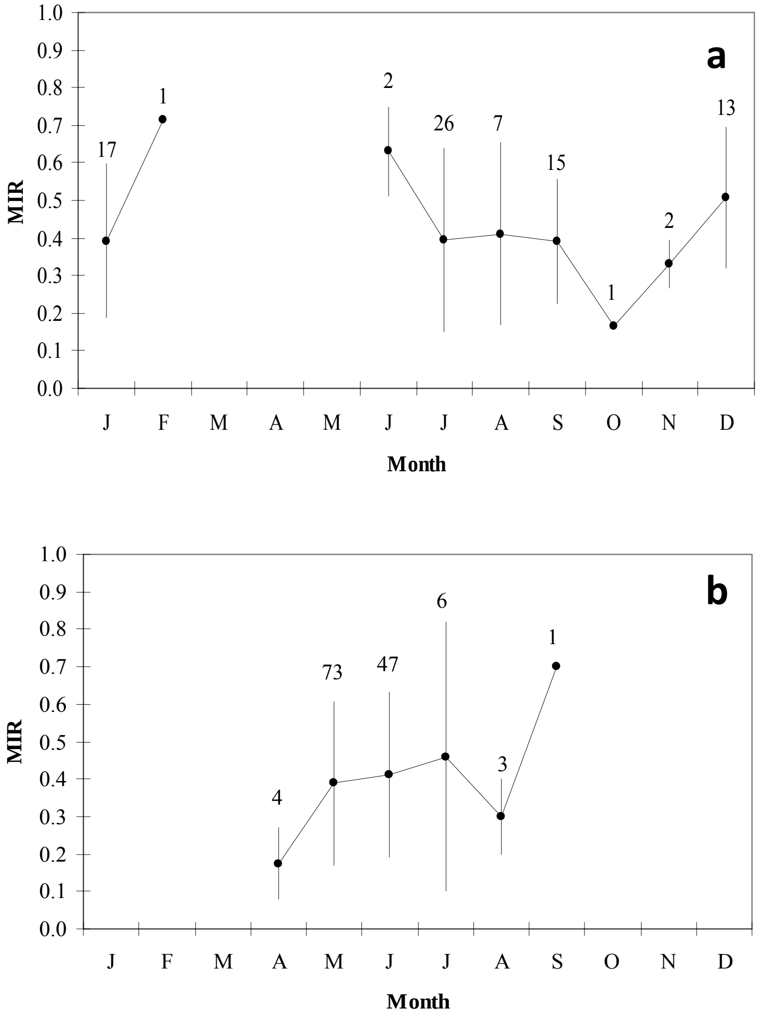

**Figure 3.** Mean vertebral marginal increment (MI) by month for the Brazilian sharpnose shark, *Rhizoprionodon lalandii* (a) and Caribbean sharpnose shark, *R. porosus* (b). Vertical bars are standard deviation of means.

**Table I.** Mean back-calculated (BC) and observed length-at-age (OL) data for Brazilian sharpnose shark (*Rhizoprionodon lalandii*) and Caribbean sharpnose shark (*R. porosus*) collected off Maranhão state (SD=standard deviation).

| Age (yr) | *R. lalandii* | | | | *R. porosus* | | | |
|---|---|---|---|---|---|---|---|---|
| | BC (cm) | SD | OL (cm) | SD | BC (cm) | SD | OL (cm) | SD |
| 0 | 26.95 | 1.49 | - | - | 29.02 | 1.08 | 42.26 | 2.37 |
| 1 | 39.68 | 2.93 | 51.12 | 1.60 | 41.53 | 1.34 | 49.10 | 2.95 |
| 2 | 48.81 | 2.21 | 55.65 | 2.46 | 52.36 | 1.48 | 57.88 | 4.94 |
| 3 | 56.16 | 1.22 | 60.13 | 2.32 | 62.07 | 1.87 | 67.78 | 4.08 |
| 4 | 62.31 | 0.21 | 64.22 | 1.07 | 70.46 | 1.53 | 76.10 | 5.97 |
| 5 | 68.14 | 0.00 | - | - | 77.08 | 0.00 | 79.83 | 4.65 |
| 6 | 72.68 | 0.00 | 76.09 | 0.60 | - | - | - | - |

All back-calculated lengths for each age were used to estimate the growth curves. For *R. lalandii*, the model that best fit the data was the generalized VBGF (g2), but due to the high values of the parameters and their respective confidence intervals, this model was discarded and the VBGF (g1), which had the second best fit, was used (Table II). For *R. porosus*, the model with the best fit was the VBGF (g1) (Table II). $L_0$ values calculated by the modified VBGF for both species (*R. lalandii* – 27.86 cm; *R. porosus* – 29.22 cm) were similar to those described using the mean back-calculated lengths for age 0. The likelihood test revealed no significant difference in growth between sexes for either species, which resulted in growth curves for combined sexes.

*R. lalandii* has very fast growth. The $L_\infty$ value was close to its maximal length ($L_{max}$=76.5 cm) (Table II, Fig. 4) and age ranged from 1 to 6 years (Fig. 5a), with the majority of individuals in the two-year-old class. According to Lessa (1988b), size at first maturity for the species in the state of Maranhão is 49 cm, but other authors report figures ranging from 50 to 66 cm (Ferreira, 1988, Motta *et al.* 2007, Andrade *et al.* 2008). Thus, we assumed a mean size at first maturity of 55 cm, corresponding to an age of 2.6 years. The majority of individuals in the sample (61.9%) were adults.

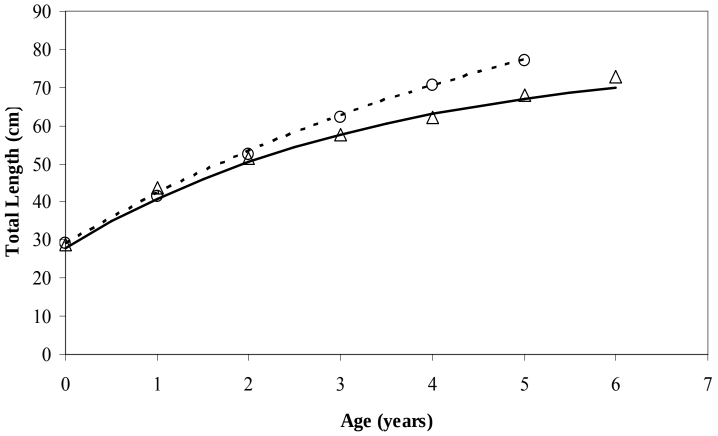

**Figure 4.** von Bertalanffy growth curves generated for Brazilian sharpnose shark, *Rhizoprionodon lalandii* (full line) with the mean back-calculated length-at-age (Δ) and for Caribbean sharpnose shark, *R. porosus* (dotted line) and the mean back-calculated length-at-age (O) off Maranhão state.

For *R. porosus*, estimated $L_\infty$ was much higher than the maximal length found in the sample (85.5 cm) and the *k* value reveals that the species also has fast growth, but nearly half that estimated for *R. lalandii* (Table II, Fig. 4). Ages varied from $0^+$ to 5 years, with the majority of individuals at 1 year of age (Fig. 5b). Machado *et al.* (2000) and Mattos *et al.* (2001) describe a size at first maturity of around 65 cm, which results in an age at first maturity of 3.3 years. The majority of the sample was made up of juveniles (72.4%).

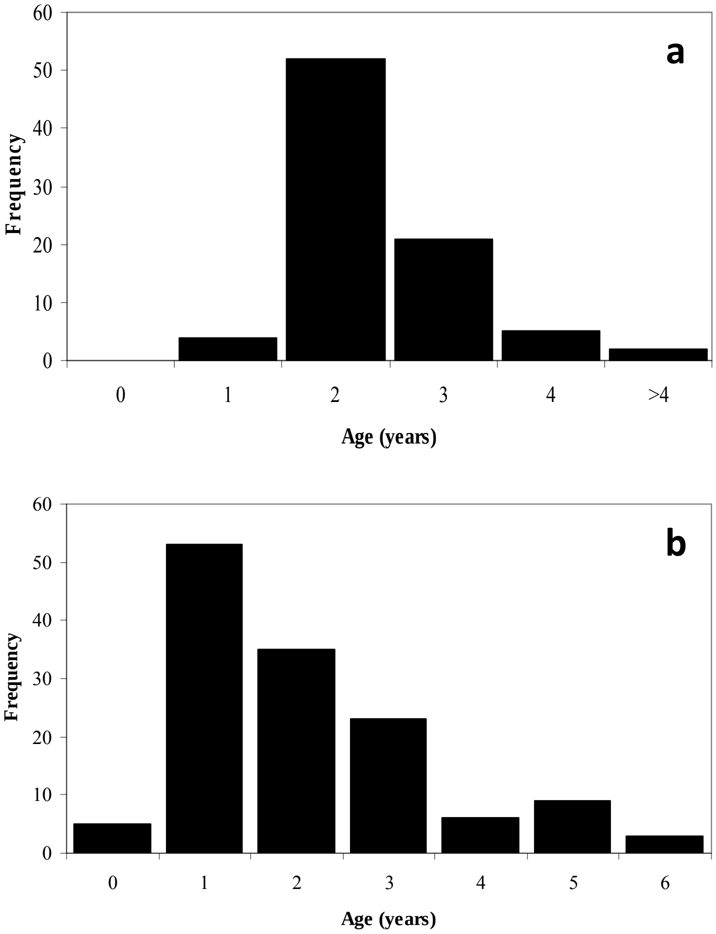

**Figure 5.** Age composition of the sample of Brazilian sharpnose shark, *Rhizoprionodon lalandii* (a) and Caribbean sharpnose shark, *R. porosus* (b) collected off Maranhão state.

## Discussion

Marginal increment analysis for *R. lalandii* and *R. porosus* did not allow accuracy in the identification of the formation of an annual growth ring due to the small number or absence of individuals in some months. However, using the example of the pattern for other species of the genus, annual formation is most likely, as demonstrated for *R. taylori* (Simpfendorfer 1993) and *R. terraenovae* (Parsons 1985, Branstetter 1987, Carlson & Baremore 2003, Loefer & Sedberry, 2003).

Little is known regarding the growth of species of *Rhizoprionodon* along the coast of Brazil. According to Branstetter (1990), Camhi *et al.* (1998) and Smith *et al.* (1998), species of small coastal sharks in the northern hemisphere have very fast growth, as is the case of the two species studied here. However, the growth of these two species, while fast, is slower than that of other species from the same genus (Table III). Analyzing the growth curves for the first year of life, the growth rate for the two species is of the same magnitude (approximately 13 cm/year), diminishing in the second year of life. The growth rate in the juvenile phase is similar between the two species (11.4 and 11.2 cm/year), with an abrupt reduction in the adult phase (> 2 years) for *R. lalandii* (4.8 cm/years), whereas *R. porosus* has a growth rate of 7.3 cm/year beginning at three years of age.

**Table II**. Comparison of the principals parameters ($L_\infty$ and $k$) estimated with the different models for *Rhizoprionodon lalandii* and *R. porosus*, with respectives values of standard error (SE), Confidence intervals for 95% (Lower and Upper CI) and Akaike's information criterion (AIC) for each

| Model | Maximum asymptotic size (L∞) | | | | Growth coefficient (k) | | | | AIC |
|---|---|---|---|---|---|---|---|---|---|
| | Estimated | SE | Lower CI | Upper CI | Estimated | SE | Lower CI | Upper CI | |
| *R. lalandii* | | | | | | | | | |
| g1: VBGF[a] | 78.103 | 0.061 | 74.681 | 82.18 | 0.301 | 0.001 | 0.268 | 0.336 | 1140.837 |
| g2: Generalized[b] | 99.103 | 7.221 | 78.489 | 1002.4 | 0.11 | 0.003 | <0.001 | 0.278 | 1136.611 |
| g3: Logistic[c] | 67.388 | 0.03 | 65.641 | 69.299 | 0.73 | 0.001 | 0.686 | 0.776 | 1181.014 |
| g4: Gompertz[d] | 71.012 | 0.038 | 68.893 | 73.572 | 0.51 | 0.001 | 0.473 | 0.548 | 1157.573 |
| g5: Richards[e] | 70.747 | 0.049 | 67.087 | 73.161 | 0.524 | 0.002 | 0.479 | 0.731 | 1161.041 |
| *R. porosus* | | | | | | | | | |
| g1: VBGF[f] | 112.99 | 0.228 | 101.605 | 129.717 | 0.171 | 0.001 | 0.136 | 0.206 | 1596.891 |
| g2: Generalized[g] | 112.486 | 15.763 | 88.659 | 2034.42 | 0.173 | 0.003 | <0.001 | 0.387 | 1598.895 |
| g3: Logistic[h] | 80.039 | 0.05 | 77.089 | 83.183 | 0.629 | 0.001 | 0.589 | 0.67 | 1610.766 |
| g4: Gompertz[i] | 88.279 | 0.085 | 83.687 | 94.582 | 1.101 | 0.001 | 0.356 | 0.435 | 1600.743 |
| g5: Richards[j] | 86.642 | 0.124 | 77.635 | 92.702 | 0.429 | 0.003 | 0.369 | 0.707 | 1603.765 |

Other parameters: *R. lalandii* - [a] $t_0 = -1.463$ and $L_0 = 27.857$; [b] $t_0 = -0.763$ and $p = 0.506$; [c] $t_0 = 0.451$; [d] $a = 0.930$; [e] $b = -2.731$ and $m = 14.647$; *R. porosus* - [f] $t_0 = -1.751$ and $L_0 = 29.220$; [g] $t_0 = -1.760$ and $p = 1.007$; [h] $t_0 = 0.855$; [i] $a = 1.101$; [j] $b = -1.857$ and $m = 7.455$.

**Table III.** Comparison of VBGF parameters of small coastal species of sharks reported by different authors (M – male; F – female).

| Species | L∞ (cm TL) | k | t0 (years) | n | Author |
|---|---|---|---|---|---|
| *Rhizoprionodon lalandii* | 78.1 | 0.3 | -1.46 | 84 | Presente study |
| *Rhizoprionodon porosus* | 112.9 | 0.17 | -1.75 | 134 | Presente study |
| *Rhizoprionodon terraenovae* | 92.5 | 0.45 | -2.01 | 215 | Parsons (1985) |
| *Rhizoprionodon terraenovae* | 108 | 0.36 | 0.98 | 20 | Branstetter (1987) |
| *Rhizoprionodon terraenovae* | 94 | 0.73 | -0.88 | 304 | Carlson and Baremore (2003) |
| *Rhizoprionodon terraenovae* | 98.3(M)/98.8(F) | 0.50(M)/0.49(F) | -0.94(M)/-0.91(F) | 116(M)/123(F) | Loefer and Sedberry (2003) |
| *Rhizoprionodon taylori* | 65.2(M)/73.2(F) | 1.34(M)/1.01(F) | 0.41(M)/0.45(F) | 52(M)/85(F) | Simpfendorfer (1993) |
| *Carcharhinus acronotus* | 130.3(M)/139.3(F) | 0.21(M)/0.18(F) | -3.90(M)/-4.07(F) | 104(M)/117(F) | Driggers *et al.* (2004) |
| *Carcharhinus porosus* | 136.4 | 0.08 | -3.27 | 504 | Lessa e Santana (1998) |
| *Isogomphodon oxyrhynchus* | 171.4 | 0.12 | -2.61 | 105 | Lessa *et al.* (2000) |
| *Sphyrna tiburo* | 89.7(M)/122.6(F) | 0.69(M)/0.28(F) | -0.04(M)/-0.79(F) | 50(M)/65(F) | Carlson and Parsons (1997) |

Specimens of *R. lalandii* were caught in all phases of life, with a maximal length in the sample of 76.5 cm, which is near to the maximal length of 77 to 78 cm reported in the literature (Compagno 1984, Motta *et al.* 2005, Andrade *et al.* 2008), and a $L_\infty$ close to the $L_{max}$ (only 2% greater). The sample was made up of individuals of all ages – from one to six years. In a study carried out by Simpfendorfer (1993) on *R. taylori*, which has a similar maximal length to that of *R. lalandii*, maximal age was seven years, but with a much greater growth constant ($k$ = 1.337 for males and 1.013 for females).

Maximal age for *R. lalandii* reveals one of the shortest lifecycles among species of small coastal sharks. Loefer & Sedberry (2003) and Carlson & Parsons (1997) found a maximal age of 11 years for *R. terraenovae* and *Sphyrna tiburo* respectively. Maximal age for *Carcharhinus porosus* (Lessa & Santana, 1998) and *Isogomphodon oxyrhynchus* (Lessa *et al.* 2000) has been found to be 12 years and *C. acronotus* (Driggers *et al.* 2004) can reach 19 years. The rapid growth, early maturation and short lifecycle of the Brazilian sharpnose shark reveal that the species must be exposed to high levels of predation by larger sharks. According to Branstetter (1990), predation on sharks under 100 cm is high due to the lesser swimming ability and more edible size. In agreement with this author, the biological characteristics of *R. lalandii* suggest that the species must undergo high natural mortality and, when added to the considerable fishery efforts, this situation may place the equilibrium of the population at risk.

For *R. porosus* on the coast of the state of Pernambuco (northeastern Brazil), the maximal age of 10 years would correspond to an individual 100.5 cm in length, with an estimated $L_\infty$ of 111.2 cm (Montealegre-Quijano 2002). However, the maximal age for the individuals on the coast of the state of Maranhão (present sample) was five years, corresponding to a $L_{max}$ = 85.5 cm and $L_\infty$ = 113. Montealegre-Quijano (2002) suggests the formation of two rings per year, whereas other studies on species from the genus *Rhizoprionodon* have demonstrated the formation of one annual ring (Parsons 1985, Branstetter 1987, Simpfendorfer 1993, Carlson & Baremore 2003, Loefer & Sedberry 2003). Similarly to the finding described by Montealegre-Quijano (2002), estimated $L_\infty$ in the present study was similar to that maximal length (110 cm) mentioned by Compagno (1984) for the species. Although the growth coefficient for *R. porosus* is lower than that for *R. lalandii*, Branstetter (1990) reports that shark species with higher $k$ values than 0.1 can be considered as having fast growth, which is a pattern linked to habitat as well as the biological and ecological characteristics of the species. Furthermore, gillnets directed at species of boney fish incidentally catch *R. lalandii* individuals of all age classes beginning at one year of age as well as *R. porosus* juveniles (72.4%) and adults up to five years of age. The strong influence on this selectivity pattern from the fishing gear is demonstrated by the mean lengths and ages of the two species, which were quite similar (*R. lalandii* – 56.5 cm, 3 years; *R. porosus* – 57.6 cm, 2.6 years).

The considerable fishery efforts directed at *R. lalandii* and juvenile *R. porosus* specimens in the state of Maranhão by the artisanal fleet, along with the biological and population characteristics of the two species (such as high natural mortality), may affect the equilibrium of the population. Thus, management measures are needed that prioritize changes in the selectivity of the fishing gear and a reduction in fishery efforts through the establishment of protected areas in order to ensure the sustainability of these important elements of the biodiversity of northern Brazil.

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# Preservación no criogénica de tejido y extracción de ADN: una aplicación para peces cartilaginosos

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**Resumen.** Conservar las muestras de tejido y la calidad del ADN, es esencial para que las técnicas moleculares funcionen apropiadamente. Por este motivo, la estandarización de los métodos de preservación de tejido y extracción de ADN, son importantes, considerando la disponibilidad de recursos y su replicabilidad. Se evaluaron cinco métodos de preservación de tejido, dos fuentes tisulares y cinco protocolos de extracción, tanto cualitativamente, cuantitativamente y estadísticamente. No se encontraron diferencias significativas entre tejidos, mientras que si las hubo entre protocolos de extracción y métodos de preservación. Si consideramos la relación costo/beneficio y la cantidad de ADN, los protocolos más eficientes fueron el seis y el nueve, con muestras preservadas en etanol a -20 °C o con un buffer de extracción sin proteasa en una condición no criogénica. Por lo tanto, se recomienda mantener de 5-20mg de tejido (o más si se requiere hacer más de una extracción) en etanol frío, seguido de una extracción usando el protocolo 9. Sin embargo, si se está trabajando con recursos más limitados, la mejor opción es mantener de 5-20mg de tejido en Etanol-EDTA (para conservación a corto plazo) o en tampón de Longmire (para preservación por más tiempo), extrayendo con protocolo 6.

**Palabras-Clave:** Chondrichthyes, tampón de preservación de tejido, preservación de ADN, calidad de ADN.

**Abstract. Non-cryogenic tissue preservation and DNA extraction: an application for cartilaginous fishes.** Conservation of tissue samples and quality of the DNA are crucial for the molecular techniques to work properly. For this reason, the standardization of the methods for tissue preservation and DNA extraction is basic, considering the availability of resources and its replicability. Five tissue preservation methods, two tissue types and five extraction protocols were evaluated qualitatively, quantitatively and statistically. No significant differences among tissues were observed, while there were differences in the preservation methods and extraction protocols. Considering the cost/benefit relation and quantity of DNA, the most efficient protocols were six and nine, which used samples preserved in ethanol at -20 °C or with an extraction buffer without protease in non-cryogenic condition. For that matter, in optimal conditions (enough time, economic resources and complete infrastructure) is recommended to maintain 5-20mg of tissue in cold ethanol (with a posterior cryogenic maintenance), coming with a DNA extraction made with P9 or an appropriate kit. However if the condition is of scarce resources, the best choice is to maintain 5-20mg in Ethanol-EDTA (For short term preservation or Longmire's buffer (for longer terms) and extract the DNA with protocol 6 or 9 depending on purity needs.

**Keywords:** Chondrichthyes, Tissue preservation buffer, DNA preservation, DNA quality.

## Introducción

En las últimas décadas, el trabajo en genética se ha dedicado al estudio de las poblaciones por medio de la aplicación de técnicas moleculares que han sido desarrolladas, aplicadas y/o estandarizadas principalmente en microorganismos (Apfalter *et al.* 2001), plantas (Milligan 1998), teleósteos (Hua Yue & Orban 2001), aves (Seutin *et al.* 1991) y mamíferos (Kilpatrick 2002).

La viabilidad de estudios moleculares recae en gran medida en la habilidad del investigador para aislar el ADN en una buena calidad y cantidad con la mínima cuantía de tejido (Hua Yue & Orban 2001), pues la fidelidad y reproducibilidad de la prueba dependen de la suficiente calidad y cantidad del ADN aislado de una mínima cantidad de tejido (Sunnucks  Hales 1996), lo que enfatiza la importancia de la investigación básica para mejorar las técnicas moleculares.

Sin embargo, la investigación básica que lleve a mejorar las técnicas de preservación de tejidos y, por ende, del ADN muchas especies o grupos de seres vivos ha sido relegada a un segundo plano, casi desconociendo que con un ADN de alta calidad, es más fácil construir genotecas de ADN y por ende aprovechar al máximo los muestreos realizados y la colaboración entre científicos que no pueden acceder fácilmente a las muestras, así como una comparación más exacta de datos entre laboratorios (Apfalter *et al.* 2001).

La información sobre las técnicas de extracción de ADN y preservación del tejido en elasmobranquios son importantes pues permiten que trabajos sobre caracterización del grupo, genética de poblaciones, filogenia, estudios de diversidad genética, entre otros, se lleven a cabo con ADN de calidad y con una mayor eficiencia en su consecución, máxime en muestreos largos en zonas cálidas y húmedas, lo que requiere de técnicas para la preservación de tejidos por amplios periodos de tiempo (Dawson *et al.* 1998). Dessauer et al. (1996) concluyeron que la congelación es el método de preservación más efectivo, sin embargo, la criopreservación no siempre es posible en muchas situaciones de campo, tales como el transporte de nitrógeno, faenas de más de tres días, problemas de transporte en aviones y barcos, entre otros (Kilpatrick 2002). Por estos motivos, la construcción de bancos de tejidos se ha dificultado, sobre todo en organismos acuáticos, donde su recolección es costosa y la congelación no es una opción viable. Por ejemplo, en elasmobraquios, no existen colecciones de tejidos ni genotecas específicas organizadas por regiones naturales, sitios de muestreo, entre otros. Esta situación ha dificultado la generación de conocimiento taxonómico, sistemático, genético y evolutivo de este grupo, capturado en muchos países como fauna acompañante de diversas pesquerías y en otros, tienen pesca dirigida al grupo, requiriéndose un mayor conocimiento genético en diferentes áreas, con el propósito de conservar, conocer y explotar el recurso de manera sostenible.

Este estudio tuvo como objetivos 1) Contribuir al desarrollo de métodos de preservación de tejidos que eviten la criogenia, 2) Apoyar el mejoramiento de protocolos de extracción de ADN de alta calidad en elasmobranquios y 3) asesorar a los investigadores en este grupo de animales en la apropiada selección de tejidos, métodos de preservación y protocolos de extracción de ácidos nucleicos, de acuerdo con la logística y los recursos disponibles en estas investigaciones

## Materiales y Métodos

### *Obtención de las muestras*

En agosto de 2003 y noviembre de 2004, se realizaron dos salidas a bordo de una embarcación camaronera, en aguas del pacífico central colombiano. 13 especímenes de las especies *Rhinobatos leucorhynchus, Sphyrna tiburo, Aetobatus narinari, Gymnura marmorata, Dasyatis longa, Sphyrna tiburo, Urotrygon aspidura, Urotrygon rogersi* y *Mustelus lunulatus* fueron capturados mediante malla de arrastre con ojo de 2 pulgadas y ¾ e identificados a bordo, a nivel de especie con la ayuda de claves taxonómicas (Compagno et al. 1995, McEachran & di Sciara 1995), obteniendo 13 muestras de hígado y 13 de músculo.

### *Preservación de los tejidos*

13 biopsias de $0.5cm^3$ de hígado y 13 de músculo, fueron sometidas a 1.5ml de cinco medios (tampones o buffers) de preservación (Etanol a -20ºC, Etanol-EDTA, Tampón de Longmire, DMSO-NaCl y CTAB-NaCl; Tabla I), es decir, 13 muestras de cada tejido por buffer, guardados en tubos Eppendorff® de 2 ml. Cada una de las 26 muestras sometidas a preservación, fueron divididas en seis submuestras de cinco, 10, 20, 40, 80 y 160 miligramos de tejido para realizar la extracción de ADN, para un total de 780 submuestras (13 individuos por dos tejidos por cinco métodos de preservación por seis concentraciones de tejido) a extraerles el ADN.

### *Extracción de ADN*

La extracción del ADN se llevó a cabo con cinco protocolos de extracción (Tabla II), obteniendo así 3900 unidades experimentales (780 submuestras por cinco protocolos de extracción).

**Tabla I.** Métodos de preservación (Tampones) usados en el estudio, indicando su composición y referencia respectiva.

| Método | Composición | Referencia |
|---|---|---|
| 1. Etanol a -20ºC | 96% Etanol absoluto (96,8%; Merck 108543) mantenido a -20ºC. | Milligan 1998 |
| 2. Etanol - EDTA (E-E) | 96% Etanol (96,8%; Merck 108543) + 0.1mM EDTA ($\geq$ 99%; Sigma E5134-250G). | Wasko *et al.* 2003 |
| 3. Tampón de Longmire | 0.1 M Tris (Trizma® base $\geq$ 99%; Sigma 77861-250G ) + 0.1 M EDTA ($\geq$ 99%; Sigma E5134-250G) + 0.01 M NaCl ($\geq$98%; Sigma S3014-500G) + 0.5% peso/volumen de SDS ($\geq$ 98,5%; Sigma 151213).[*] | Longmire *et al.* 1997 |
| 4. DMSO-NaCl | 20% DMSO ($\geq$ 99.9%; Sigma 67685-100G) + Sobresaturación con NaCl ($\geq$98%; Sigma S3014-500G) | Shiogama et al. 1987;<br>Shah 1983 |
| 5. CTAB – NaCl | Solución CTAB ($\geq$ 99%; Sigma 57090-100G) + Sobresaturación con NaCl ($\geq$98%; Sigma S3014-500G) | Milligan 1998 |

*http://research.amnh.org/amcc/labfacilities6.html, última consulta: Septiembre 2009

**Tabla II.** Protocolos de extracción usados en el estudio, indicando su composición principal, el primer y segundo paso de purificación y su referencia respectiva. En todos los casos el método de disrupción del tejido fue por maceración. Los números corresponden a la notación usada por Milligan (1998).

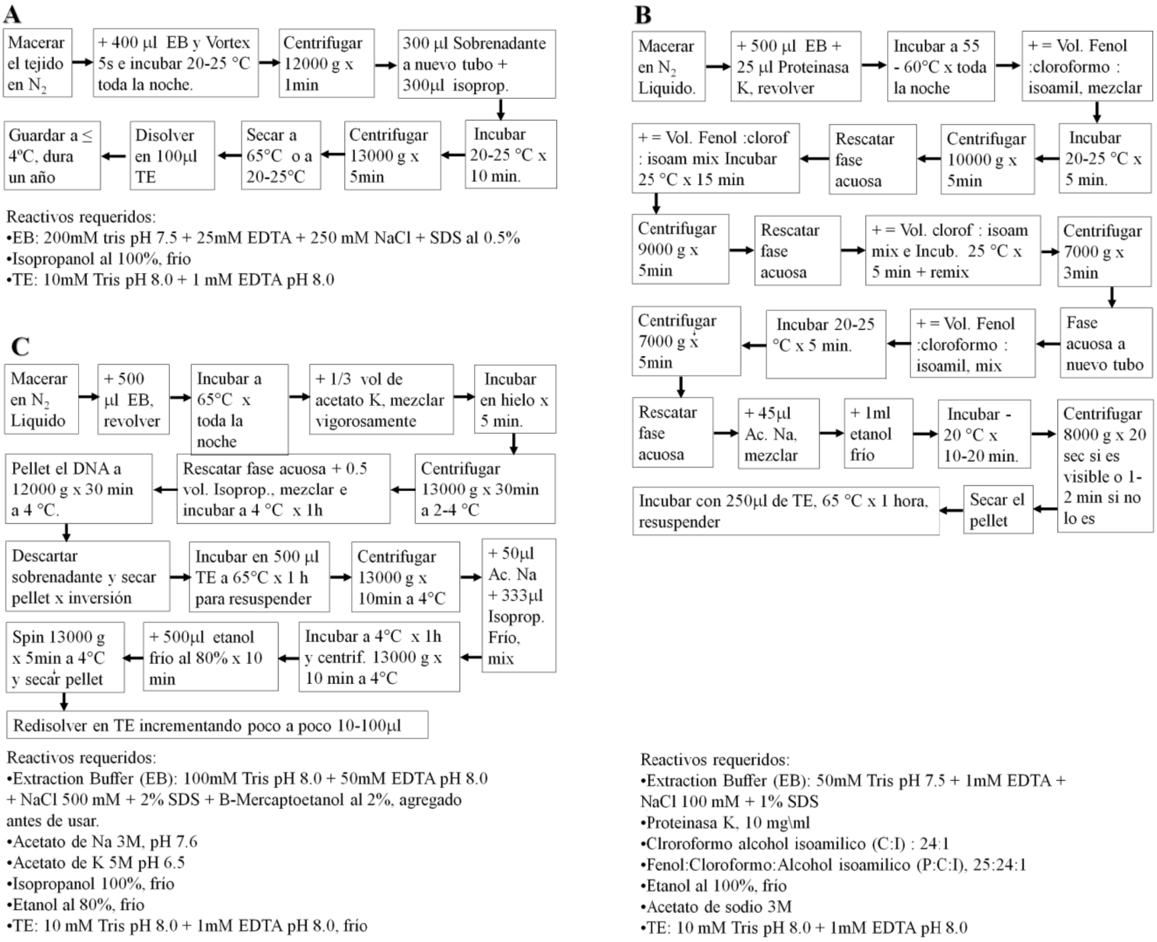
| Protocolo | Solubilización del tejido | Purificación inicial | Segunda purificación | Referencias |
|---|---|---|---|---|
| 5. Chelex-100 (Bio-Rad 1421253) | Agua | Ninguna | Ninguna | Walsh et al. 1991; Ellegren 1994; Sensabaugh 1994 |
| 6. SDS | SDS ($\geq$ 98,5%; Sigma 151213) | Precipitación con isopropanol | Ninguna | Edwards et al. 1991 |
| 7. CTAB | CTAB ($\geq$ 99%; Sigma 57090-100G) | Cloroformo | Precipitación con isopropanol | Doyle & Dickson 1987; Doyle & Doyle 1987; Lodhi et al. 1994 |
| 9. Digestión de proteínas | SDS ($\geq$ 98,5%; Sigma 151213) | Fenol : Cloroformo (2X), Cloroformo | Precipitación con etanol | Koebner et al. 1986; Kawasaki 1990; Hillis et al. 1990; Pääbo S. 1990; Cooper 1994; |
| 10. Precipitación de proteínas | SDS ($\geq$ 98,5%; Sigma 151213) | Precipitación de proteínas | Precipitación con isopropanol (2X) | Dellaporta et al. 1983; Fang et al. 1992; del Castillo-Agudo et al 1995 |

Los volúmenes de cada protocolo fueron idénticos en cada concentración de tejido, realizando estandarizaciones del tiempo y del número de centrifugaciones (Figura 1). Estas estandarizaciones se compararon con el kit de extracción de ADN DNeasy® de QIAGEN®, siguiendo las especificaciones del fabricante. En esta investigación, los protocolos extracción basados en

Chelex y CTAB no se incluyeron en los análisis posteriores, pues no mostraron bandas en gel de agarosa (1%; Sigma 9012366) indicadora de la existencia de ADN en cantidad apropiada para realizar diversas técnicas moleculares (PCR, clonación, RAPDS, RFLPs, VNTRs, FISH, entre otras). Todos los procedimientos de extracción fueron realizados en el laboratorio de biología molecular del Instituto Alexander Von Humboldt en el Centro Internacional de Agricultura Tropical (CIAT, Palmira–Colombia).

*Cualificación y cuantificación del ADN*

El ADN se cualificó por medio de electroforesis en gel de agarosa al 1% (Sigma 9012366), corrido en tampón TBE y revelado con 2µl de solución de bromuro de etidio al 0,01%, observando el grado de degradación que hubiera en cada muestra así como también la prueba con diluciones, para detectar sobresaturación del ADN y por ende un falso negativo. La visualización de los geles se realizó en un transiluminador de luz ultravioleta Uvitec®. La cuantificación como tal, fue realizada por fluorometría utilizando el fluorocromo HOECHST® 33258 y revelada en un fluorómetro digital DyNAquant 200 (Hoefer, Pharmacia Biotech®), siguiendo las especificaciones del laboratorio de biología molecular del Instituto Von Humboldt en el CIAT.



Reactivos requeridos:
- EB: 200mM tris pH 7.5 + 25mM EDTA + 250 mM NaCl + SDS al 0.5%
- Isopropanol al 100%, frío
- TE: 10mM Tris pH 8.0 + 1 mM EDTA pH 8.0

Reactivos requeridos:
- Extraction Buffer (EB): 50mM Tris pH 7.5 + 1mM EDTA + NaCl 100 mM + 1% SDS
- Proteinasa K, 10 mg\ml
- Clroroformo alcohol isoamilico (C:I) : 24:1
- Fenol:Cloroformo:Alcohol isoamilico (P:C:I), 25:24:1
- Etanol al 100%, frío
- Acetato de sodio 3M
- TE: 10 mM Tris pH 8.0 + 1mM EDTA pH 8.0

Reactivos requeridos:
- Extraction Buffer (EB): 100mM Tris pH 8.0 + 50mM EDTA pH 8.0 + NaCl 500 mM + 2% SDS + B-Mercaptoetanol al 2%, agregado antes de usar.
- Acetato de Na 3M, pH 7.6
- Acetato de K 5M pH 6.5
- Isopropanol 100%, frío
- Etanol al 80%, frío
- TE: 10 mM Tris pH 8.0 + 1mM EDTA pH 8.0, frío

**Figura 1.** Diagramas de flujo de los protocolos que fueron positivos para ADN en agarosa al 1%. A. Protodolo SDS (6; Milligan 1998), B. Protocolo de digestión proteica (9; Milligan 1998). C. Protocolo de precipitación proteica (10; Milligan 1998).

*Análisis de datos*

*Análisis cuantitativos*

Con el ADN extraído y cuantificado, se realizaron matrices de datos por tejido, por protocolo de preservación y por protocolo de extracción para comparar la efectividad de cada uno.Dichas matrices fueron visualizadas en gráficas de líneas simples y planos de 3 dimensiones (3D), realizadas en el programa "STATISTICA 7.0", usando como ejes: El tiempo que toma cada extracción de ADN y mantenimiento del tejido, el costo de cada extracción (medido como la cantidad de dólares gastados en el procesamiento de una muestra) y la cantidad de ADN en nanogramos. Esta metodología, es una adaptación a la usada por Cortés (1997). De acuerdo con estas gráficas se determinó qué protocolos y tipo tisulares son más eficientes, considerando el tiempo empleado en cada método, la facilidad en su implementación y costo. También se consideró como criterio, el tipo de tejido y la cantidad y calidad de ADN extraído. Por último, se correlacionó el tipo y la cantidad de tejido con la cantidad de ADN extraído por protocolo y medio de preservación.

*Análisis estadísticos*

Para saber si los datos se distribuian normalmente se llevó a cabo una prueba de Kolmogorov-Smirnov usando el programa STATISTICA 7.0 2007. Debido a que los datos no se ajustaron a la distribución normal se realizaron análisis no paramétricos usando el mismo programa, para evaluar las diferencias en la cantidad de ADN entre los métodos de preservación y protocolos de extracción usados (prueba de Kruskall-Wallis) y entre tipos tisulares (Prueba de Mann-Whitney).

*Análisis de la relación costo/beneficio*

Para cada protocolo se calculó el tiempo de extracción de ADN, el costo por muestra, la cantidad promedio de ADN obtenida, el valor por nanogramo de ADN, el valor de un nanogramo de ADN por hora de trabajo y la cantidad de ADN por hora por dólar. Para cada protocolo, el tiempo de duración se calculó sumando la cantidad de horas usadas en cada paso, incluyendo las incubaciones y el procesamiento. El costo por muestra se calculó utilizando el costo por unidad utilizada de reactivos en la extracción en cada muestra. Con la información anterior, se calculó el valor de extracción de un nanogramo de ADN dividiendo del costo por la cantidad promedio de ADN extraída y posteriormente, se calculó el valor de cada nanogramo extraído en una hora de trabajo, dividiendo el costo por muestra, sobre la multiplicación del tiempo que toma la extracción y la cantidad promedio obtenida. Estas estimaciones no incluyen el tiempo y costo del investigador. Finalmente, se estimó la cantidad de ADN obtenida en una hora con un dólar, dividiendo la cantidad promedio de ADN extraído por la multiplicación del costo y el tiempo que toma la extracción.

## Resultados

No hubo diferencias significativas entre tejidos para la cantidad promedio de ADN extraído (M-W U: 3464.500; $p > 0.05$), pero el hígado mostró mayor variabilidad (Desviación estándar [DE] = 271.39) que el músculo (DE = 186.54). Con respecto a la cantidad de tejido utilizado, hubo diferencias significativas entre los categorías usadas [K-W: H (5, N= 180) = 48.83; $p < 0.0001$], mostrando que 5mg tiene diferencias con 40, 80 y 160mg, pero no con 10 ni 20mg; la categoría de 10mg tuvo diferencias con las de 80 y160mg, pero no con el resto de ellos; la de 20mg mostró diferencias significativas únicamente con la categoría de 160mg. En todos los casos se cumplió la expectativa de que a mayor cantidad de tejido, mayor cantidad de ADN extraído. Se observaron diferencias significativas en la cantidad de ADN promedio obtenido entre los tampones de preservación [K-W H: (4, N= 180) = 24.26819; p =0.0001]. La postANOVA no paramétrica mostró que la cantidad de ADN obtenida de los tejidos preservados en la solución de CTAB buffer fue significativamente menor que todos los demás tampones, exceptuando el tampón de Longmire, mientras que este último no mostró diferencias significativas con ninguno de las soluciones persevantes evaluadas. La preservación en etanol frío produjo el mejor resultado en cuanto a obtención de ADN, seguido por DMSO, E-E y el tampón de Longmire buffer y el que obtuvo la menor cantidad de ADN fue la solución de CTAB-NaCl.

Los protocolos de extracción cinco (Chelex 100) y siete (CTAB) no mostraron banda en la cualificación en gel de agarosa, mientras que los protocolos seis (SDS), nueve (digestión de proteínas) y diez (precipitación de proteínas), dieron positivos en la visualización y cuantificación del ADN, obteniendo geles como las mostradas en la figura 2 (en esta figura no nos interesa cuantificar la cantidad de ADN, sino visualizar la integridad de la banda, por tal motivo, las imágenes de 2A a 2H no muestran como referente el marcador de peso molecular). Un análisis de Kruskall-Wallis mostró diferencias significativas entre los protocolos de extracción en la cantidad de ADN promedio obtenido [K-W: H (2, N= 180) = 11.19939; p = 0.0037], donde los protocolos basados en SDS, y Digestión proteica, tuvieron un mejor rendimiento que el basado en precipitación de proteínas y no hubo diferencias significativas entre los dos primeros. La extracción de ADN con el kit de extracción de Qiagen$^{®}$, no fue tan efectivo como se esperaba según la casa fabricante (Fig. 2I), a pesar de trabajar con los diferentes cantidades de tejido mencionadas, dando un mejor resultado con el tejido preservado con el método Longmire (línea 6) pero fue la única banda definida en el gel.

El protocolo de extracción basado en SDS fue un método corto y fácil para la extracción de ácidos nucleicos, consistiendo en ocho pasos obteniendo, en general, buenos resultados (Figs. 2A y 2B). Para la extracción de ácidos nucléicos totales fue uno de los más deseables en términos de la relación costo-beneficio (Figs. 2 y 3) siendo el protocolo que requiere la menor infraestructura. Sin embargo, el botón de ADN (Pellet) no fue completamente blanco, sugiriendo la presencia de fibras, proteínas y lípidos, dejando muchas impurezas que puede causar problemas en futuros ensayos moleculares. Para este protocolo, el mejor método de preservación para músculo y para hígado fue el etanol frío, seguido del tampón DMSO-NaCl (DMSO; Fig. 4A). El método menos efectivo fue el de la solución CTAB- NaCl mientras que el tampón de Longmire mostró un desempeño intermedio, pero sirve para rescatar ADN en casi todos los métodos de preservación (Fig. 4A). Es importante recordar que la preservación con etanol frío fue el control criogénico.

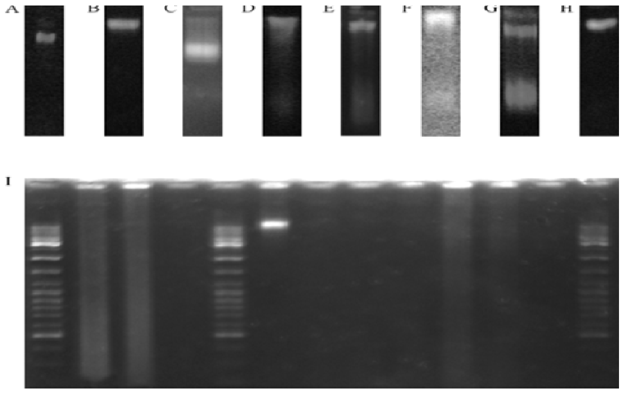


**Figura 2.** Resultado de electroforesis en geles de agarosa al 1%, corridas con TBE A) Protocolo de SDS con tejido preservado en DMSO; B) Protocolo de SDS con tejido preservado en solución de Longmire; C) Protocolo de digestión proteica con tejido preservado en CTAB; D) Protocolo de digestión proteica con tejido preservado en DMSO; E) Protocolo de digestión proteica con tejido preservado en Etanol frío; F) Protocolo de digestión proteica con tejido preservado en tampón de Longmire; G) Protocolo de precipitación de proteínas con tejido preservado en DMSO; H) Protocolo de precipitación de proteínas con tejido preservado en solución de Longmire e I) Kit de extracción de ADN DNeasy® de QUIAGEN® DNA extracción con preservantes diferentes, la única banda observada fue obtenida con hígado preservado en tampón de Longmire.

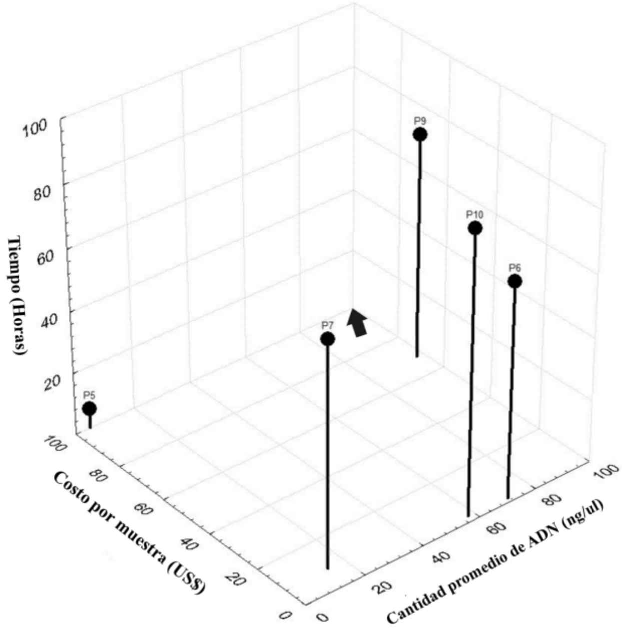


**Figura 3.** Relación costo-beneficio entre los cinco protocolos evaluados. Todos los ejes se encuentran en porcentaje. Las barras más cercanas al vértice señalado por la flecha, son los más eficientes. P5 (Protocolo Chelex 100), P6 (Protocolo SDS), P7 (Protocolo CTAB), P9 (Protocolo de digestión proteica) y P10 (Protocolo de precipitación proteica) según notación de Milligan (1998).

El protocolo más ampliamente usado en casi todos los laboratorios es el de digestión proteica con Proteinasa K seguido de varias purificaciones con Fenol – Cloroformo (protocolo de digestión proteica; protocolo 9 de Milligan 1998) y tiene un sinnúmero de variantes. De los protocolos evaluados, es el que más TE (250µl) usa para re suspender, proveyendo más material de trabajo. Sin embargo, es el único que requiere una purificación relativamente compleja y altamente tóxica, lo que lo hace más largo y peligroso. La fluctuación de la cantidad de ADN en cada cantidad de tejido (Fig. 4B) es mayor que en el protocolo de SDS (Fig. 4A), teniendo una variación más amplia (Tabla III) en la obtención de ADN, siendo el protocolo SDS superior solo en el caso del hígado preservado en etanol frío. (Figs. 4A, 4B y 4D), y teniendo (el protocolo de digestión proteica) "ruido" por sobresaturación en casi todos los casos.

**Tabla III.** Desviaciones estándar de la cantidad de ADN (ng/µl) respecto a la cantidad de tejido en los mejores protocolos de extracción.

| Protocolo | 5mg | 10mg | 20mg | 40mg | 80mg | 160mg |
|---|---|---|---|---|---|---|
| SDS | 48.099 | 104.38 | 110.668 | 164.165 | 181.717 | 340.910 |
| Digestión proteica | 49.424 | 34.751 | 60.6711 | 119.848 | 196.302 | 348.536 |
| Precipitación de proteínas | 19.668 | 65.262 | 49.7562 | 91.496 | 209.679 | 110.769 |

Por otro lado, el protocolo de extracción por precipitación de proteínas es el que posee un mayor número de pasos (16) y requiere más incubación, pero los reactivos usados son más baratos que los usados en el protocolo de digestión de proteínas. A pesar de esto, es un protocolo simple que requiere una infraestructura intermedia (la misma usada en el protocolo de digestión proteica) y da una buena calidad de ADN (Fig. 2G y 2H), pero el botón de ADN es un poco menos claro que en el obtenido en el protocolo de digestión proteica 9. En este protocolo la cantidad de ADN en hígado preservado en etanol frío tiene el mejor comportamiento, dando más de 50 ng/µl de ADN con tan solo 5mg de tejido, suficiente ADN para hacer casi cualquier prueba molecular[1]. Sin embargo, este protocolo no fue muy eficiente en las muestras musculares (Fig. 2C). Los mejores resultados en cada protocolo fueron graficados con sus regresiones en la figura 2D.

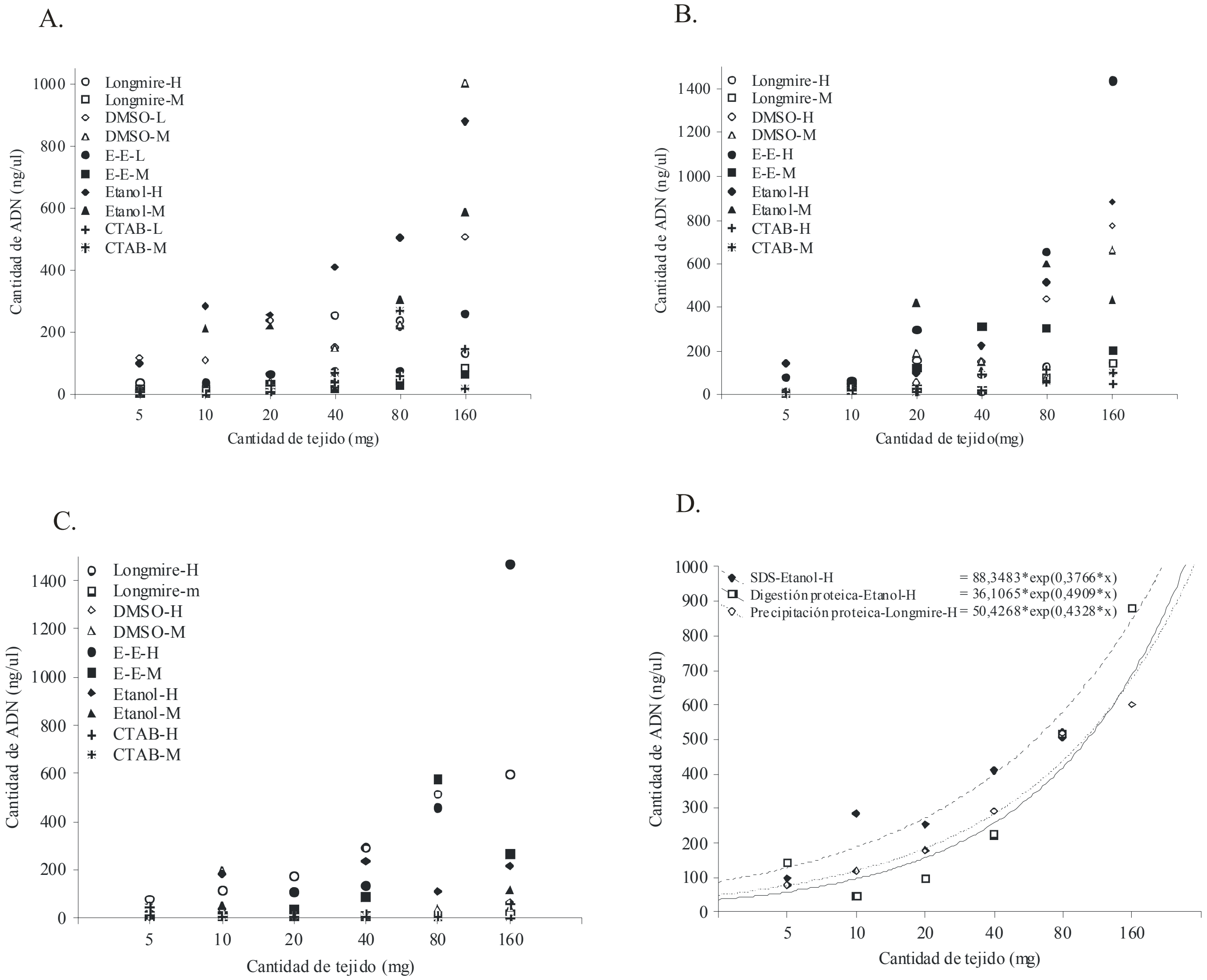


**Figura 4.** Cantidad de ADN extraída en cada rango de cantidad de tejido en A. Protocolo de SDS, B. Protocolo de digestión proteica, C. Protocolo de precipitación proteica, y D. Comparaciones de los mejores resultados para cada protocolo con su regresión.

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[1] Juan Diego Palacio. 2003. Comunicación personal en el marco de la fase de laboratorio del presente estudio.

## Discusión

Las diferencias en la variabilidad respecto a la cantidad de ADN extraído entre los tipos tisulares, puede deberse a que la baja densidad del hígado en los peces cartilaginosos (son peces magros que almacenan la energía en forma de aceites en el hígado en vez de producir tejido adiposo) hace que este tienda a flotar sobre el tampón de preservación, afectando los resultados y/o haciéndolos más variables. De acuerdo con este estudio, la mejwwor combinación es hígado preservado en a -20 ºC, extrayendo el ADN con el protocolo SDS de Milligan (1998). Sin embargo, la figura 4 muestra al protocolo de digestión de proteínas como el más efectivo en la recuperación de ADN para Chondrichthyes, con mejor calidad pero con un costo más elevado.

Las diferencias significativas entre los métodos de preservación encontrados en el presente estudio, exhortan a conocer el tipo de tejido y la naturaleza de la unidad experimental (o muestral) antes de realizar una extracción de ADN para garantizar una alta calidad y cantidad. Al parecer, no existe un mejor método de preservación *per se,* pero sí mejores combinaciones. A pesar de ello, el tampón de lisis de Longmire parece funcionar bien con todos los protocolos, pero es recomendable tener un conocimiento previo del tipo de tejido a ser preservado y cuál será el protocolo de extracción a usar.

Actualmente se sabe que los mejores métodos para la preservación de ADN son criogénicos (sea en nitrógeno liquido o en etanol a temperaturas inferiores a -20ºC) para jornadas de muestreo inferiores a tres días (Zhang & Hewitt 1998). Sin embargo, si la fase de muestreo en campo es mayor, la criopreservación no es posible ni operativa y requiere métodos no criogénicos. Los tampones de preservación E-E y Longmire son formas baratas, efectivas y no-criogénicas para la preservación del tejido, manteniendo el ADN con buena calidad y baja toxicidad (para la manipulación en campo por ejemplo) que otros preservantes como el DMSO que es altamente tóxico en contacto con la piel y la mucosa (Creus *et al.* 2002; Shah 1983; Sperling & Larsen 1979; Vogin *et al.* 1970), por esta razón, su manipulación en campo es difícil y peligrosa. El tampón E-E es la mejor opción si la preservación se hace en un lapso inferior a 3 meses, pues el medio de preservación se acidifica y afecta la preservación del ADN, por esto, para lapsos de preservación más largos, la solución de Longmire es una mejor opción.

Con el kit de extracción, solo se obtuvo una banda nítida de 10 muestras analizadas en el gel de agarosa (Fig. 2). Esto pudo ocurrir por errores experimentales, por este motivo dichos resultados fueron excluidos de los análisis. Sin embargo, el hecho de que a pesar de los costos sigue existiendo altas probabilidades de errores que llevan a una pérdida de tiempo y dinero.

La decisión de qué combinación usar debe hacerse de acuerdo a las necesidades; si la técnica molecular que va a ser aplicada requiere un ADN muy limpio (P.ej. AFLPs), el protocolo de SDS (el más barato y corto) no es la mejor opción, en dicho caso los protocolos de digestión de proteínas o de precipitación de proteínas son una mejor opción. Sin embargo, el protocolo de digestión de proteínas tiene la limitante de la toxicidad y volatilidad de los químicos de la purificación, por ende la manipulación debe hacerse con cuidado, o en su defecto cambiar los reactivos de purificación por otros menos tóxicos y volátiles (P.ej. NaCl) pero en general también son menos efectivos en la purificación. Además de la seguridad, todos los químicos usados durante la purificación (Fenol, cloroformo, alcohol isoamílico) son inhibidores de la PCR, siendo posible obtener falsos negativos en la amplificación si la técnica de purificación no se hace correctamente.

La otra opción para obtener un ADN muy limpio es el protocolo de precipitación de proteínas, pero éste obtiene menos ADN que el anterior y toma mucho más tiempo por muestra (Tabla IV) y a pesar de la menor toxicidad de los químicos usados, el β-Mercaptoethanol es altamente tóxico y volátil haciéndolo difícil de manejar. Otro problema asociado con este protocolo es la naturaleza altamente fibrosa del músculo (resultando negativo en el revelado en agarosa en varias oportunidades), pues con la precipitación de las proteínas, alguna cantidad de ADN puede ser arrastrada y debido a que el hígado tiene una mayor densidad de núcleos y menos fibras, se obtiene un mayor número de resultados positivos tanto en calidad como en cantidad de ADN.

**Tabla IV.** Comparaciones entre tiempo y costo invertido en obtener ADN. En el costo económico no se incluye el pago del investigador.

| Protocolos | Tiempo (horas) | Costo por muestra (US$) | Cantidad promedio de ADN (ng/μl) | Valor por nanogramo de ADN (US$/ng) | Valor por nanogramo de ADN hora de trabajo [US$/(ng*h)] | Cantidad de ADN obtenida con un dólar en una hora [ADN/(US1*1h)] |
|---|---|---|---|---|---|---|
| Chelex 100 | 1,27 | 10000 | 10 | 1000,00 | 787,40 | 0,00079 |
| SDS | 13,6 | 160,61 | 142,86 | 1,12 | 0,08 | 0,06540 |
| CTAB | 15,28 | 855,66 | 29,05 | 29,45 | 1,93 | 0,00222 |
| Digestión proteica | 16,03 | 6898,03 | 195,32 | 35,32 | 2,20 | 0,00177 |
| Precipitación de proteínas | 17,25 | 242,88 | 115,66 | 2,10 | 0,12 | 0,02761 |

Hasta ahora nos hemos referido a los tejidos, métodos de preservación y protocolos de extracción en relación con la cantidad de ADN extraído, sin embargo, la relación costo/beneficio fue evaluada para cada protocolo (Figura 3 y Tabla IV), correlacionando el tiempo empleado, recursos necesarios para la extracción del ADN y la cantidad promedio de ADN extraído. La Tabla IV muestra que el protocolo de digestión proteica es el que obtiene más ADN (Fig. 5) pero es el segundo en términos de costo y tiempo empleado por muestra (Fig. 3). El protocolo de precipitación de proteínas tiene un excelente costo por muestra (el segundo después del protocolo de SDS; Tabla IV) y mostró una buena obtención de ADN (la tercera) pero es el que más tiempo toma por muestra procesada (Fig. 3). Por otra parte, el protocolo de SDS es el más barato, el segundo en obtención de ADN y duración del procesamiento por muestra (Tabla IV), lo que lo convierte en una buena opción como método de extracción de ADN (Fig. 3) cuando los recursos económicos y de infraestructura son limitados y si los futuros usos del ADN no demandan extremada pureza.

En el caso de los métodos de preservación, la solución que mejor preservó no criogénicamente el ADN entre todos los protocolos, fue el tampón E-E, sobre los tampones CTAB-NaCl (Milligan 1998), DMSO-NaCl y el de Longmire, pero este último mostró un desempeño más regular entre los protocolos de extracción, cantidad de tejido y tipos tisulares.

A pesar que la relación costo/beneficio del protocolo de SDS es evidente, las impurezas dejadas, lo hace depender de las condiciones que exijan las técnicas moleculares a usar posteriormente. El protocolo de digestión de proteínas mostró una buena relación costo/beneficio, usado en conjunto con el mencionado tampón de Longmire (o con el de E-E) y tomando hígado como muestra de tejido, se obtiene muy buenos resultados en términos de la calidad y cantidad de ADN obtenido. Cuando los recursos son muy limitados y no existe una necesidad imperativa de un ADN extremadamente puro, el protocolo de SDS con tejido preservado en E-E o en tampón de Longmire es la mejor opción. Sin embargo, si se requiere ADN con alta pureza y no existen limitaciones de recursos, el protocolo de digestión de proteínas usando tejidos preservados tanto en E-E como en solución de Longmire es la opción más adecuada

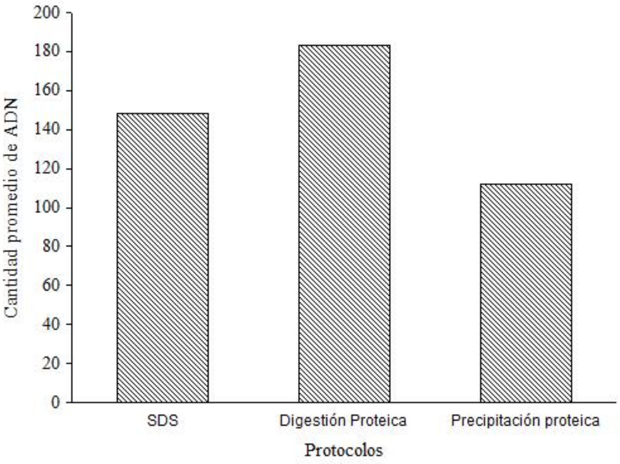

**Figura 5.** Cantidad promedio de ADN obtenidas con los protocolos SDS, digestión proteica y por precipitación de proteínas. Las unidades del eje y están dadas en μg/μl.

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# Descripción de la dieta de los tiburones zorro (*Alopias pelagicus*) y (*Alopias superciliosus*) durante la época lluviosa en aguas ecuatorianas.

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**Resumen.** Se determinaron los hábitos tróficos de los tiburones zorro *Alopias pelagicus* y *Alopias superciliosus* de Manta, Ecuador, durante Enero a Octubre de 2004. Se analizaron un total de 243 estómagos, de los cuales 103 pertenecían a *A. pelagicus* y 140 de *A. superciliosus*. Se identificaron 20 componentes alimenticios para *A. pelagicus* y 26 para *A. superciliosus*. Se aplico el índice de importancia relativa (IIR) para el análisis de contenidos estomacales. Las presas principales en la dieta de *A. pelagicus*, fueron *Dosidicus gigas*, *Sthenoteuthis oualaniensis* y *Benthosema panamense*. Para *A. superciliosus*, las presas dominantes fueron *Merluccius gayi*, seguido por *Larimus argenteus*, *D. gigas*, *B. panamense* y *Exocoetus* sp. Los valores de amplitud trófica fueron bajos para los dos depredadores, por sexo y estadio de madurez, lo cual indica que fueron depredadores especialistas para esta zona durante esta temporada. Asimismo, se presentó un traslapo alto entre sexos y estadios de madurez para cada especie; sin embargo al comparar entre especies no hubo un traslapo trófico debido a que estos tiburones se alimentan de presas diferentes en distintos hábitats. El nivel trófico para *A. pelagicus* fue de 3.9; mientras que en *A. superciliosus* fue de 3.7, permitiendo clasificarlos como depredadores secundarios-terciarios.

**Palavras Clave:** hábitos alimenticios, nivel trófico, traslapo trófico, amplitud trófica, Pacífico Ecuatoriano

**Abstract. Diet description in the pelagic thresher sharks (*Alopias pelagicus*) and bigeye thresher shark (*Alopias superciliosus*) during rainy season in Ecuadorian waters.** Trophic habits of the pelagic thresher shark *Alopias pelagicus* and the bigeye thresher shark *Alopias superciliosus* from Manta, Ecuador were determined during January to October of 2004. A total of 243 shark stomachs; 103 from *A. pelagicus* and 140 from *A. supercilious* were analyzed showing the presence of 20 prey for the first specie and 26 for the latter. We used the index of relative importance (IRI) method to analyze the stomach contents. The main preys for *A. pelagicus*, were *Dosidicus gigas*, *Sthenoteuthis oualaniensis* and *Benthosema panamense*. Whereas for *A. superciliosus*, the *Merluccius gayi* was the most important followed by *Larimus argenteus*, *D. gigas*, *B. panamense*, and *Exocoetus* sp. The trophic width values were low by sex and maturity stage of both predators which were as specialists predators. In the trophic overlapping we found a high overlap between sex and maturity stage in each shark species; however comparing both, there is not a overlapping because they feed on different prey species from different habitat. The average trophic level for both shark species was 3.9 for *A. pelagicus* and 3.7 for *A. superciliosus* which allow classify these sharks as secondary-tertiary predators.

**Keywords:** Feeding habits, trophic level, trophic overlapping, width trophic niche, Ecuadorian Pacific

## Introducción

En aguas ecuatorianas se han registrado, un total de 38 especies de tiburones, donde los tiburones zorro *Alopias pelagicus* y *Alopias superciliosus*, aportan más del 35% de la captura de tiburones en Ecuador (Martínez y Galván 2007). A pesar de ser especies muy frecuentes en la pesquería ecuatoriana, poco se conoce acerca de su biología. Los tiburones zorro son especies que se distribuyen en aguas tropicales y subtropicales alrededor del mundo y se caracterizan por presentar el lóbulo superior de la aleta caudal tan largo como su cuerpo, el cual utilizan para aturdir y capturar a sus presas (Gruber & Compagno 1981, Nakano et al. 2003, Compagno 2005). *A. pelagicus* es una especie que se captura cerca de la plataforma continental desde la superficie hasta 152 m de profundidad (Compagno 2005, Liu et al. 2006); mientras que *A. superciliosus* es más común en zonas costeras; sin embargo se le ha capturado a profundidades mayores de 600 m (Weng & Block 2004, Compagno, 2005). Debido al poco conocimiento de la biología de las especies *Alopias pelagicus* y *A. superciliosus* a nivel mundial, es importante aportar elementos biológicos para recomendar medidas de manejo pesquero o de conservación para mantener los niveles poblacionales de estas especies de tiburón que están siendo explotadas a gran escala en Ecuador. Al respecto, el presente estudio incluye información relacionada con los hábitos alimenticios de las dos especies de tiburones zorros registrados en Ecuador, por sexo y estadio de madurez, determinando si se presenta competencia alimentaria entre estas dos especies simpátricas. Los resultados se comparan con la información obtenida en *A. superciliosus* en la misma zona para la época seca y de esta forma reconocer si se presenta flexibilidad o estabilidad en la dieta de este depredador

A nivel mundial se conocen pocos estudios enfocados a la alimentación de estas dos especies de tiburones, entre estos se encuentra el desarrollado por Cortés (1999), el cual determina un nivel trófico para *A. superciliosus* de 4.2, basado en el análisis de tres tiburones, siendo las categorías teleósteos y cefalópodos las que dominaron la dieta. Asimismo Moteki et al. (2001) analizaron 20 ejemplares de *A. pelagicus* de aguas japonesas, los cuales consumieron peces pelágicos de las familias Paralepididae, Phosichthyidae y Gempylidae. En Ecuador, Polo et al. (2007), hacen una descripción del alimento de *A. superciliosus* durante la época seca. Estos autores encontraron que este tiburón se alimentó principalmente de peces como: *Larimus argenteus* (Gill, 1983), *Merlucius gayi* (Guichenot, 1848) y *Benthosema panamense* (Tåning, 1932), así como de calamares *Dosidicus gigas* (Orbigny 1835) y *Sthenoteuthis oualaniesis* (Lesson, 1830), presentando una segregación alimentaria por estadio de madurez, siendo la zona costera su principal hábitat trófico. En esta misma área Rendón & Pacheco (2007) describieron la dieta de este depredadores (abarcando toda la temporada lluviosa y parte de la seca), encontrando que *A. pelagicus* presentó una dieta constituida principalmente por los calamares *D. gigas* y *S. oualaniensis* y el pez mesopelágico *B. panamense*; mientras que *A. superciliosus* mostró una mayor dominancia de teleósteos, encontrando entre las más representativas a la merluza *M. gayi*, peces de la familia Exocoetidae, el sciaenidae *L. argenteus* y el mictófido *B. panamense*.

## Materiales y Métodos

*Área de estudio*. Las muestras fueron recolectadas mensualmente de enero a octubre de 2004 en Manta, Ecuador, que se localiza en la costa del Pacífico Oriental 00º 57' LS y 80º 42' LW (Fig. 1). La captura de los tiburones fue realizada por pescadores utilizando una red de enmalle de superficie, la cual tiene 173 m de largo y una altura de 8m, con luz de malla de 140 mm (5 a 7 paños) (Martínez 1999), la cual es mantenida en el agua de 8 a 10 horas. Las embarcaciones son de fibra de vidrio con motor fuera de borda (Villon & Beltran 1999, Aguilar et al. 2007). La pesca artesanal efectúa sus maniobras de pesca entre 25-30 millas y hasta 60-90 millas naúticas. Los *Alopias* son capturados cerca del talud continental hasta a 10 brazas de profundidad (Martínez 1999, Coayla & Rivera 2008).

**Figura 1.** Ubicación de la zona de descarga de tiburones en Manta, Ecuador .

A cada tiburón se le tomó la longitud total, precaudal y se registró el sexo y estadio de madurez (maduro e inmaduro). Teniendo en cuenta la longitud de los gonopterios, grado de rotación, condición del rifiodón y presencia de semen en los machos. Los machos maduros presentaron gonopterios totalmente calcificados con una rotación mayor a 360°, el rifiodón abierto y presencia de semen. Para las hembras maduras se encontraron marcas de cópula en aletas y dorso, abertura vaginal mayor a 3 cm de diámetro y el peso del ovario mayor de 100 g (Polo et al. 2007, Castañeda & Sandoval 2004).

Los estómagos se mantuvieron congelados hasta su proceso en el laboratorio. Las presas se separaron por grupos mayores y se fijaron con formol al 10%. En el caso de los peces en estado de digestión avanzado, la determinación taxonómica se realizó con base en las características del esqueleto axial y los otolitos. Para el conteo de vértebras se utilizaron los trabajos de Clothier (1950) y Clothier & Baxter (1969), para otolitos el trabajo de García (2001); los peces en estado de digestión mínima se identificaron siguiendo a Fischer et al. (1995) y Chirichigno (1998); los crustáceos con las claves de Garth & Stephenson (1966) y los cefalópodos usando Clarke (1962, 1986) y Wolff (1982, 1984).

Para determinar si el número de estómagos fue representativo, se realizaron curvas acumulativas de diversidad de especies presa con el programa Estimate 8.0 (Jiménez-Valverde & Hortal 2003, Colwell 2006). En el análisis cuantitativo de los contenidos gástricos se utilizaron los métodos numérico (N), gravimétrico (expresado en gramos) y frecuencia de aparición (FA) propuesto por Hyslop (1980). El índice de importancia relativa (IIR) (Pinkas et al. 1971) se empleó para analizar las variaciones mensuales de la dieta por sexos y estadios de madurez. La amplitud de la dieta se determinó mediante el índice estandarizado de Levin (Krebs 1989) expresado por Labropoulou & Eleftheriou (1997) como:

$$Bi = 1/\mathrm{n} - 1[(1/\sum_{Pij}{}^{2}) - 1]$$

Donde $Bi$ = Amplitud de dieta del depredador, $Pij$ = proporción de la dieta del depredador $i$ sobre la presa $j$, $n$ = número de categorías de presas. Los valores de este índice fluctúan de 0 a 1, por debajo de 0,6 indican una dieta dominada por pocas presas, por lo tanto se trata de un depredador especialista y valores mayores a 0,6 indica que son depredadores generalistas (Krebs 1989, Labropoulou & Eleftheriou 1997). Se realizó un análisis de traslapo trófico por sexos y estadios de madurez, con el fin de determinar si existían diferencias en el tipo de alimento, utilizando el índice de Morisita-Horn (Smith & Zaret 1982) , utilizando la siguiente fórmula:

$$C\lambda = \frac{2\sum_{i-1}^{n}(Pxi * Pyi)}{(\sum_{i-1}^{n} Pxi^2 + \sum_{i-1}^{n} Pyi^2)}$$

Donde $C\lambda$ es el índice de Morisita–Horn entre sexo o estadio de madurez $x$ y entre sexo o estado de madurez $y$, $Pxi$ es la proporción de presa $i$ del total de presas consumidas por el sexo o estado de madurez $x$, $Pyi$ es la proporción de presa $i$ del total de presas consumidas por el sexo o estado de madurez $y$ y $n$ es el número total de presas. Este índice oscila entre 0 y 1, donde valores mayores a 0,6 indican un traslapo en la dieta (Langton 1982). Asimismo se utilizó la prueba estadística de ANOSIM (análisis de similitud de una vía) con el fin de determinar si la composición específica de las presas fue significativamente diferente entre sexo y estadio de madurez. ANOSIM es un procedimiento no paramétrico, análogo al análisis de varianza, que se basa en el re-muestreo multifactorial utilizando permutaciones (Clarke & Warwick 2001).

Para la comparación de las dietas en las dos épocas (seca y lluviosa) para *A. superciliosus* se tuvo en cuenta los datos obtenidos en el estudio de Polo et al. (2007) y fue evaluada mediante una tabla de contingencia teniendo en cuenta la abundancia de las presas más representativas en cada periodo. Para determinar el nivel trófico a partir de las presas encontradas en los estómagos analizados, se utilizó el método propuesto por Cortés (1999), el cual aporta información con respecto a la posición relativa de los organismos en la red trófica. Se utilizó la siguiente fórmula:

$$NT = 1 + (\sum_{j=1}^{n} DC_{ij})(NT_j)$$

Donde: *DCij* referida como la composición de la dieta, es la proporción de presas (j) en la dieta del depredador (i). *NT* = nivel trófico de las presas (j). *n* = número de grupos en el sistema. El valor del nivel trófico (TL) de los peces se consultó en el programa Fishbase (Froese & Pauly, 2007) y en el estudio de Cortés (1999).

## Resultados

Se analizó un total de 243 tiburones zorros, 103 *Alopias pelagicus* y 140 *A. superciliosus*. El número de estómagos analizados fue suficiente para describir gran parte la dieta para las dos especies, representando el 93% de la dieta y un valor de la pendiente de 0,0003 para *A. pelagicus* y un 90% con un valor de la pendiente de 0,0001 para *A. superciliosus* (Fig. 2).

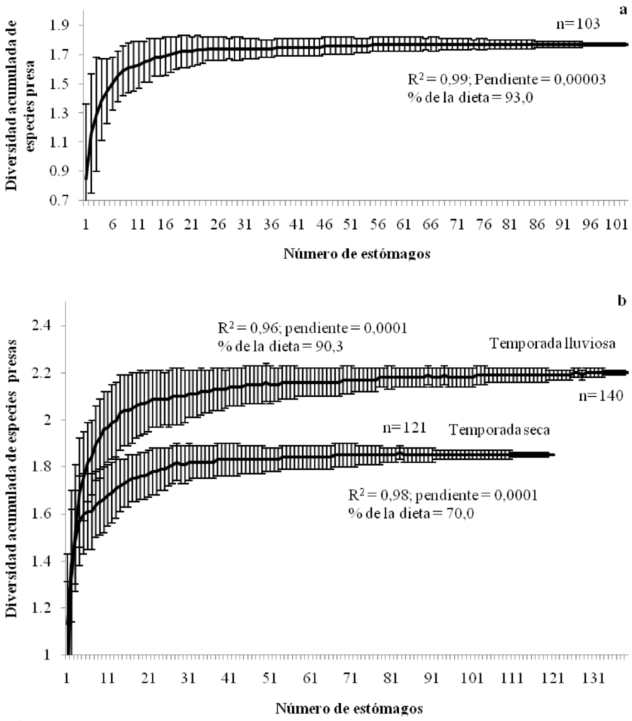

**Figura 2.** Curvas de diversidad acumulada de especies presa para los tiburones zorro (a) *A. pelagicus* y (b) *A. superciliosus* durante la temporada lluviosa y comparada con la temporada seca en Polo et al. (2007).

*Dieta y hábitos tróficos*

*Alopias pelagicus*. De 103 estómagos analizados, 94 presentaron contenido estomacal (91,3%) y 9 estuvieron vacíos (8,7%), de los cuales 42 fueron machos y 61 hembras. Se identificaron 20 especies presas, 11 fueron teleósteos y 9 cefalópodos (Tabla I). De acuerdo al IIR, las presas de mayor importancia fueron el calamar gigante *D. gigas*, registrando el 75,4%, seguido por el calamar *S. oualaniensis* con 12,4% y el pez linterna *B. panamense* con 9,2%. (Tabla I). Al analizar el tipo de alimento mensual consumido por *A. pelagicus,* se observó que esta especie se alimento de sus tres presas principales durante la época lluviosa encontrándose diferencias significativas ($X^2 = 169{,}7$, $d.f. = 6$, $\alpha < 0{,}05$) en la proporción de estas durante los 7 meses de muestreo, manteniéndose los dos calamares con las mayores abundancias (Fig. 3).

De los 61 estómagos de hembras 53 presentaron contenido estomacal, identificándose 17 presas. De acuerdo al ÍIR el calamar gigante *D. gigas* presentó 75,9%, el calamar *S. oualaniensis* con 14,3%, y el pez linterna *B. panamense* con 7,5%, apareciendo como única presa secundaria *M. gayi* (0,9%). En los 42 estómagos de machos, solo uno no presentó contenido, se encontraron 12 especies presa, las principales fueron el calamar gigante *D. gigas* con el 71,4%, el pez linterna *B. panamense* con 13,3%, y *S. oualaniensis* con el 9,5%.

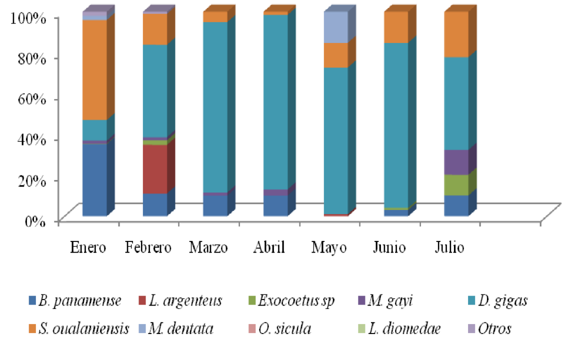

**Figura 3.** Índice de importancia relativa (IIR) de las presas principales del tiburón zorro pelágico *A. pelagicus* en Manta Ecuador durante la temporada lluviosa.

Al comparar la dieta entre organismos maduros e inmaduros, se encontró que las hembras maduras presentaron una dieta constituida por 16 presas en 43 estómagos con alimento, donde las presas más relevantes de acuerdo al IIR fueron el calamar gigante *D. gigas* (75,7%), el calamar *S. oualaniensis* (14,2%) y el pez linterna *B. panamense* (7,5%). En las hembras inmaduras se observó una dieta menos diversa conformada por seis componentes alimenticios en 10 estómagos, compartiendo las mismas presas principales que las hembras maduras: *D. gigas* (78,2%), *S. oualaniensis* (13,2 %) y *B. panamense* (7,1 %) (Fig. 4).

Los machos maduros de *A. pelagicus* mostraron un espectro conformado por nueve especies presa en 19 estómagos con alimento, donde la presa principal fue el calamar gigante *D. gigas* (97,4%); mientras que los tiburones inmaduros presentaron una dieta constituida por nueve especies en 22 estómagos con alimento. Las presas principales de los inmaduros fueron: *D. gigas* (54,7%) y el pez linterna *B. panamense* (30,5%) (Fig. 4).

De acuerdo al índice de amplitud trófica para *A. pelagicus,* se encontraron valores bajos (por debajo de 0,6), tanto a nivel general como por sexo y estadio de madurez (Tabla II), lo cual indica que esta especie de tiburón es especialista debido al mayor consumo de pocas presas como se observa en los valores porcentuales de *D. gigas*, *S. oualaniensis* y *B. panamense* tanto por sexo como por estadio de madurez.

Con respecto al índice de traslapo trófico

(Morisita-Horn), se registraron valores altos por sexo y estadio de madurez que oscilaron entre Cλ = 0,82 a 0,96, lo cual indica que consumen los mismos recursos alimenticios. Asimismo los análisis de similitud (ANOSIM) mostraron que no existieron diferencias alimenticias entre sexo y estadios de madurez (R = -0,04 a 0,12) (Tabla II). Se calculo el nivel trófico promedio para *A. pelagicus,* considerando las presas encontradas en los estómagos, obteniendo un valor de 3,9 (Tabla III).

*Alopias superciliosus*. Se analizaron un total de 140 estómagos, de los cuales 121 presentaron contenido estomacal (86,4%) y 19 estuvieron vacíos (13,6%). Se identificaron 26 especies presa, divididas en 20 teleósteos, 5 cefalópodos y 1 crustáceo (Tabla IV).

**Tabla I.** Espectro trófico del tiburón zorro pelágico *Alopias pelagicus,* en Manta Ecuador; expresado en valores absolutos y porcentuales de los métodos numérico (N), gravimétrico (P), frecuencia de aparición (FA) e índice de importancia relativa (IIR).

| Especies presa | N | %N | P (g) | % P | FA | %FA | IIR | % IIR | Hábitat |
|---|---|---|---|---|---|---|---|---|---|
| *Auxi thazard* | 3 | 0,7 | 316,7 | 0,3 | 3,0 | 3,2 | 3,2 | 0,0 | Costero- Oceánico |
| *Benthosema panamense* | 55 | 12,6 | 5,5 | 0,0 | 55,0 | 58,5 | 736,7 | 9,2 | Mesopelágico |
| Familia Exocoetidae | 4 | 0,9 | 21,9 | 0,0 | 2,0 | 2,1 | 2,0 | 0,0 | Oceánico |
| *Exocoetus* sp. | 29 | 6,6 | 139,3 | 0,1 | 10,0 | 10,6 | 72,1 | 0,9 | Oceánico |
| *Genypterus chilensis* | 1 | 0,2 | 7,7 | 0,0 | 1,0 | 1,1 | 0,3 | 0,0 | Bentónico |
| Familia Hemirrhamphidae | 1 | 0,2 | 10,4 | 0,0 | 1,0 | 1,1 | 0,3 | 0,0 | Oceánico |
| *Larimus argenteus* | 26 | 5,9 | 675,3 | 0,7 | 5,0 | 5,3 | 35,4 | 0,4 | Costero |
| *Merluccius gayi* | 19 | 4,3 | 289,7 | 0,3 | 16,0 | 17,0 | 79,1 | 1,0 | Bentónico |
| Familia Ophichthidae | 2 | 0,5 | 0,2 | 0,0 | 2,0 | 2,1 | 1,0 | 0,0 | Bentónico |
| *Ophichthus* sp. | 1 | 0,2 | 0,1 | 0,0 | 1,0 | 1,1 | 0,2 | 0,0 | Bentónico |
| *Oxiporhamphus micropterus* | 1 | 0,2 | 0,1 | 0,0 | 1,0 | 1,1 | 0,2 | 0,0 | Oceánico |
| Restos de pez | * |  | 1371,1 | 1,4 | 4,0 | 4,3 | * | * | Oceánico |
| **Subtotal** | **142** | **32,5** | **2838,0** | **2,9** | **101** | **107,4** | **930,5** | **11,6** |  |
| *Dosidicus gigas* | 211 | 48,3 | 67778,7 | 69,9 | 48,0 | 51,1 | 6034,2 | 75,4 | Oceánico |
| *Mastigoteuthis dentata* | 22 | 5,0 | 928,8 | 1,0 | 7,0 | 7,4 | 44,6 | 0,6 | Batipelágico |
| *Sthenoteutis oualaniensis* | 48 | 11,0 | 22778,8 | 23,5 | 27,0 | 28,7 | 990,1 | 12,4 | Oceánico |
| *Gonatus* sp. | 3 | 0,7 | 15,0 | 0,0 | 1,0 | 1,1 | 0,7 | 0,0 | Oceánico |
| *Loliolopsis diomedae* | 3 | 0,7 | 170,0 | 0,2 | 1,0 | 1,1 | 0,9 | 0,0 | Costero |
| *Octopodoteuthis sicula* | 2 | 0,5 | 68,5 | 0,1 | 1,0 | 1,1 | 0,6 | 0,0 | Costero |
| *Octopus* sp. | 2 | 0,5 | 7,2 | 0,0 | 1,0 | 1,1 | 0,5 | 0,0 | Bentónico |
| *Onychoteuthis banksii* | 3 | 0,7 | 18,0 | 0,0 | 1,0 | 1,1 | 0,8 | 0,0 | Oceánico |
| Restos de calamar | * | * | 2322,4 | 2.4 | 29,0 | 30.9 | * | * |  |
| **Subtotal** | **295** | **67,5** | **94146,4** | **97,1** | **117** | **124,5** | **7072,7** | **88,4** |  |
| **Total** | **437** | **100** | **96984,4** | **100** |  |  | **8003,2** | 100 |  |

**Tabla II.** Valores de amplitud trófica (Índice de Levin) y traslapo trófico (Índice de Morisita Horn) por sexo y estadio de madurez de los tiburones zorro *Alopias pelagicus* y *Alopias superciliosus* en Manta, Ecuador durante la temporada lluviosa.

|  | Tiburones | Índice estandarizado de Levin (Bi) | Índice Morisita- Horn | ANOSIM (número de in) |
|---|---|---|---|---|
|  | Hembras | 0,30 |  |  |
|  | Machos | 0,21 | 0,96 | R= -0,004, p= 0,6 |
|  | Hembras maduras | 0,30 |  |  |
| *Alopias pelagicus* | Hembras inmaduras | 0,47 | 0,60 | R= 0,124, p= 0,10 |
|  | Machos maduros | 0,21 |  |  |
|  | Machos inmaduros | 0,49 | 0,67 | R= 0,056, p = 0,20 |
|  | Hembras | 0,16 |  |  |
|  | Machos | 0,23 | 0,95 | R= 0,009, p= 0,27 |
|  | Hembras maduras | 0,17 |  |  |
| *Alopias superciliosus* | Hembras inmaduras | 0,40 | 0,96 | R= -0,04, p= 0,27 |
|  | Machos maduros | 0,21 |  |  |
|  | Machos inmaduros | 0,47 | 0,82 | R= 0,03, p = 0,34 |

Según el IIR, las presas principales fueron el pez *M. gayi* con un porcentaje del 68,7% seguido por el pez *L. argenteus* (7,9%), el calamar gigante *D. gigas* (6.2%), el pez linterna *B. panamense* (4,5%), y el pez volador *Exocoetus* sp (4,2%) (Tabla IV).

Al analizar la composición mensual de presas de *A. superciliosus*, se encontró una afinidad por cinco componentes alimenticios: *M. gayi, L. argenteus, D. gigas, B. panamense* y *Exocoetus* sp. Sin embargo en el mes de enero hubo un mayor número de presas, siendo dominada por los teleósteos: *L. argenteus, M. gayi, Exocoetus* sp. y en menor cantidad por el cefalópodo *D. gigas* (Fig. 5).

Se analizaron 66 estómagos de hembras, 58 de ellos presentaron contenido estomacal, identificándose 21 componentes alimenticios, donde las presas principales fueron: *M. gayi* con 64,1%, *B. panamense* aportando un 7,2%, *D. gigas* con 6,15%, *S. oualaniensis* con 5,4%, *Exocoetus* sp con 5,3% y *L. argenteus* con 4,7%. Asimismo se analizaron 74 estómagos de machos, donde 63 presentaron contenido estomacal y el mismo número de ítems tróficos que en las hembras, siendo las presas más importantes: *M. gayi* (70,7%), *L. argenteus* (11,2%), *D. gigas* (6,2%) y *Exocoetus* sp. (3,2%). Mediante una tabla de contingencia que incluye la abundancia numérica de las presas más relevantes comunes en los periodos de lluvia y seca, se evaluó si existía diferencias en la proporción de las presas, encontrado que si se encontró diferencias entre hembras ($X^2 = 136,4$, *d.f.* = 6, $\alpha < 0,05$) y machos ($X^2 = 95,5$, *d.f.* = 4, $\alpha < 0,05$).

Las hembras maduras de *A. superciliosus* presentaron una dieta conformada por 19 especies presa en 52 estómagos con alimento, donde las presas más importantes según el IIR fueron el pez *M. gayi* (67.0%), *B. panamense* (8,4%), *D. gigas* (7,1%), *L. argenteus* (4,6%) y *S. oualaniensis* (14,2%) (Fig. 6). En las hembras inmaduras se encontró una dieta menos diversa constituida por 7 especies presa en 6 estómagos con alimento, donde las presas de mayor importancia fueron: *S. oualaniensis* (44,3%), *Exocoetus* sp.(38,0%), *Loliolopsis diomedae* (Hoyle 1904) con 6,2% y *M. gayi* (5,3%) (Fig. 6).

Los machos maduros presentaron un espectro alimenticio conformado por 19 especies presa en 51 estómagos con alimento, siendo las presas principales *M. gayi* (70,7%), *L. argenteus* (14,6%) y *D. gigas* (8,6%) (Fig. 6); mientras que los machos inmaduros presentaron 9 especies presa en 12 estómagos con alimento, donde las presas más importantes fueron: *M. gayi* (49,5%), *Exocoetus* sp (21,1%) y *S. oualaniensis* (10%) (Fig. 6).Las tablas de contingencia aplicadas entre cada estadio de madurez para los dos periodos arrojaron diferencias significativas entre las hembras maduras ($X^2 = 44,7$, *d.f.* = 3, $\alpha < 0,05$) y machos maduros ($X^2 = 68,7$, *d.f.* = 3, $\alpha<0,05$), mientras que las hembras inmaduras no presentaron diferencias significativa ($X^2 = 4,9$, *d.f.* = 2, $\alpha > 0,08$). Para los machos inmaduros no se aplicó esta prueba debido a que no presentaron presas comunes.

El índice de amplitud trófica en el espectro trófico de *A. superciliosus* presentó valores bajos por sexo y estadio de madurez (Cλ = 0,16 a 0,47), lo cual indica que este tiburón es un depredador especialista al consumir principalmente a la merluza *M. gayi*

**Tabla III.** . Niveles tróficos de los tiburones zorro *A. pelagicus* y *A. superciliosus* por sexo y estadio de madurez, determinado a partir de los análisis de contenido estomacal para el área de Manta, Ecuador, durante la temporada lluviosa

| Especies | Grupo | TL |
|---|---|---|
| | **Promedio** | 3,9 |
| | Hembras | 3,9 |
| *A. pelagicus* | Machos | 3,8 |
| | Maduros | 4,0 |
| | Inmaduros | 3,8 |
| | **Promedio** | 3,7 |
| | Hembras | 3,4 |
| *A. superciliosus* | Machos | 3,7 |
| | Maduros | 3,8 |
| | Inmaduros | 3,8 |

Al aplicar el índice de traslapo trófico (Morisita- Horn) se registraron valores altos por sexo y estadios de madurez, oscilando entre Cλ = 0,60 a 0,96, indicando que se alimentan de recursos alimenticios similares. Sin embargo, los valores por estadios de madurez son menores a los encontrados en la misma categoría en *A. pelagicus*, de igual forma los análisis de similitud (ANOSIM) corroboraron lo anteriormente encontrado al no observarse diferencias significativas entre sexo y estadios de madurez (R = -0,04 a 0,009) (Tabla II). La determinación del nivel trófico promedio calculado en *A. superciliosus* fue de 3,7 (Tabla III).

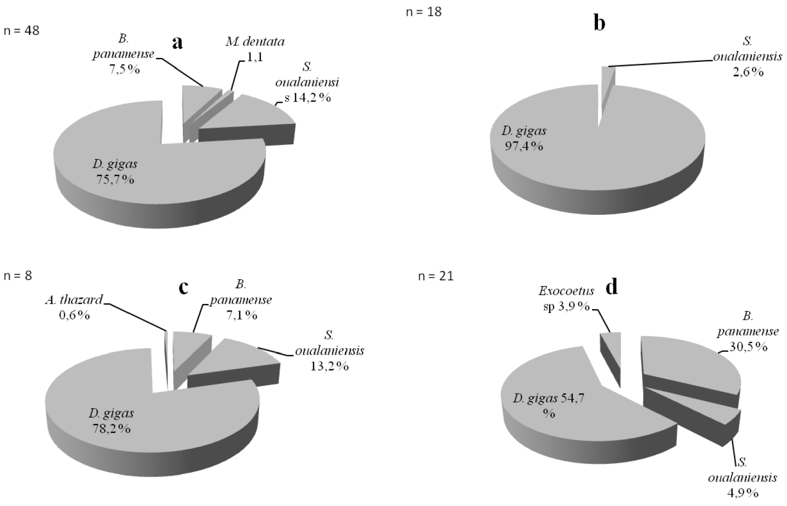

**Figura 4.** Índice de importancia relativa (IIR) de las presas principales de las (**a**) hembras maduras, (**b**) machos maduros, (**c**) hembras inmaduras y (**d**) machos inmaduros del tiburón zorro *Alopias pelagicus* en Manta, Ecuador durante la temporada lluviosa.

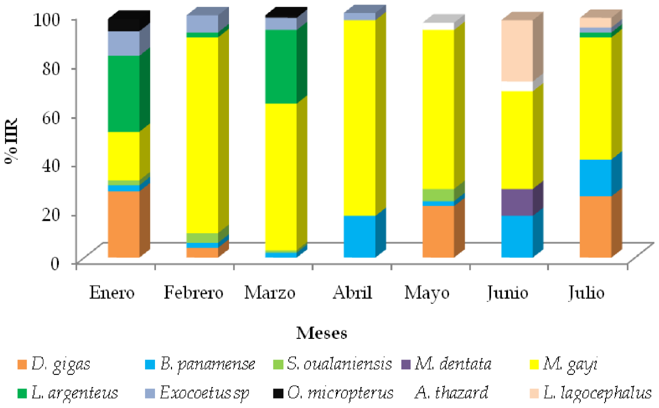

**Figura 5.** Índice de importancia relativa (IIR) de las presas principales del tiburón zorro *Alopias superciliosus* en Manta, Ecuador durante la temporada lluviosa

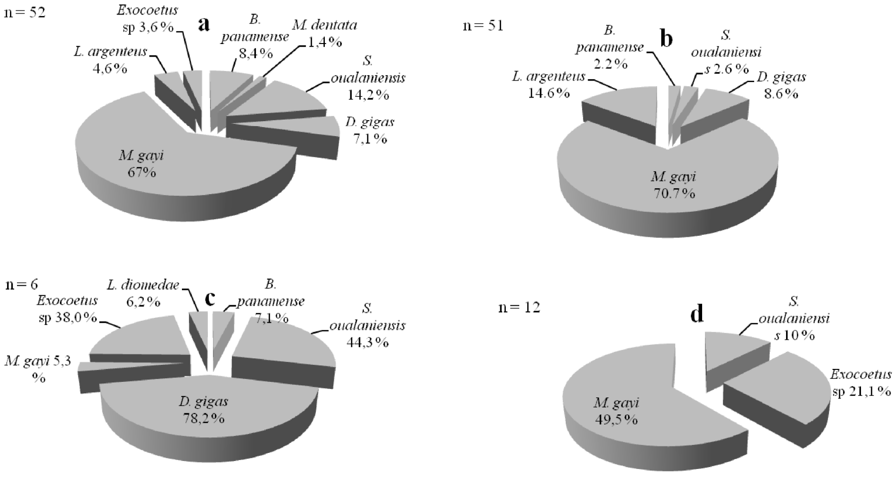

**Figura 6.** Índice de importancia relativa (IIR) de las presas principales de las (**a**) hembras maduras, (**b**) machos maduros, (**c**) hembras inmaduras y (**d**) machos inmaduros del tiburón zorro *Alopias superciliosus* en Manta, Ecuador durante la temporada lluviosa.

**Tabla IV.** Dieta de los tiburones zorro *Alopias superciliosus,* en Manta Ecuador, durante la temporada lluviosa y seca; expresado en valores porcentuales de los métodos numérico (N), gravimétrico (P), frecuencia de aparición (FA), índice de importancia relativa y características de hábitat de las presas. Morftipos 2 y 3 pertenecen a la familia Ophichthidae

| | *Alopias superciliosus* (temporada lluviosa) | | | | *Alopias superciliosus* (temporada seca) (Polo et al 2007) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 121 estómagos con alimento | | | | 107 estómagos con alimento | | | | |
| **Especies presa** | **%N** | **% Peso** | **%FA** | **% IIR** | **%N** | **% Peso** | **%FA** | **% IIR** | **Hábitat** |
| *Sardinop sagax* | 0,2 | 0,1 | 0,8 | 0,0 | 9,2 | 2,6 | 7,3 | 3,0 | Costero |
| *Larimus argenteus* | 13,2 | 4,4 | 19,0 | 7,9 | 31,0 | 15,0 | 39,0 | 58,4 | Costero |
| *Brotula clarkae* | 2,0 | 0,1 | 1,1 | <0,1 | | | | | Bentónico |
| *Exocoetus* sp | 8,4 | 0,9 | 19,0 | 4,2 | | | | | Oceánico |
| *Oxyporhamphus micropterus* | 4,6 | 0,5 | 2,5 | 0,3 | | | | | Oceánico |
| *Coryphaena hippurus* | 0,2 | 1,3 | 0,8 | <0,1 | 0,2 | 0,1 | 1,0 | <0,1 | Oceánico |
| *Hemanthias signifer* | | | | | 0,1 | 0,6 | 1,0 | <0,1 | Bentónico |
| *Auxis thazard* | 2,0 | 2,4 | 8,3 | 0,9 | 1,6 | 3,2 | 14,0 | 2,5 | Costero- Oceánico |
| *Benthosema panamense* | 7,6 | 0,1 | 24,8 | 4,5 | 38,0 | 0,3 | 6,3 | 9,3 | Mesopelágico |
| *Fodiatur acutus* | 0,2 | <0,1 | 0,8 | <0,1 | | | | | Costero |
| Familia Lutjanidae | | | | | 0,1 | <0,1 | 1,0 | <0,1 | Costero |
| *Ophichthus* sp | | | | | 0,1 | 0,1 | 1,0 | <0,1 | Bentónico |
| *Morfotipo 2* | | | | | 0,1 | <0,1 | 1,0 | <0,1 | Bentónico |
| *Morfotipo 3* | | | | | 0,4 | 0,1 | 2,1 | <0,1 | Bentónico |
| *Merluccis gayi* | 33,1 | 10,1 | 67,8 | 68,7 | 9,2 | 5,3 | 28,0 | 13,0 | Bentónico |
| *Lagocephalus lagocephalus* | 1,6 | 2,2 | 4,1 | 0,4 | 0,2 | 0,4 | 2,1 | <0,1 | Oceánico |
| *Paralichthys* sp. | 0,2 | <0,1 | 0,8 | <0,1 | | | | | |

**Tabla IV (Cont.).**

| | *Alopias superciliosus* (temporada lluviosa) | | | | *Alopias superciliosus*(temporada seca) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 121 estómagos con alimento | | | | 107 estómagos con alimento | | | | |
| **Especies presa** | **%N** | **% Peso** | **%FA** | **% IIR** | **%N** | **% Peso** | **%FA** | **% IIR** | **Hábitat** |
| *Remora remora* | | | | | 0,1 | <0,1 | 1,0 | <0,1 | Oceánico |
| *Umbrina bussingi* | 1,0 | 0,1 | 3,3 | 0,1 | | | | | Costero |
| *Fistularia corneta* | 0,4 | 0,6 | 1,7 | <0,1 | 0,1 | 0,1 | 1,0 | <0,1 | Costero |
| *Katsuwonus pelamis* | 0,4 | 0,9 | 1,7 | <0,1 | 0,1 | <0,1 | 1,0 | <0,1 | Oceánico |
| Familia Hemirramphidae | 1,4 | <0,1 | 3,3 | 0,1 | | | | | Costero |
| Familia Ophichthidae | 0,2 | <0,1 | 0,8 | <0,1 | | | | | Bentónico |
| Familia Exocoetidae | 14,0 | 1,2 | 9,1 | 3,3 | 0,1 | <0,1 | 1,0 | <0,1 | Oceánico |
| Familia Trachipteridae | | | | | 0,1 | <0,1 | 1,0 | <0,1 | Mesopelágico |
| Familia Scorpaenidae | | | | | 0,1 | <0,1 | 1,0 | <0,1 | Bentónico |
| *Ablennes hians* | 0,2 | 0,7 | 0,8 | <0,1 | 0,6 | 1,0 | 1,0 | 0,1 | Oceánico |
| *Pontinus sierra* | 1,4 | 0,1 | 5,0 | 0,2 | | | | | Bentónico |
| *Dosidicus gigas* | 4,0 | 31,5 | 7,4 | 6,2 | 2,4 | 44,0 | 12,0 | 11,0 | Oceánico |
| *Sthenoteuthis oulaniensis* | 2,0 | 17,3 | 5,0 | 2,2 | 0,5 | 23,0 | 2,1 | 1,0 | Oceánico |
| *Abraliopsis affinis* | | | | | 2,5 | <0,1 | 4,2 | 0,4 | Oceánico |
| *Ancistrocheirus lesueurii* | | | | | 2,0 | 14,6 | 15,0 | 1,1 | Oceánico |
| *Loliolopsis diomedae* | 0,2 | 0,1 | 0,8 | <0,1 | | | | | Costero |
| *Octopodoteuthis sícula* | | | | | 0,2 | <0,1 | 1,0 | <0,1 | Oceánico |
| *Histioteuthis* sp | 0,2 | 0,1 | 0,8 | <0,1 | 0,1 | <0,1 | 1,0 | <0,1 | Oceánico |
| *Mastigoteuthis dentata* | 2,6 | 2,4 | 8,3 | 1,0 | 0,4 | <0,1 | 1,0 | <0,1 | Batipelágico |
| *Xiphopenaeus riveti* | 0,4 | <0,1 | 0,8 | <0,1 | | | | | Bentónico |
| *Solenocera agassizi* | | | | | 0,1 | <0,1 | 1,0 | <0,1 | Bentónico |

## Discusión

*Análisis del número de muestras.*

Al analizar las curvas acumulativas de diversidad de presas de las dos especies de tiburón zorro, se observó que el número de estómagos analizados fue suficiente para representar la dieta de ambos tiburones. En *A. pelagicus* la curva alcanza la asíntota alrededor de los 94 estómagos; mientras que en *A. superciliosus* la estabilización de la curva se alcanzó alrededor de los 129 estómagos. Sin embargo al comparar la información de la dieta de *A. superciliosus* de la época seca (Polo *et al*. 2007), se puede observar que el valor máximo de diversidad alcanzado fue menor (1,85) comparado con el obtenido en el presente estudio (2.2) (Fig. 2), lo cual este posiblemente influenciado por el mayor número de estómagos colectados durante el periodo de lluvias (140); en comparación a la temporada seca (121) (Polo *et al*. 2007). Sin embargo se observaron las mismas presas dominantes en ambos periodos de estudio, en la cual sobresale la merluza *M. gayi* y el pez sciaenido *L. argenteus*. Los dos depredadores en términos globales mostraron una dieta bastante diversa, compartiendo cierto tipo de presas que alternaron su importancia tiendo en cuenta las características del hábitat que presenta cada tiburón.

*Análisis de los componentes tróficos*

*Alopias pelagicus*. Este depredador mostró una dieta dominada por presas de hábitos oceánicos, principalmente los calamares *D. gigas* y *S. oualaniensis*, las cuales son especies pertenecientes a la familia Ommastrephidae, caracterizada por tener una amplia distribución en todo el Pacifico Oriental, distribuyéndose aproximadamente entre 40° N y 45° S (Nigmatulin et al. 2001). *D. gigas* se desplaza en grandes grupos y viven en aguas oceánicas profundas, se acercan a la costa cuando realizan migraciones verticales con fines alimenticios o reproductivos, lo cual depende del estado de madurez de los organismos, así como de la hora del día. Los juveniles realizan migraciones hacia la superficie durante la noche para alimentarse; mientras que los adultos migran, pero se mantienen entre 10 y 35 m durante la noche. Tanto los juveniles como los adultos de *D. gigas* migran hacia las profundidades (>700 m), cuando esta amaneciendo, haciéndose menos vulnerables a los depredadores (Markaida & Sosa 2003). Por ello la presencia de estas presas en la dieta de *A. pelagicus* puede ser debido a que se encuentran dentro del área de distribución de los calamares. Además existe evidencia en otras áreas geográficas y para otras especies de tiburones, que los calamares juveniles pueden constituir gran parte de su dieta (Aguilar-Castro & Galván-Magaña 2003).

La tercer presa principal dentro de la dieta de *A. pelagicus* fue el pez linterna *B. panamense* de la familia Myctophidae, la cual se caracteriza por encontrarse entre los 300 y 1500 m de profundidad durante el día; son mesopelágicos activos que son comunes en la superficie durante la noche, siendo este patrón reportado para otras especies en diferentes regiones (Armstrong & Prosch 1991, Compagno 2005, Cornejo & Koppelman 2006). Además existen evidencias de una alta dominancia de esta familia de peces mesopelágicos en aguas del Pacífico oriental tropical cercanas a Perú y Chile, debido a la elevada disponibilidad de alimento (zooplancton) (Ayón & Giron 1997, Brodeur & Yamamura 2005). Cabe resaltar que los mictófidos (principalmente *Benthosema panamense*) son las presas principales del calamar gigante *D. gigas* en el Golfo de California, México. Asimismo en aguas peruanas *D. gigas* se alimenta de peces mesopelágicos (Carvajal 2009), lo cual puede ser debido a que esta especie de cefalópodo prefiere presas que formen grandes cardúmenes, característica típica de estos peces (Shchetinnikov 1989, Nigmatilum et al. 2001; Markaida & Sosa, 2003), permitiendo explicar la mayor presencia de esta presa en la dieta del tiburón *A. pelagicus* al compartir el mismo hábitat en aguas oceánicas. Es importante resaltar la información de la dieta de *A. pelagicus*, del presente estudio, debido a que no se conoce información trófica de esta especie en las zonas en las cuales se distribuye (Smith et al. 2008).

*Alopias superciliosus*. Este tiburón presentó una dieta constituida principalmente por especies bentónicas, costeras y algunas oceánicas, lo cual permite inferir que este depredador tiende a migrar entre las zonas costeras y oceánicas en busca de alimento. La merluza *M. gayi* ocupó el primer lugar en la dieta de *A. superciliosus*. La merluza es un pez demersal que se encuentra entre la zona somera de la plataforma continental (80 m) hasta las región superior del talud (500 m. de profundidad) y se alimenta de invertebrados (Cohen 1990). Esta especie se caracteriza por realizar migraciones verticales para consumir especies pelágicas durante la noche, principalmente peces, calamares y eufausidos (Nakamura et al. 1986, Arancibia 1987, Stobberup 1992, Castillo et al. 1996).

La presencia importante de la merluza *M. gayi* en la dieta de *A. superciliosus,* permite deducir que este tiburón tiende a realizar migraciones cerca del bentos en busca de las merluzas, ya que es un tiburón de gran capacidad para hacer buceos y se han registrado sus movimientos verticales con marcas satelitales, en los cuales permanece durante el día entre 400 y 500 m; mientras que en la noche se encuentra entre 10 y 50 m en aguas cercanas a Hawaii. Asimismo en el Golfo de México presento un comportamiento muy similar, pero la profundidad en la que se encontró durante la noche fue de 10 a 100 m; mientras que en el día se mantenía entre 300 y 500 m (Weng & Block 2004).

La segunda presa principal dentro de la dieta de este depredador fue el pez *L. argenteus*, especie que se caracteriza por encontrarse en fondos por encima de los 100 m y habita sustratos blandos de la plataforma continental en regiones tropicales y subtropicales (Chirichigno 1998). Esta presa también fue registrada por Polo et al (2007) en *A. superciliosus* durante la época de secas. Las otras especies menos importantes de *A. superciliosus* fueron: *D. gigas,* el mictófido *B. panamense* y el pez volador *Exocoetus* sp, lo que podría indicar que este tiburón permaneció más tiempo en la zona costera alimentándose de presas bentónicas como la merluza. Esto se corrobora con lo encontrado por Polo et al. (2007), aunque el porcentaje de *L. argenteus* fue mayor al encontrado en el presente estudio, debido probablemente a la mayor abundancia de esta presa durante los primeros meses de la temporada seca (Polo et al. 2007).

*Análisis trófico mensual*. Se observó que *A. pelagicus* mantuvo su afinidad por las tres presas principales *D. gigas*, *S. oualaniensis* y *B. panamense*, lo cual indica una preferencia por estas presas durante el tiempo del estudio (época lluviosa). La presa más importante para este tiburón *D. gigas*, es un cefalópodo que se captura comercialmente durante todo el año en aguas al norte de Perú, donde las capturas promedio mensual en 2009 son de 16 000 toneladas y una captura total en 2008 de 301 mil toneladas (Carvajal 2009), por ello podría ser la presa más importante para *A. pelagicus* en aguas oceánicas, No se conoce la abundancia de *S. oualaniensis* y *B. panamense* debido a que no son especies comerciales; sin embargo se conoce una gran abundancia de peces mesopelágicos en la zona de Perú y Chile (Ayón & Giron 1997, Brodeur & Yamamura 2005

Para *A. superciliosus* se observaron fluctuaciones mensuales en la dieta, lo cual coincide en las capturas mensuales de esta especie a nivel comercial, donde es menor la captura en los meses de enero a marzo, e incrementándose de abril a mayo (Caccha, 2009). Esta abundancia de merluza registrada en las capturas indica que puede soportar el consumo mensual de sus depredadores en estas áreas geográficas. La merluza (*M. gayi*) es una especie comercial de gran demanda en el norte de aguas peruanas y se capturan en promedio mensual 3 mil toneladas con un limite de cuota de 45000 toneladas anuales (Caccha, 2009). Esta especie es la de mayor captura en aguas peruanas, lo que podría indicar capturas similares en aguas ecuatorianas. En los meses de enero a marzo *A. superciliosus* se alimento en la zona costera, corroborado por la alta abundancia de *M. gayi* y *L. argenteus* en su dieta, mientras que de abril a septiembre este tiburón prefirió alternar sus zonas de alimentación entre la zona costera y oceánica confirmado por el incremento de *D. gigas*, *B. panamense* y *S. oualaniensis*. En sus estómagos.

*Análisis trófico por sexos y estadios de madurez*. Se observó que tanto hembras como machos de ambas especies mantienen preferencia por las mismas especies presas importantes; sin embargo las hembras presentaron un mayor número de componentes tróficos. En *A. pelagicus* las hembras presentaron una dieta más variada (17 presas) en comparación a los machos (12). En *A. superciliosus* las hembras presentaron 22 presas en comparación con los machos (13 presas), lo cual indica que las hembras tienen requerimientos energéticos diferentes a los machos. Este patrón también ha sido observado en otras especies de tiburones como *Carcharhinus plumbeus*, *C. falciformis* y *Mustelus schmitti* (Van der Molen & Caille 2001, McElroy et al. 2006). Al comparar estos resultados con los obtenidos por Polo et al. (2007) se encontró que registraron las mismas presas principales en ambos sexos de esta especie de tiburón; sin embargo las hembras mantienen el mismo comportamiento durante todo el año alimentándose en la zona costera y oceánica, mientras que los machos consumieron *L. argenteus* y *M. gayi*, lo cual indica una mayor afinidad de alimentarse en aguas costeras. De igual forma las diferencias estadísticas arrojadas por las tablas de contingencia entre las presas comunes consumidas por este depredador en ambos periodos corrobora lo anteriormente descrito, siendo notorio que durante la temporada seca se presentó un mayor consumo de *L. argenteus* y *B. panamense*, (Polo et al. (2007), mientras que durante la temporada lluviosa la presa de mayor consumo fue *M. gayi*.

Con respecto al estadio de madurez, se observo que los tiburones adultos de ambas especies presentaron una dieta con un mayor número de presas en comparación a los individuos inmaduros. En *A pelagicus*, las presas principales provienen de hábitat oceánico (Matallanas 1982, Stillwell & Kohler 1982, Lyle 1983, Watson 1996, Nigmatilum et al. 2001, Markaida & Sosa, 2003, Cornejo & Koppelman, 2006) corroborando la constancia de este depredador de alimentarse en esta zona. En *A.*

superciliosus las hembras y los machos maduros consumieron más presas de áreas costeras (*M. gayi* y *L. argenteus*) y oceánicas (*D. gigas, B. panamense* y *S. oualaniensis*), mientras que las hembras inmaduras presentaron un mayor consumo de presas oceánicas, corroborado por la alta importancia del calamar *S. oualaniensis* y el pez volador *Exocoetus* sp. Los machos inmaduros presentaron preferencia por presas más costeras-bentónicas como el pez *M. gayi* el cual ocupo el 50% de su dieta. En muchas especies de tiburones los cambios ontogénicos han sido reportados cuando se comparan entre estadios de madurez e intervalos de talla (Cortés & Gruber 1990, Wetherbee & Cortés 2004). El aumento de la talla y el desarrollo gonadal de los depredadores promueven cambios en su dieta, debido al incremento de patrones de movimiento, velocidad de nado, crecimiento de dientes, requerimientos energéticos y selección de hábitat (Wetherbee et al. 1990, Cortés & Gruber 1990, Lowe et al. 1996, Simpfendorfer et al. 2001, Alonso et al. 2002, Wetherbee & Córtes, 2004). Los tiburones maduros presentaron una dieta constituida por peces y calamares, los cuales equilibran sus requerimientos calóricos, considerando que los cefalópodos presentan bajo contenido de energía; mientras que los peces almacenan más lípidos en sus vísceras y músculo aportando mayores densidades energéticas a los depredadores (Grove et al. 1978, Olson & Galván, 2002).

### *Análisis de los índices ecológicos*

*Amplitud trófica*. Los valores del índice de amplitud trófica para *A. pelagicus* y *A. superciliosus* fueron bajos por sexo y estadios de madurez permitiendo catalogar a estos depredadores como especialistas durante la época lluviosa, debido al mayor consumo de pocas presas que ocupan los mayores porcentajes de su espectro trófico. Al comparar nuestros resultados en *A. superciliosus* con los reportados por Polo et al. (2007), durante la temporada seca encontraron resultados similares, con valores bajos (*Bi* = 0,06 a 0,49) por sexo y estadio de madurez, lo que permite inferir que esta especie de tiburón mantiene una selectividad de presas en cada época, influenciada por la disponibilidad de dichas presas.

*Traslapo trófico*. El índice de traslapo y el análisis de similitud confirmaron que estos depredadores no presentaron segregación alimenticia por sexo ni estadios de madurez en cada una de las especies; sin embargo al comparar entre las dos especies de tiburones zorros, se encuentra que no hay traslape ($C\lambda = 0,3$), debido principalmente a que consumen a sus presas en hábitats diferentes, lo cual indicaría que no hay una competencia por los recursos tróficos de ambos depredadores. *A. pelagicus* consume a sus presas en zonas oceánicas (epipelágicas) y probablemente lo hace durante la noche cuando los calamares y peces mesopelágicos realizan su migración vertical hacia la superficie; en cambio *A. superciliosus* tiende a bajar hacia aguas profundas (200-400 m) para consumir a la merluza.

Es probable que *A. pelagicus* no resista cambios en la temperatura del agua debido a su menor tamaño (2 m LT en promedio), comparado con las otras dos especies que son de mayor tamaño (hasta 4 metros). Estos cambios en la temperatura del agua los pueden soportar debido a un órgano termorregulador que permite que puedan bucear en aguas profundas (Carey et al., 1985, Goldman, 2005). Weng y Block (2004), descubrieron un órgano termorregulador cerca del ojo de *A. superciliosus*, lo cual sugiere que mantienen un calor metabólico en el ojo y el cerebro para soportar cambios en la temperatura del agua durante las migraciones verticales hacia aguas profundas en búsqueda de presas bentónicas o mesopelágicas.

*Nivel trófico*. El nivel trófico para las dos especies de tiburones permite ubicarlos en la red trófica como carnívoros secundarios-terciario para esta zona del Pacífico ecuatorial, siendo notorio que presentan posiciones tróficas muy cercanas, aunque el nivel trófico de *A. pelagicus* (NT = 3,9) fue mayor que el de *A. superciliosus* (NT = 3,7), tal vez influenciado por el mayor consumo de calamares y otras especies de alto nivel trófico. Asimismo es evidente que las dos especies tiburones presentan una dieta mixta constituida por cefalópodos y teleósteos de niveles tróficos altos e intermedios (3,2 y 3,24 NT, Cortés 1999). *A. pelagicus* presentó una mayor afinidad por los cefalópodos; mientras que *A. superciliosus* consumió principalmente peces como *M. gayi*, *L. argenteus* y *Exocoetus* sp. Es probable que los menores valores (NT =3,7) encontrados en *A. superciliosus* están influenciados por la presencia del pez volador del genero *Exocoetus* sp ya que esta especie se alimenta de peces planctónicos (Watson 1996), los cuales son catalogados como consumidores de segundo orden, conduciendo en la disminución del nivel trófico de *A. superciliosus*.

Cortés (1999), reportó un nivel trófico de 4,2 para *A. superciliosus* en California, siendo un valor mayor al reportado en el presente estudio debido probablemente a la dieta mixta (cefalópodos y teleósteos) que consumió este tiburón en esa zona donde la trama trófica podría tener presas de mayor nivel trófico que las encontradas en el Pacífico ecuatoriano, permitiendo deducir que esta dieta mixta encontrada para esta especie se mantiene en diferentes áreas geográficas.

*A. superciliosus* presentó una dieta más diversa que *A. pelagicus*, permitiendo deducir que a pesar de ser especies simpátricas que comparten varias especies presa tienen afinidades o preferencias alimentarias diferentes, las cuales pueden variar estacionalmente como fue el caso de *A. superciliosus* en la época seca, el cual se alimento en mayor proporción del pez costero *L. argenteus* (Polo et al. 2007); mientras que en la temporada lluviosa incrementó el consumo de la merluza *M. gayi*. Asimismo, se podría afirmar que estas dos especies presa (*L. argenteus* y *M. gayi*) son preferidas por este depredador en esta área del Pacífico ecuatoriano; sin embargo cuando la disponibilidad de presas cambia debido a las condiciones oceanográficas tienden a remplazar el consumo de las presas.

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# Polychromatism in the thornback ray, *Raja clavata* (Chondrichthyes: Rajidae) off northern Tunisian coast (central Mediterranean)

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**Abstract.** Colour pattern changes in dorsal surface of thornback ray *Raja clavata* Linnaeus 1758 allowed to record seven different types among specimens caught off northern coast of Tunisia which are presented in this paper.

**Keywords:** Morphomeric measurements, meristic counts, Aloncle's line, nictitating lamellae, taxonomy.

**Resumen. Policromatismo en la raya de clavos *Raja clavata* (Chondrichthyes: Rajidae) aguas fuera de la costa norte de Túnez (Mediterráneo Central).** Cambios en el patrón de coloración de la superficie dorsal de la raya de clavos *Raja clavata* Linnaeus 1758 permitió registrar siete tipos diferentes entre especimenes capturados aguas fuera de la costa de Túnez, los cuales son presentados en este trabajo.

**Palabras-Clave:** Mediciones morfométricas, cuenteo merístico, línea de Aloncle, lamellae nictitante, taxonomía.

Diversity of coloration patterns or polychromatism was previously reported in batoid species such as torpedinids (Cadenat *et al.* 1978, Capapé & Desoutter 1980, 1981, Fechhelm & McEachran 1984, Capapé *et al.* 2006,), rajids (Aloncle 1966, Capapé *et al.* 1980, McEachran and Matheson, 1985), dasyatids (Capapé & Desoutter 1990) and potamotrygonids (Almeida *et al.* 2002, 2003). For instance, polychromatism in the thornback ray *Raja clavata* Linnaeus 1758 caused misidentifications with the close relative species *R. maderensis* Lowe 1887 according to Lozano Rey (1928) and Aloncle (1966).

The latter noted that a thornback ray captured in southern Moroccan waters and deposited in the Ichthyological Collection of the Institut Scientifique Chérifien of Rabat (Morocco) was wrongly identified as *R. maderensis*. Consequently, Aloncle (1966) described four types of colour patterns in *R. clavata* from Moroccan waters.

*Raja clavata* is rather commonly landed in Tunisian fishing sites, even if it is locally considered as by-catch species (Bradaï *et al.* 2004, Mnasri 2008). Observations made on specimens caught off Bizerte, city located in northern Tunisia showed changes in colour patterns of the dorsal surface. These specimens are described in the present paper and compared with those of Aloncle (1966), in order to improve the knowledge on both morphology and systematics of the species.

Thornback rays were collected during investigations conducted off Bizerte (northern Tunisia) from September 2006 to June 2009. They were identified as *Raja clavata* following Clark (1926), Tortonese (1956), Quignard (1965), Bini (1967), Quéro *et al.* (2003) and Hemida (2005). In all 64 specimens were caught by trawlers using demersal gill-nets at depths between 150 and 300 m, on sandy-muddy or rocky bottoms. The disc width specimens were measured to the nearest mm following Clark (1926), Mejri *et al.* (2004) and Mnasri et *al.* (2009), clasper length following Collenot (1969), and weighed to the nearest gramme, while meristic counts were carried out following Quignard (1965), Capapé & Quignard (1981) and Mnasri *et al.* (2009). Morphometric measurements and meristic counts were carried out in 7 specimens (summarized in Table I) showed different colour patterns and were arbitrary divided in 7 types, according to colour of dorsal surface and, especially, morphology and arrangement of ornamentation. For each type, we give the number of observed specimens (n). They were preserved in 5 % buffered form aline and deposited in the Ichthyological Collection of the Faculté des Sciences of Bizerte (Tunisia) under the catalogue numbers, FSB- Raj- clav 01 to FSB- Raj- clav 07.

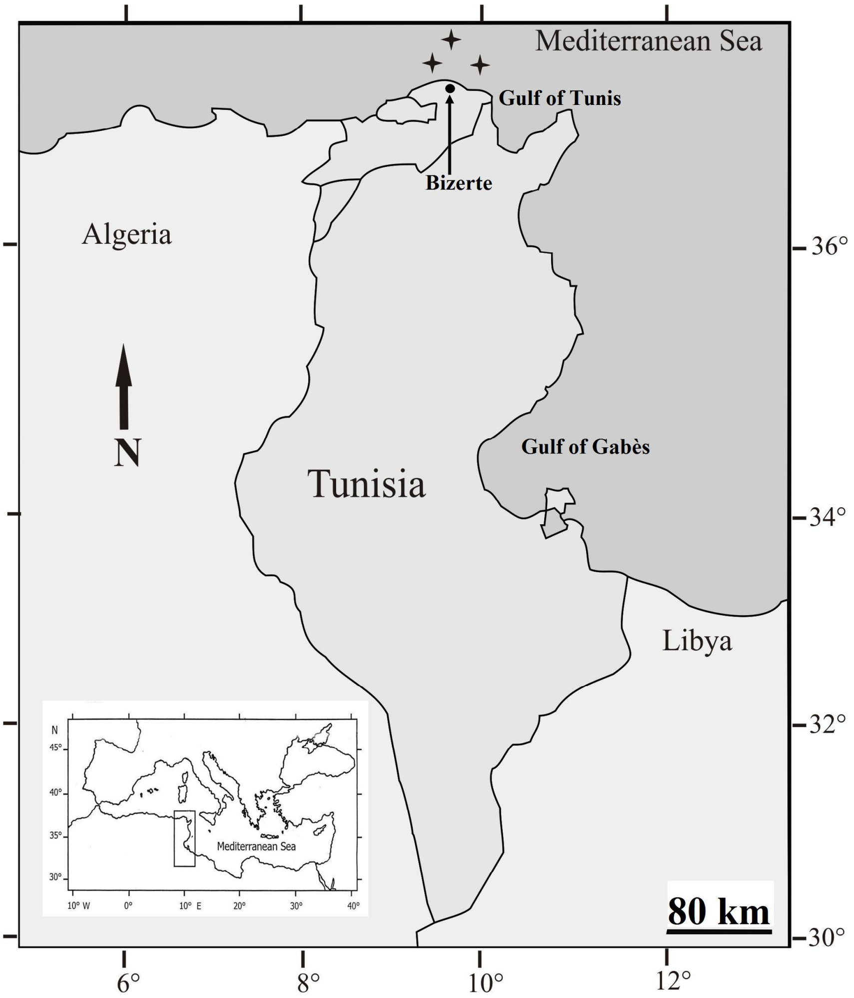

**Figure1.** Map of Tunisia showing the capture sites (black stars) of *Raja clavata* off Bizerte (northern Tunisia),

**Table I.** Morphomeric measurements and meristic counts carried out in seven types of polychromatism in *Raja clavata* from the northern Tunisian coast.

| **References** | **FSB- Raj-clav-01** | | **FSB- Raj-clav-02** | | **FSB- Raj-clav-03** | | **FSB- Raj-clav-04** | | **FSB- Raj-clav-05** | | **FSB- Raj-clav-06** | | **FSB- Raj-clav-07** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total mass (g) | 162 | | 2028.4 | | 2321.4 | | 1395.6 | | 310 | | 1184.2 | | 1263 | |
| Measurements | mm | %DW | mm | %DW | mm | %DW | mm | %DW | mm | %DW | mm | %DW | mm | %DW |
| Total length | 635 | 157.6 | 734 | 156.2 | 794 | 139.3 | 715 | 152.8 | 790 | 177.5 | 570 | 144.7 | 690 | 164.3 |
| Disc-length | 302 | 74.9 | 315 | 67 | 415 | 72.8 | 360 | 76.9 | 391 | 87.9 | 275 | 69.8 | 335 | 79.8 |
| Disc-width (DW) | 403 | 100 | 470 | 100 | 570 | 100 | 468 | 100 | 445 | 100 | 394 | 100 | 420 | 100 |
| Disc-depth | 32 | 7.9 | 28 | 6 | 48 | 8.4 | 29 | 6.2 | 35 | 7.9 | 28 | 7.1 | 27 | 6.4 |
| Eyball length | 18 | 4.5 | 23 | 4.9 | 23 | 4 | 23 | 4.9 | 23 | 5.2 | 19.5 | 4.9 | 20 | 4.8 |
| Cornea | 15 | 3.7 | 18 | 3.8 | 16 | 2.8 | 16 | 3.4 | 17 | 3.8 | 15 | 3.8 | 15 | 3.6 |
| Pre-orbital length | 75 | 18.6 | 83 | 17.7 | 96 | 16.8 | 97 | 20.7 | 95 | 21.3 | 72 | 18.3 | 83 | 19.8 |
| Inter-orbital width | 26 | 6.5 | 35 | 7.4 | 40 | 7 | 33 | 7.1 | 39 | 8.8 | 28 | 7.1 | 33 | 7.9 |
| Spiracle length | 17 | 4.2 | 22 | 4.7 | 27 | 4.7 | 21 | 4.5 | 23 | 5.2 | 17 | 4.3 | 23 | 5.5 |
| Spiracle width | 13 | 3.2 | 13 | 2.8 | 17 | 3.0 | 10 | 2.1 | 18 | 4 | 11 | 2.8 | 12 | 2.9 |
| Inter-nasal width | 51 | 12.7 | 52 | 11.1 | 65 | 11.4 | 59 | 12.6 | 65 | 14.6 | 43 | 10.9 | 50 | 11.9 |
| Nasal curtain | 54 | 13.4 | 65 | 13.8 | 68 | 11.9 | 65 | 13.9 | 72 | 16.2 | 51 | 12.9 | 55 | 13.1 |
| Interspiracular width | 38 | 9.4 | 45 | 9.6 | 54 | 9.5 | 45 | 9.6 | 52 | 11.7 | 39 | 9.9 | 42 | 10 |
| Pre-oral length | 75 | 18.6 | 73 | 15.5 | 86 | 15.1 | 83 | 17.7 | 88 | 19.8 | 59 | 15 | 70 | 16.7 |
| Mouth width | 46 | 11.4 | 58 | 12.3 | 63 | 11.1 | 53 | 11.3 | 60 | 13.5 | 47 | 11.9 | 53 | 12.6 |
| First gill slit | 12 | 3 | 18 | 3.8 | 21 | 3.7 | 17 | 3.6 | 19 | 4.3 | 13 | 3.3 | 17 | 4 |
| Second gill slit | 12 | 3 | 17 | 3.6 | 22 | 3.9 | 16 | 3.4 | 21 | 4.7 | 14 | 3.6 | 17 | 4 |
| Third gill slit | 14 | 3.5 | 18 | 3.8 | 21 | 3.7 | 16 | 3.4 | 20 | 4.5 | 13 | 3.3 | 17 | 4 |
| Forth gill slit | 14 | 3.5 | 18 | 3.8 | 20 | 3.5 | 15 | 3.2 | 18 | 4 | 13 | 3.3 | 15 | 3.6 |
| Fifth gill slit | 12 | 3 | 16 | 3.4 | 15 | 2.6 | 14 | 3 | 14 | 3.1 | 11 | 2.8 | 10 | 2.4 |
| Width between first gill slit | 89 | 22.1 | 98 | 20.9 | 125 | 21.9 | 110 | 23.5 | 121 | 27.2 | 79 | 20.1 | 93 | 22.1 |
| Width between fifth gill slit | 45 | 11.2 | 44 | 9.4 | 63 | 11.1 | 55 | 11.8 | 66 | 14.8 | 39 | 9.9 | 44 | 10.5 |
| Snout tip to eye | 89 | 22.1 | 96 | 20.4 | 110 | 19.3 | 107 | 22.9 | 105 | 23.6 | 80 | 20.3 | 93 | 22.1 |
| Snout tip to mouth | 85 | 21.1 | 85 | 18.1 | 101 | 17.7 | 100 | 21.4 | 100 | 22.5 | 70 | 17.8 | 85 | 20.2 |
| Snout tip to first gill slit | 126 | 31.3 | 140 | 29.8 | 150 | 26.3 | 147 | 31.4 | 167 | 37.5 | 110 | 27.9 | 136 | 32.4 |
| Snout tip to fifth gill slit | 171 | 42.4 | 190 | 40.4 | 215 | 37.7 | 198 | 42.3 | 200 | 44.9 | 155 | 39.3 | 176 | 41.9 |
| Snout tip to pelvic fin | 260 | 64.5 | 300 | 63.8 | 345 | 60.5 | 288 | 61.5 | 330 | 74.2 | 245 | 62.2 | 270 | 64.3 |
| Snout tip to vent | 280 | 69.5 | 325 | 69.1 | 367 | 64.4 | 315 | 67.3 | 360 | 80.9 | 270 | 68.5 | 310 | 73.8 |
| Pectoral fin anterior margin | 263 | 65.3 | 305 | 64.9 | 360 | 63.2 | 315 | 67.3 | 343 | 77.1 | 252 | 64 | 288 | 68.6 |
| Pectoral fin posterior margin | 194 | 48.1 | 215 | 45.7 | 270 | 47.4 | 225 | 48.1 | 255 | 57.3 | 182 | 46.2 | 196 | 46.7 |
| Pectoral fin inner margin | 36 | 8.9 | 23 | 4.9 | 35 | 6.1 | 33 | 7.1 | 37 | 8.3 | 29 | 7.4 | 35 | 8.3 |
| Pelvic fin anterior margin | 55 | 13.6 | 66 | 14 | 66 | 11.6 | 58 | 12.4 | 55 | 12.4 | 55 | 14 | 58 | 13.8 |

**Table I.** Morphomeric measurements and meristic counts carried out in seven types of polychromatism in *Raja clavata* from the northern Tunisian coast (cont.).

| References | FSB- Raj-clav-01 | | FSB- Raj-clav-02 | | FSB- Raj-clav-03 | | FSB- Raj-clav-04 | | FSB- Raj-clav-05 | | FSB- Raj-clav-06 | | FSB- Raj-clav-07 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pelvic fin posterior margin | 75 | 18.6 | 99 | 21.1 | 90 | 15.8 | 67 | 14.3 | 70 | 15.7 | 69 | 17.5 | 75 | 17.9 |
| Pelvic fin inner margin | 28 | 6.9 | 20 | 4.3 | 31 | 5.4 | 29 | 6.2 | 34 | 7.6 | 14 | 3.6 | 13 | 3.1 |
| Span of pelvic fin | 142 | 35.2 | 171 | 36.4 | 180 | 31.6 | 150 | 32.1 | 180 | 40.4 | 130 | 33 | 158 | 37.6 |
| Tail base width | 33 | 8.2 | 32 | 6.8 | 37 | 6.5 | 32 | 6.8 | 45 | 10.1 | 32 | 8.1 | 33 | 7.9 |
| Tail base depth | 21 | 5.2 | 20 | 4.3 | 26 | 4.6 | 21 | 4.5 | 32 | 7.2 | 17 | 4.3 | 22 | 5.2 |
| Tail length | 350 | 86.8 | 370 | 78.7 | 375 | 65.8 | 362 | 77.4 | 410 | 92.1 | 290 | 73.6 | 340 | 81 |
| Snout tip to first dorsal | 517 | 128.3 | 603 | 128.3 | 660 | 115.8 | 588 | 125.6 | 645 | 144.9 | 490 | 124.4 | 570 | 135.7 |
| Snout tip to second dorsal | 560 | 139.0 | 652 | 138.7 | 712 | 124.9 | 640 | 136.8 | 702 | 157.8 | 526 | 133.5 | 620 | 147.6 |
| Superior caudal edge | 33 | 8.2 | 31 | 6.6 | 26 | 4.6 | 41 | 8.8 | 36 | 8.1 | 26 | 6.6 | 27 | 6.4 |
| Inferior caudal edge | 4 | 1 | 4 | 0.9 | 6 | 1.1 | 2 | 0.4 | 5 | 1.1 | 3 | 0.8 | 5 | 1.2 |
| First dorsal anterior edge | 35 | 8.7 | 41 | 8.7 | 42 | 7.4 | 38 | 8.1 | 40 | 9 | 27 | 6.9 | 32 | 7.6 |
| First dorsal posterior edge | 15 | 3.7 | 22 | 4.7 | 19 | 3.3 | 21 | 4.5 | 22 | 4.9 | 19 | 4.8 | 23 | 5.5 |
| First dorsal base | 37 | 9.2 | 38 | 8.1 | 44 | 7.7 | 38 | 8.1 | 41 | 9.2 | 32 | 8.1 | 35 | 8.3 |
| Second dorsal anterior edge | 34 | 8.4 | 37 | 7.9 | 41 | 7.2 | 37 | 7.9 | 36 | 8.1 | 32 | 8.1 | 38 | 9 |
| Second dorsal posterior edge | 17 | 4.2 | 23 | 4.9 | 18 | 3.2 | 23 | 4.9 | 24 | 5.4 | 16 | 4.1 | 20 | 4.8 |
| Second dorsal base | 37 | 9.2 | 43 | 9.1 | 48 | 8.4 | 39 | 8.3 | 55 | 12.4 | 36 | 9.1 | 39 | 9.3 |
| Inter-dorsal distance | 10 | 2.5 | 12 | 2.6 | 16 | 2.8 | 12 | 2.6 | 13 | 2.9 | 8 | 2 | 12 | 2.9 |
| Clasper length | 93 | 23.1 | 205 | 43.6 | | | | | | | 185 | 47 | 202 | 48.1 |
| **Counts** | | | | | | | | | | | | | | |
| Tooth rows upper jaw | 38 | | 41 | | 38 | | 42 | | 37 | | 39 | | - | |
| Tooth rows lower jaw | 45 | | 44 | | 42 | | 40 | | 40 | | 43 | | - | |
| Trunchal vertebrae | - | | 26 | | - | | - | | - | | - | | - | |
| Pectoral fin rays | 93 | | 91 | | - | | - | | - | | - | | - | |
| Pseudobranchial lamellae | 13 | | 14 | | 14 | | 13 | | 14 | | 14 | | - | |
| Nictitating lamellae | 13 | | 11 | | 12 | | - | | 12 | | 11 | | - | |

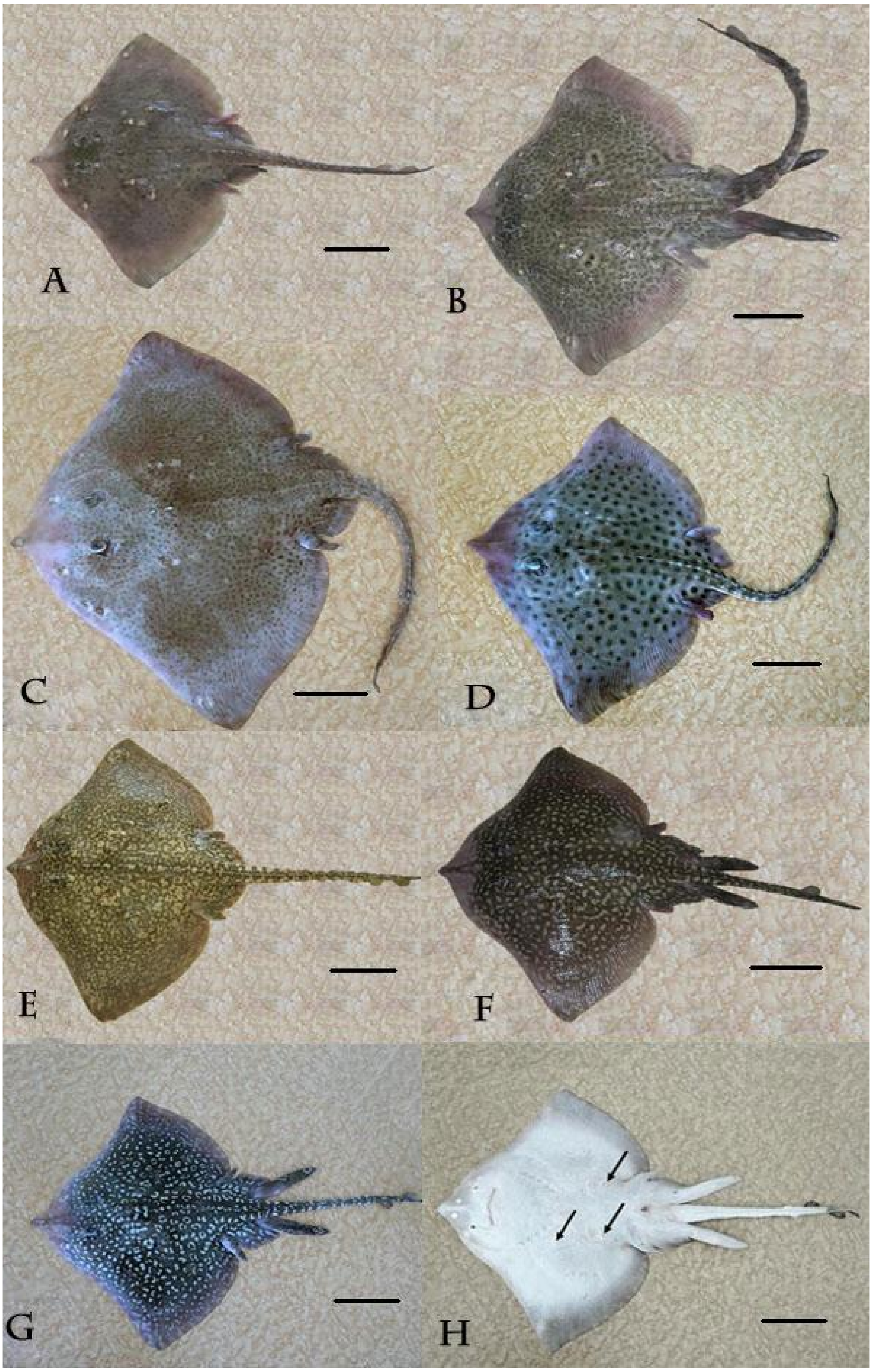

**Figure 2.** Colour patten changes observed in specimens of *Raja clavata* caught off Bizerte, scale bar = 100 mm (photos N. Mnasri). **A**: Type 1, uniform, FSB- Raj- clav 01. **B**: Type 2, ocellated, FSB- Raj- clav 02. **C**: *Raja clavata*. Type 3, speckled, FSB- Raj- clav 03. **D:** Type 4, spotted, FSB- Raj- clav 04. **E**: Type 5, reticulated, FSB- Raj-clav 05. **F**: Type 6, marbled, FSB- Raj-clav 06. **G**: Type 7, vermiculated, FSB-Raj-clav 07, dorsal surface. **H**: Type 7, ventral surface showing thorns (black arrows).

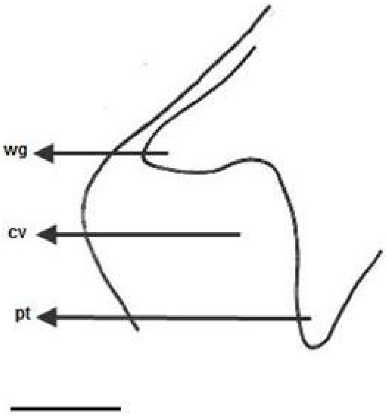

**Figure 3.** Line of Aloncle drawn from external distribution of mucous pores (ampullae of Lorenzini) on ventral surface of *Raja clavata* showing wing (wg), curve (cv) and point (pt), scale bar = 100 mm.

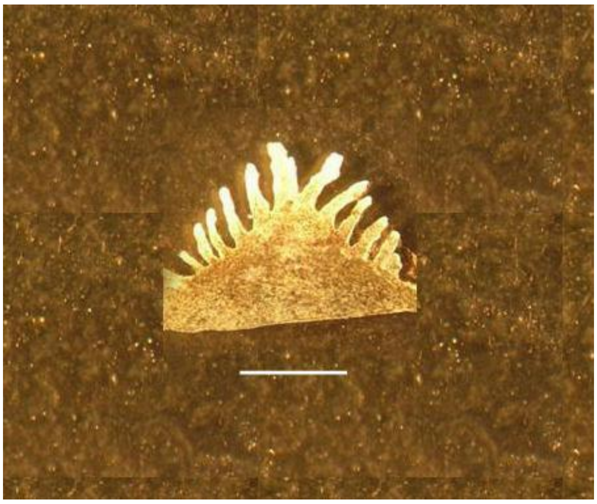

**Figure 4.** Nictitating lamellae removed from eye of *Raja clavata*, scale bar = 3 mm (photo N. Mnasri).

All the described types concerned juveniles and adults of both sexes. Morphology morphometric measurement, meristic counts are in agreement with Clark (1926), Tortonese (1956), Quignard (1965), Aloncle (1966), Bini (1967), Quéro *et al.* (2003) and Hemida (2005). However, specimens of Type 6, marbled, did not clearly show alternance of light and dark crossbars, characterisitic pattern in *R. clavata* (see Fig. 2F), but in contrast exhibited conspicuous thorns on the ventral surface. Additionally, specimens of Type 4, spotted, were juveniles and did not present characteristic thorns, but an alternance of light and dark crossbars, even if these latter were not complete at the end of the tail (see Fig. 2D), pattern we have often observed in other thornback rays.

Type 1, uniform, was the most frequently observed, 39 specimens, then type 3 spekled, 10 specimens, representing 60.93% and 15.62% of total sample, respectively. A chi-square test showed that these differences in numbers in the seven types were significant (df = 6; $p< 0.001$). Aloncle (1966) considered four types, 2, 3, 4 and 6. We think that the three other types, 1, 5 and 7 deserved to be distinguished and added in our description. Type 1 could be confused with specimens of the speckled ray, *R. polystigma* Regan 1923 even if the dorsal surface of this skate is entirely smooth (Capapé *et al.* 1980), while type 5 with the rough ray *R. radula* Delaroche 1809. Type 7 was very close to the Madeira ray *Raja maderensis* Lowe 1839, but presence of large thorns on both dorsal and ventral surfaces and alternance of light and dark crossbars on tail (see Fig . 2 H) allow to identify it as *R. clavata*. Additionally, Table 1 shows that it does not exist both morphological and meristic differences between the 7 types.

Aloncle (1966) suggested the use of the external distribution of the mucous pores (ampullae of Lorenzini) in ventral surface, for taxonomy of rajid species. Similar pattern was also used by Bini (1967) and Gomes & Parago (2005) for distinguish some skate species from off Italian Seas and Brazil, respectively. Aloncle (1966) drawed a line subdivided in three different regions (see Fig. 6): wing, curve and point, presenting interspecific variations in skate species from off the Moroccan coast. Aloncle's line is presented in Fig. 3; it and shows a wing slightly rounded in its distal end, the curve is rather concave while the point is elongated, all patterns in agreement with Aloncle (1966). Capapé & Quignard (1981) noted the role of shape and number of nictitating lamellae in taxonomy of rajids, so in Fig. 4 is presented a photograph of these features similar to those drawn by Capapé & Quignard (1981).

This paper completes and enlarges the works of Aloncle (1966) and Hemida (2005) on polychromatism in *Raja clavata*, and try to avoid possible misidentifications with close relative rajids especially from the eastern Mediterranean and the neighbouring eastern Atlantic (Hemida *et al.* 2007). Moreover, it confirms the diversity of colour patterns already shown by Capapé *et al.* (1980) and Hemida (2005) in other skate species such as *R. polystigma* and *R. montagui*.

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## Scientific Note

# Oviposition rate of the fanskate *Sympterygia bonapartii* (Elasmobranchii, Rajidae) (Müller & Henle, 1841) held in captivity.

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**Abstract**. The oviposition rate in captive *Sympterygia bonapartii* was reported. In a year period one female laid a total of 152 egg cases at a rate of 0.4 egg cases per day and a second one laid a total of 200 egg cases at a rate of 0.5 egg cases per day.

**Key words:** egg cases, skate, aquarium, egg cases laying, controlled conditions

**Resumen. Tasa de oviposición de la raya marmolada *Sympterygia bonapartii* (Elasmobranchii, Rajidae) (Müller & Henle, 1841) mantenida en cautiverio.** Se registró la tasa de oviposición de *Symperygia bonapartii* en cautiverio. En un período de un año una hembra depositó 152 ovicápsulas a una tasa de 0.4 huevos por día y la otra depositó 200 ovicápsulas a una tasa de 0.5 huevos por día.

**Palabras clave:** ovicápsulas, rayas, acuario, puesta de ovicápsulas, condiciones controladas**.**

The skate genus *Sympterygia* comprises four species endemic to the temperate Atlantic and Pacific waters of South America. The smallnose fanskate *S. bonapartii* is one of the most commonly landed skate off northern Argentina and Uruguay (Massa *et al.*, 2004). This species occurs from Rio Grande do Sul State, Brazil (33° S) to Rawson City, Argentina (44° S) (Paesch & Meneses, 1999), from the intertidal to 100 m deep (Menni & Stehmann, 2000). Studies on *S. bonapartii* have focused on taxonomy (Cousseau *et al*., 2000, McEachran, 1982), reproductive biology and abundance (Mabragaña *et al*., 2002), distribution (Menni & Stehmann, 2000), size at maturity (Oddone & Velasco, 2004), incubation period and size at hatching (Jañez & Sueiro, 2007) and some aspects of trophic ecology (Barrera Oro & Maranta 1996; Paesch, 2000). However several aspects of the life-history of *S. bonapartii i.e.* fecundity are still unknown (Mabragaña *et al*., 2002). Elasmobrachs (including the skates and rays) are considered to be particularly vulnerable to over-exploitation by fisheries as a result of their K-selected life-history strategy (Camhi *et al*., 1998). Since 1994 elasmobranchs have became increasingly important in south-west Atlantic fisheries (Massa & Hozbor, 2003; Paesch & Meneses, 1999). Biological data, especially regarding reproduction of skates are needed for proper management of their fisheries (Mabragaña *et al*., 2002). Observation conducted on captive smallnose skates allowed us to report the first contribution concerning the rate of egg-laying for this species.

Two mature female *Sympterygia bonapartii* (female A: total length, *TL* 65 cm, disc width, *DW* 42 cm; female B: *TL* 65 cm, *DW* 47 cm) were caught by demersal otter trawl off Mar del Plata City, Argentina (38°09´ S; 57°33´ W) in July 2002. Specimens were maintained in a tank (1000 $m^3$) with constant temperature (16.5 °C), salinity (35-37), and photoperiod (12L:12D), with at least one mature male, at Temaiken Aquarium, Escobar, Province of Buenos Aires, Argentina. At the time of the first egg-laying, the females were placed in separate tanks (15 $m^3$) under the same conditions, as mentioned above. For the period between the capture and the beginning of this study data on egg-laying are lacking.

The number of egg cases in each tank was counted daily and the following data recorded: date, egg-layer female and presence of yolk examined under transmitted light. The total number of egg cases laid per month per female was pooled for a 12-month period. Total length and width of 30 egg cases were recorded following Clark (1922).

The mean total length of egg cases was (mean ± SD) 77.5 ± 2.6 mm and the mean width was 45.4 ± 2.2 mm (n=30). Female A first deposited an egg case on 1 August 2005. Over a period of 12 months, 152 egg cases were deposited, giving an average rate of 0.4 egg cases per day. The time interval between each pair ranged from 2 to 12 days (mean ± SD; 5.4 ± 2.1). Parturition peaked in September and January and reached a minimum in October (Fig. 1a). Female B laid her firs egg case on 28 October 2005. Over a period of 12 months, 200 egg cases were produced, giving an average rate of 0.5 egg cases per day. The interval between subsequent laying of egg cases pairs ranged from 1 to 14 days (mean ± SD; 4.1 ± 2.4). Parturition peaked in December and the minimum in February (Fig. 1b). Duration of parturition was approximately one to three hours per pairs of egg cases. Of all egg cases laid by both females, 342 (97.2 %) contained a single embryo, 3 (0.8 %) contained two embryos (Fig. 2) and 7 (2.0 %) were empty. Egg cases that were empty or containing two embryos were always paired with an egg case with a simple embryo. The presence of more than one embryo per egg case is recorded for the first time in *S. bonapartii*. Similar cases were reported in *Leucoraja erinacea* (Mitchill, 1825) by Richards *et al*., (1963), although in *L. erinacea* the other capsule of the pair did not contain an embryo, just conversely as described in this work. In *Amblyraja radiata* (Donovan, 1808), it has been suggested that the passage of the eggs through the ostium and into the egg case in formation in the oviducal gland, could be delayed so they cannot reach the forming egg case before it fully formed and closed (Templeman, 1982). According to Mabragaña *et al*. (2002) egg case length and width for *S. bonapartii* in natural environment are 76.5 ± 3.92 mm and 48.37 ± 0.74 mm respectively. These values are similar with the data recorded in this work (length and width 77.5 ± 2.6 mm and 45.4 ± 2.2 mm, respectively). The time interval between laying egg cases of the same pair in the smallnose fanskate agrees with observations made by Luer & Gilbert (1985) in *Raja eglanteria* maintained in captivity, who observed that this interval varies from several minutes to a few hours. Mabragaña *et al*. (2002) suggested that females of *S. bonapartii* lay their egg cases in late spring (November) and the beginning of summer (December- January). However, the environment conditions in the aquaria were constant and this could have masked seasonal variations. The presence of embryos and yolk in over 90 % of the egg cases laid indicates that this species is capable of a successful reproduction in aquaria. The results of this study are the first data on oviposition rate for the genus *Sympterygia* in controlled conditions. This is an approach to estimate the fecundity of this species, but it's necessary to continue the studies simulated the environment condition.

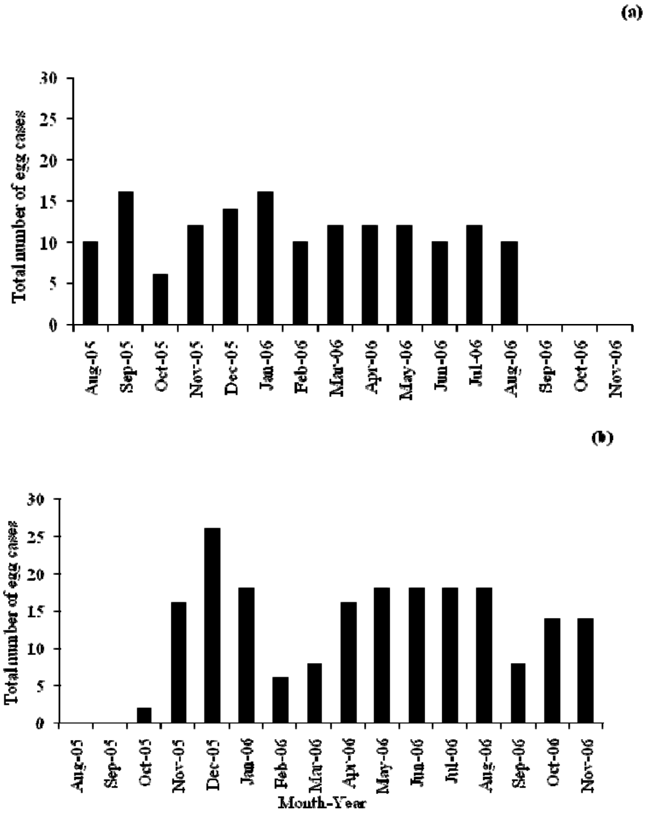

**Figure 1.** Egg laying frequency of female A (a) and female B (b) during a twelve- month period.

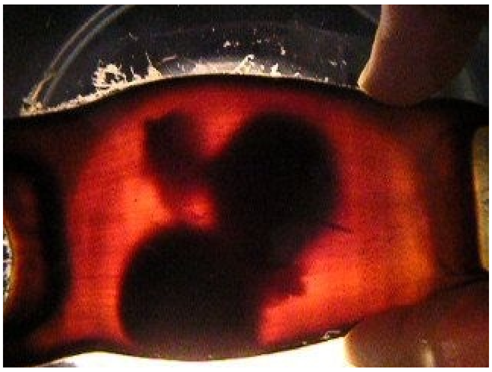

**Figure 2.** View of an egg case contained two embryos, observed by transmitted light.

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## Scientific Note

# New record of *Chimaera cubana* Howell-Rivero (Chondrichthyes: Holocephali: Chimaeridae) from the western Caribbean Sea

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**Abstract.** A new record of *Chimaera cubana* is described from San Andrés Archipelago (Colombia), western Caribbean Sea. This record provides evidence of a more extensive distribution of *C. cubana* in the western central Atlantic. Morphometric data are given.

**Key words:** Caribbean Sea, *Chimaera cubana*, longline, San Andrés Archipelago, Colombia.

**Resumen. Nuevo registro de *Chimaera cubana* Howell-Rivero (Chondrichthyes: Holocephali: Chimaeridae) en el Mar del Caribe Occidental.** Un nuevo registro de *Chimaera cubana* del Archipiélago de San Andrés (Colombia), Mar Caribe occidental es presentado. Este registro provee evidencia de una distribución más amplia de *C. cubana* en el Atlántico centro occidental.

**Palabras clave:** Mar Caribe, *Chimaera cubana*, palangre, Archipiélago San Andrés, Colombia.

The family Chimaeridae, commonly known as shortnose chimaeras, ratfishes or ghost sharks, is the most speciose of the chimaeroid clade with seven species of *Chimaera* and 15 of *Hydrolagus.* These two genera are distinguished by the presence of a notch anterior to the ventral caudal fin that separates it from the anal fin (*Chimaera*) or absence of such notch (*Hydrolagus*). This family has a worldwide distribution, with the greatest diversity of species known from the Pacific coasts of Japan and New Zealand. All members have a blunt, rounded snout, and lateral line canals that are open grooves that become widened in the snout region. The tail is diphycercal with dorsal and ventral caudal-fin lobes of nearly equal size. Tooth plates are bladelike and occlude along their anterior edges to form a sharp nipping beak. (Didier, 1993, 1995, 2002a, 2004).

From a total number of seven species of *Chimaera* recognized (Didier, 2002b, 2004), the only species present in the western Atlantic is *C. cubana* Howell-Rivero, 1936, originally described from Cuba, off Matanzas Bay. *Chimaera cubana* is in fact widely distributed throughout the Caribbean including Jamaica, Puerto Rico, and the Lesser Antilles (Caldwell, 1966; Didier, 2002a). This is the first report from the San Andrés Archipelago, Colombia.

From December 2000 to December 2001, the composition, abundance and distribution of the incidental fish fauna associated with the industrial fishery in San Andrés Archipelago (western Caribbean Sea, Colombia) were evaluated during three cruises. A total of 28 specimens of *C. cubana* were captured in Quitasueño Bank (14° 00.73 N / 81° 11.26 W to 14° 04.45 N / 81° 88.83 W) at 234 to 360 m depth in five sets, using an 11160 m bottom longline hoisted from 100 to 360 m depth and containing 2500 to 3000 hooks.

Four individuals were measured using a dial caliper and ruler or measuring tape, based on Compagno *et al*. (1990) and Didier and Séret (2002). The following measurements were taken: Total length (TL); precaudal length (PCL); body length (BDL); dorsal edge of gill opening to origin of upper lobe of caudal fin; snout-vent length (SVL); distal tip of snout to cloacal opening; trunk length (TRL); ventral edge of gill opening to cloaca; pre-second dorsal length (PD2); pre-first dorsal length (PD1); pre-oral length (POR), snout tip to end of upper labial fold; pre-narial length (PRN); snout tip to anterior edge of nasal apertures; pre-orbital length (POB); snout tip to anterior edge of orbit; second dorsal-fin base (D2B); maximum height of anterior 1/3 of the second dorsal fin (D2PH); first dorsal-fin base (D1B); from anterior edge of fin spine to insertion of first dorsal fin; dorsal spine length along anterior margin (DSA); maximum height to first dorsal fin (D1H); dorsal caudal margin length (CDM); maximum height of dorsal lobe of caudal fin (CDH); ventral caudal margin from origin to insertion of lower caudal fin(CVM); total caudal length (CTL); from origin of upper caudal fin to end of caudal filament; maximum height of ventral lobe of caudal fin (CVH); head length (HDL); pectoral-fin anterior margin (P1A); pelvic-fin anterior margin (P2A); interdorsal space (IDS); dorsal-caudal space (DCS); anterior edge of first dorsal-fin base to anterior edge of pectoral-fin base (D1P1); anterior edge of base of first dorsal-fin to anterior edge of pelvic-fin base (D1P2); anterior edge of second dorsal-fin base to anterior edge of pectoral-fin base (D2P1); anterior edge of second dorsal-fin base to anterior edge of pelvic-fin base (D2P2); eye length (EYL); eye height (EYH); total length of claspers from pelvic-fin base to tip (CLT); length of medial branch of claspers from fork to tip (CLM); length of lateral branch of claspers from fork to tip (CLL).

Eight measurements from the lateral-line canals of the head were taken: distance from anterior oronasal fold to center of nasal canal (ONC); length of the rostral canal (LRC); length of the nasal canal measured as a straight line distance from right to left side (LNC); distance between infraorbital and angular canal measured as the straight line distance from junction of the oral and infraorbital canal to the junction of the oral and angular canal (IOA); distance between preopercular canal and main trunk canal measured from their junction with the infraorbital canal (OTM); distance between main trunk canal and supratemporal canal measured from their junctions with the infraorbital and postorbital canals, respectively (OCL); length of supratemporal canal measured across the head from its junctions with the postorbital canal (STL); distance from anterior base of spine to the center of the supratemporal canal (SPS).

Comparative data, including measurements, description and geographical distribution of the holotype, paratype and 10 additional non-type specimens were also obtained by D. A. Didier. The following description of *C. cubana* is based on those original observations plus the four additional Colombian specimens captured in the present study. Institutional acronyms are based on Levinton *et al*. (1985).

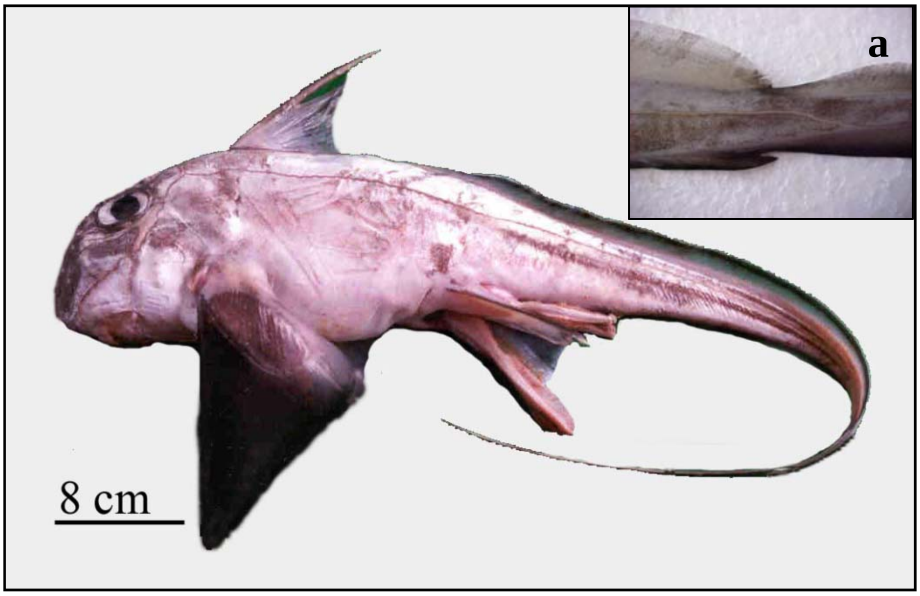

**Figure 1.** Lateral view of *Chimaera cubana*, adult male. **a** Notch to the ventral caudal fin.

*Material examined.* INVEMAR PEC 6201, female, 719 mm TL, 450 mm BDL; Specimens Discarded, 2 males, 609/803 mm TL, 369/410 mm BDL; female, 745 mm TL, 407 mm BDL.

*Comparative material. Holotype.* – MCZ 1464, male, 728 mm TL, 427 mm BDL, Matanzas Bay, Cuba; *Paratype* – MCZ 1385, male, 664 mm TL, 319 mm BDL, Matanzas Bay, Cuba.

*Additional non-type specimens.* – 10 specimens. FMNH 71595, female, 283 mm TL, 118.3 mm BDL, off Puerto Rico; MCZ 40682, 2 males, 258/277 mm TL, 111/116 mm BDL, Caribbean; USNM 222711, female, 429 mm LT, 211 mm BDL, Caribbean; USNM 222796, male, 549 mm LT, 241 mm BDL, Western Atlantic; USNM 222800, 2 females, 300/406 mm LT, 115.4/171 mm BDL, 3 males, 215/267/386 mm LT, 109/129.1/164 mm BDL, Lesser Antilles, Leeward islands.

*Diagnosis.* A small to medium-bodied *Chimaera* with preopercular and oral lateral line canals branching separately from the infraorbital canal with a prominent space between their respective origins. The anterior portion of lateral line of the body is undulated, gradually becoming straight posteriorly; second dorsal fin evenly tall along its length, not indented. Color uniform silvery gray on a soft pink background in fresh specimens; but in preserved individuals body color pale brown.

*Description.* Measurements of holotype, paratype and 14 additional specimens are shown in Table 1. A small to medium-bodied species (TL 215-803.4 mm; BDL 143-554 mm) with bluntly rounded snout. Body tapers to a slender tail that ends in a whip-like filament. Body color a silvery gray on a soft pink background in fresh specimens; but pale brown in preserved individuals; in some, faint longitudinal stripes are visible on the trunk and especially on the base of the tail. Dark margins present on the second dorsal and caudal fins. A dark leading edge on the pectoral fin was also observed in one small juvenile (FMNH 71595), and may be representative of colors in life. Lateral line canals of the head appear as open grooves, canals on the snout characterized by wide dilations.

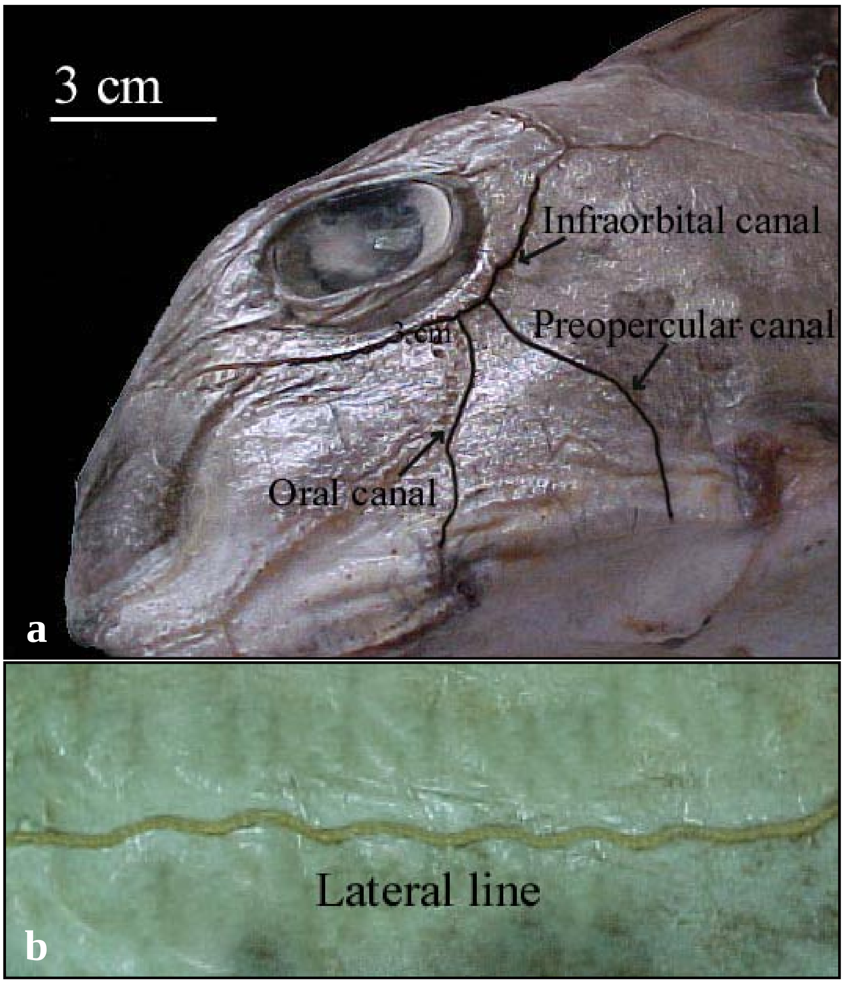

**Figure 2.** (a) Distribution of lateral line canals of the head and (b) form lateral line on the anterior part of the trunk.

Paired fins (pectoral and pelvic) are stout and triangular in shape, darker in color than the body. Anal fin clearly separated from ventral caudal lobe by a notch. First dorsal fin erectile, preceded by a stout spine longer than height of first dorsal fin and reaching to or just beyond origin of second dorsal fin when depressed. Spine with posterior serrations present along distal one-half of spine.

Males characterized by a frontal tenaculum that is small, gently rounded with small bulbous tip bearing 7-8 rows of denticles on the ventral surface. Pelvic claspers slender, divided at its mid-length, pale in color with long fleshy lobes covered in a fine shagreen of denticles. Pelvic claspers do not extend beyond the distal margin of the pectoral fins.

*Remarks.* From a total of 28 specimens captured off the San Andrés Archipelago, Colombia, 16 were collected in one set. This may indicate aggregative behavior in this species. In addition, the species was previously recorded from depths of 238 - 450 m (Bigelow and Schroeder, 1953; Caldwell, 1966), but appears to occur in shallower depths; 234 m in the present study and 180 m reported by Bunkley-Williams and Williams (2004). This is the first record of this genus and species from the western Caribbean Sea and Colombia; only *Hydrolagus alberti* and *Neoharriotta carri* were previously reported from Colombian continental shelf (Rey and Acero, 1983).

This new record of *C. cubana* from the western Caribbean Sea (Fig. 3) provides evidence for a wider distribution in the western central Atlantic, and has specific locations of aggregations, like Quitasueño Bank.

*C. cubana* with the present report is the only species of Chimaera occurring in the western Atlantic Ocean and it is very important to generate guidelines for its conservation. In addition, there is little information of this taxon, and nothing is known of its biology, ecology and behavior (Didier, 2002a, 2004).

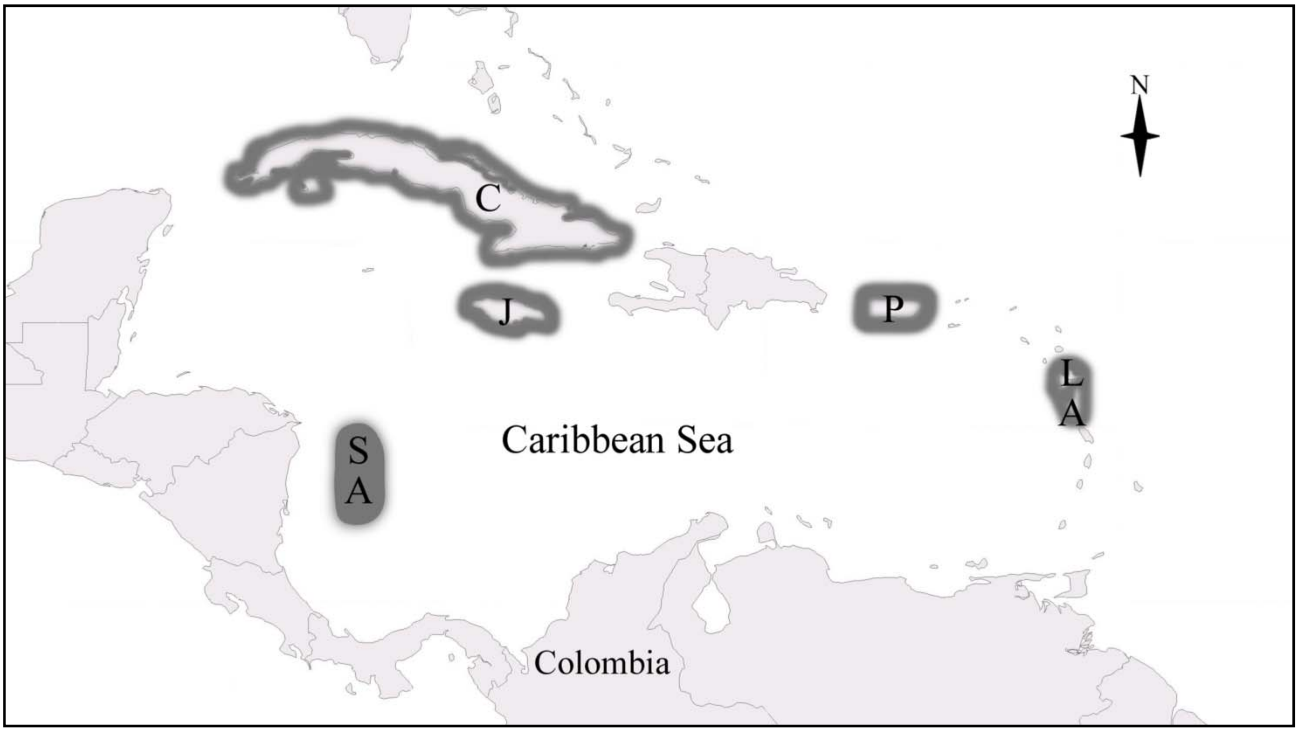

**Figure 3.** Distribution of *Chimaera cubana* on Caribbean Sea. C: Cuba, P: Puerto Rico, J: Jamaica, LA: Lesser Antilles, SA: San Andrés Archipelago.

**Table I.** Measurements in mm and in percentage of the body length (%BDL) for specimens of *Chimaera cubana* (n=16). (*) represent the measurements taken only from specimens examined from Quitasueño Bank.

| | Holotype MCZ-1464-H | | Paratype MCZ-1385-P | | non-type specimens (n = 14) | |
|---|---|---|---|---|---|---|
| | mm | %BDL | range mm | range %BDL | range mm | range %BDL |
| **TL** | 728 | 131 | 664 | 208 | 215-803.4 | 150-196 |
| **PCL** | 427 | 77 | 383 | 120 | 109-528 | 76-128 |
| **BDL** | 554 | 100 | 319 | 100 | 143-450 | 100 |
| **SVL** | 250 | 45 | 191 | 60 | 60.9-276 | 43-61 |
| **TRL** | 154 | 28 | 95.5 | 30 | 33.8-156 | 24-36 |
| **PD2** | 256 | 46 | 175 | 55 | 54.4-251 | 38-56 |
| **PD1** | 159 | 29 | 115 | 36 | 35.7-135 | 25-30 |
| **POR*** | | | | | 31-52 | 8-13 |
| **PRN*** | | | | | 23-42 | 6-9 |
| **POB** | 53.5 | 10 | 42.3 | 13 | 14-50 | 10-12 |
| **D2B** | 324 | 58 | 236 | 74 | 82.5-328 | 55-76 |
| **D2AH*** | | | | | 12.4-17.1 | 3-4 |
| **D2PH*** | | | | | 11.4-16.1 | 3-4 |
| **D1B** | 67.7 | 12 | 51.1 | 16 | 19.2-89.7 | 13-20 |
| **DSA** | 108.9 | 20 | 81 | 25 | 26.4-118.5 | 18-28 |
| **D1H** | 103.5 | 19 | 80.4 | 25 | 33.2-98.7 | 22-25 |
| **CDM** | 57.1 | 10 | 57.1 | 18 | 23.6-74.4 | 14-17 |
| **CDH*** | | | | | 4.9-9.6 | 1-2 |
| **CTL*** | | | | | 138.7-281.7 | 31-69 |
| **CVM** | 160.2 | 29 | 110.5 | 35 | 48.9-143.3 | 32-34 |
| **CVH*** | | | | | 6-11.4 | 2-3 |
| **HDL** | 107.8 | 19 | 78.5 | 25 | 28.4-132 | 20-29 |
| **P1A** | 144.2 | 26 | 111.5 | 35 | 42.1-188.3 | 29-42 |
| **P2A** | 75.8 | 14 | 54.7 | 17 | 21.3-93 | 14-20 |
| **IDS** | 39.8 | 7 | 29.2 | 9 | 1.3-44.1 | 1-10 |
| **DCS** | 7.2 | 1 | 1.6 | 1 | 0.9-4.5 | 0.25-1 |
| **D1P1*** | | | | | 71.5-102.2 | 17-23 |
| **D1P2*** | | | | | 140.5-183.1 | 35-41 |
| **D2P1*** | | | | | 108.4-146 | 29-32 |
| **D2P2*** | | | | | 77.1-98.2 | 19-23 |
| **EYL** | 34.7 | 6 | 24.5 | 8 | 10.7-38.9 | 7-10 |
| **EYH** | 21.3 | 4 | 16.2 | 5 | 7.4-25.9 | 5-6 |
| **CLT** | 74.4 | 13 | 13.8 | 4 | 1.9-94.9 | 1-23 |
| **CLM*** | 45.2 | 8 | | | 49.8-55.2 | 13 |
| **CLL*** | 40.3 | 7 | | | 56.1-65.3 | 15-16 |
| **ONC*** | | | | | 9.1-13.7 | 2-3 |
| **LRC*** | | | | | 5-6.6 | 1 |
| **LNC*** | | | | | 28.7-37.8 | 7-8 |
| **IOA*** | | | | | 15..7-18.9 | 4 |
| **OTM*** | | | | | 33.8-44.9 | 9-10 |
| **OCL*** | | | | | 14.6-18.9 | 4 |
| **STL*** | | | | | 17-28 | 5-6 |
| **SPS*** | | | | | 20.3-24.4 | 5-7 |

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## Scientific Note

# Absence of metazoan gill parasites on *Potamotrygon falkneri* (Potamotrygonidae) and its ecological implications in the upper Paraná River floodplain, Brazil

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**Abstract.** Specimens of *Potamotrygon falkneri* were analyzed for metazoan parasites on the gills, and none of them was parasitized. This species was translocated to the studied region, and the unusual result is explained by some hypothesis.

**Keywords:** Stingrays, elasmobranch, ectoparasites, translocated species.

**Resumo. Ausência de metazoários parasitas branquiais em *Potamotrygon falkneri* (Potamotrygonidae) e suas implicações ecológicas na planície alagável do alto rio Paraná, Brazil.** Espécimes de *Potamotrygon falkneri* foram analisados em busca de metazoários parasitas de brânquias e nenhum deles estava parasitado. Esta espécie não é nativa da região de estudo e o resultado incomum é explicado por algumas hipóteses.

**Palavras-chave:** Raias, elasmobrânquios, ectoparasitos, espécies translocadas.

The Paraná River is the most important river of the La Plata basin and the tenth largest in discharge in the world (Paiva 1982). Before the creation of the reservoir of the Itaipu hydroelectric power plant, the Sete Quedas Falls served as a natural barrier against the dispersion of numerous species of fish, including stingrays, from the lower and middle portions of the Paraná River to the upper Paraná River. With the construction of the Itaipu dam, this natural barrier was moved about 150 km upstream, and allowed some species to be translocated to this new environment, including *Potamotrygon falkneri* Castex & Maciel 1963, which was restricted to the lower and middle portions of the Paraná River (Agostinho *et al.* 2004a).

Family Potamotrygonidae Garman, 1877 includes the only group of elasmobranchs completely adapted to life in freshwater habitats (Compagno & Cook 1995). Within this family, there are three valid genera, but the vast majority belong to the genus *Potamotrygon* Garman 1877 (Carvalho *et al.* 2003). Only in the Paraguay-Paraná basin around seven species occur, and this number can vary with the occurrence of synonyms and/or undescribed species (Rosa 1985, Carvalho *et al.* 2003).

Potamotrygonids have features similar to their marine relatives, such as low fecundity, late maturity and slow growth, making them very vulnerable (Compagno & Cook 1995). Moreover, they are very sensitive to the lack of oxygen in the water, being the first to rise to the surface when the oxygen is scarce (Achenbach & Achenbach 1976, Araújo 1998). They also have low tolerance to environmental and anthropogenic impacts (Compagno & Cook 1995, Marques 1996).

*Potamotrygon falkneri* has predominantly benthic habits and is found preferably in places from two to four meters deep, with highly variable flow and substrate (Neto *et al.* 2007). It exerts an important role in the food chain, since it is positioned at the top. Its diet consists mainly of fish and mollusks (Lonardoni *et al.* 2006).

Studies on the parasitic fauna of *P. falkneri* have been made, but regarding endoparasites (Brooks & Amato 1992, Campbell 1999, Ivanov 2005, Lacerda *et al.* 2008, 2009). Only one species of ectoparasite was described from the gills of *P. falkneri*, the monogenean *Potamotrygonocotyle eurypotamoxenus* Domingues & Marques 2007. This species also parasitizes other species of potamotrygonids: *Potamotrygon motoro* (Müller & Henle 1841), *P. castexi* Castello & Yagolkowski 1969 and *P. histrix* (Müller & Henle 1841) (Domingues & Marques 2007).

Studies on gill parasites have great importance because they can be very pathogenic to the host (Whittington & Chisholm 2008). As the studied species was translocated and is well adapted to the new environment, further studies are necessary to investigate if it was infested by new species of gill parasites, or brought its native parasites with them. This study aimed to investigate the fauna of metazoan gill parasites in *Potamotrygon falkneri* in the floodplain of the upper Paraná River.

Stingrays were collected quarterly from March 2005 to September 2006, using fishing rods and nets exposed for 24 hours in different locations of the upper Paraná River floodplain (Fig. 1). In the field, gills were removed with the aid of a scalpel and fixated in 5% formalin. The branchial arches were separated and analyzed for metazoan parasites (especially monogeneans) in the laboratory, under an Olympus SZ40 stereomicroscope with 4.0 zoom. Methodology was according to Eiras *et al.* (2006).

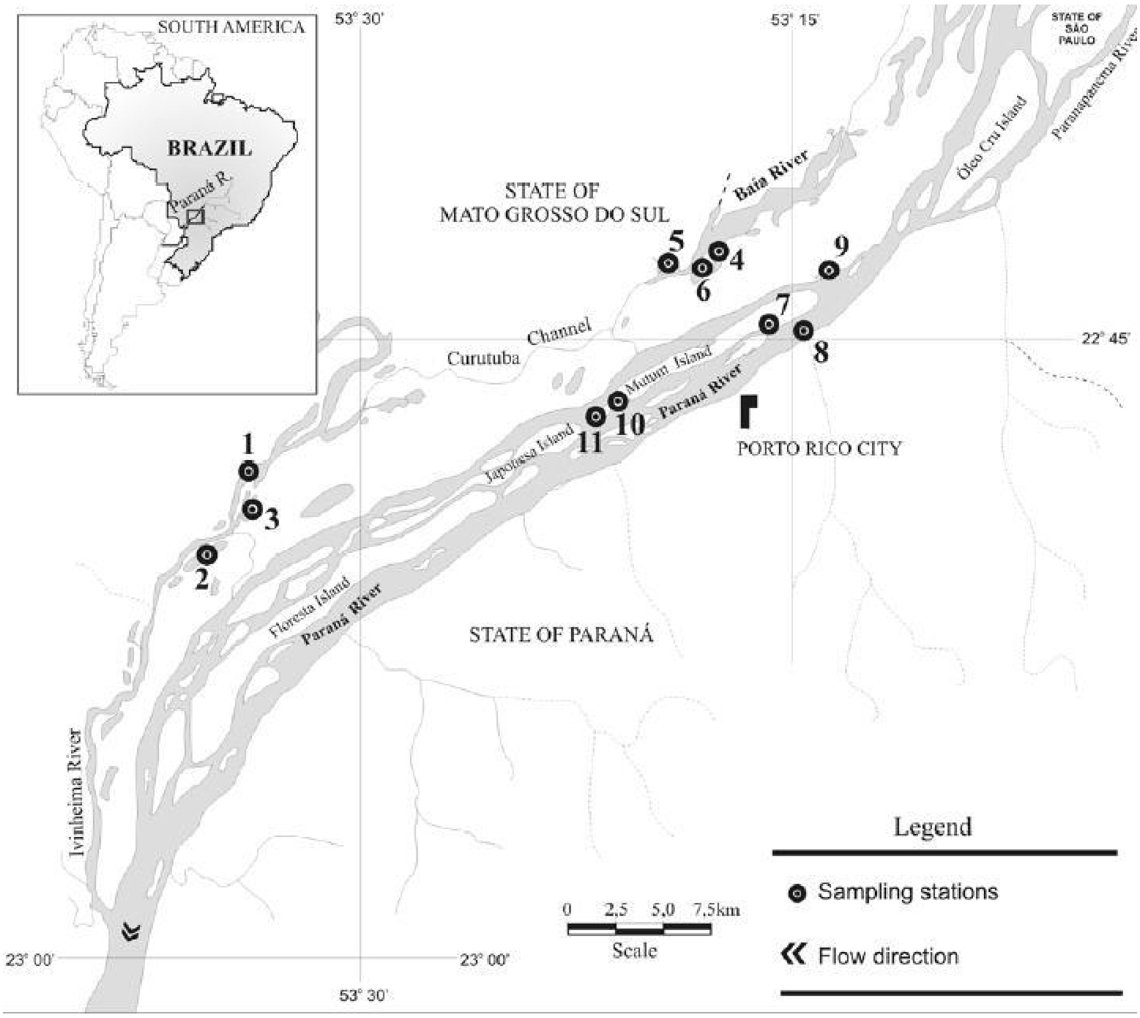

**Figure 1.** Upper Paraná River floodplain. Sampling stations: 1-Ivinheima River; 2-Ventura Lagoon; 3-Patos Lagoon; 4-Fechada Lagoon; 5-Guaraná Lagoon; 6-Baía River; 7-Pau Véio Backwater; 8-Paraná River; 9-Garças Lagoon; 10-Osmar Lagoon; 11-Mutum Island.

Thirty specimens of *Potamotrygon falkneri* were analyzed, 18 males and 22 females, with total length ranging from 40.0 to 80.0 cm (52.2±10.2) and disc length from 21.6 to 50.0 cm (29.9±6.9). None of them was parasitized by metazoans. This result is very unusual in nature, leading us to elaborate some hypothesis to explain it.

Recent studies show the importance of parasites within the community and their relationship as indicators of the ecosystem health (Marcogliese 2005). Parasites present a great variety of life cycles and adaptations for survival, inside and outside their hosts (Thatcher 1991) and the ectoparasitic fauna can provide answers regarding the host`s behavioral habits and environment (Yamada *et al.* 2008).

For example, many helminthes have a complex life cycle, with hosts ranging from invertebrates to vertebrates. The absence of only one organism or host within that process would mean the interruption of their life cycles, and the end of their disposal in the environment (Thatcher 1981).

According to Almeida *et al.* (2009), stingrays exhibit distinct environment occupation and habitat use patterns, that may lead to spatial segregation processes. *Potamotrygon falkneri* was translocated to the floodplain of the upper Paraná River. This species went through a process of moving from its place of origin to a new habitat. In this process, the stingrays could have gained, or lost, forms of parasitism. Biological invasions are a big problem for the world's biodiversity and parasites may have a key role in modifying the environment (Prenter *et al.* 2004).

The absence of ectoparasites in *P. falkneri* in the floodplain of the upper Paraná River is somewhat intriguing. One species of gill parasite was described from *P. falkneri*, *Potamotrygonocotyle eurypotamoxenus*, but in another area (Salobra River, District of Salobra, Municipality of Miranda, Mato Grosso do Sul, Brazil) (Domingues & Marques 2007). The same authors recorded other species of monegeneans in the La Plata basin (Corrientes, Argentina), downstream the upper Paraná River floodplain. This fact may indicate that these stingrays had these parasites prior to the translocation. We suggest that maybe these parasites were lost during the change of habitat as the stingray reached new environments after the flooding of the Sete Quedas Falls, with the construction of the Itaipu hydoelectric power plant.

This hypothesis is supported by some studies showing that invasive species can have fewer parasites than if they were in their place of origin, because of the typical aggregate distribution and the "bottleneck" effect (Mitchell 2003, Torchin *et al.* 2003, Prenter *et al.* 2004). Individuals that are not parasitized, especially on the gills, which are related to gas exchange and movement, should have advantage over parasitized ones. Maybe non-parasitized fish had advantage colonizing the new environment. A second possible scenario would be the loss of parasites during the translocation from the place of origin (lower and middle Paraná River), to the upper Paraná River.

Another factor that cannot be forgotten when we consider the difference in the parasitic fauna between the two observed locations, is the contrast of anthropogenic impacts between the two regions. Pollution is a major factor in the change of the parasite`s population and community (Kennedy 1997). The region of the upper Paraná River is probably less impacted than the region of Itaipu when we consider the construction of dams, as it is the largest stretch of the river without them (Agostinho *et al.* 2004b). Nevertheless, it may have limnological characteristics that did not encourage the establishment of ectoparasites on stingrays present in this region. In addition, this new environment for the stingrays is constantly being changed in relation to the transparency of water due to the construction of the Porto Primavera dam, placed upstream from this portion of the river (Universidade Estadual de Maringá. Nupélia/PELD/CNPq 2000).

The higher probability of success in the invasion of specimens with few or no parasites may increase their advantages in the competition with native species that suffer the negative effects from parasites (enemy release hypothesis, see Colautti *et al.* 2004).

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## Scientific Note

# Notas sobre a biologia reprodutiva e alimentar de elasmobrânquios no Parque Estadual Marinho Parcel Manoel Luís, Maranhão – Brasil

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**Abstract**. **Data on the reproductive and feeding biology of elasmobranchs from Manoel Luís Reefs, Maranhão State, Brazil.** Nine species were recorded and evidences that the area is important for the reproduction and feeding activity of sharks and rays were obtained.

**Keywords:** sharks, rays, marine protected areas, reproduction, feeding habits

**Resumo.** São apresentados dados sobre a biologia reprodutiva e alimentar de elasmobrânquios nos Recifes Manoel Luís, Maranhão. Foram registradas nove espécies e encontradas evidências de que a área é importante para atividade reprodutiva e alimentar de tubarões e raias.

**Palavras-chave**: tubarões, raias, áreas marinhas protegidas, reprodução, hábitos alimentares

O conhecimento sobre diversidade e biologia básica de elasmobrânquios associados a formações recifais na costa brasileira ainda é escasso. A maioria das informações existentes compreende dados e registros pontuais em pesquisas mais amplas acerca da ictiofauna recifal de algumas localidades (*e.g.* Rosa & Moura 1997, Rocha *et al.* 1998, Rocha & Rosa 2001). Estudos sobre ocorrência e biologia básica de elasmobrânquios associados a substratos consolidados foram realizados no Arquipélago de São Pedro e São Paulo (Edwards & Lubbock 1982, Hazin *et al.* 2008), no Atol das Rocas, Rio Grande do Norte (Castro & Rosa 2005, Freitas *et al.* 2006, Oliveira *et al.* 2007, Wetherbee *et al.* 2007), no Arquipélago de Fernando de Noronha, Pernambuco (Soto 1997, Garla *et al.* 2005, 2006, 2008) e na Laje de Santos, São Paulo (Luiz Jr *et al.* 2008). O presente trabalho tem por objetivo fornecer dados preliminares sobre a biologia alimentar e reprodutiva de elasmobrânquios em uma área próxima ao limite norte de distribuição da fauna recifal brasileira (Moura *et al.* 1999).

Os Recifes Manoel Luís estão localizados a cerca de 180 km ao norte da cidade de São Luís, Maranhão (00° 52' S, 44° 15' W; Figura 1), representando as formações recifais mais próximas à foz do Rio Amazonas (Moura *et al.* 1999). Apesar de estarem inseridos em uma Unidade de Conservação Estadual (Parque Estadual Marinho Parcel Manoel Luís) com cerca de 460 $km^2$, legalmente protegida desde 1991, bem como em uma Zona Úmida de Importância Internacional (reconhecida pela Convenção de Ramsar), poucas pesquisas e ações de proteção foram realizadas até o momento. A formação recifal principal possui cerca de 10 km de extensão em seu eixo SE-NE, sendo constituída por pináculos circulares entre 50 e 300 m de diâmetro, os quais se elevam de 25-30 m de profundidade até próximos a superfície. O substrato recifal é formado por algas coralináceas incrustantes e colônias esparsas de corais (Moura *et al.* 1999).

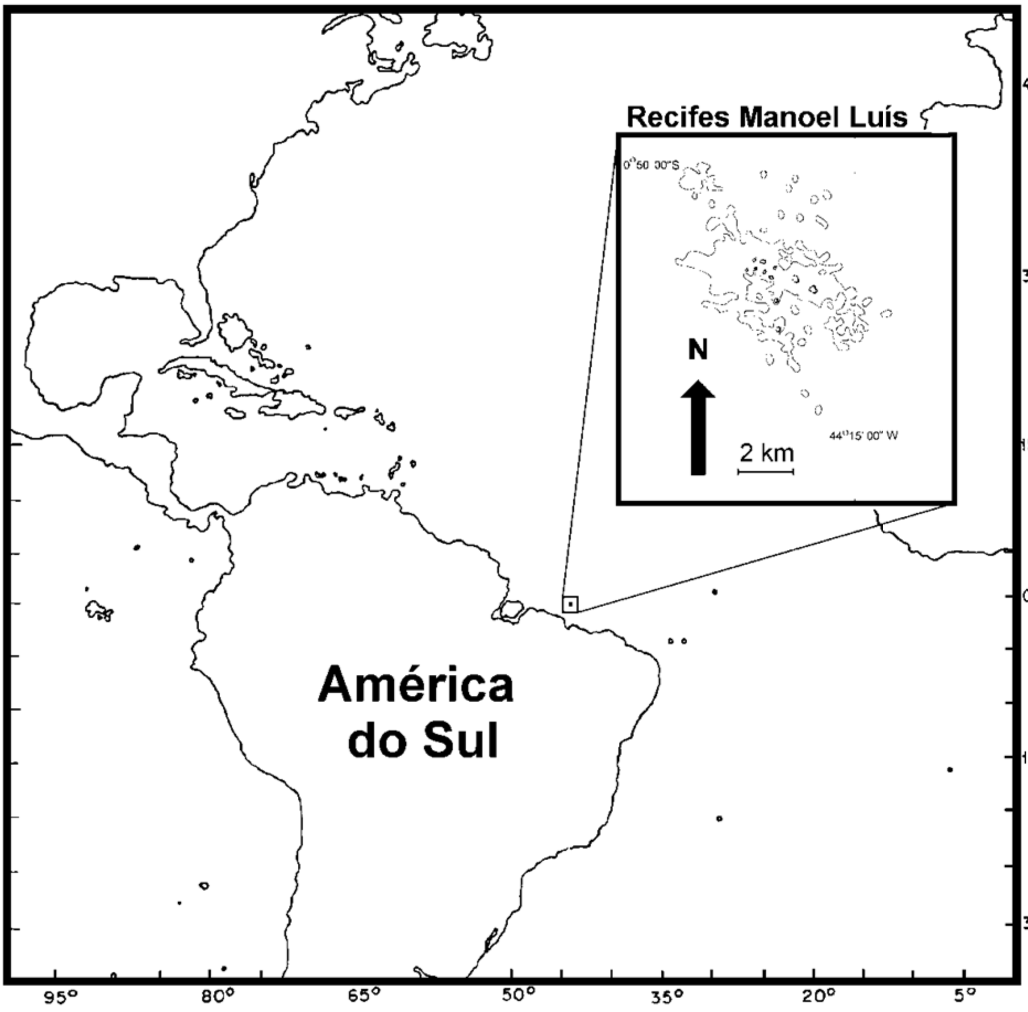

**Figura 1.** Localização dos Recifes Manoel Luís, Maranhão – Brasil.

As coletas e observações subaquáticas com mergulho autônomo (SCUBA) aqui reportadas foram realizadas entre 28 de junho e 5 de julho de 1998. Os exemplares foram coletados com linhas-de-mão e anzóis, operados a uma profundidade média de 25 m, coincidindo com a profundidade máxima dos mergulhos. Todos os indivíduos coletados foram identificados, sexados e medidos (comprimento total, CT). As vísceras (estômagos e gônadas) foram fixadas em formol a 10 % para exame posterior em laboratório. O estádio de maturidade dos exemplares foi determinado de acordo com os critérios de Castro (1993), Simpfendorfer & Milward (1993) e Garla *et al.* (2006), a saber:

Neonatos: orifício do cordão umbilical (localizado entre as nadadeiras peitorais) aberto;

Jovens-do-ano: orifício do cordão umbilical fechado apresentando cicatriz evidente;

Jovens: machos com clásper flexível e fêmeas com ovário pouco evidente;

Adultos: machos com clásper alongado e totalmente calcificado e fêmeas com ovócitos vitelogênicos no ovário ou com ovos/embriões no útero.

Foram registrados 23 exemplares de elasmobrânquios pertencentes a seis famílias, sete gêneros e nove espécies: *Rhizoprionodon porosus* (n = 10), *Carcharhinus perezi* (n = 4) (Carcharhinidae), *Ginglymostoma cirratum* (n = 2) (Ginglymostomatidae), *Dasyatis marianae* (n = 2), *D. americana* (n = 1), *D. guttata* (n = 1) (Dasyatidae), *Aetobatus narinari* (n =1) (Myliobatidae), *Mobula* sp. (n = 1) (Mobulidae) e *Sphyrna* sp. (n = 1) (Sphyrnidae).

A espécie de tubarão mais freqüente (n=10) nas capturas foi o tubarão rabo-seco, *Rhizoprionodon porosus* (Tabela I). Apenas adultos foram capturados, sendo um macho de 755 mm e nove fêmeas entre 740 e 840 mm CT. O exame do útero de seis fêmeas revelou a presença de ovos e embriões em diferentes estágios de desenvolvimento. A fecundidade uterina (número de ovos e/ou embriões), variou entre 3 e 7 (média = 4,83 ± 1,47 DP) por fêmea e de 1 a 4 por útero. Não foi registrada correlação significativa entre a fecundidade e o tamanho corporal das fêmeas (r = -0,39; p = 0,43), mas este resultado deve ser considerado com cautela levando-se em conta o baixo número de amostras (n = 6). Onze embriões foram medidos com CT variando entre 18 e 146 mm. A proporção sexual dos embriões, obtida por meio do exame de duas fêmeas foi de 1:2,5 em favor das fêmeas. Dos sete estômagos examinados, provenientes de exemplares adultos, três estavam vazios, três apresentavam dentes, escamas e fragmentos de musculatura e esqueleto de teleósteos da família Scaridae (“budiões”, *Sparisoma* spp.) e um apresentava dois indivíduos da família Diodontidae (“baiacus-de-espinho”, *Diodon hystrix*).

O tubarão-dos-recifes, *Carcharhinus perezi*, foi a segunda espécie mais freqüente nas capturas, tendo sido coletados quatro indivíduos jovens, um macho e três fêmeas, entre 815 e 945 mm CT. Foram examinados os estômagos de dois exemplares, contendo bicos de cefalópodes e um teleósteo da família Scaridae (gênero *Sparisoma*). Foram examinados dois exemplares machos do tubarão-lixa, *Ginglymostoma cirratum*, um jovem, medindo 970 mm, e outro sub-adulto com 1500 mm CT. Essa espécie foi a mais freqüentemente observada durante os mergulhos, ocorrendo sobre o substrato recifal e suas adjacências imediatas. O registro de *Sphyrna* sp. foi feito durante operação de mergulho, mas não foi possível a identificação da espécie.

O tubarão-rabo-seco, *Rhizoprionodon porosus*, compõe uma parcela importante dos desembarques pesqueiro costeiros no Maranhão, representando entre 18 e 45% da produção de elasmobrânquios (Lessa 1986, Almeida 1999).

Esta mesma espécie também apresentou uma importante participação nas capturas nos Recifes Manoel Luís, demonstrando que sua abundância também é relativamente alta em áreas recifais afastadas da costa.

Os dados de fecundidade aqui registrados para *R. porosus* foram superiores aos previamente reportados. Ferreira (1988) registra uma média de 2,9 embriões/fêmea para o Rio de Janeiro, Mattos *et al.* (2001) reporta 3,71 embriões/fêmea para Pernambuco e Machado *et al.* (2001) registra um máximo de 3 embriões/fêmea para o Maranhão. A captura exclusiva de exemplares adultos de *R. porosus*, sobretudo fêmeas grávidas, sugere que, durante a gestação, esta espécie costeira migre para áreas com alta disponibilidade de alimento. A migração de indivíduos adultos, afastando-se da costa para outras áreas após o parto e cópula, foi registrada para espécies do gênero *Rhizoprionodon* em outras regiões (Motta *et al.* 2005, Parsons 1983, Castro & Wourms 1993 ). Até o presente estudo, não existiam informações, ainda que preliminares, sobre o destino dessas migrações e os hábitos alimentares nessas áreas mais externas da plataforma continental. Apesar de as fêmeas de algumas espécies de tubarões reduzirem ou até mesmo interromperem sua atividade alimentar durante a gestação ou durante a permanência em áreas de berçário (Springer 1960, Olsen 1984), esse padrão não se aplica para *R. porosus* nos Recifes Manoel Luís. Ainda com relação aos hábitos alimentares, Silva & Almeida (2001) citam, com base no exame de exemplares provenientes de águas costeiras do Maranhão, que *R. porosus* é um predador oportunista, alimentando-se predominantemente de peixes abundantes nestas áreas costeiras de fundos moles. Apesar de os peixes recifais da família Scaridae, que são particularmente abundantes nos recifes Manuel Luís (Rocha & Rosa 2001), terem representado o item mais freqüente nos conteúdos estomacais de *R. porosus*, o pequeno número de exemplares analisados no presente estudo impede uma análise mais detalhada do caráter oportunista *versus* especialista na atividade de forrageio de *R. porosus*.

O conhecimento sobre a distribuição e a biologia do tubarão-dos-recifes, *C. perezi*, é extremamente fragmentário, adicionando valor às observações aqui reportadas para essa espécie classificada como próxima de ameaça de extinção (“Near Threathened”) pela União Internacional para Conservação da Natureza (IUCN 2009). O tubarão-dos-recifes é de fato bastante raro, tendo sido registrada no Norte/Nordeste do Brasil apenas na década de 1980, com base em um único exemplar capturado em águas rasas do Maranhão (Lessa 1986). Observações adicionais sobre a espécie foram reportadas apenas após uma década (Gadig *et al.* 1996), sugerindo que a plataforma do Maranhão e Pará são utilizadas para o parto e cópula. Os espécimes aqui reportados, capturados entre junho e julho, também eram jovens, sendo que três deles (815, 860 e 870 mm CT) eram possivelmente jovens-do-ano (indivíduos nascidos na última estação reprodutiva), corroborando a hipótese proposta por Gadig *et al.* (1996). Alguns poucos ambientes recifais da costa brasileira tem sido apontados como áreas de berçários para *C. perezi* (Garla *et al.* 2006) e os Recifes Manoel Luís também parecem ser uma dessas áreas-chave, considerando o registro de jovens-do-ano na área durante o inverno.

**Tabela I.** Dados biológicos dos elasmobrânquios capturados nos Recifes Manoel Luís, Maranhão – Brasil, durante expedição de pesquisa realizada na região.

| Data | Hora | Espécie | Sexo | CT (mm) | LD (mm) | PT (g) | Conteúdo estomacal | Dados reprodutivos |
|---|---|---|---|---|---|---|---|---|
| 28/06/1998 | 17:15 | *R. porosus* | fêmea | 760 | - | - | - | - |
| 28/06/1998 | 17:30 | *C. perezi* | fêmea | 870 | - | - | - | - |
| 28/06/1998 | 18:40 | *D. marianae* | fêmea | 640 | 340 | - | - | - |
| 29/06/1998 | 14:15 | *G. cirratum* | macho | 1500 | - | - | - | - |
| 29/06/1998 | 21:00 | *R. porosus* | fêmea | 785 | - | 1950 | dentes de peixe (Scaridae) | 6 ovos no útero; |
| 29/06/1998 | 21:00 | *R. porosus* | fêmea | 825 | - | 2300 | estômago vazio | 3 embriões no útero (CT médio = 145mm ); |
| 29/06/1998 | 21:00 | *R. porosus* | fêmea | 745 | - | 1500 | 1 peixe (*Sparisoma* sp.) e 3 cristalinos de peixes ósseos | 4 embriões no útero (CTmédio = 25mm) |
| 29/06/1998 | 21:00 | *R. porosus* | fêmea | 760 | - | 1700 | - | - |
| 29/06/1998 | 21:00 | *R. porosus* | fêmea | 835 | - | 2400 | estômago vazio | 4 embriões no útero (CT médio = 87,5mm ) |
| 29/06/1998 | 21:00 | *C. perezi* | fêmea | 815 | - | - | - | - |
| 30/06/1998 | 12:25 | *C. perezi* | macho | 945 | - | 4000 | 2 bicos de lula (Cephalopoda) | - |
| 30/06/1998 | 14:45 | *D. marianae* | fêmea | 680 | 380 | 2600 | 2 peixes (Scaridae) | 1 embrião a termo no útero (CT = 295mm; LD = 170mm; PT = 200g |
| 30/06/1998 | 22:00 | *R. porosus* | fêmea | 840 | - | 2250 | 2 indivíduos de *D. hystrix* | 5 embriões no útero (CTmédio = 70mm |
| 30/06/1998 | 22:00 | *R. porosus* | macho | 755 | - | 1750 | Estômago vazio | - |
| 01/07/1998 | 04:53 | *R. porosus* | fêmea | 765 | - | 1850 | dentes de peixe (Scaridae) | 7 ovos no útero |
| 01/07/1998 | 21:00 | *C. perezi* | fêmea | 860 | - | 4000 | 1 bico de lula (Cephalopoda)<br>1 peixe (*Sparisoma* sp.) | - |
| 02/07/1998 | 21:00 | *R. porosus* | fêmea | 740 | - | 1750 | - | - |
| 02/07/1998 | 21:30 | *G. cirratum* | macho | 970 | - | 4000 | - | - |

(-) sem dados; CT (comprimento total); LD (largura do disco); PT (peso total);

Duas fêmeas adultas da raia marianinha, *Dasyatis marianae*, medindo 340 e 380 mm de largura do disco (LD) foram examinadas. O maior exemplar, assim que capturado, abortou um embrião macho, aparentemente à termo, medindo 170 mm LD. Foram encontrados indivíduos inteiros e dentes de peixes da família Scaridae no estômago dos exemplares adultos. No Rio Grande do Norte, Yokota & Lessa (2007) estimaram entre 130 e 140 mm LD o tamanho de nascimento de *D. marianae*, reforçando a observação de que o embrião examinado estava prestes a nascer. Além disso, estes mesmo autores sugerem que a espécie se reproduz duas vezes ao ano, na primavera e no inverno. Os dados apresentados aqui corroboram a hipótese de que *D. marianae* também se reproduz no inverno nos Recifes Manoel Luís. As demais espécies de raias de *D. guttata*, *D. americana*, *Aetobatus narinari* e *Mobula* sp. foram registradas apenas visualmente.

Os dados do presente estudo, ainda que preliminares, reforçam a importância do Sítio Ramsar e Parque Estadual Marinho Parcel Manoel Luís como área de alimentação e reprodução de elasmobrânquios, inclusive de espécies com importância comercial (*R. porosus*) e/ou consideradas ameaçadas pela legislação brasileira (*G. cirratum*). Assim, ressalta-se aqui a importância da implementação efetiva desta Unidade de Conservação, com vistas a proteger fases críticas do ciclo de vida de diferentes espécies de tubarões e raias, predadores que desempenham função importante na estruturação das comunidades marinhas (Heithaus 2004).

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## Scientific Note

# Captura incidental de um tubarão-baleia, *Rhincodon typus* (Orectolobiformes, Rhincodontidae), na costa do Ceará, Nordeste do Brasil

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**Resumo.** Um tubarão-baleia, *Rhincodon typus*, foi incidentalmente capturado ao largo do Ceará em janeiro de 2009, durante pesca de rede-de-emalhe. Este é o segundo registro de ocorrência da espécie no Estado e o primeiro com material depositado em coleção científica.

**Palavras-chave**: Elasmobrânquios, espécies ameaçadas, captura incidental, registro de ocorrência.

**Abstract. Incidental capture of a whale shark, *Rhincodon typus* (Orectolobiformes, Rhincodontidae), off Ceará, Northeastern Brazil.** A whale shark, *Rhincodon typus*, was incidentally captured off Ceará on January 2009, during gillnet fishery. This is the second occurrence record for this species off the State and the first including material deposited in a scientific collection.

**Key words**: Elasmobranch, endangered species, incidental capture, occurrence record.

O tubarão-baleia *Rhincodon typus* (Smith, 1928), família Rhincodontidae, é o maior vertebrado semelhante a peixe conhecido, podendo atingir cerca de 20 m de comprimento total (CT) e 34 toneladas, embora a maioria dos registros não ultrapasse os 12 m de CT (Stevens 2007). Possui distribuição mundial na zona pelágica de águas costeiras e oceânicas, principalmente em águas tropicais e subtropicais. Morfologicamente é inconfundível, já que possui corpo robusto, recoberto por manchas claras circulares dispostas longitudinalmente sobre um fundo marrom acinzentado uniformes. Os flancos exibem cristas dérmicas longitudinais. A cabeça e boca são largas, esta última semi-terminal (Compagno *et al*. 2005). É uma das três espécies modernas de tubarões cujos hábitos alimentares envolve o consumo de organismos do zooplâncton, os quais normalmente são filtrados nas estruturas branquiais. Aspectos da sua reprodução só recentemente foram esclarecidos, quando uma fêmea de 10,6 m de comprimento toal (CT) e 16 toneladas, carregando 300 embriões (Joung *et al*. 1996) foi capturada, confirmando que o modo reprodutivo da espécie é a viviparidade lecitotrófica, com tamanho ao nascer estimado entre 58 e 64 cm de CT.

Quanto ao *status* de conservação, a espécie está classificada como vulnerável à extinção pela União Internacional para Conservação da Natureza – IUCN (Norman 2005). Existem evidências de declínio de capturas por unidade de esforço em áreas de pesca direcionada e também a redução das avistagens em áreas de agregação (Stewart & Wilson 2005, Bradshaw *et al*. 2008). As capturas incidentais ocorrem globalmente e são um dos principais fatores de risco para a espécie (CITES 2002, Stevens 2007). Capturas incidentais em redes-de-emalhar já foram registradas no Brasil, onde a espécie não tem importância comercial (Gadig & Rosa 2008). A captura e desembarque desta espécie são proibidos por lei (anexo I da Instrução Normativa nº05 do Ministério do Meio ambiente - MMA, 2004), que o define como espécie "ameaçada de extinção".

De um modo geral, registros de ocorrência de tubarão-baleia em águas brasileiras são escassos, totalizando pouco mais de 60 até o estudo de Hazin *et al*. (2008), que relataram uma série de avistagens no Arquipélago de São Pedro e São Paulo, Atlântico central ocidental, entre os anos de 2000 e 2005. O conhecimento atual sobre a ocorrência de tubarão-baleia no estado do Ceará, Nordeste do Brasil, se baseia no registro de um jovem medindo 1,88 m de CT, encontrado morto em novembro de 1991, em Acaraú, além de informações não confirmadas fornecidas por alguns pescadores, citando esta espécie nominalmente como "cação-estrela" já que, segundo eles, as pintas claras do animal, vistas logo abaixo da superfície se assemelham a estrelas (Gadig 1994). No presente trabalho é apresentado o segundo registro da ocorrência desta espécie na costa do Ceará, baseado na captura incidental de um exemplar em janeiro de 2009, sendo este registro, o primeiro com material testemunho depositado em coleção científica.

Em 23 de janeiro de 2009, foi acompanhada a comercialização de um exemplar de tubarão-baleia recém-desembarcado por pescadores na enseada do Mucuripe, Fortaleza-CE (Fig. 1). Foram examinados caracteres morfológicos externos do exemplar para confirmação da identificação. A arcada dentária foi removida, fotografada, congelada e depositada na Coleção Ictiológica Prof. Dias da Rocha, do Instituto de Ciências do Mar – LABOMAR, sob o número de catálogo CIDRO 065 (Fig. 2). Amostras de tecido muscular foram tomadas da região do entorno da arcada, envolvidas em papel alumínio e congeladas a –180 °C, com a finalidade de realizar estudos posteriores sobre filogeografia molecular.

**Figura 1.** Tubarão-baleia *Rhincodon typus*, capturado ao largo da costa do estado do Ceará e desembarcado/ comercializado na Enseada do Mucuripe, Fortaleza, CE, Brasil, em 23 de Janeiro de 2009 (Foto: Talita Rocha/Jornal O POVO)

**Figura 2.** Arcada dentária do tubarão-baleia, *Rhincodon typus*, capturado ao largo da costa do estado do Ceará e desembarcado/comercializado na enseada do Mucuripe, Fortaleza, CE, Brasil, em 23 de Janeiro de 2009 (Foto: Thiago H. Basilio).

Informações adicionais sobre a captura, o desembarque e a comercialização do tubarão foram obtidas junto aos pescadores envolvidos. Para obtenção de informações complementares sobre avistagens da espécie ao largo do Ceará, foram realizadas conversas informais com pescadores da frota pesqueira que atua principalmente com linha-de-mão.

O tubarão foi capturado por ~~redes~~-de-espera durante pesca direcionada a Serra (*Scomberomorus brasiliensis*) e Cavala (*Scomberomorus cavalla), teleósteos da* família Scombridae. O tubarão foi capturado em 23 de janeiro de 2009 a cerca de 15 milhas náuticas da costa. Logo após a captura, os pescadores retornaram a costa, trazendo o tubarão preso paralelamente à embarcação, mas ainda dentro da água. O desembarque na enseada do Mucuripe, Fortaleza-CE, foi realizado ao final da manhã do mesmo dia. De acordo com relatos, o tubarão foi trazido à praia ainda com vida, tendo inclusive mordido a perna, sem ferimento grave, de um dos pescadores envolvidos no desembarque. O comprimento total (CT) foi estimado pelos pescadores, como sendo de aproximadamente 5,5 m e se tratava de uma fêmea.

O animal foi cortado e sua carne comercializada ainda na praia. Horas depois, agentes do Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA) autuaram o mestre da embarcação. Pescadores envolvidos alegaram desconhecimento da lei de proteção da espécie. Os agentes do IBAMA apreenderam 580 kg da carne, os quais foram doados a entidades filantrópicas da cidade. Houve repercussão na mídia local [jornais O POVO (24 e 26/01/2009) e Diário do Nordeste (26/01/2009), além de reportagens de TV].

Embora registros de ocorrência tão pontuais sejam, em princípio, sugestivos da raridade de tubarão-baleia ao largo do Ceará, a consulta com os pescadores locais revelou que as avistagens não são incomuns. Localmente, os pescadores conhecem o tubarão baleia como "pintadinho" ou, como já mencionado, "cação-estrela".

Um mestre de pesca relatou avistagens em sete de 21 pescarias de espinhel-de-fundo realizadas no talude continental da Região Nordeste, principalmente ao largo da costa do Ceará, entre 2004 e 2006 (Jucá-Queiroz, dados não publicados). Outros relatos de avistagens foram obtidos com pescadores que atuam na frota motorizada que utiliza a linha pargueira. Avistagens também foram mencionadas por mestres jangadeiros. Ainda de acordo com eles, alguns exemplares possuíam CT maiores do que o comprimento da própria embarcação motorizada (14 m). Apenas tubarões solitários foram avistados. Em alguns casos, o tubarão se aproximou da embarcação, ficando paralelo à mesma, e às vezes, "no lado sombreado" do barco.

Encalhes de *R. typus* já foram reportados em diferentes regiões do mundo (Stevens 2007). O primeiro registro atribuído ao Ceará também foi nestas condições e se refere a um neonato de 1,88 m de CT encontrado morto no litoral do município de Acaraú em novembro de 1991 (Gadig 1994). Como nenhum programa de pesquisa investigando a presença de tubarões-baleia no Ceará foi conduzido até o momento, nenhuma informação adicional era conhecida. Inventários da fauna de peixes cartilaginosos ao largo do estado já realizados (Gadig *et al*. 2000, Jucá-Queiroz *et al*. 2008) se basearam no registro de Gadig (1994). Dessa forma, este estudo apresenta o segundo registro da ocorrência desta espécie na "costa do Ceará".

A ocorrência da espécie no mundo e mesmo no Brasil usualmente é associada à área com alta produtividade primária e secundária (Taylor 1994, Gadig & Rosa 2008). A maioria dos registros pontuais de indivíduos solitários no Brasil é procedente do litoral norte do estado do Rio de Janeiro e costa de São Paulo, áreas de ocorrência de ressurgência e sob influência desta, respectivamente (Gadig & Rosa 2008). De um modo geral, o ambiente pelágico do Nordeste brasileiro possui características oligotróficas, com biomassa primária geralmente baixa (Rossi-Wongtschowski *et al*. 2006). Não existem informações publicadas sobre valores elevados de biomassa primária na região do talude continental cearense. No entanto, o revolvimento de sedimentos ricos em nutrientes e matéria orgânica ao largo do talude da costa Nordeste, causados pela ação de massas d'água em suas encostas, já foi citado como fator relevante à maior abundância da biocenose em zonas bentônicas (Fonteles-Filho 2007). Caso este fenômeno tenha influência também em águas superficiais, a presença de *R. typus* nesses ambientes ao longo do talude poderia ser explicada pela provável maior disponibilidade de alimento, em relação a áreas oceânicas adjacentes. É importante notar, no entanto, que avistagens na região do talude podem se dever também a um maior esforço de pesca nesta área, em relação a áreas adjacentes.

Registros de ocorrência de tubarão baleia ao largo da costa brasileira se estendem por todas regiões sobre a plataforma continental, além do Arquipélago de Fernando de Noronha, Reserva Biológica do Atol das Rocas, Arquipélago de Abrolhos e Arquipélago de São Pedro e São Paulo

(Gadig 1994, Soto & Nisa-Castro-Neto 2000, Gadig 2001, Gadig & Rosa 2008, Hazin *et al*. 2008). As informações obtidas no presente estudo reiteram a presença da espécie em águas ao largo do Ceará, embora elementos que indicam qual o uso da região para a espécie sejam ainda desconhecidos. Estudos recentes de filogeografia molecular em escala global indicam uma significante, porém pequena estruturação de populações entre os diferentes oceanos (Castro *et al*. 2007, Schmidt *et al*. 2009). No entanto, nenhum dos estudos citados incluiu amostra de tubarões em águas do Atlântico Sul. A amostra de tecido obtida no presente estudo pode ser útil em estudos de filogeografia molecular que possam contribuir para a elucidação de padrões de estruturação populacional de tubarões-baleia da costa brasileira.

Os dois exemplares de tubarão baleia registrados para costa do Ceará eram jovens imaturos (Gadig 1994, presente estudo), embora os relatos de pescadores atuando em regiões próximas ao talude continental atestam para avistagens de animais com tamanhos de adultos. Isto sugere a ocorrência de extremos de classes de comprimento total de tubarões-baleia ao largo da costa do estado do Ceará. Estudos adicionais são necessários para se conhecer a faixa de maturidade de tubarões-baleia na região. As informações obtidas com pescadores podem servir como uma base para se desenvolver um programa científico de investigação por meio de questionário e monitoramento em longo prazo (Jonahson & Harding 2007).

Em diversas partes do mundo, os tubarões baleia exibem um padrão sazonal de ocorrência (Stewart & Wilson 2005), muitas vezes associadas à disponibilidade local de alimento. No Atlântico oeste, agregações foram observadas em áreas recifais de Belize para se alimentar da desova de cardumes do dentão *Lutjanus jocu* e da caranha *L. cyanopterus* entre março e junho (Heyman *et al*. 2001). No Brasil, avistagens de tubarões baleia no Arquipélago de São Pedro e São Paulo (ASPSP) são mais freqüentes no primeiro semestre do ano, possivelmente associadas à desova de peixe-voador (*Cypselurus cyanopterus*) (Hazin *et al*. 2008). Não existem informações sobre sazonalidade de ocorrência de tubarões-baleia ao largo do Ceará, sendo possível apenas notar que o mês de captura do juvenil (janeiro) coincide com o início do primeiro semestre, período de maior freqüência de avistagens em ASPSP.

Agregações de tubarões-baleia são conhecidas em diversas regiões no mundo, incluindo o Golfo do México (Baughman & Springer 1950), Mar do Caribe (Gudger 1939) e Belize (Heyman *et al*. 2001) no Atlântico Oeste. No entanto, no presente estudo, apenas avistagens de indivíduos solitários foram relatadas pelos pescadores. Pelo menos em parte, uma ausência de agregações na região pode se dever às características oligotróficas do ambiente pelágico na ZEE no nordeste do Brasil (Rossi-Wongtschowski *et al*. 2006).

No Brasil, não existem dados estatísticos oficiais sobre capturas de tubarão-baleia. Gadig & Rosa (2008) citam que a espécie é capturada de forma incidental em redes-de-emalhe, sendo este o caso da captura descrita no presente estudo. No entanto, nenhuma outra captura de tubarão-baleia foi mencionada por pescadores durante conversas informais. Localmente, um estudo recente, monitorou desembarques e descreveu a pescaria de redes-de-emalhe realizada pela frota pesqueira da enseada do Mucuripe e, entre 2006 e 2008, nenhum tubarão baleia foi capturado ou reportado (Carneiro 2008). Atividades pesqueiras em área de talude são principalmente de espinhel e linha de mão, que podem propiciar avistagens, mas que não resultam em capturas incidentais. As informações obtidas até o momento não indicam que a espécie seja vítima constante de capturas incidentais na região.

Pescadores alegaram desconhecimento da lei que proíbe a captura de tubarões-baleia ao serem autuados por agentes do IBAMA. Atividades de Educação Ambiental podem levar informações sobre espécies protegidas por lei a pescadores, bem como da sociedade em geral. Exemplos de atividades incluem feiras ambientais para público em geral, oficinas de trabalho com pescadores, e atividades específicas para o público infantil (como teatros, jogos e atividades de pintura, etc.). Estas atividades são importantes meios de divulgação do status do tubarão-baleia, bem como de outras espécies marinhas em risco. Associadas às medidas informativas, a atuação de autoridades responsáveis pela fiscalização e aplicação da lei são igualmente indispensáveis. Ressalta-se que a atuação dos agentes do IBAMA na autuação e confisco da carne do tubarão-baleia teve também um efeito de divulgação da proibição de capturas desta espécie.

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## Scientific Note

# First reported occurrence of pregnant and neonato, *Rhinoptera brasiliensis* (Chondrichthyes, Rhinopteridae) caught off Guaruja city, São Paulo state, Brazil

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**Abstract.** This paper presents the occurrence pregnant female and neonate of *Rhinoptera brasiliensis*, Muller, 1836 caught off Pereque and Guaiuba beaches, Guaruja City, Sao Paulo State (23º59’18”S-46º14'32"W).

**Keywords:** reproduction, embryo, rays, rhinopteridae, fisheries

**Resumo. Primeiro registro de ocorrência de fêmea grávida e neonato de *Rhinoptera brasiliensis* (Chondrichthyes – Rhinopteridae), capturados em Guarujá, São Paulo, Brasil.** Este trabalho apresenta a ocorrência de uma fêmea prenha e um neonato de *Rhinoptera brasiliensis*, Muller, 1836, no litoral do Estado de São Paulo, capturados frente às praias de Perequê e Guaiúba, Guarujá-SP, (23º59’18”S-46º14'32"O).

**Palavras-chave:** reprodução, embrião, raias, rhinopteridae, pesca.

The genus *Rhinoptera*, Cuvier, 1829, is represented by eight species of rays, distributed around the world. They are present in tropical, subtropical and warm-temperate waters, except around Oriental Pacific Island (Last & Stevens 1994). They are very common in coastal and estuarine regions (Last & Stevens 1994). According to Cavalcanti *et al.* (1997), two species occurred off the Brazilian coast, the cownose ray *Rhinoptera bonasus* (Mitchill 1815) and the Brazilian cownose ray *R. brasiliensis*, Muller 1836.

Bigelow & Schroeder (1953) noted that the species was identified as *R. brasiliensis*, based on 9 series upper jaws teeth in samples collected in Brazil. Nevertheless, the species validity was questioned by Compagno (1999), and after confirmed by Menni & Stehmann (2000); based on the species occurrence off Rio de Janeiro, and Rio Grande do Sul.

The ticon cownose Ray, *R. brasiliensis* is distributed from Rio de Janeiro to Rio Grande do Sul States, 23°–32°S (Bigelow & Schroeder 1953, Menni & Stehmann 2000). It is found in depths up to 20 m off Rio Grande do Sul State, suffering intensive artisanal fishery pressure (Vooren *et al.* 2005). Reproductive information is poorly known. A case of matrotrophic viviparity (incipient histotrophy *sensu* Hamlett *et al.* 2005), was observed in embryos feeding initially on yolk, and then receiving nourishment from the mother by indirect absorption of uterine fluid enriched with mucus, fat and protein through specialized structures (Breder & Rosen 1966, Carrier *et al.* 2004). Generally one embryo per litter was observed (Vooren *et al*. 2005).

A pregnant female and a neonate of *R. brasiliensis* were caught by artisanal fishery (depths of 3 to 20 m) off Pereque and Guaiuba beaches, in Guaruja City (23º 59’ 18” S; 46º 14' 32"W), Sao Paulo State, in March and October 2008, respectively (Fig. 1).

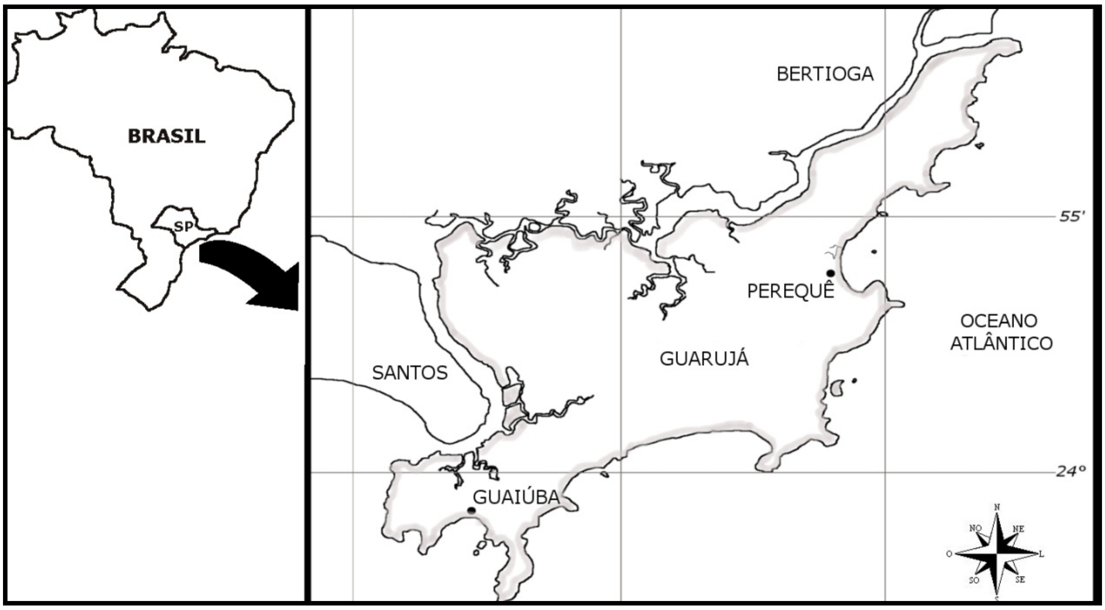

**Figure 1.** Guaiuba and Pereque beaches at Guaruja City, Sao Paulo State, location of cownose ray catch.

The neonate was caught by the bob-shrimp double throw boat Maria Gabriela, and a pregnant female was caught by the boat 'Gabriela' operating with gill net for bone fish. Both were donated by fisherman of artisanal fishery.

The identification was based on Bigelow & Schroeder (1953) and morphometric measurements followed Figueiredo (1977), Last & Stevens (1994) and Notarbartolo-di-Scaria (1987) (Table I). The morphometric data are expressed in percentages of the disc width (DW). The identification of the exemplars as *Rhinoptera brasiliensis* can be considered as the first record in the region.

Table I presented the average percentage of the specimens in order to contribute with the species identification. Also it was observed nine tooth plates in all jaws specimens. Comparing the biometrics parameters, the female and neonate were very similar to each other and a little different from embryo.

**Table I.** Morphometric measurements (in mm) and percents of disc width (DW) carried out in the adult female and its embryo and the neonate of *Rhinoptera brasiliensis*.

| Measurements | Female | % | Embryo | % | Neonate | % |
|---|---|---|---|---|---|---|
| **Sex** | F | | M | | M | |
| **Disk Width** | 94 | 100 | 27.5 | 100 | 36 | 100 |
| **Snout to pectoral fin** | 58 | 61.70 | 17.2 | 62.55 | 22 | 61.11 |
| **Snout to pelvic fin** | 62 | 65.96 | 17.5 | 63.64 | 24 | 66.67 |
| **Snout to nostril** | 6,5 | 6.91 | 2 | 7.27 | 3 | 8.33 |
| **Snout to mouth** | 10,9 | 11.60 | 2.5 | 9.09 | 4 | 11.11 |
| **Snout to cloaca** | 56 | 59.57 | 15.1 | 54.91 | 20 | 55.56 |
| **Snout to eye** | 4 | 4.26 | 1.8 | 6.55 | 1,5 | 4.17 |
| **Snout to 1ª branchial cleft** | 15,5 | 16.49 | 4.7 | 17.09 | 6 | 16.67 |
| **Snout to 2ª branchial cleft** | 18 | 19.15 | 5.6 | 20.36 | 6,7 | 18.61 |
| **Snout to 3ª branchial cleft** | 21 | 22.34 | 6.4 | 23.27 | 7,7 | 21.39 |
| **Snout to 4ª branchial cleft** | 23 | 24.47 | 6.9 | 25.09 | 8,6 | 23.89 |
| **Snout to 5ª branchial cleft** | 25 | 26.60 | 7.3 | 26.55 | 9,4 | 26.11 |
| **Distance between 1 e 5 branchial cleft** | 9,7 | 10.32 | 2.8 | 10.18 | 3,6 | 10.00 |
| **Spine Length** | # | # | 2.3 | 8.36 | 3 | 8.,33 |

The male of 36 cm DW hooked was considered neonate because of the umbilical cord scar. Nevertheless, according to Bigelow & Schroeder (1953) the birth size of that species ranges from 43 cm to 48 cm and Vooren *et al.* (2005) observing pregnant female at Rio Grande do Sul inshore found embryos up to 37 cm DW.

With the dissection of the pregnant female, it could be observed the typical fetal position (enrolled with the pectoral fins overlapping the dorsal region) of the single embryo (Figs. 2 and 3). Apparently the right uterus was not functional. According to Vooren *et al.* (2005), the species presents only one embryo per litter.

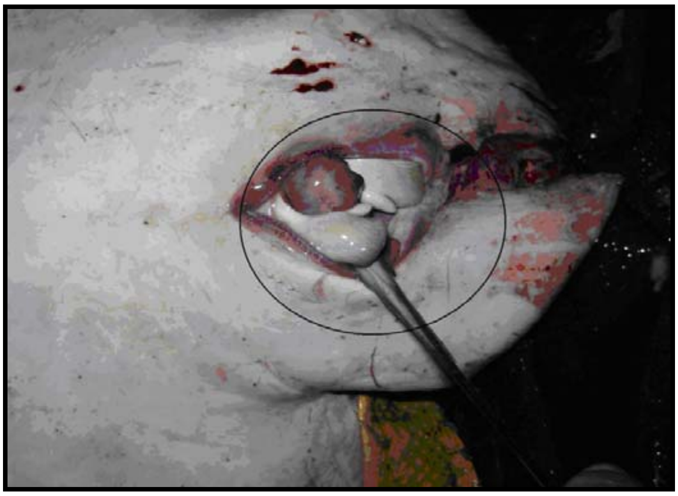

**Figure 2.** Female cloacae showed the posterior region from one embryo.

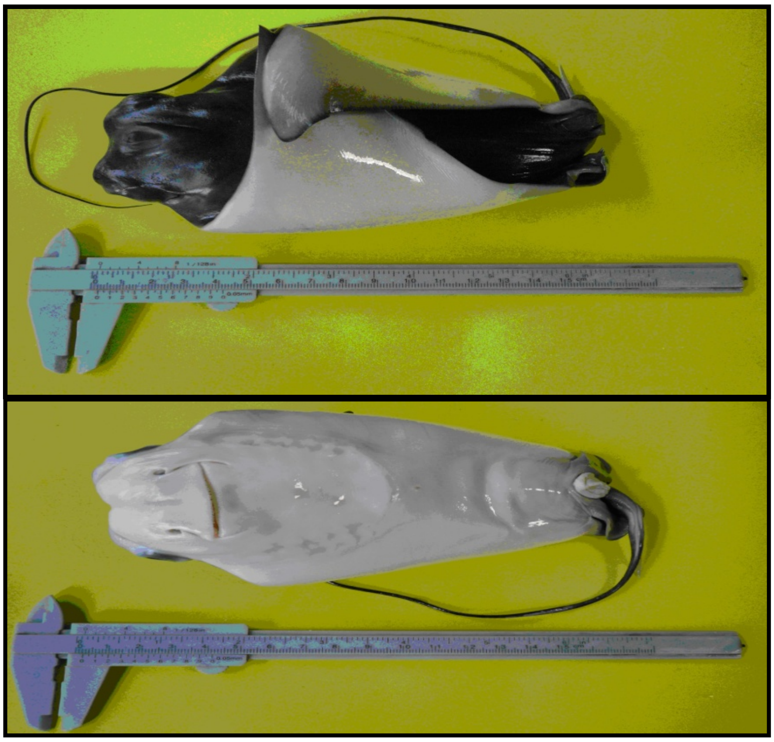

**Figure 3.** Dorsal and ventral view of embryo.

The embryo measured 27.5 cm DW and weighed 5.1 g (Table I). It showed dark gray uniform color darker than the neonate color. Also it was observed “uterine milk” which nourishes the developing embryos.

The presence of neonate in March and pregnant female in October off Guaruja City, Sao Paulo State, suggests that this place could be one of the nursery areas for the species.

According to the fisherman *R. brasiliensis* is rejected in the fishery because of its low value. Nevertheless the species must be better studied because it was included in the Red List as endangered (Vooren 2004).

The specimens were deposited in the Ichthyological Collection of the “Nucleo de Pesquisa e Estudo em Chondrichthyes-NUPEC” (neonate No 2146, female No 2147 and embryo No 2147.1).

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## Scientific Note

# Observations on a rare shark, *Oxynotus centrina* (Chondrichthyes: Oxynotidae), in the Sea of Marmara (north-western Turkey)

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**Abstract.** A female angular rough shark, *Oxynotus centrina* (Linnaeus 1758), ca. 60 cm of TL, was observed in the Sea of Marmara, Turkey. It never exhibited any aggressiveness when it was immobilized by divers.

**Key words:** Locomotion, carangiform swim, rough sharks, protection.

**Resumen: Observaciones sobre el tiburón raro, *Oxynotus centrina* (Chondrichthyes: Oxynotidae) el mar de Mármara (noroeste de Turquía).** Una hembra del tiburón cerdo marino *Oxynotus centrina* (Linnaeus 1758), de aproximadamente 60 cm de longitud, fue obervada en el mar de Mármara, Turquía. La misma se mostro inofensiva para on los buzos.

**Palabras clave:** De movimiento, natación carangiform, tiburon cerdo marino, la protección.

The angular rough shark, *Oxynotus centrina* (Linnaeus 1758), is an uncommon, little-known shark, reported throughout the entire Mediterranean Sea (Serena 2005) and eastern Atlantic from the British Isles (Calderwood 1892) to South Africa (Compagno 1984). *O. centrina* is a sluggish shark found across continental shelves and upper slopes at depths ranging between 30 and 800 m (Compagno 1984; Sion *et al*. 2004).

In the Mediterranean Sea, *O. centrina* has been obsereved in rare numbers (*e.g.* Tortonese 1956; Golani *et al*. 2006) since 19th century. Due to this rarity, little is known about the biology of *O. centrina* within this region. For example, only a description of embryos (Megalofonou & Damalas, 2004) and observations on the reproductive tract of a mature female exist (Dragičević *et al*. 2009). Some aspects of the diet of *O. centrina* also exist (Capapé 1975; Barrull & Mate 2001; Capapé 2008), but the research is incomplete.

The aim of this paper is to present a record of an angular rough shark from the northern coast of the Sea of Marmara, north-western Turkey (Fig. 1), at a depth of 30 m, with observations on it's behaviour.

A compact digital camera (SEA&SEA 860G) in an underwater housing was used to record the behaviour of said shark. Species identification of the present specimen follows Compagno (1984). The total length of the examined shark was approximated using to the nearest centimeter with a tape measure. A total of 03:48 minutes underwater video footage was recorded and is available on http://derintakip.blogspot.com/2009/11/angular-rough-shark-in-sea-of-marmara.html

Based on the following characteristics, the female shark was identified as *O. centrina*: Two large dorsal fins with spines buried in the fins; stout, compressed and high trunk with strong abdominal ridges; large spiracles behind the eyes; enlarged nostrils close each other; long labial furrows encircling the mouth. Total length of the specimen was ca. 60 cm.

At 16:00 hours the angular rough shark was observed slowly moving across the muddy/sandy bottom and frequently stopping and hovering over the sea floor at irregular intervals. During the non-swimming phase, the angular rough shark maintained it's body in an oblique position, snout in contact with the bottom and kept itself in this oblique hovering for a few seconds before returning to a horizontal swimming pattern.

The observed specimen exhibited a clear avoidance to bright light. Under illumination, the shark maintained it's swimming direction for a short time (max. 15 seconds), then changed it's course again, rising nearly one meter off the bottom while gently arching it's body, and turned in the opposite direction to the light source and immediately descended to the bottom again and continued swimming. When not illuminated, the angular rough shark kept swimming alongside the divers and did not exhibit any sudden changes in course.

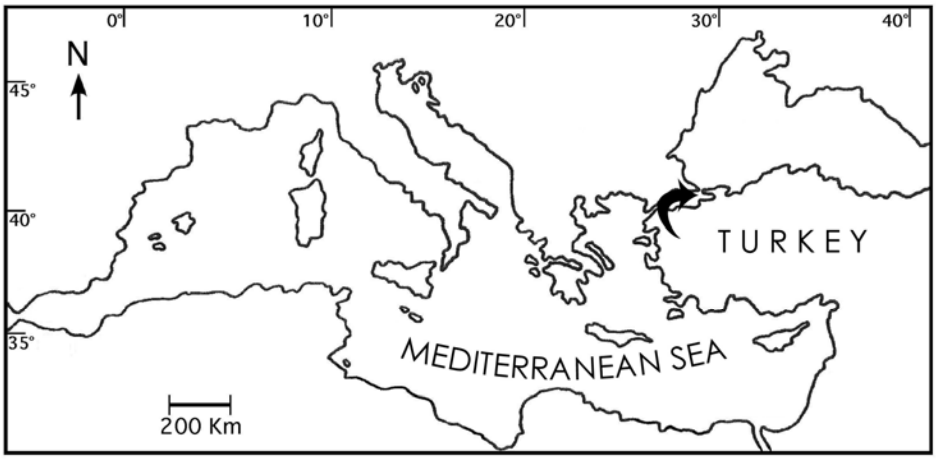

**Figure 1**. Map indicating the locality of encounter with the angular rough shark, *Oxynotus centrina*, in the Sea of Marmara, NW Turkey (arrow denotes the approximate locality).

During steady swimming in the horizontal plane, undulations were mostly confined to the posterior half of the body with less than one wave present. However, the amplitude of body motion increases markedly over the posterior half of the body. In addition, the posture of the pectoral fins changed, relative to the direction of movement (Fig. 2). During vertical movements or hovering activity, the shark rapidly moved the trailing pectoral fin edge ventrally (Fig. 2) until the movement/activity was complete. During descent in the water column (maneuvering down or sinking), the angular rough shark rapidly elevated the trailing pectoral fin edge. Before touching down, the angular rough shark elevated the leading pectoral fin edge, and even undulated the pectoral fins in a clockwise rotational movement for several times to reduce the speed of sinking, and to maintain a horizontal position over the bottom (Fig. 2). During ascent in the water column (maneuvering up or rising), the angular rough shark rapidly elevated the leading pectoral fin edge, and undulated the posterior half of it's body rapidly.

According to Wilga & Lauder (2004), *O. centrina* fits to body type 4, since it lacks an anal fin but does have a large epicaudal lobe. In contrast Capapé (2008) mentioned *O. centrina* as a shark with body type 3; however, sharks of this type have relatively large heads, more anterior pelvic fins, more posterior first dorsal fins and a low heterocercal tail angle (Wilga & Lauder 2004). In *O. centrina*, position of the pelvic fins on the body is more posterior, close to caudal fin, and the leading edge of the first dorsal fin is almost on the same perpendicular with the leading edges of the pectoral fins. Furthermore, heterocercal tail angle of the angular rough shark is clearly high. According to Wilga & Lauder (2004), sharks with body type 3 are demersal sharks such as *Scyliorhinus*, *Ginglymostoma*, *Chiloscyllium*, *Galeus*, *Apristurus*, *Pseudotriakis* and Hexanchiformes. Therefore, *O. centrina* should be included in body type 4.

All sharks swim using continous lateral undulations of the axial skeleton. Based on decreasing proportion of the body that is undulated during locomotion, Wilga & Lauder (2004) described four modes of axial undulatory propulsion from anguilliform to thunniform. Following their descriptions, *O. centrina* is a carangiform swimmer, where undulations are mostly confined to the posterior half of the body with less than one wave present (Wilga & Lauder 2004). *O. centrina* moves over the bottom slowly but constantly, and uses pectoral fins effectively to change its' orientation in the water column.

Our observations of *O. centrina* contrast those from the literature. For example, several authors (Compagno 1984, Lipej *et al*. 2004, Capapé

2008) suggest that this species is a 'sluggish' bottom-dwelling shark. In addition Compagno (1984) suggests that *O. centrina* relies on their expanded body cavities and large oil livers to attain neutral buoyancy, so they can hover and slowly swim above the substrate without needing forward motion for lift. Although *O. centrina* was observed sinking slowly towards the substrate in the current study, it was also observed needing forward motion for lift in deep water. In addition Lipej *et al*. (2004) suggest *O. centrina* is a slow, timid, nocturnal shark. Our observations suggest that despite the specimen's avoidance of bright light, the shark did not avoid the divers. Finally, the suction behavior suggested by Capapé (2008) to capture wormlike prey along with sediments was only observed once during the video footage.

Due to the limited knowledge on the biology of *O. centrina*, the observations put forth herein on a solitary individual, has increase the general understanding of this species in Mediterranean waters (*e.g*. Barrull & Mate 2001, Megalofonou & Damalas 2004, Dragičevic *et al*. 2009).

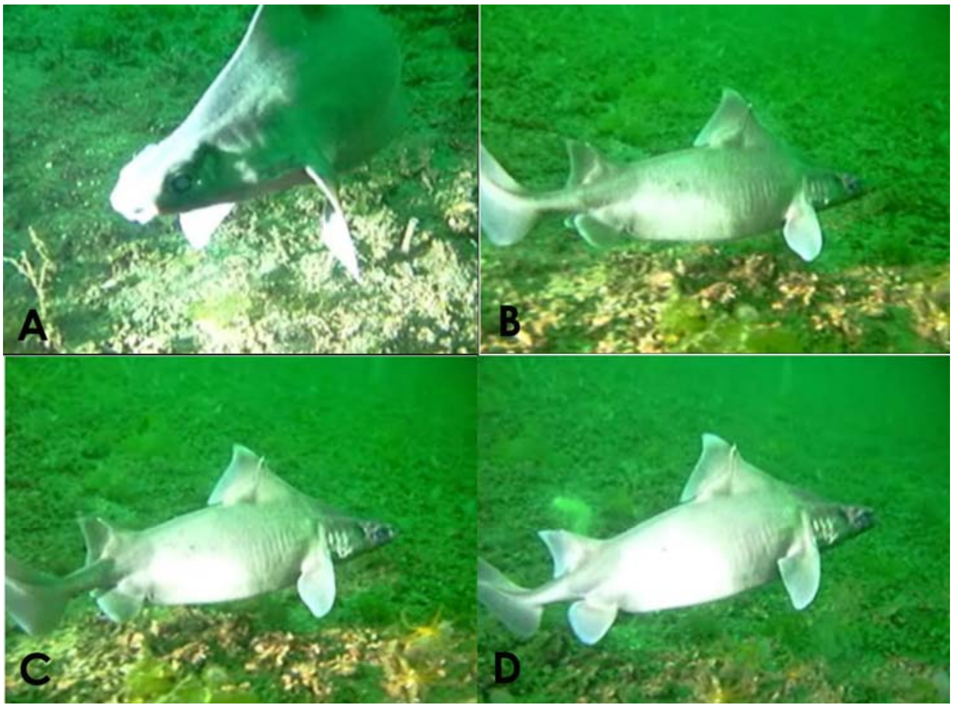

**Figure 2.** Patterns of movement observed in the present specimen of *Oxynotus centrina*. Posture of the pectoral fins is markedly changed relative to the direction of movement; (a) posture of pectoral fins during vertical maneuvering or hovering; (b) at the begining of maneuver up, trailing edge of the pectoral fins are lowered; (c) during the progression of maneuver up, trailing edges of pectoral fins are kept in the lowered posture; and (d) before the begining of horizontal movement, pectoral fins are returned to natural posture. All images are captured from the video footage recorded on 27 September 2009, between 16:00 to 16:05 hours.

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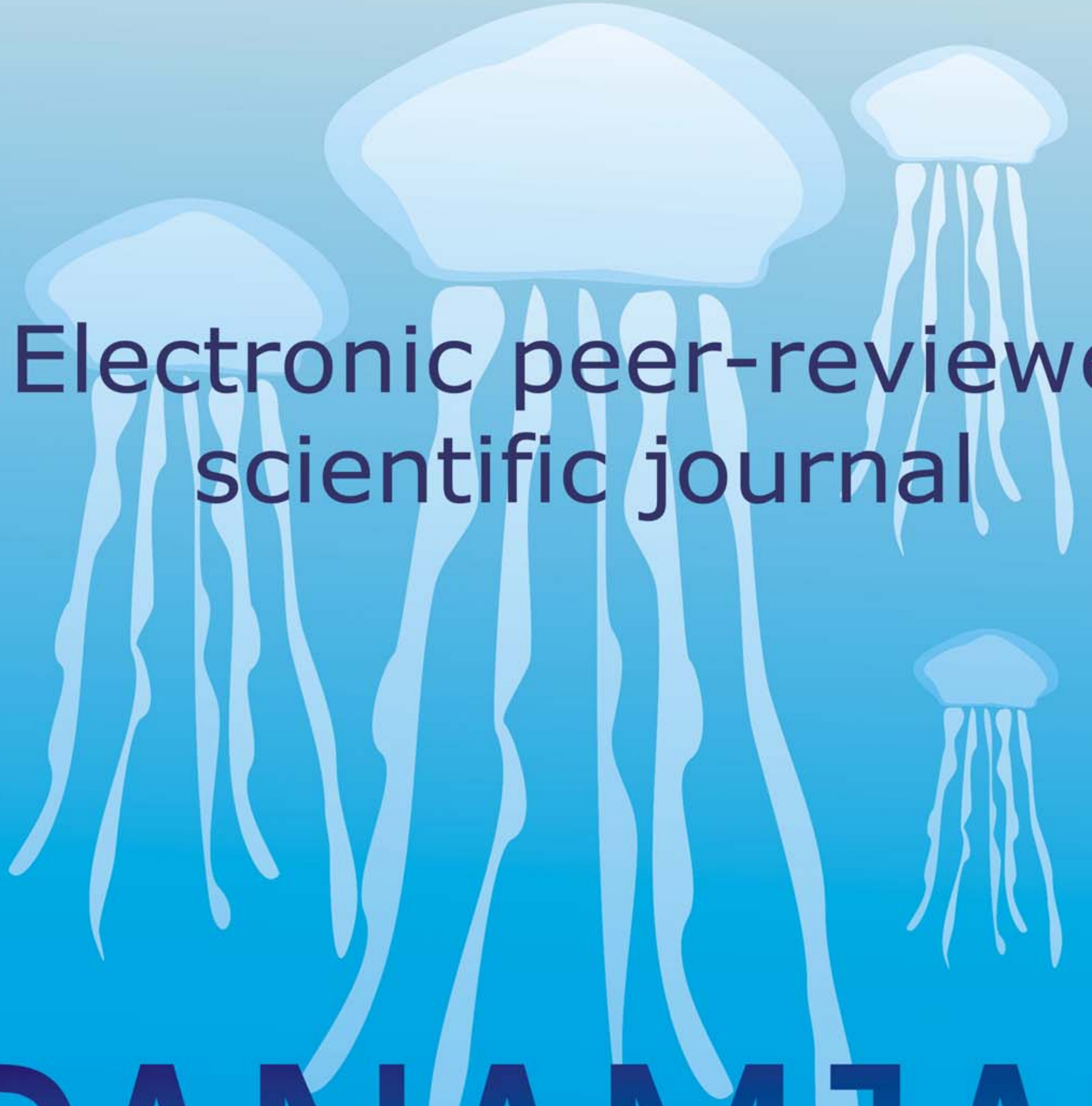

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