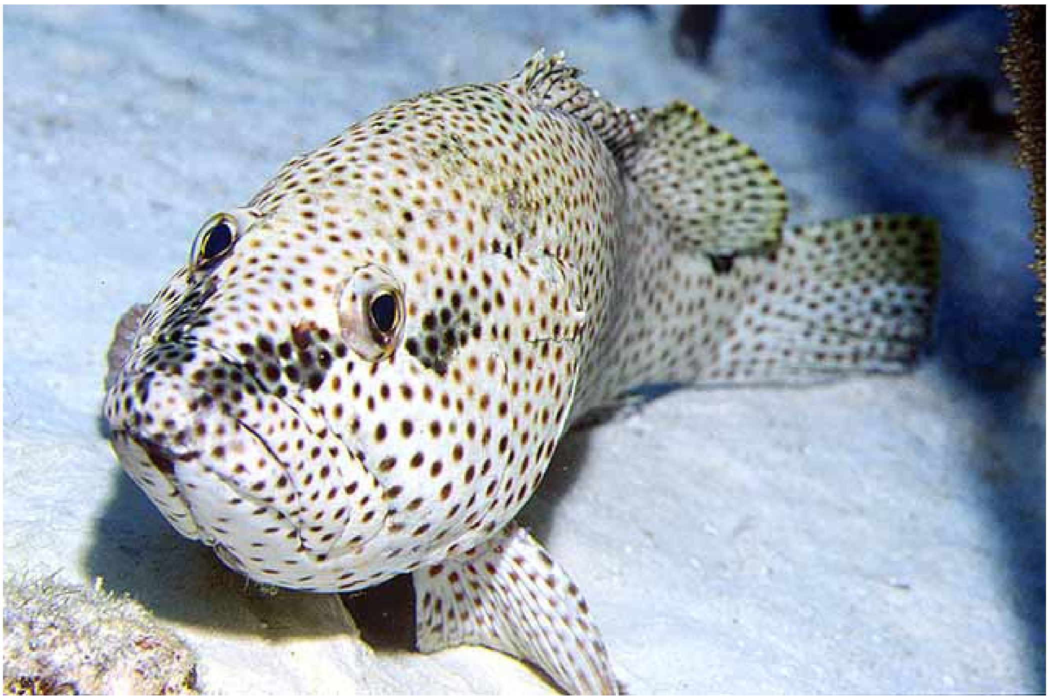
AN ECOLOGICAL SURVEY OF THE ST HELENA AND ASCENSION ISLAND POPULATIONS OF THE JACK (*EPINEPHELUS ADSCENSIONIS*) WITH A REVIEW OF MANAGEMENT OPTIONS.



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Executive summary

The St Helena Jack *Epinephelus adscensionis* is a widely distributed grouper (Family Serranidae) that occurs throughout the reefs of the western tropical Atlantic and the eastern Atlantic island of Sao Tome and the mid Atlantic islands of St Helena and Ascension. Comparison between islands was helped by the similarity in island size, the amount of subtidal reef habitat, and the nature of the reef fish fauna. Both St Helena and Ascension support high densities of Jack with abundances at these mid Atlantic islands being greater than those recorded from tropical western Atlantic reefs by a factor of 4 to 780. At Ascension Island groupers were found to be three times as abundant as at St Helena. An underwater census program demonstrated that grouper abundance and size varied on the island's reefs as a function of human access and activity. On St Helena grouper abundances and size increased in a systematic fashion with increasing distance from points of human access. A similar, but much weaker, pattern was observed at Ascension.

In terms of size and age the averages and maximum values obtained were surprisingly similar for each island which was also reflected in the similar growth and mortality rates. One small but consistent difference was that groupers on Ascension achieved a larger size due largely to a faster growth rate in older individuals. Both populations displayed very similar relationships between size and weight. However as growth rates differ between the islands it takes longer for a St Helena grouper to achieve the same weight as an Ascension grouper. A difference was also seen in deep and shallow water populations at St Helena where deeper water groupers had a lower weight for a given size than shallow water groupers. Slower growth rates and lower condition in deep water groupers suggest that increased fishing in deeper water is unlikely to prove sustainable.

In both populations there is strong evidence of a protogynous mode of sexual development with all individuals commencing life as females and transforming to males

by sex-reversal at approximately 5 to 8 years of age. There is evidence of significant differences between the two populations in terms of the schedule of sex reversal and the dynamics of male recruitment. The average age and size at which sex change occurs is much younger and smaller at St Helena. Consequently the sex-ratio in small groupers is biased towards males in St Helena, and there are relatively fewer reproductive females than at Ascension Island. Finally the similar life spans and maximum ages of groupers on the two islands is unusual when compared to four other reef fish species found at both islands, which are distinctly longer lived at St Helena.

Differences in abundance between Ascension and St Helena populations, lower densities and smaller size of groupers adjacent to human activities on St Helena, sex reversal at smaller sizes and younger ages on St Helena and the absence of older males all point to a fishing effect impacting the larger members of the population. The most parsimonious explanation is that this reflects the greater human population on St Helena and the presence of a commercial fishery. Although grouper populations on St Helena appear to be abundant and healthy the present evidence for overfishing indicates any increase will result in the systematic decline of grouper stocks. Severe declines in grouper populations are a predictable consequence of continued fishing of grouper population, especially in Atlantic island localities.

In the light of the emerging evidence of overfishing, the historical record of severe overfishing in other grouper island populations and the likelihood of increased future access to St Helena the following recommendations are made.

- In the face of evidence of current fishing impacts no increase in the catch rates of groupers in the commercial fishery be permitted.
- That total catch rates of groupers be recorded on a monthly basis with monitoring of a subsample for size and weight so that changes in the average size of harvested groupers over time may be obtained. In addition it is recommended that a sample of 100 otoliths covering the fished size range of grouper be collected on an annual basis.

- A system of at least 3 no-fishing reserves be established on the north and west coasts of the island, with each reserve including at least one km of coastline and extending seawards to the 100m depth profile. These reserves and adjacent control areas with similar dimensions should be monitored thereafter on an annual basis for grouper abundance and size structure.
- Given the fact that most groupers form spawning aggregations it is also recommended that a program to determine the nature, location and frequency of spawning in St Helena groupers be instituted as part of a management plan for this species.
- A minimum size limit of 35 cm total length/1 kg weight be imposed to enable the majority of females to live through at least one spawning season.

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Introduction.

Groupers are a widely distributed family (Serranidae) of demersal reef fishes that occur in all tropical and subtropical oceans of the world. They are amongst the most intensively targeted fishes in the international trade of reef fish products and command very high prices, especially in Asian "live-fish" food markets. This report deals with the biological status of the grouper *(Epinephelus adscensionis)*, locally known as ***Jack***, populations at St. Helena island and nearby Ascension Island. This species is widely distributed in the sub-tropical and tropical Atlantic Ocean.(Fig 1) Here we deal with the impact of a commercial fishery on the population at St Helena, and ways in which the fishery can be managed in the future.

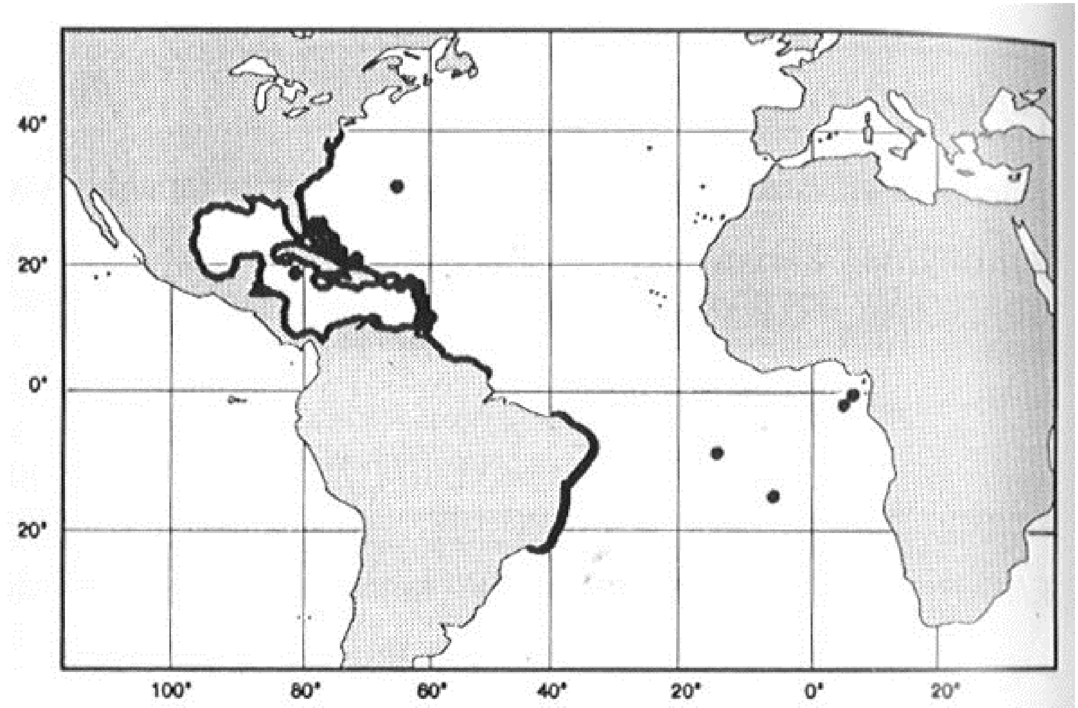

Figure 1: Geographic range of *Epinephelus adscensionis*

Populations of Jack at St Helena and Ascension are unusual in that, in comparison to most other shallow water groupers, and to populations of Jack elsewhere within its geographic range, they occur at very high abundances in shallow reef environments of both islands. The biology of these two populations and the potential impacts of fishing needs to be considered in the context of the unusual features of the St Helena and Ascension marine environments: (i) the very small areas of habitat that support Jack populations in these two tiny islands; (ii) the extreme isolation of both islands, which must mean that the Jack stock at each island is demographically self sustaining, even though they may be genetically connected by occasional transport on ocean currents of small numbers of pelagic larvae; and (iii) the variable and low productivity oceanic environment in the area of those islands, an environment that is driven by the gyres associated with the South Equatorial and Benguela currents. This combination of biological and environmental features must be taken into account when considering the behaviour and status of grouper populations, their response to fishing, and measures that need to be taken to ensure a fishery that is sustained at a high level of productivity.

At present, access to both islands in terms of trade and export possibilities is strongly influenced by their isolation. The two islands lie 2300 to 3000 kilometers from southern African ports, over 7000 and 9000 kilometers from European and North American ports respectively and are separated by 1200 kilometers. Ascension Island is served by ship and a military airfield, while St Helena is accessed exclusively by ship. However the planned development of an airport on St Helena catering to wide-bodied jet aircraft will have a profound impact on access to the island and its trade opportunities. Grouper fisheries are not only valuable but also extremely vulnerable to over-fishing leading to very rapid, drastic and long-term declines in abundance, and collapse of fisheries. Modern transport facilities including air freight have played a major role in the development of grouper fisheries as the remaining tropical grouper populations occur at isolated sites thousands of kilometers from major markets. Such situations are directly equivalent to those at St Helena and Ascension. Since the value of Jack in any live-fish export trade would be much higher than in the current export fishery it behooves both fisheries authorities and fishers to ensure that this resource remains highly productive for the foreseeable future, and is not threatened by short-term considerations

The primary purpose of this report is to provide a comprehensive picture of the biology of the Jack at St. Helena Island, focusing on vital statistics that include abundance patterns, the size, age and sex structure of its population, and the growth and mortality rates of members of that population. This information is an essential prerequisite for the development of a sound management plan for the grouper fishery aimed at maintaining that stock at a high level of productivity. A commercial fishery for Jack, and other pelagic species, has operated on St Helena since at least 1977. In 2007 that fishery harvested 40 metric tons of groupers, with the average annual harvest being about half that level since the fishery started. To assess effects of current levels of commercial fishing on the St Helena Jack population we compared the population biology of this species at St Helena with that at Ascension. Ascension can act as a "control" area to assess fishing impacts on the St Helena Jack population because Jack are abundant at both islands, but Ascension lacks a commercial fishery and has limited sport fishery by a much smaller human population (~15% the size of the St Helena population). In addition, Ascension Island lies 1200 km to the north of St. Helena and has a more tropical environment than that of St Helena. Previous studies have demonstrated that this degree of difference in latitude has substantial effects on the growth rates and age structure of populations of fishes through the effects of sea temperature on growth and reproductive seasonality. To take this pattern into account in the Jack assessment a comparison was also made of the demography at both islands of four species of reef-fishes that are not subject to commercial fishing at either island.

One crucial aspect of any biological survey of any grouper that could not be completed in a one month survey concerns the spawning pattern and spawning seasonality of the Jack. Almost all species of groupers in the subfamily Epinephelinae (to which the Jack belongs) form spawning aggregations during a very restricted part of the year. Such aggregations, which usually become the primary focus of fishing, are extremely vulnerable to rapid over-fishing, leading to the dramatic, long-term declines in local stocks (Sadovy & Eklund 1999, Claydon 2005). Given that its close relatives typically form spawning aggregations it is highly likely that the Jack also forms such aggregations at St Helena and Ascension. To establish when and where any such spawning aggregations form at St Helena and Ascension would require a dedicated project extending throughout the year, as well as monitoring of the seasonal and interannual dynamics of recruitment of pelagic juveniles. Obtaining such information obviously was not possible in the present, one-month survey. However it was possible to collect sufficient reproductive samples to establish (i) the age and size at maturity of Ascension populations (the only island at which males and females had active gonads) and (ii) that both populations were protogynous hermaphrodites with males recruited through the sex reversal of females, the usual sexual pattern in epinepheline groupers.

This report is organized to provide an introduction to the special features of both the St.Helena and Ascension Islands and their reef habitats and comprehensive survey of the abundance patterns and demographic characteristics of each population. These data will allow estimates of variation in abundances at different localities at each island partitioned into different levels of fishing activity and degree of exposure to the prevailing wind; estimates of growth rate and longevity partitioned by sex from different location on each island and between each island; estimates of the age and size at sexual maturity and the pattern of sexual development for each population; estimates of recruitment and mortality rates for each island population. A summary of the fishery-based information available is included.

Combined, this information will allow us to estimate the probable impact of fishing on the St Helena grouper population and provide a credible basis for management recommendations. However, this report cannot provide estimates of allowable future harvesting rates based on the calculation of maximum sustainable yields (MSY). Although estimates of sustainable yields are sought by fisheries managers the assumptions made in calculating MSY are considered by most fisheries biologists to be unrealistic. Moreover in many cases where this information (derived largely from fishery-based statistics) is used as a basis for management of fisheries the conclusion that a fishery is declining due to unsustainable levels of exploitation typically is reached well after that has already come to pass. However, all the data collected during our survey will be of use to fisheries biologists employing such methods.

In the context of management our primary recommendation will concern the incorporation of a substantial proportion of the shelf around each island in no-fishing areas, with those and adjacent fished areas being monitored to assess fishing impacts. In addition we will recommend a more detailed analysis of grouper catches including recording of trends in the mean size and age, and reproductive activity over the annual cycle. Recent studies have demonstrated that the establishment of substantial closed areas as a tool for identifying and monitoring the impacts of fishing has been highly successful with reef-based grouper fisheries at other locations. Those studies will be reviewed and summarized in the management section.

St. Helena and Ascension Islands; Review of geographical and biological information.

Geographical: Both islands occur as reef habitat isolates in the tropical South Atlantic Ocean. St Helena (15^o 57 S, 5^o 42 W) lies 1300 km to the SE of Ascension (7^o 57 S, 14^o 22 W). The islands have areas of 122 sq km and 90 sq km respectively. St. Helena is the eroded summit of a vulcano rising from a depth of 4,000m and lies 800 km to the east of the mid-Atlantic ridge. The age of the Island is in the vicinity of 14-20 million years (my) with active vulcanism occurring 7.3 my ago. Ascension Island, 90 km west of the crest of the mid-Atlantic ridge is considerably younger. Radiometric dating suggests a maximum age of 1.5 million years with volcanism occurring up to approximately 200 years ago (Table 1).

Table 1 Summary of geographical features of St Helena and Ascension

VARIABLE	ISLAND	
	ST. HELENA	**ASCENSION**
Island geographical and geological features		
Island Area	122 km2	93 km2
Distance from continental land mass	1870 km (West Africa)	1509 km (West Africa)
Island Age	14.6 million yrs	1.5 million yrs
Coastline length	72 km	60 km

Reef habitats at both islands are subtropical, and, although the rock substratum supports an encrusting sessile biota that includes scattered tiny scleractinian coral colonies, both lack any structural coral formations. In structural terms the sub-tidal habitat of both islands is dominated by rocky reefs dissected by crevices and with fields of loose rock and boulders interspersed with sand areas. A major contrast between the two systems is the greater cover of a sessile biota, especially benthic algae at St. Helena. The two islands have similar areas of subtidal reef environment (Ascension 39 km^2, St Helena 37 km^2), although sea-level changes during the past 500,000 yrs produced considerable fluctuations in the amounts of such habitat, from 24-39 km^2 at Ascension and 36-110 km^2 at St Helena. In terms of ocean transport both islands are exposed to the northwards flowing Benguela and south Equatorial currents and the clockwise transport of the Equatorial Counter current in the central Atlantic. During the year of the survey (2006) the monthly sea surface temperatures varied for Ascension from 23^{o}C (Sept) to 29^o C (April) and for St Helena 20^{o}C (Nov) to 26^{o}C (April). The colder average temperatures at St Helena (23 ^{o} C vs 26^o C at Ascension) reflect in part the greater influence of the Benguela Current on St Helena. Both islands and especially St Helena are subject to prevailing south-easterly winds (Fig 2).

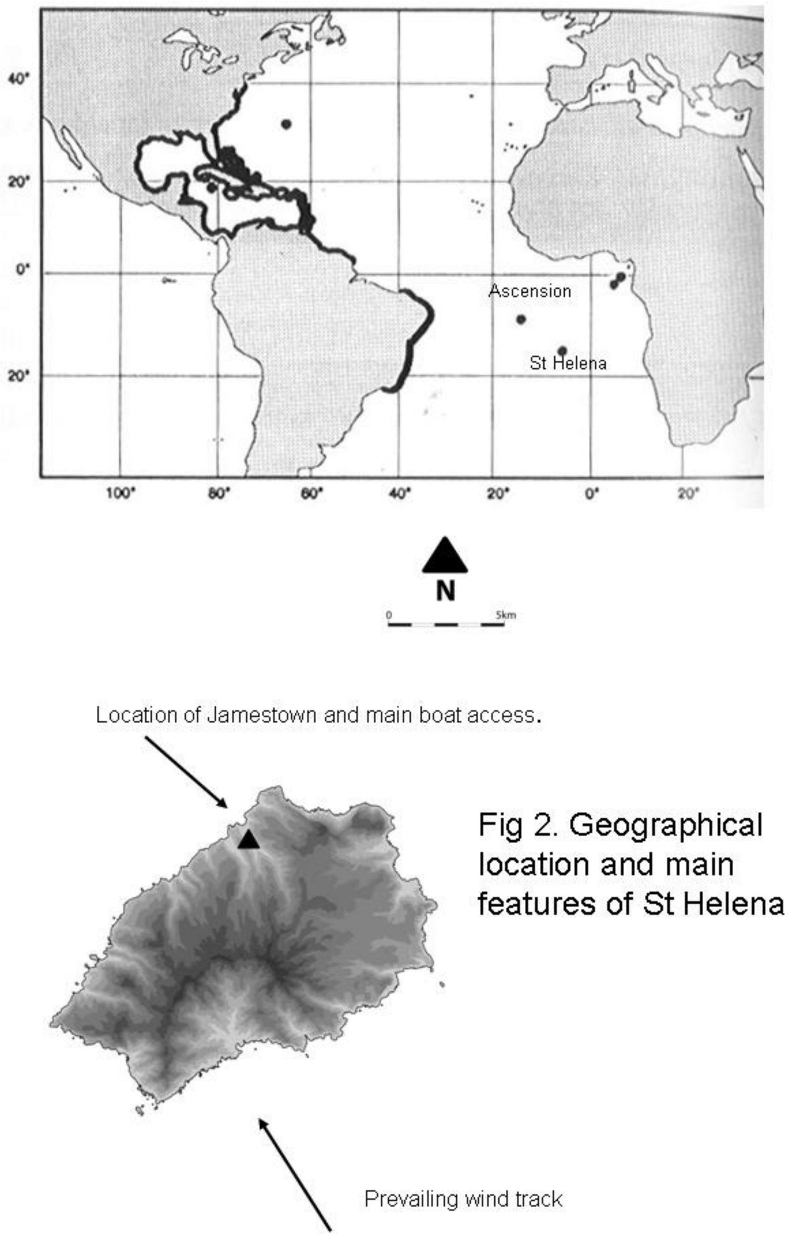

Figure 2: Composite showing geographical location of St Helena and Ascension and the main feature of St Helena Island.

Biological: The highly distinctive fish fauna of the two islands constitutes the Mid-Atlantic Ridge biogeographic province (Floeter et al 2007). The two islands have similar numbers of shore fish species (Ascension 79, St Helena 86) with similar levels of endemism 25.3% and 22.1% respectively, and share a number of co-endemics (Robertson 2000). The main affinities of this fish fauna are with the tropical eastern Atlantic itself a region of low species diversity. Low species diversity is seen in the main shore fish families at the two islands; for example there are six species of serranids compared to 27 in the tropical eastern Atlantic and 88 in the tropical western Atlantic. However as in many areas with low species diversity population densities of individual species can be very high. . This is the case at both St. Helena and Ascension where *Epinephelus adscensionis* reaches very high local densities when compared with other parts of its geographic range. However, despite strong similarities in many aspects, there are some significant differences between the reef fish communities of the two islands. Ecologically the most important biological distinction between those reef-fish communities relates to the abundance of the aggressively grazing triggerfish, the Black Durgon, *Melichthys niger,* which is extremely common at Ascension, but virtually absent from St Helena.

In summary both islands have reef habitats that are similar in extent and structure which despite their tropical location do not support habitat-forming stands of sessile organisms such as corals. (Table 2)In both locations the reefs support large numbers of a few species including groupers the target species of this survey.

Table 2 Summary of biological features of St Helena and Ascension.

ISLAND CHARACTERISTIC	ASCENSION	ST HELENA	INTER - ISLAND DIFFERENCE?
Habitat (<100m deep, km^2)	39	37	**Similar**
Temperature (Average, degrees C)	26C	23C	**St Helena more subtropical**
Fauna & flora	Tropical/Subtropical	Subtropical	**Minor**
Number fish species	79	86	**Similar**
Percent endemic fish species	25.3	22.1	**Similar**
Black Durgon numbers	Abundant	Rare	**Ascension much more abundant**
Benthic algae	Uncommon	Abundant	**St Helena much more abundant**

Epinephelus adscensionis: biological synopsis

Epinephelus adscensionis, known as the Rock Hind in the west Atlantic and Jack at St Helena and Ascension, is a relatively uncommon species in most of the tropical Atlantic. The western distribution extends along the continental Americas and through the islands and reef systems of the Caribbean area, from 34^{o}N to 23^{o}S with an extensive gap on the Brazilian continental coast that corresponds to the Amazon outflow, and south to Southern Brazil. The northern distribution extends to Bermuda although it is rare at this locality. *E adscensionis* is absent from the offshore reefs and Islands of Brazil and in the eastern Atlantic is reliably recorded from Sao Tome (although whether it has a resident population or is a vagrant there is unclear), and reaches its greatest densities at Ascension and St. Helena.

A recent study of the genetic relationships of populations of *E adscensionis* in different parts of the tropical Atlantic (Carlin et al 2003) provided a surprising result in terms of population connectivity and migration of larvae. Some differentiation of rock hind populations was found in the broader tropical Atlantic (Bahamas populations showed significant differentiation from St.Helena and Ascension populations). However the main feature of the analysis was a deep genetic division across the Florida strait between populations in the extreme northern part of its range (Florida and South Carolina) and populations in the remainder of the Caribbean and rest of the Atlantic.There was evidence of genetic connectivity between many of the Caribbean and the Brazilian localities and the Mid Atlantic Islands. The distinction between ecological (demographic) connections and genetic connections is of fundamental importance for isolated populations like those at Ascension and St Helena. While large numbers of larvae migrating into an area are needed to have an impact on the local density of adults of a species, genetic connectivity can be “fully” maintained by the occasional interchange of tiny numbers of larvae, numbers that have zero impact on the local abundance of adults. It is highly unlikely that ecologically significant numbers of larvae regularly colonize Ascension and St. Helena from the Americas. Further, since the prevailing ocean current flow is from St Helena towards Ascension it is also unlikely that Ascension could act as a source of sufficient numbers of larvae to have an impact on the abundance of Jack at St Helena. Thus the abundance of Jack at St Helena most likely is determined entirely by events affecting adults at the island and larvae in its surrounding waters.

Although the distributional center of *Epinephelus adscensionis* is the tropical western Atlantic; in that area it achieves only moderate abundances of approximately 0.2 individuals per 100 m^2, (Table 3). Variation in the abundance of Jack at different sites in the tropical western Atlantic appeared to be associated primarily with fishing, with the greatest abundances being recorded from sites with reserve status. At the isolated reef habitats of Ascension and St. Helena the Jack achieves very high abundances, on the order of 4-780 times higher than those on tropical western Atlantic reefs. These abundances represent some of the highest recorded for a medium sized grouper species at any reef environment surveyed anywhere in the tropics.

The biological information available for western Atlantic populations suggests a moderately size (maximum length 60 cm) fast growing grouper with a recorded maximum age of 12 years with sexual maturity occurring at ~ 25 cm. Depth distribution records indicate that this is a relatively shallow water species but with some individuals occurring down to 100m depth. While there is only limited information relating to reproductive activity most epinepheline groupers of this size range in the West Atlantic locality form spawning aggregations.

Material and methods

Field work was carried out through intensive sampling between 5/5/06 to 7/6/06 by Dr D Ross Robertson (Smithsonian Tropical Research Institute, Balboa, Republic of Panama) and Dr J Howard Choat (James Cook University, Townsville, Australia).

Abundance estimates: Underwater visual censuses (UVC) are an important source of information on the abundance, distribution and size structure of reef fishes. As groupers are often secretive and select cryptic habitats, UVCs of this group often require special techniques involving searching of reef structure, or baiting to induce groupers to leave cover. However the relatively simple reef habitats of Ascension and St. Helena and the absence of cryptic behaviour by the Jack, which is extremely curious of divers, made counts of adult *E adscensionis* relatively straightforward. However, more detailed searching was required for counts of small juveniles, which are secretive and seem to be restricted to bottoms composed of small cobble in sheltered shallow water. Both counters have had wide experience with UVC designed to estimate abundances of reef fishes in tropical waters and the counts described here avoid sources of error that may be associated with the use of numerous counters with different levels of skill and experience.

Counts of Jack were made by both observers using replicated belt transects of 30 × 6m dimensions with the length determined by a 30m tape deployed as the diver performed the count (Fig 3). This reduced disturbance and attraction of groupers associated with laying out the tape before a count. Counts were made over reef substrata generally parallel to the shore and deployed haphazardly between 4 to 15m depth. Counts were replicated at each sampling site with a minimum of four transects per site. Counts included all *E adscensionis* in the belt transect area with total length of each individual estimated within 10cm size classes. Careful searches of each transect area were made to detect cryptic individuals of _< 20 cm total length. Individual groupers encountered in belt transects were assigned to one of five size classes (total length) from juveniles <15 cm to the largest adults >42 cm.

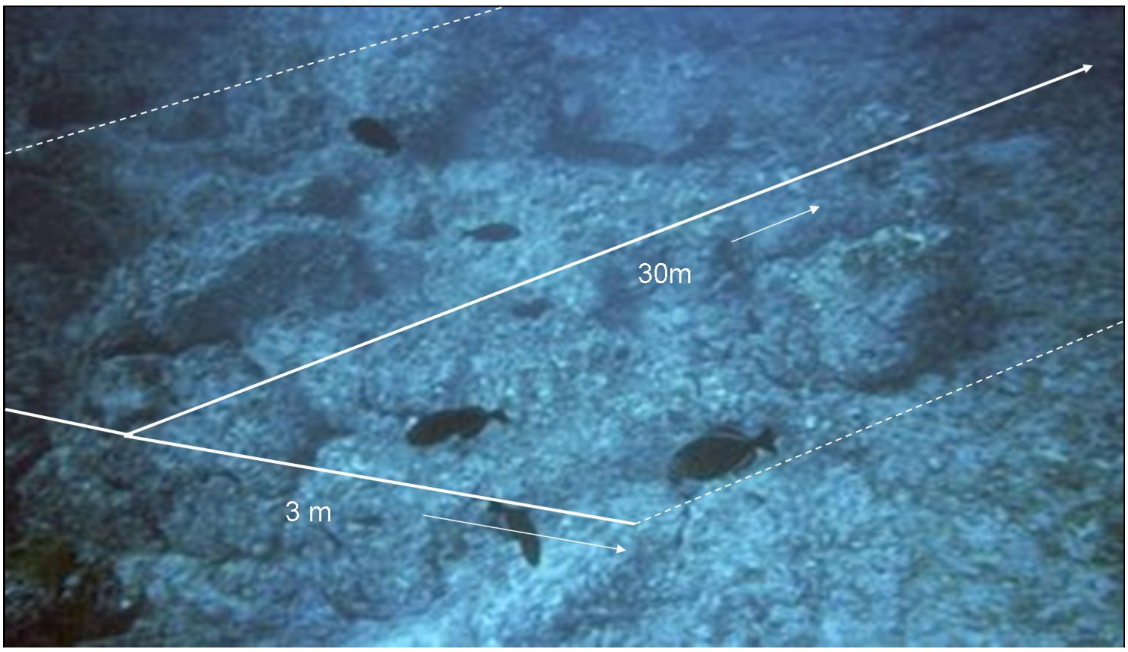

Figure 3: Diagram of 30x6m transect deployment over open reef environment typical of Ascension and St Helena Islands. The 30m tape is anchored at the base of the transect and groupers counted within the 3m estimated distance each side of the tape.

The objectives of our censuses were to investigate i) differences in grouper abundances between the two islands, ii) the importance of different habitats within each island and iii) the impacts of human activity on grouper abundance and size structure. On both islands logistic constraints and weather conditions made it impossible to survey the entire coast, particularly the coast exposed to the prevailing trade-winds. However on both islands both sheltered and moderately exposed localities were censused. Human impact was assessed by making counts at increasing distances from centers of human activity and fishing pressure - Jamestown on St Helena and Georgetown and English Bay on Ascension. Subsistence, recreational and commercial fishing all occurred on St. Helena with the former concentrated on the west and NW coast in the vicinity of Jamestown. Fishing activity was less on Ascension due partly to a much lower human population and difficulty of access to small boats from Georgetown. Counts on both islands were allocated to sheltered and exposed coast localities, with census sites deployed at increasing distances from centers of human activity. For St Helena this covered the relatively sheltered west and north-west coasts and the semi-exposed northern and southwestern coasts. The data were displayed as mean numbers of groupers per transect aggregated at different scales and the mean size of groupers per transect.

A total of 230 180m^2 belt transects were censused at St. Helena (134) and Ascension (96). The counts on each island were partitioned into groups at increasing distances (length of coastline from Jamestown to sampling site) from the centers of human activity. On St. Helena counts were extended from Jamestown to two coastal areas, northwest coast to the exposed north and to the west and exposed southwesterly coast (Fig 4). In the northern sector the northwest sampling site was ~1.7 km from Jamestown and the exposed north coast ~4.5 km. The west and south westerly sampling sites were ~ 6.5 km and ~ 11 km respectively. On Ascension weather conditions and availability of boat access restricted sampling to five localities around Georgetown, and four localities on the northwest and north coast.Two localities Georgetown (Site 3) and English Bay (Site 8) were at centers of human activity with sufficient shelter to allow regular access to the coastal reef habitat. (Fig 5).

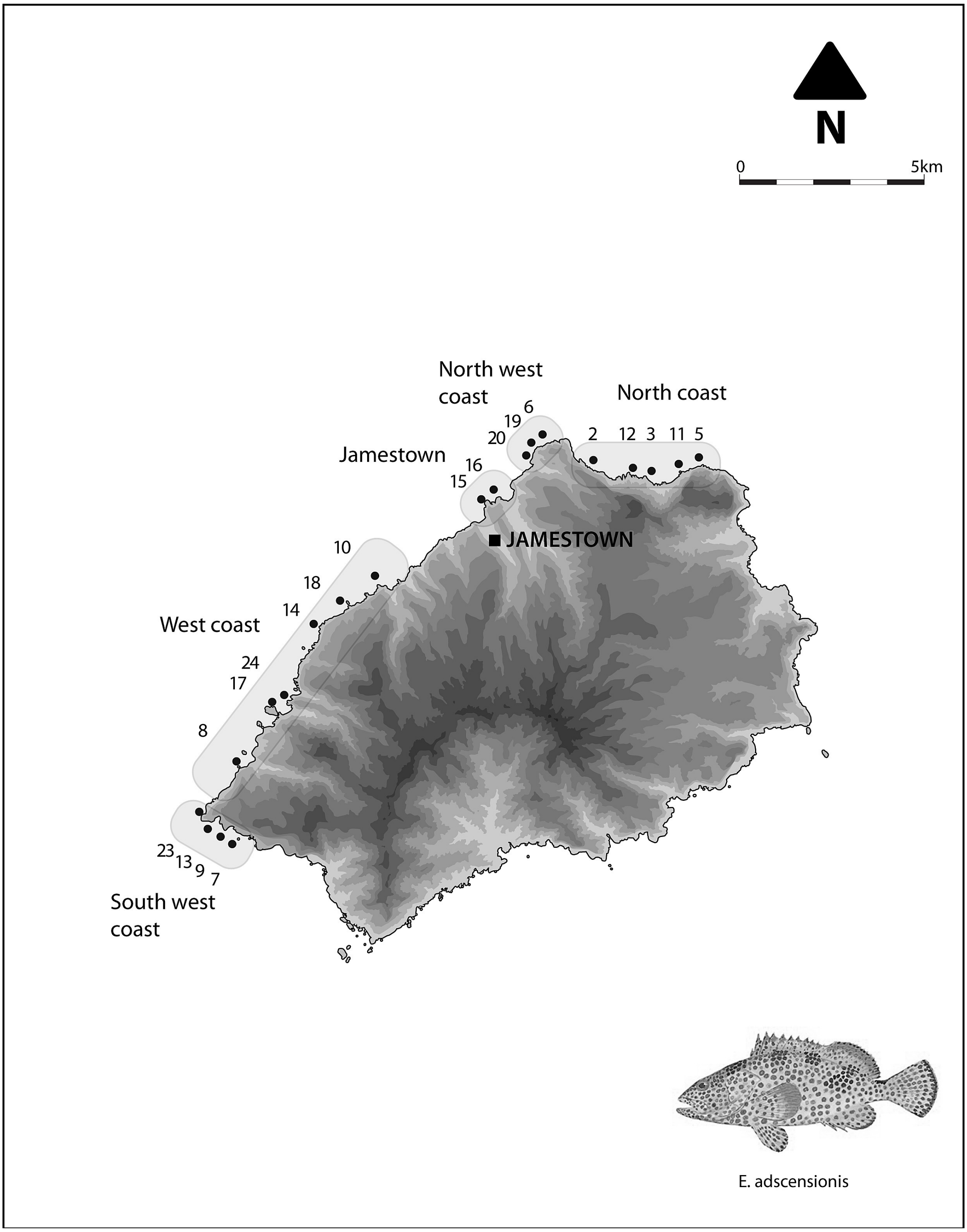

Figure 4: Map of St Helena showing the sites 2-24 at which 30x6m belt transect counts were made. The sites are grouped into 5 localities covering the western, southwestern and northern coasts of the Island.

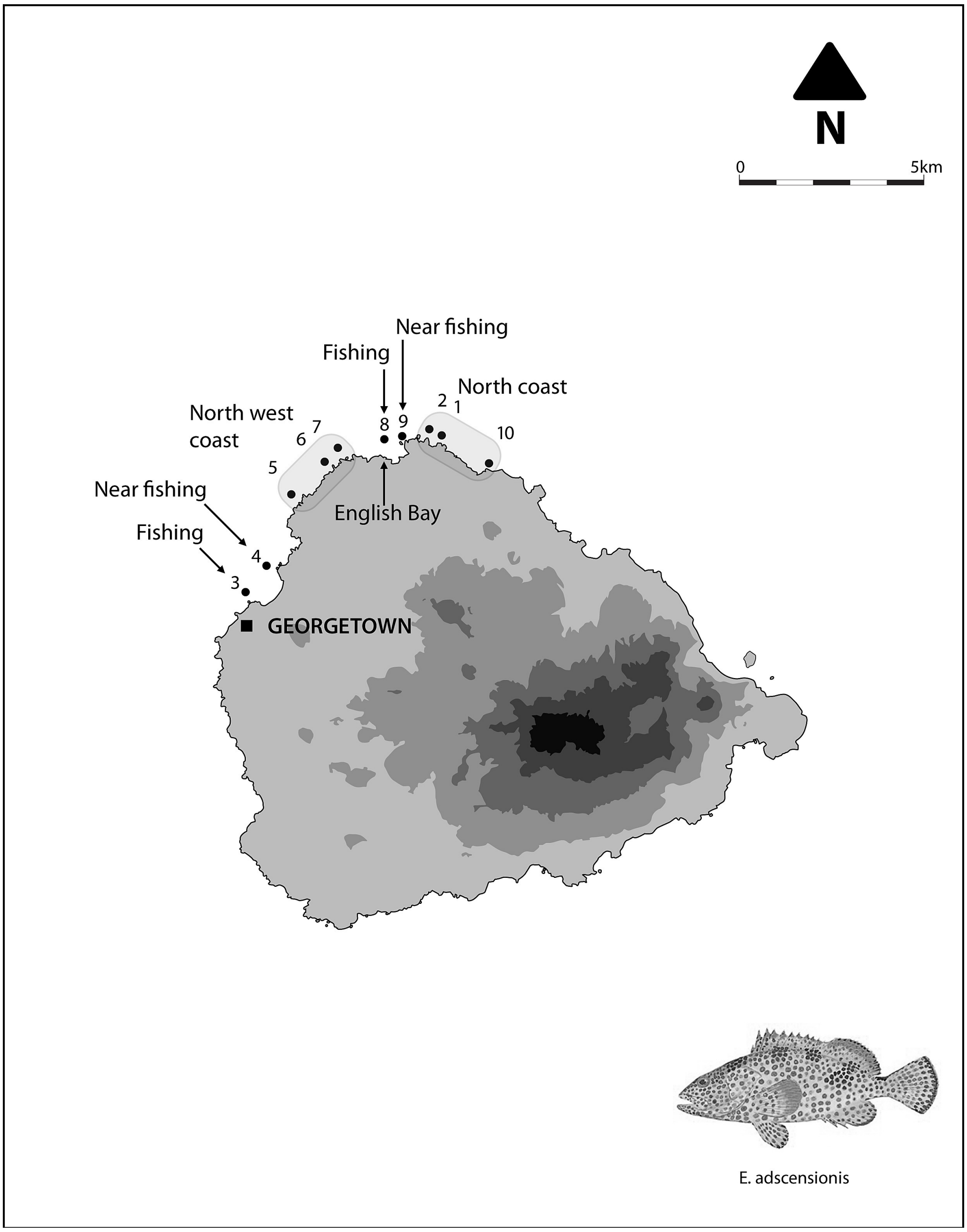

Figure 5: Map of Ascension showing the sites 1-10 at which 30x6m belt transect counts were made. The sites are grouped into 4 localities covering the northwestern and northern coasts of the Island.

Estimates of age, growth and reproductive status: Jack were sampled at St Helena and Ascension at the Locations and Sites indicated in Figs 4 & 5. On St Helena two sites (1 &

4) adjacent to sites 15 and 16 were sampled by spearing but no counts were made at these sites. The majority of groupers on both islands were collected by spearing, after the days count program had been completed or at distances > 100m from the count site. In addition a smaller number were obtained from the commercial line fishery. At St Helena a total of 299 *E. adscensionis* were sampled, 196 by spearing (<20m depth), 50 by shallow line fishing (<20m depth), and 53 by deep line fishing (62-84m). A number of juvenile groupers (< 10cm TL) were collected at two sites on St. Helena with multi-prong hand spear and by using small quantities of Rotenone, an organic insecticide commonly used to collect cryptic reef-fishes that degrades rapidly after such usage (Robertson and Smith-Vaniz, 2008). All groupers were measured (Total Length, mm) and Weighed (Total Weight, gm) sexed and sagittal otoliths removed at the time of capture. Otoliths were extracted after removal of the top of the skull, cleaned and stored dry. One sagitta of each pair of otoliths was chosen randomly and weighed to the nearest 0.1 mg for adults, and to the nearest 0.01 mg for juveniles. These weights were used to establish the relationship between otolith weight and age. A transverse section was obtained by grinding down both rostral and distal ends of the otolith using wet and dry sandpaper or lapping film, resulting in a thin section containing the nucleus. Each section was then covered with clear Crystalbond™ thermoplastic cement for reading. Annual increments were counted under a stereo dissector, and daily rings under a high-power microscope using transmitted light. Annuli were visualized as opaque bands in the otolith matrix.

Growth curves: Growth curves were generated from size at age data obtained from the analysis of sagittal otoliths. Growth parameters were estimated by fitting the von Bertalanffy growth function (VGBF): $Lt = L\infty\ (1 - exp(-k(t - t0))$ where Lt is the estimated standard length at age t, $L\infty$ is the mean asymptotic standard length, k is a curvature parameter and $t0$ is the age at which fish have theoretical length of zero. Growth parameters were estimated using the iterative non-linear least squares method. Because estimates of VBGF parameters can be sensitive to the range of ages and sizes used (Ferreira & Russ 1994, Craig 1999), the intercept was constrained to 10 cm. The annual nature of growth checks in the sagittal otolith was validated by marginal zone analysis. The relationship between otolith weight and increment number was examined using regression analysis.

Inter-island variation in sexual patterns: All groupers with the exception of small (<10cm juveniles) were dissected to record sexual identity. Sex was identified macroscopically. In order to confirm our macroscopic identification of sexes and to examine the pattern of sexual development in more detail a sub-sample of 15 gonads (St Helena) and 51 gonads (Ascension) were dissected out, weighed, and retained for histological analysis. Those data were used to analyze size and age at maturity and at the time of sex-change from female to male.

Variation in longevity in relation to temperature and fishing pressure: Reef fish in colder waters usually have longer life spans than those from warmer waters (Choat and Robertson 2002). Our prediction was that fish populations at St Helena would be longer lived than those at Ascension. However if the St Helena fishery targeted large individuals we would predict that age and size distributions would be truncated. Similar maximum ages at both islands could be the result of a strong fishing pressure directed against larger individuals at St Helena. We investigated the size and age structures of a species subject to fishing on St Helena (*E.adscensionis*) and of four species that were largely unfished on both islands as a control. These fish covered a wide taxonomic and ecological range but were not impacted by a fishery. These are the endemic parrot fish *Sparisoma strigatum,* (Rockfish), the surgeon fish *Acanthurus bahianus,* (Shitty trooper), the blenny *Ophiblennius atlanticus,* (Devilfish) and two very closely related sister-species of damselfish *Stegastes* (Bastard Cunning Pilots) *S sanctaehelenae,* (endemic to St. Helena) and *S lubbocki*,(endemic to Ascension). For each of these species otolith analysis was used to compare age and growth in samples collected from each island in the same localities where groupers were collected.

The St Helena fishery for Jack: the dynamics of annual catches, 1977-2007.
Data on the total weight of Jack caught each year at St Helena between 1977-2007 were provided by the St Helena Fisheries Dept. (see Fig 6). This shows a trend of gradually

increasing catches up to the late 1990s, interspersed with the occasional year with very low catches, then a distinct reduction between 2000-2006, and finally a sharp increase in 2007. Maximum annual catch was 48 metric tons in 1996, and the mean ~24 tons/y. The catch in 2007 (40 tons) was the third highest recorded. It is important to note that sampling for this study was conducted in mid 2006, after 6-7 years of relatively low catches: an average ~15 tons/y, which is about half the average annual catch rate over the preceding 18y.

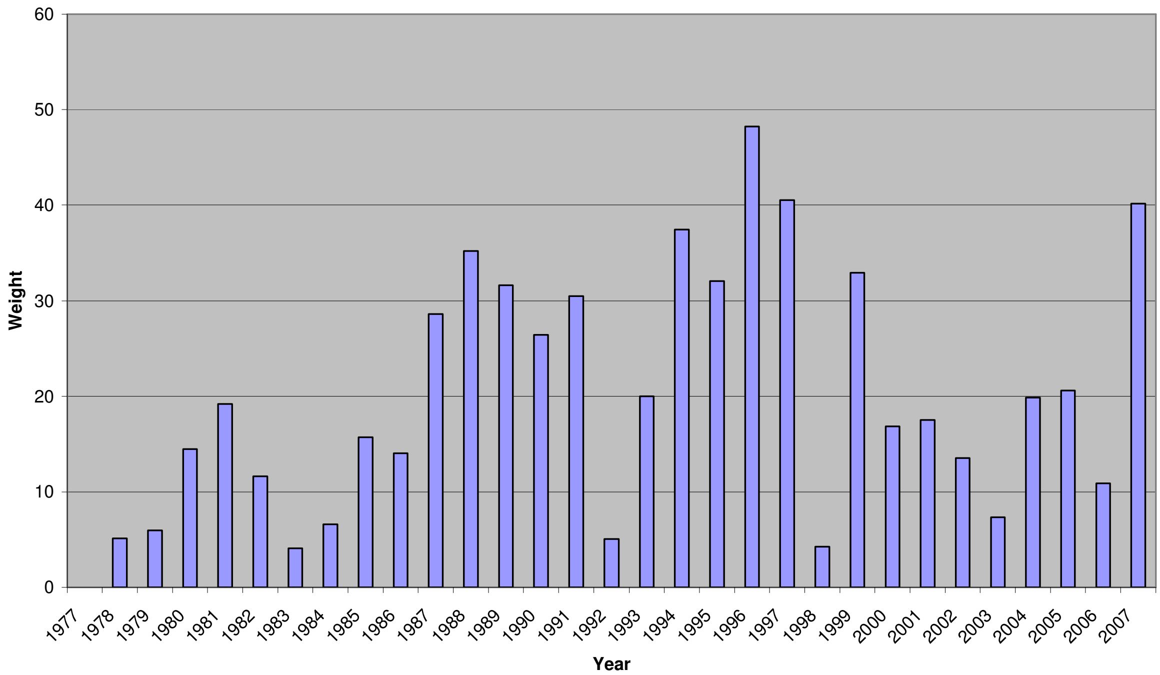

Figure 6: Annual records of total weight of grouper in metric tons from the St Helena fishery.

Results

Abundances of E adscensionis: At the broadest level of analysis we detected clear differences between the two island populations of groupers. Combining all counts from each island revealed on average of 5.2 groupers 180 m^{-2} for St. Helena versus 14.1 for Ascension (Table 3).

Table 3: Mean densities (±Standard Error) of *Epinephelus adscensionus* from eight Western Atlantic locations and from the Mid Atlantic Ridge Islands St.Helena and Ascension. Data for St.Helena and Ascension adjusted to mean density 100m^2.

Location	Status	Area censused	Mean density (100 m^{-2})	S_x	Source
Dominican republic	Heavily fished	100 m^{-2}	0.04	0.02	Chiappone *et al* (2000)
Florida keys	Heavily fished	100 m^{-2}	0.04	0.05	
S. Exumas	Lightly fished	100 m^{-2}	0.01	0.04	
N. Exumas	Lightly fished	100 m^{-2}	0.01	0.01	
ECLSP	Reserve	100 m^{-2}	0.04	0.03	
St Barthelmey	Reserve	100 m^{-2}	0.8	0.5	Brosnan D *et al* (2002)
St Eustatius	Reserve	100 m^{-2}	0.4	0.1	White *et al* (2006)
Sian ka'an	Reserve	100 m^{-2}	0.1	0.05	Walker *et al* (2003)
Western Atlantic Total			0.18	0.10	
St. Helena	Fished	180 m^{-2}	2.9(5.2 180 m^{-2})	0.2	
Ascension	Fished	180 m^{-2}	7.8(14.1 180 m^{-2})	0.5	

A comparison with published accounts of *E.adscensionis* abundances from eight localities in the tropical western Atlantic (Table 3) shows that these represented the highest abundances recorded for this species over its geographic range. The mean abundance of *E.adcensionis* over the standardized area of 100 m^2 varied from .01 to 0.8 individuals with an overall mean of 0.18 individuals 180 m^{-2}. The equivalent adjusted mean densities per 100 m^{-2} for St.Helena and Ascension are 2.9 and 7.8 individuals respectively. Thus the abundances at the mid Atlantic ridge Islands were greater than those of the tropical western Atlantic reefs by a factor of 4 to 780. Variation in the site-specific abundances in the tropical western Atlantic appears to be associated primarily with fishing, as the greatest abundances were recorded from sites with reserve status.

Abundances of related groupers elsewhere in tropical Atlantic and Pacific: In addition we checked abundance patterns of similar size members of the genus *Epinephelus* on protected Indo-Pacific reefs (e.g. the Australian Great Barrier Reef). The adjusted collective abundances of five species was 0.5 100 m^{-2} (Pears 2005). Thus the abundances of *E adscensionis* on the Mid Atlantic Ridge islands are 10-30 times higher than those recorded for similar sized species on Indo-Pacific coral reefs.

***Variation in abundance around St Helena Island*:** The coast of St Helena was partitioned into five sampling regions; Locality 1 Jamestown, 2 Northwest coast, 3 North coast, 4 West coast and 5 Southwest coast (Fig 4). A total of 21 sampling sites were partitioned amongst these localities (Table 4). Within these localities the abundance of groupers varied by a factor of six. The lowest abundances were recorded for the Jamestown locality (sites 15, 16, 22) (Fig 4) which had an overall mean of 1.4 fish 180 m^{-2}. The greatest abundances were recorded on the northern and southwestern coasts where overall means of 8.1 and 8.8 groupers 180 m^{-2} were recorded. Analysis of the site-specific abundance data showed that numbers of *E adscensionis* increased with increasing coastal distance from Jamestown (Fig 7) as on both coasts there was a linear increase in the abundance of *E.adscensionis* with distance from Jamestown . However the rate at which abundances increased differed by coastal orientation with the rate change on the west coast lower than on the northwest and north coasts. Ease of access to a nine km stretch of the west coast sheltered from prevailing southeasterly winds was greater than for sites adjacent to South West Point and the Barn on the north coast. These were influenced by seas generated by the prevailing southeasterlies wrapping around to the north and southwest coasts. The major differences in grouper abundance of the St.Helena reefs indicate a gradient extending north and south from Jamestown and correlate with ease of access to coastal localities.

Table 4: Abundance estimates of *Epinephelus adscensionis*, Mean ± SE $180m^{-2}$ sampled at 21 sites at St. Helena by underwater censuses. Sites as in Fig 4.

Location	**Distance from Jamestown (km)**	**Site**	**Mean density**	**SE**	**Replicate counts**
Jamestown	0.3	15	0.2	0.2	9
	0.4	16	1.6	0.7	10
	0.7	22	2.3	0.5	12
NW coast	1.9	6	4.8	1.8	4
	1.6	19	2.0	1.1	4
	1.4	20	2.3	0.5	4
N coast	2.8	2	5.3	0.7	3
	3.9	3	9.0	1.7	4
	5.6	5	10.0	1.3	5
	5.3	11	8.3	1.9	4
	3.2	12	7.0	0.7	4
W coast	5.5	10	3.2	1.3	5
	6	18	4.9	0.6	9
	6.5	14	5.0	0.9	8
	7.3	24	6.3	0.6	9
	7.6	17	4.5	0.7	10
	8.6	8	4.6	0.7	5
SW coast	11.7	7	10.0	1.7	4
	11.6	9	7.8	1.1	4
	11.5	13	9.7	1.1	7
	10.2	23	8.1	0.6	10

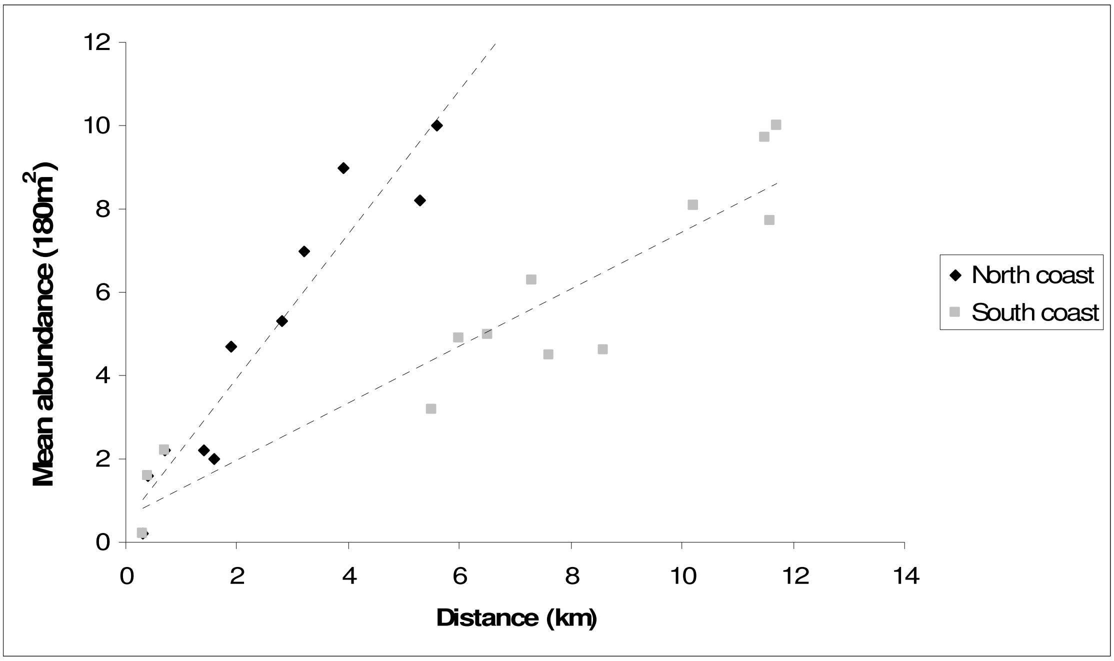

Figure 7: Mean abundances of *E.adscensionis* per site vs distance from Jamestown. Linear regression analysis. South west (includes W coast and SW coast locations) y = 0.68x + 0.61, R^2 = 0.88. North coast (includes NW coast and N coats locations) y = 1.73x + 0.52, R^2 = 0.91

***Variation in abundance around Ascension Island*:** Estimates of abundance from Ascension Island were based on fewer localities and sampling sites than those from St. Helena with counts being restricted to the northwest coast (Fig 5). This reflected both prevailing weather conditions and the difficulties associated with both boat and land access to large areas of the Islands coast. A total of 96 transects were deployed over four sampling localities partitioned into ten sites. A major difference from St Helena was that two localities, Georgetown and English Bay, were readily accessible by road whereas boat access was more restricted due to difficulties associated with launching and entering smaller boats under conditions of oceanic swell that frequently prevail at Georgetown. The localities were therefore classified into Fished (sites 3, 8) and localities at increasing distance from these sites; Near Fishing (4,9), Northwest coast (5,6,7) and North coast (1,2,10). The overall mean abundances of *E.adscensionis* when the sites at each locality were combined was *Fished 14.6, Near Fishing 16.4, Northwest 12.2, North 13.9* *groupers 180 m^{-2}* (Table 5). Unlike St. Helena there was no clear trend associated with access of locations to fishing activity; all localities displayed uniform and relatively high abundances. However examination of abundances by site revealed localized variation in abundances. The second lowest abundance of groupers recorded in the surveys was from the west side of English Bay adjacent to the jetty entry point while the areas around Georgetown (Turtle ponds and Wharves) returned the third highest abundances recorded on Ascension. Grouper abundances were in most instances higher than those recorded at St. Helena and there was no general trend associated with fishing activities (Table 5).

Table 5 Abundance estimates of *Epinephelus adscensionis,* Mean±Sx 180m^{-2} sampled at 9 sites at **Ascension Island**. n = number of transects. Refer to Fig 5 for location of sites.

Classification	Site	Mean Density	SE	n
Fished	3	19.7	1.7	9
	8	9.4	1.6	9
Near Fishing	4	23.4	2.6	8
	9	10.2	2.2	9
NW Coast	5	11.9	1.5	8
	6	12.1	2.0	8
	7	12.5	2.1	8
North coast	1	9.6	2.0	10
	2	13.3	1.2	9

At two sites we recorded very high abundances of large groupers per transect. These were site 4, (0.7 km NW of the most frequented fishing site at Georgetown) with a mean of 23.4 and Site 10 Deep on the north coast with a mean of 23.1 groupers 180 m^{-2}. These abundance patterns and the size structure (see below) were indicative of aggregation by sexually mature groupers. Sampling in shallow water (3-5m) revealed very low numbers of groupers (3.8 180 m^{-2}) (Table 6) with a smaller mean size than those in deeper water. Analysis of the combined count data from Site 10 still revealed high abundances (16.7 180 m^{-2}) but with a predictably higher variance to mean ratio than recorded from other sites. It is probably that local abundances at this site were inflated by aggregative behaviour with individuals from shallow water moving out to deeper reef regions at the time of counting.

Table 6 Abundance estimates of *Epinephelus adscensionis,* Mean±Sx 180m^{-2} Sampled at site 10 **Ascension Island** illustrating the aggregation of large individuals in deep water.

Classification	Site	Mean Density	Sx	n
North coast	Shallow 10	3.8	1.5	6
	Deep 10	23.1	3.1	12

Size frequency distributions from censuses:

Between island variation: Size frequency distributions (Fig 8) for all sites at each island combined revealed distinct differences between jack populations on the two islands: The St. Helena population was dominated by a single size class (26-35 cm) with relatively fewer larger individuals and few small individuals. In contrast the Ascension populations had a more even size-frequency distribution with greater proportions of both larger (36->42cm) and smaller individuals.

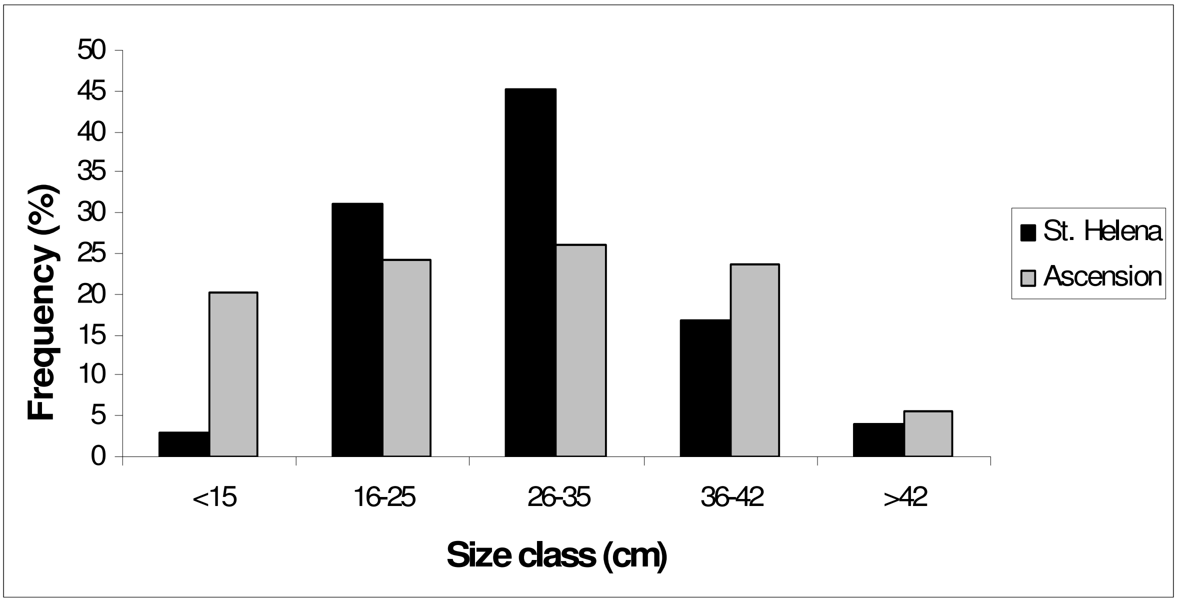

Figure 8: Aggregated size frequency distributions of all *E.adscensionis* recorded in UVC at sampling sites on both islands. Individuals placed in 5 size classes.

Within Island variation:

St Helena Island*:* Size distributions at the different localities were fairly similar with populations dominated by the 16-25cm and 26-35 cm size classes (Fig 9). However individuals in the largest size class <42 cm were observed only at the West, Southwest and North sampling localities, ie those at the greatest distance from Jamestown. Moreover at the Jamestown sites 42% of the population occurred in the two smallest size classes, a greater proportion of small individuals (15-25 cm) than that of any other locality.

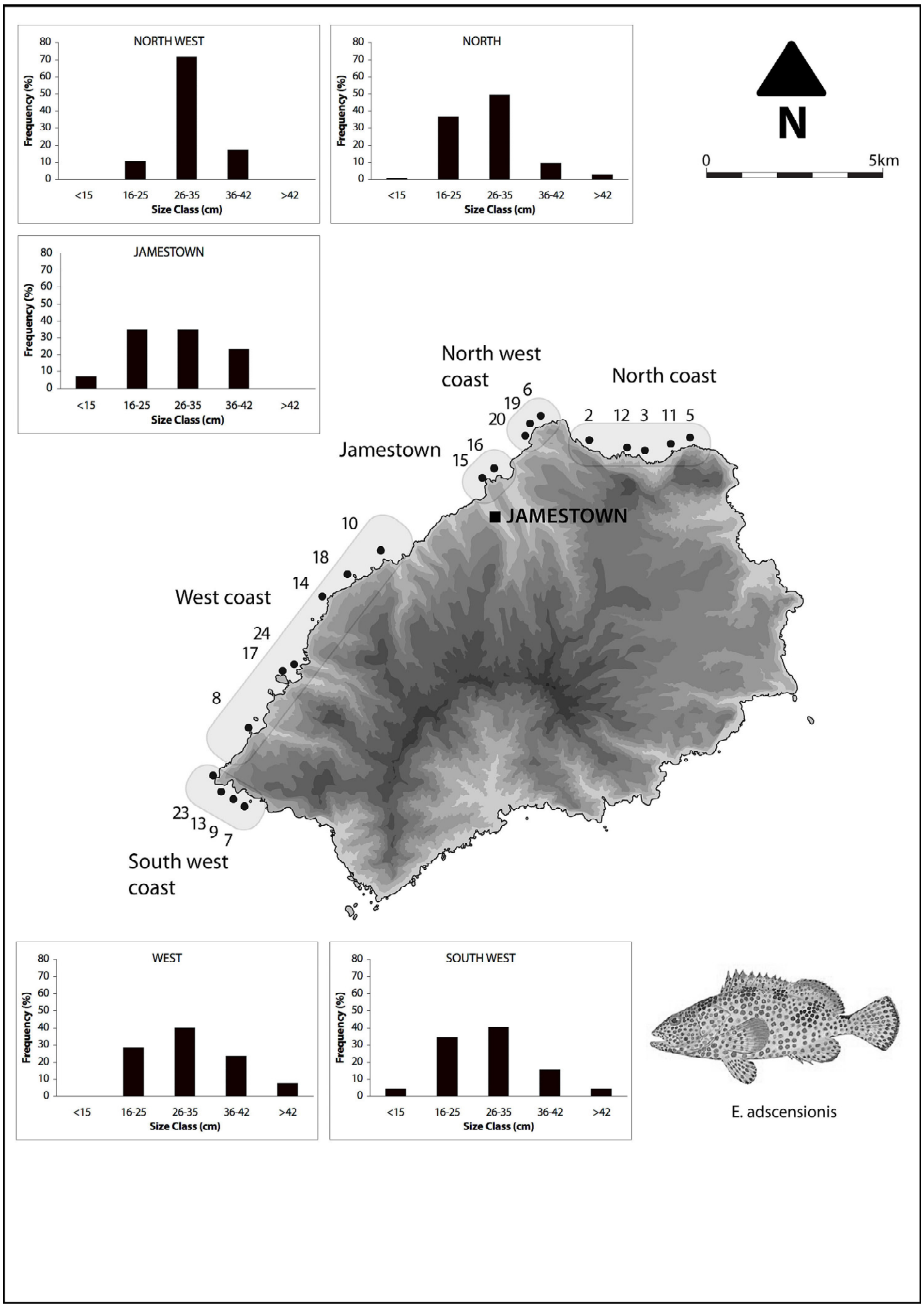

Figure 9: Size frequencies of E.adscensionis recorded by UVC at the four sampling localities at St. Helena

Thus, while the island-wide size distribution was unimodal distribution with the grouper population dominated (45%) by the 26-35cm size class, with few very small and very large fish, a more detailed examination of size distributions revealed some important locality-specific differences, with small fish concentrated near Jamestown, large fish occurring only at least 2 km away and the largest fish at the furthest distances.

Ascension Island: Size frequency distributions of Jack at the Georgetown site were dominated by smaller individuals, and the combined frequencies of the two smallest size classes (72%) at that site was far greater than at any other site (Table 7). Moreover and unlike all other localities size distributions at Georgetown showed a sharp decline from the 15-26cm to the >42 cm size class. The site adjacent to Georgetown also was dominated by small groupers. This was in marked contrast to the size distribution of groupers recorded from the most distant site (~ km coastal distance from Georgetown) 10. Groupers recorded from the deeper part of this range (a ledge at 11m adjacent to a sharp drop-off) had 46% of the population in the two largest size classes, a substantially greater proportion than that recorded from any other site, although site 4 also had a high proportion of very large groupers. At the shallow area of site 10 less than 50m from the deep site no individuals from the largest size class were recorded.

Table 7 Size frequencies of E.adscensionis recorded from UVC by Site, Ascension Island. Values are percentage frequencies. **Site 10** included counts at shallow and deep sites. Deep sites supported large numbers of reproductively active females.

Locations	**Sites**	**Size classes (cm)**				
		<15	**16-25**	**26-35**	**36-42**	**>42**
Fishing	3	28.8	42.9	18.6	8.5	1.1
	8	9.4	27.1	34.1	28.2	1.2
Near Fishing	4	21.4	13.9	28.9	23.0	12.8
	9	19.5	31.0	28.7	19.5	1.1
NW coast	5	18.9	20.0	30.5	22.1	8.4
	6	17.5	16.5	27.8	32.0	6.2
	7	22.0	22.0	32.0	23.0	1.0
North coast	2	18.3	25.0	35.0	17.5	4.2
	1	26.0	21.9	29.2	20.8	2.1
	10 S	0.0	43.5	43.5	13.0	0.0
	10 D	19.5	18.8	15.9	36.1	9.7

In summary the major differences that we observed in our visual census are as follows:

- Jack were three times as abundant on shallow reefs at Ascension as at St Helena.
- Jack displayed high abundances at all sites at Ascension except that at Georgetown dock, vs increasing abundance with increasing distance from the human population center at St Helena.
- Median and maxium sizes were similar at the two islands.
- While fish of a variety of size classes were common at Ascension there were relatively fewer small and large fish at St Helena.
- Large fish were more abundant at sites furthest from townships, with this trend noticeably stronger at St Helena.

Condition, size, age, growth and mortality estimates from samples: A total of 506 groupers sampled during the survey (St Helena 299, Ascension 207) provided data on size and age distributions for each island, length weight relationships, growth curves and distribution of sex by size and age.

Condition: Analysis of length-weight relationships provides a simple but powerful tool for comparing populations. The relationship is represented by the equation y (weight) = ax (length)^b where the exponent b is usually approximately 3. While the relationship between the two variables typically is exceedingly tight at a single location it often varies considerably among locations, indicating that the rate at which weight accumulates with the size of the fish varies at different sites. If for a given length fish consistently weigh less at one locality than another this suggests the fish at the first location are in poorer condition.

The length-weight relationships for the groupers sampled at St Helena and Ascension are very similar. (Fig 10) The equations describing the relationship indicated that length and weight were closely associated at both island, and that those relationships were very similar at both islands. In large groupers (mainly older males) the weights for a given length were lower than expected from the curves, a situation that occurred at both islands. However a total of 44 Jack ranging from 326 to 609 mm in length were sampled from deeper water (62-84 m) substantially deeper than the 5-15m from which the majority were collected by spearing. These individuals showed a different length-weight relationship than those sampled from shallow water only on St Helena (Fig 11). Groupers collected in deeper water weighed slightly less than individuals of the same size taken in shallow water. This suggests that fish from deeper water were in poorer condition, and that shallow water is the preferred habitat.

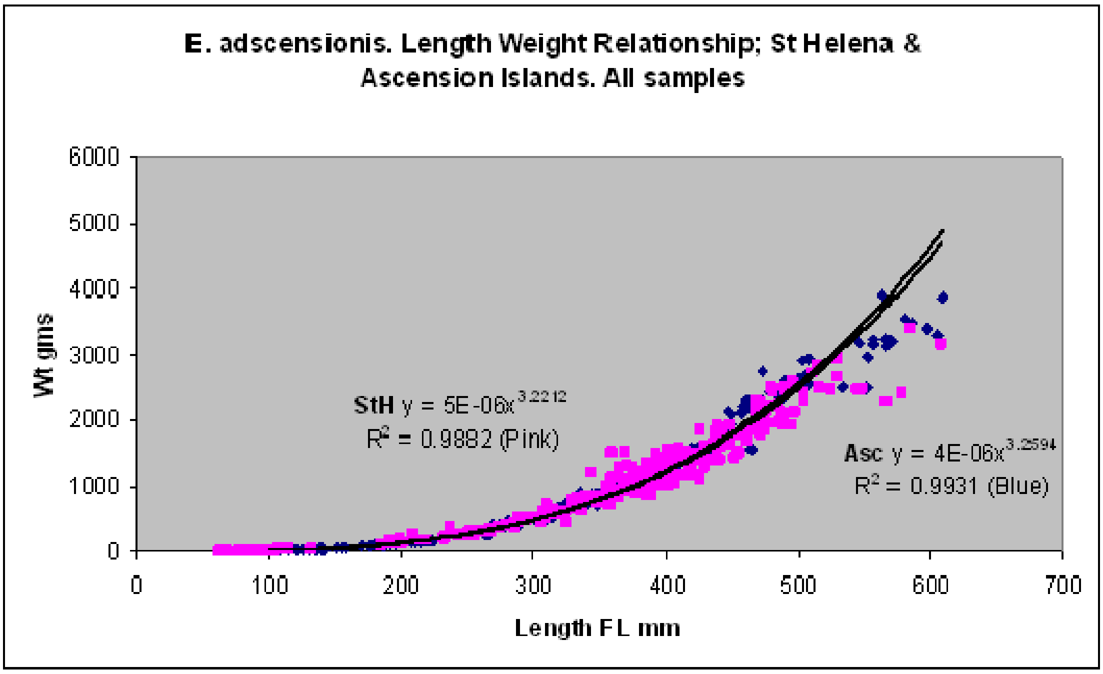

Figure 10: Length weight relationships of *E.adscensionis* from St.Helena and Ascension Islands. All samples included. Power curves have been fitted to the data plots.

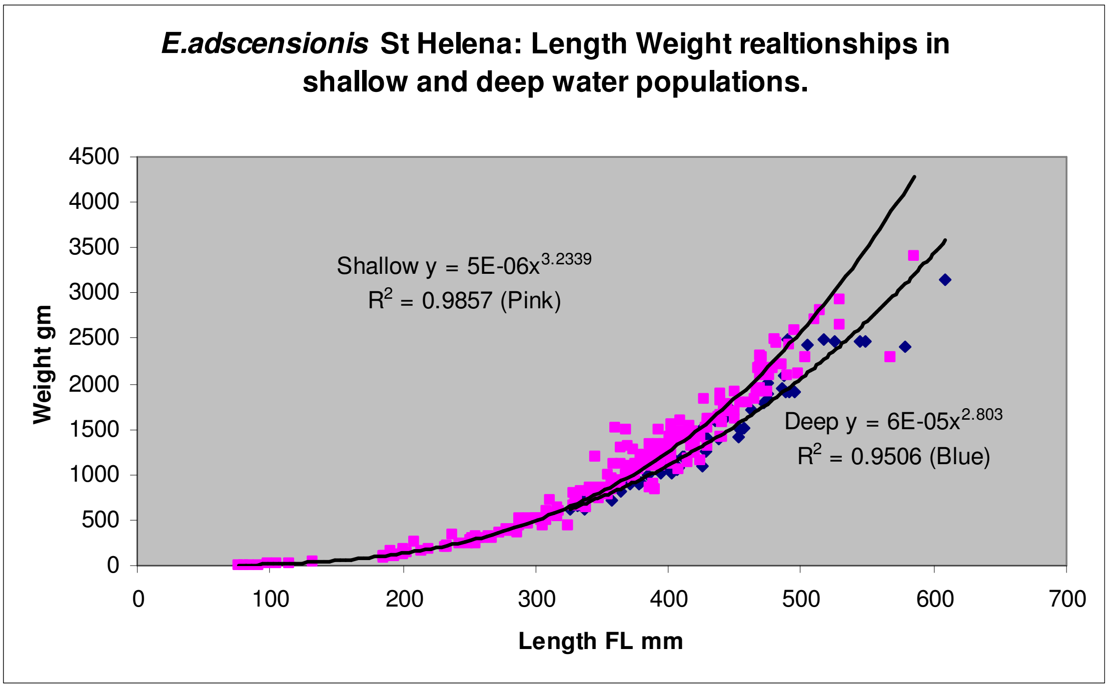

Figure 11: Length weight relationships of *E.adscensionis* from St.Helena Shallow and deep water populations. Power curves have been fitted to the data plots.

Size frequency distributions: All groupers sampled were measured and aged. Comparisons of the size and age distributions of the St Helena and Ascension total samples showed the following (Figs 12 , 13). The size distribution of the groupers sampled from St Helena was strongly unimodal with a peak at 400-470 mm. Small individuals (up to 260 mm) and large individuals (>500 mm) made up 6.8% and 3.8% of the sample respectively. A very similar pattern was recorded in our underwater censuses. The sample from Ascension Island was not unimodal and displayed numerous smaller peaks of abundance and a greater proportion of small (9.2%) and large (13.2%) groupers than those sampled from St. Helena. This same pattern was observed in out censuses at that island. This leads to three conclusions.

- The size structure of our samples reflected the size structure observed in the field censuses at both islands.
- The upper limits of the sizes were similar for both islands, with relatively few individuals > 500 mm being either observed or collected.

- In both censuses and samples there was a decline in the number of larger individuals (from 480 to 600 mm) observed at each island.

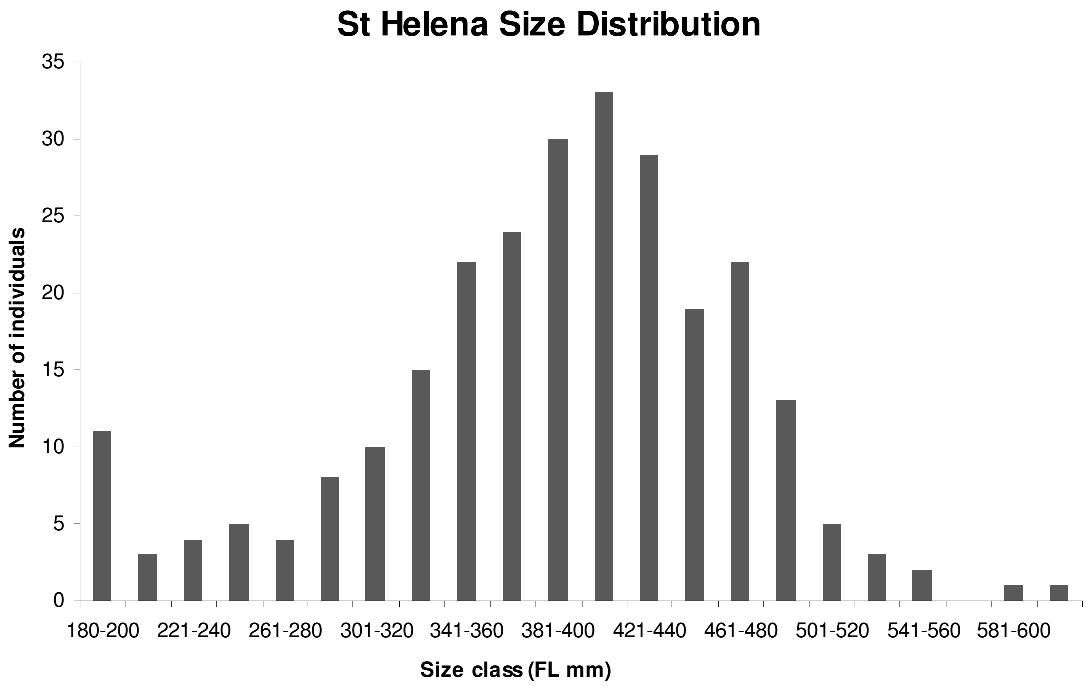

Fig 12 St Helena. Size frequency distribution of all groupers sampled.

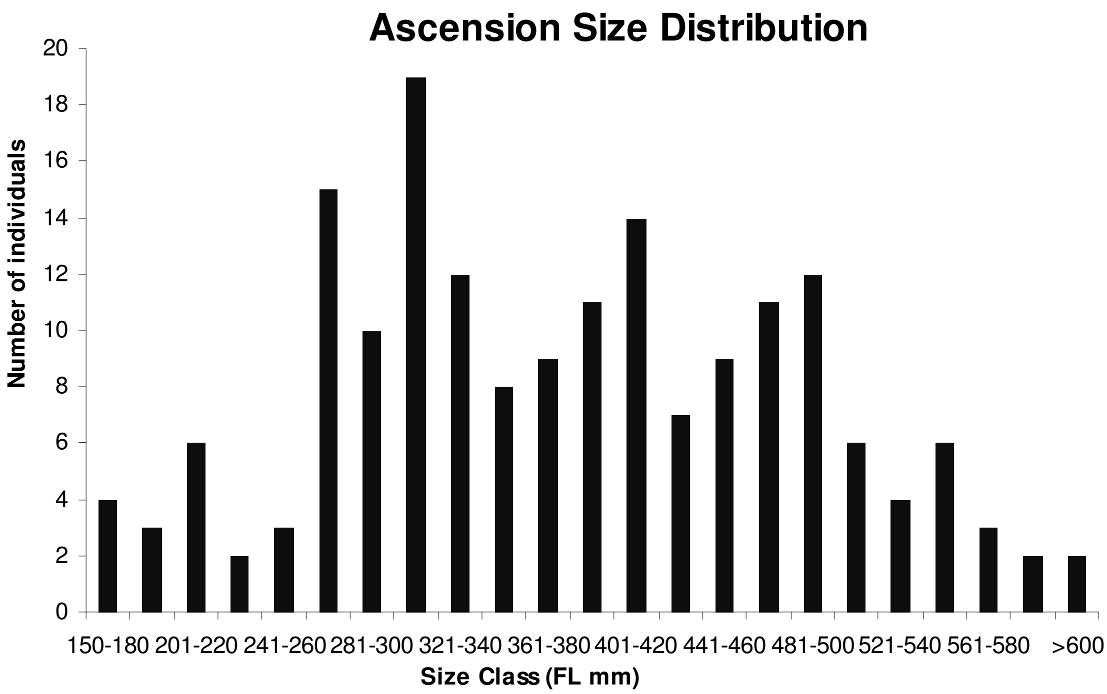

Figure 13: Ascension. Size frequency distribution of all groupers sampled.

*Age structure***:** Understanding the underlying dynamics of reef fish populations requires an analysis of age structure and growth rates. As all groupers collected were aged we are able to construct age distributions from both islands. The age structure of the St Helena population was again strongly unimodal and skewed toward the younger age classes. The modal age was 6-7 years but there were also appreciable numbers of 1-5 year old fishes. Over 35% of the groupers sampled were 5 years of age or less suggesting rapid growth in smaller individuals. From 6 years of age the number of individuals declined with individuals older than 10 years relatively rare. The oldest individuals recorded were 15 and 16 years of age. Individuals older than 10 years were relatively rare. The Ascension Island age distribution differed from that at St Helena in that it was strongly bimodal with the sample dominated by 2-3 and 7-8 yr individuals. However, as with St Helena, older individuals rapidly declined in the sampled population. (Fig 14).

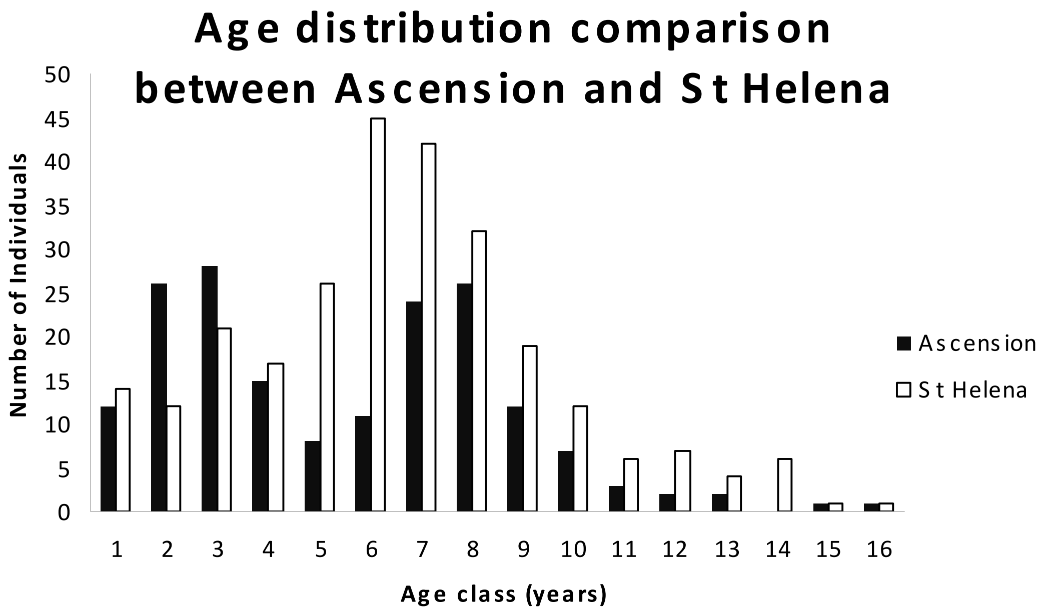

Figure 14: Combined age distribution of all groupers collected from St. Helena and Ascension.

Otolith analyses and validation of the annual pattern of growth-ring formation: Age structure estimates were obtained from sectioned otoliths (see Material and Methods). Fig

15 shows the form of the whole otolith. In whole otoliths growth check marks on which the estimates of age are based can be seen in the whole otolith (Fig 15A). However as we determined in this study and has been confirmed in much of the fisheries literature for most fish the crucial outer rings that record age in long-lived species become difficult to read in whole otoliths. However for a majority of shallow water reef species (Choat & Robertson 2002) sectioned otoliths which expose check marks on the outer margin of the otoliths provide a consistent and accurate estimate of the age of the fish. The sectioned otolith illustrated (Fig 15B) is from a 504 mm male grouper collected from St Helena clearly shows the alternating opaque and translucent bands by which age is estimated. The broad distances between the bands in the interior of the otolith are indicative of the period of rapid juvenile growth. This fish had an estimated age of 10 years.

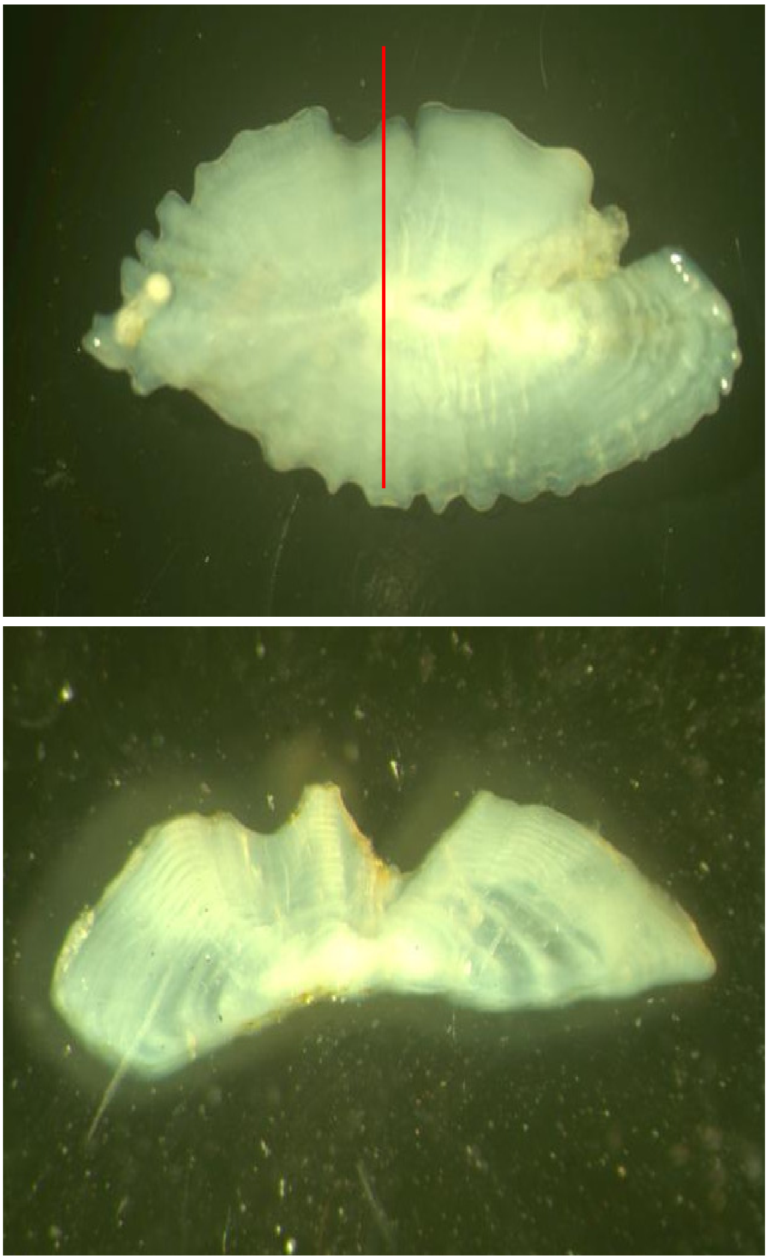

Figure 15: (A) Whole otolith from a 416 mm *E.adscensionus* collected from St Helena showing the location of the transverse section, reflected light. (**B**) Transverse section of an otolith from a 504 mm *E.adscensionus* collected from St Helena showing the growth check marks in the otolith matrix

Sagittal otoliths increase in weight with the age of the fish in a simple linear fashion. Otoliths keep growing for the life of the fish and otolith weight is thus an indicator of age. However the rate at which otoliths grow is related to the size of the fish. These aspects of fish age and growth can be seen in Fig 16. For both St Helena and Ascension the otolith weight increases with age in a highly predictable linear fashion (Fig 16 A & B). However due to a higher growth rate of Ascension fish (see below) and thus a greater size for a given age the rate of increase in otolith weight is higher at Ascension than St Helena (Fig 16 C).

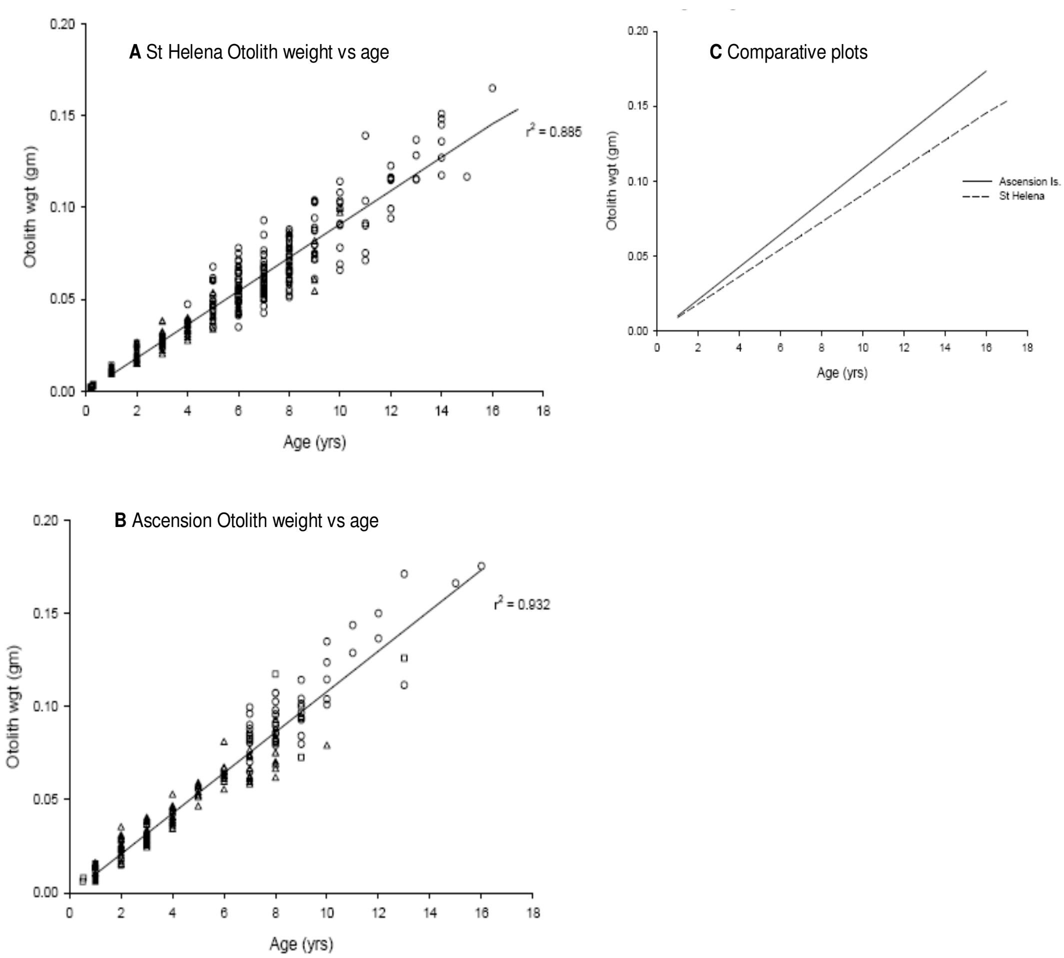

Figure 16: Regression analysis of otolith weight *vs* age of fish for all St Helena and Ascension samples. Linear regression equations fitted to each plot. Filled points females, Open points males. **A** St Helena samples **B** Ascension samples **C** Comparative plot for both islands.

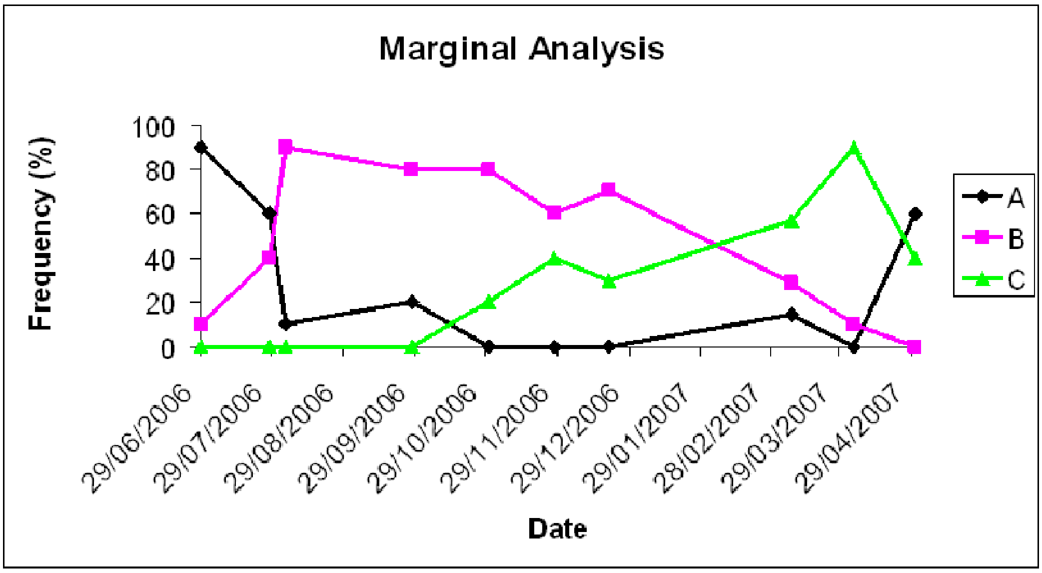

Figure 17: Otolith marginal analysis *E.adscensionus* St Helena 2006/2007

Key: (**A**) opaque material is visible on the otolith edge. (**B**) a continuous band of translucent material is visible on the outermost edge of the opaque zone. The marginal translucent zone is less than 2/3 complete. (**C**) marginal translucent zone is more than 2/3 complete.

The validity of the check marks seen in the sectioned otoliths as annual signals was checked by analysis of the otolith margin. The percentage of otoliths with the opaque bands at the outer edge was tabulated over the period June 2006 to late April 2007 and compared to the percentage with translucent band material at the edge. The results are plotted in Fig 17. Opaque material dominated the outer margin of the otolith at two times of the year, June 2006 and April 2007. For the remainder of the year the margins were dominated by the development of the broader translucent zone which was completed in March 2007 after which a new opaque zone was detected at the margin. We conclude that one opaque zone was formed annually during the period April to June. However we suggest that this be checked for Ascension island and if possible through mark recapture experiments at St Helena.

Mortality rates: An important point emerging from the age frequency distributions is that each population showed a very similar distribution of older individuals with 16 being the maximum age achieved on both island. Estimates of the rate of decline in numbers as a function of age provide an estimate of mortality rate through regression analysis. For both islands the numbers of groupers collected in our samples declined with age in a linear fashion when the numbers in each age class were log transformed. . The slope of this descending line provides an estimate of the mortality rate in groupers older than 6yrs. The graphs show the slopes of the regression were very similar for each population with the St Helena population showing a slightly (but probably not biologically significant) greater rate (-0.39 vs -0.35) than the Ascension population. (Figs 18,19). This represents an approximately 70% annual survival rate for the two populations.

Figure 18: Age-based mortality estimate of St. Helena groupers.

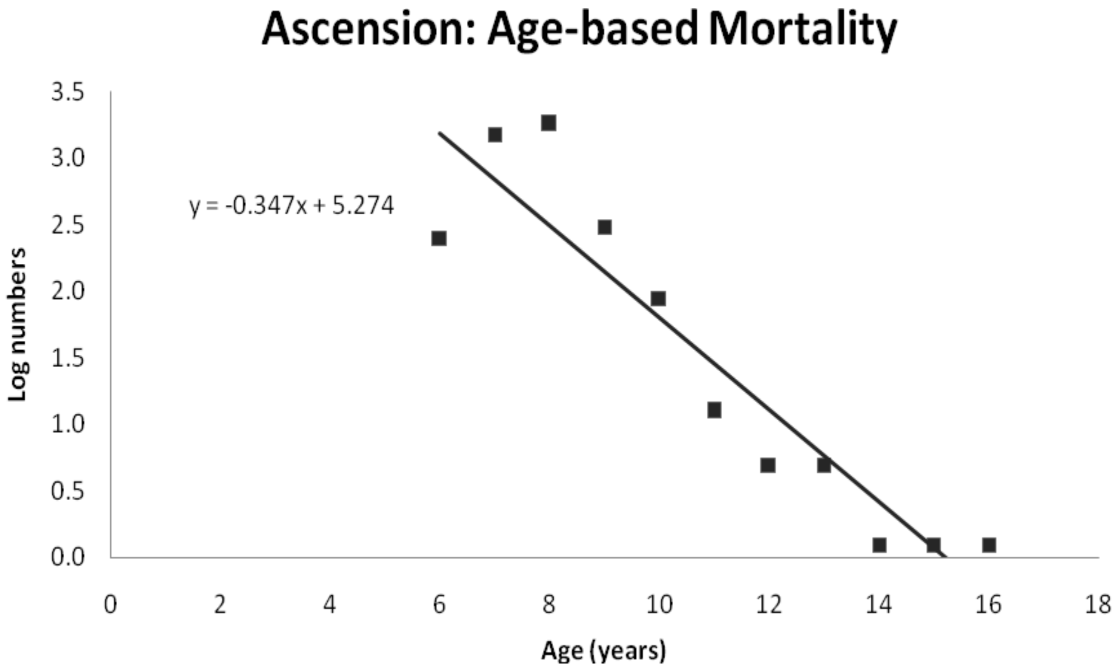

Figure 19: Age-based mortality estimate of St. Ascension groupers

Growth rates: The age distribution plots provide a single snapshot of each grouper population. However by linking the age of each grouper to its size at capture it is possible to produce size-at-age plots that describe the pattern of growth at different islands. Equations describing growth in mathematical terms may then be fitted to the size at age data points. The size at age plots for the grouper populations sampled at each island are shown in (Fig 20). Both curves show a pattern typical of many reef-fishes in which growth is initially rapid, but, with increase in size and age, growth slows. This characteristic reduction in rate produces an asymptotic growth curve. In both the St Helena and Ascension populations growth is relatively rapid up to ~ 7 years, then gradually slows. After 7 years the growth curves of the two islands diverge, with Ascension populations showing a faster growth rate and thus achieving a larger size in older individuals than occurs at St Helena. Note the equation provides a relatively poor fit for older fish. These are mainly males and this issue of differential growth of the sexes will be dealt with below.

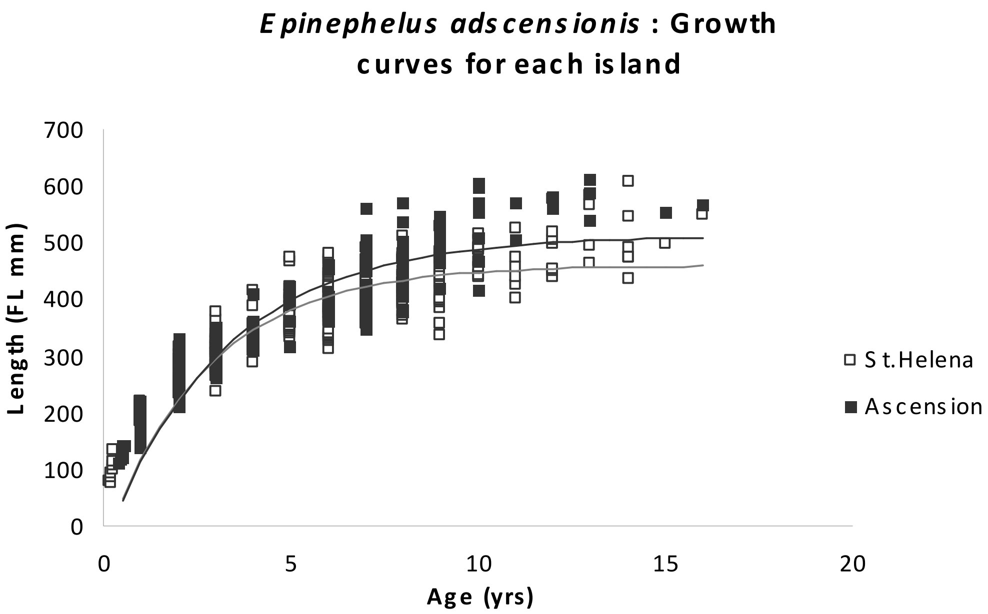

Figure 20: Size at age plots for all groupers aged from St Helena and Ascension Islands. The von Bertalanffy growth function has been fitted to each data set. VBGF St Helena $L_t = L_{459.6}(1-e^{-0.37(t-0.050)})$. VBGF Ascension $L_t = L_{513.0}(1-e^{-0.31(t-0.050)})$

To examine the consequences of different growth rates between the two populations we compared the mean size of individuals from particular age classes. Although growth rates in the St Helena and Ascension populations diverged with increasing age due to the relative scarcity of large individuals it was not possible to adequately compare individuals from the older age classes. However relatively large numbers of groupers in the 8 year class were collected. As expected from the growth curves 8 year old males from Ascension were larger than 8 year old males from St Helena; Ascension mean size at 8 years was 458.6 ± 8.9 mm; for St Helena it was 432.6 ± 6.7mm. This confirms that once an age in excess of 6 years is achieved groupers at St Helena will display a marginally slower growth rate (in terms of length) than Ascension.

Comparison of St. Helena deep and shallow water populations: A total of 44 Jack ranging from 326 to 609 mm in length were sampled from deeper water (62-84 m) substantially deeper than the 5-15m from which the majority were collected by spearing. A growth curve was reconstructed from the deep water samples (Fig 21)Comparisons of condition, growth rate and the distribution of sexes were made between deep and shallow water populations.

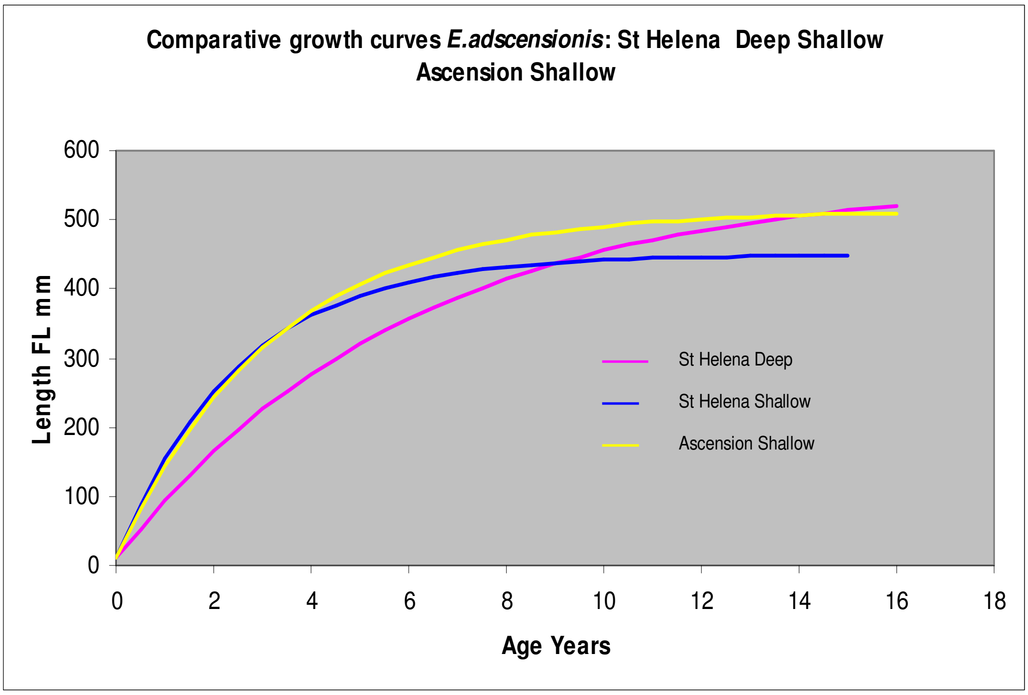

Figure 21: Comparative growth curves reconstructed from St Helena (Deep and Shallow) and Ascension (Shallow) samples.

Deep water populations of Jack accumulated weight over time at a lower rate than those from shallow water populations resulting in large groupers (500 mm) from deep water being 17% lighter than equivalent sized individuals from shallow water. This is demonstrated by the length/weight plots and the equations describing the relationship (Fig 11). Groupers from Ascension Island shallow water were also slightly lighter than shallow water St Helena groupers although the difference was not as great as that seen in deeper water groupers.

Analysis of growth rates of deep and shallow water populations also revealed differences in growth rate between depth and between shallow water populations on the two islands. Groupers in deep water showed a reduced growth rate compared to shallow water populations from both islands. The growth trajectory of deep water groupers gradually increased but only reached parity with shallow water individuals at 10-11 years of age (Fig 21). At 5 years, the age of onset of female sexual maturity and at 8 years, the approximate age of sex reversal deep water groupers were 18 % and 4 % smaller respectively than shallow water populations. After 10 years the size at age for deep water groupers was marginally greater than those from shallow water, driven mainly by the number of large males in the deep water population. In deep water populations there were relatively fewer males in the 5-8 year age classes compared with shallow water St Helena populations but larger numbers of older males. In summary deep water grouper populations have initially slower growth rates, especially during the earlier years of life, a lower condition factor expressed as length/weight relationships and an indication that sex-reversal to males may occur later in life in deep water populations. Deep water populations from St Helena displayed even slower growth when compared to Ascension groupers.

For St Helena populations deeper water groupers have reduced condition and growth rate compared with those from shallow (< 20m) water. However, given that weight is roughly a cube of length, these relatively small differences in length actually represent more substantial differences in weight: an 8 year old fish at Ascension is only 8% longer but weighs 25 % more than an 8 year old fish caught in shallow water at St Helena, and is 11.5 % longer and 37% heavier than one of the same age caught in deep water at St Helena.

In summary: (i) There were no differences in maximum ages and mortality rates of grouper populations at the two islands.

(ii) Growth rates are very similar at the two islands up to 7 years of age.

(ii) Fish older than 7 years continued to grow on both islands, but grew at faster rates at Ascension than at St Helena, with 8 year old fish being 25 % heavier at Ascension than at St Helena.

Reproductive Biology:

Distribution of sex by size and age: When the size and age frequency plots of grouper populations from each island are partitioned by sex it can be seen that the sexes have different distributions (Figs 22-25). Males were not recorded from either population in individuals less than 4 years of age, or less than 340 mm in length. The largest and oldest members of both populations were exclusively males. These patterns suggest that *E. adscensionis* is a protogynous hermaphrodite with individuals commencing life as females, and change sex to become males after reaching sexual maturity and spawning as females. This is a common pattern in many species of groupers where males are recruited from females by sex-reversal with males subsequently growing rapidly and achieving large size. A number of steps are required to confirm protogynous sex reversal in groupers. These include the demonstration that males occur only in the upper size ranges and older age classes and that evidence of reversal from female to male sex is provided through histological analysis. These issues are dealt with below and support the argument that *E. adscensionis* is a protogynous hermaphrodite.

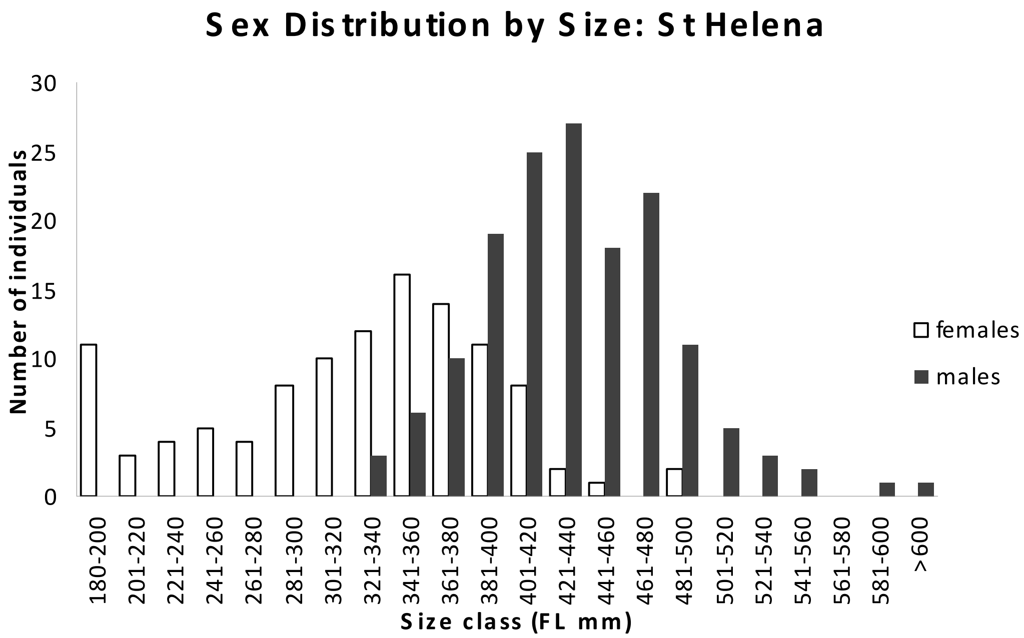

Figure 22: St. Helena. Distribution of grouper sex by size.

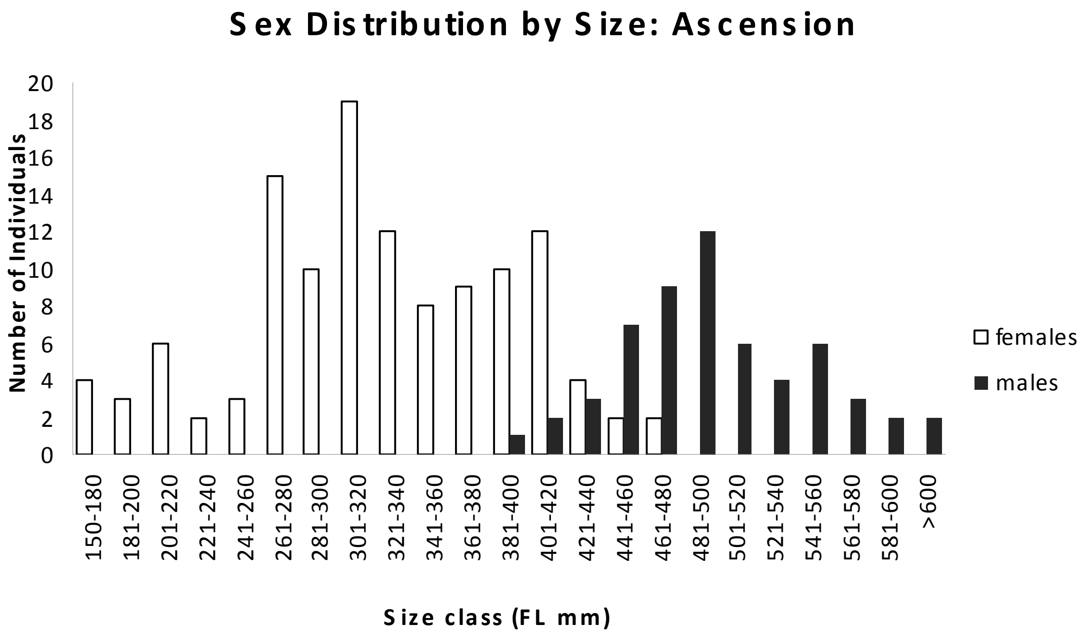

Figure 23: Ascension**.** Distribution of grouper sex by size

Of considerable interest is that the detail of the sex distributions is different between the two islands with respect to both size and age. The size (Figs 22, 23) and age (Figs 24, 25) of males overlaps considerably with that of females on St Helena Is but not on Ascension Is. At St Helena males appear in the population at a smaller size and a younger age than at Ascension. Consequently at the ages of 5-7 years the St. Helena population is dominated by males which contrasts with the Ascension population where females predominate at these ages.

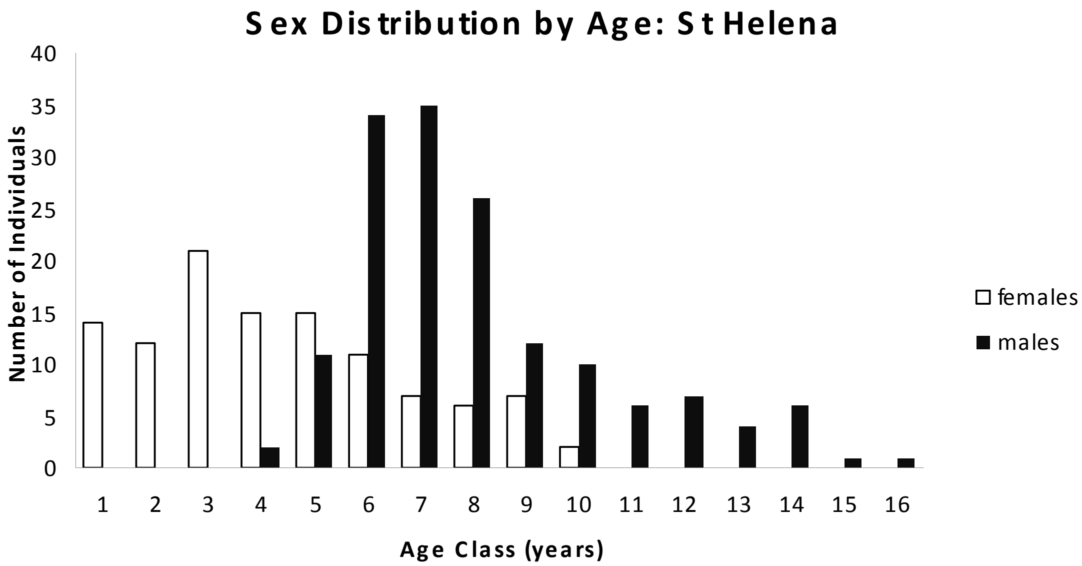

Figure 24: St. Helena. Distribution of grouper sex by age.

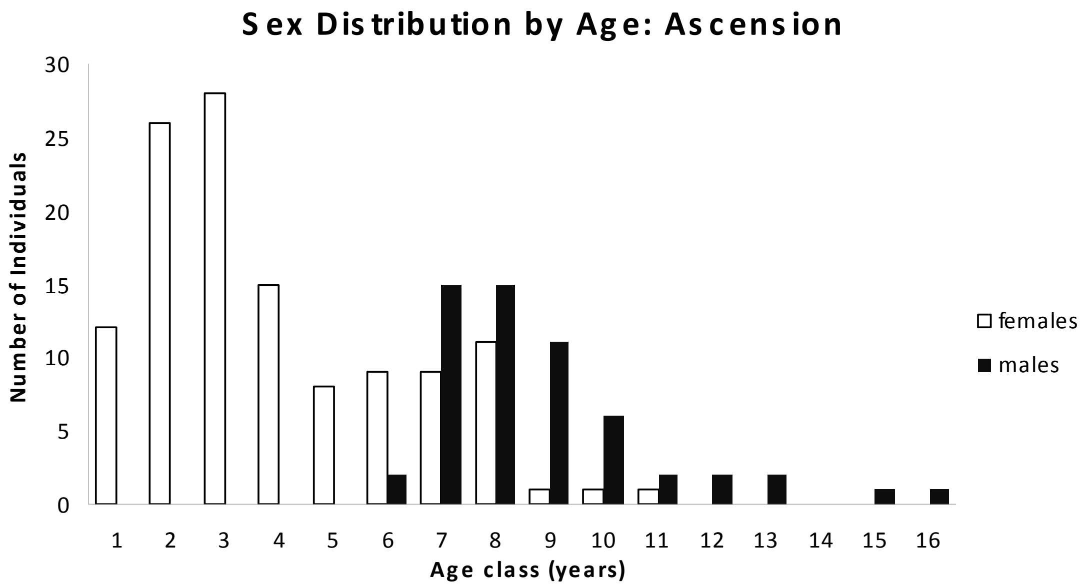

Figure 25: Ascension. Distribution of grouper sex by age

The different distribution of males and females by size and age is also shown in the sex-specific growth curves for each island (Figs 26 27). The size at age plots confirm that males only occur in the larger and older members of the population and the different distribution of males for each island. In addition as these plots show growth rates it can be seen that for each island males achieve a greater size than females by two means. Firstly all females appear to have the capacity to change sex so only males are represented in the larger size classes. Secondly males have a higher growth rate than females of equivalent age. In both populations female growth rate declines after four years of age resulting in an asymptotic growth curve. In contrast males maintain a higher growth rate throughout life including the largest individuals. An exception to this is seen in the Ascension population where two females maintained high growth rate achieving sizes in excess of 500 mm FL (Fig 27). Fitting separate growth curves to each sex provides a more realistic description of growth than that seen when curves were fitted to the whole population (Fig 20).

Figure 26: St Helena. Sex specific growth curves. The von Bertalanffy growth function has been fitted to each data set.

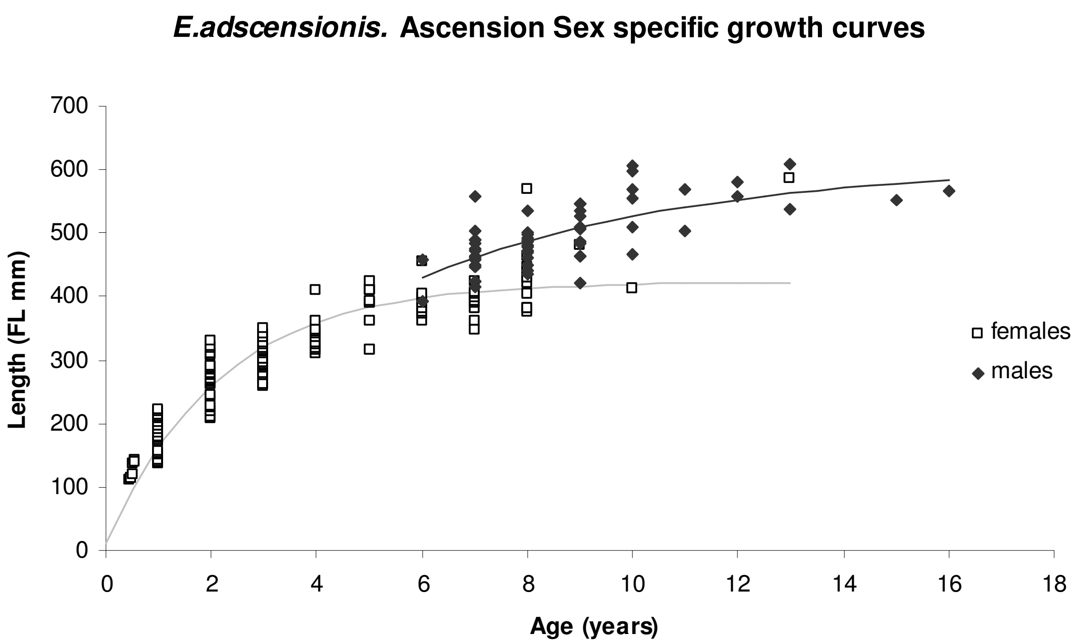

Figure 27: Ascension. Sex specific growth curves. The von Bertalanffy growth function has been fitted to each data set.

In terms of the maximum ages and sizes of the sexes the two populations were remarkably similar. The largest and oldest females recorded for each population were between 480-500mm TL and 10-11 yrs. The mean maximum age achieved by the oldest 10% of fish in each population was also similar being 12.7 ±0.3 years for St Helena and 11.1± 0.5 for Ascension. These individuals of maximal age were exclusively males, a reflection of the protogynous pattern of sexual development.

A more detailed analysis of the distribution of sex by age and size showed that the dynamics of sex-reversal were different for each population. In many fishes the age and size at which sex reversal occurs varies by location within a single species. Although the patterns of growth and longevity in St Helena and Ascension Island populations were remarkably similar the patterns of sex distribution by size and age suggested that the internal dynamics of each population were very different. The preliminary analysis showed that the smallest size at which males recruited into both populations was ~ 340 mm and at an age of 4 years. Large samples of groupers between 340-440 mm TL were collected to check for differences in the pattern of male recruitment for each island population. Histograms of the distribution of sexes by size and age revealed that recruitment of males into each population commenced earlier and at much smaller sizes at St Helena compared to Ascension. Of 140 individuals of 340-440 mm TL 63% from St Helena were males. For Ascension only 12% of the 48 individuals in that same size class were males. Age based dynamics of sex reversal were similar. Of 162 groupers between 4-8 yrs of age sampled from St Helena 67% were males. For Ascension the figure was only 37% of 83 individuals. As it is not possible to distinguish sex of groupers in the field the sampling was not biased by selecting particular sexes in the sampling. The results show that there are differences in the sex ratio of intermediate size groupers with St Helena characterized by a much larger proportion (two fold) of males. This bias in the sex ratio towards males is the result of sex reversal commencing earlier at St Helena than Ascension.

Age and size at maturity: No sexually active females were recorded at St.Helena during the survey. In contrast numerous females whose ovaries were actively producing eggs were recorded at Ascension, where fish were sampled from large groups that may have represented reproductive aggregations. Plotting of gonad weight against fish length ovary weight increased as a power function of body length. Ovary weight increased rapidly at 310-320 mm FL, and maintained a high rate of increase over the sampled size range. This pattern is typical of many reef fishes. Female sexual maturity occurred at approximately 300 mm FL which corresponds to an age of 3.5 to 4 years for the Ascension population. Male recruitment by the sex-reversal of females commenced at 6 years of age. Male maturity occurred at between 6-7 years but the gonad size relationship and the rate of increase with size was different from that observed in females. (Fig 28) Testes were relatively small compared to ovaries. The mean weight of mature testis, 7 ± 0.6gms contrasts with 45 ± 7.1 gms for mature ovaries. The pattern of testis increase in weight with body length was linear. This pattern is highly characteristic of fish with a protogynous reproductive mode. The distribution of ovary and testis weights with size and age is shown for the Ascension Island population (Fig 29). This shows clearly the gradual increase in ovary weight with increasing age and size, the age at which males appear in the population and the relatively small size of the male reproductive organs compared to those of the female.

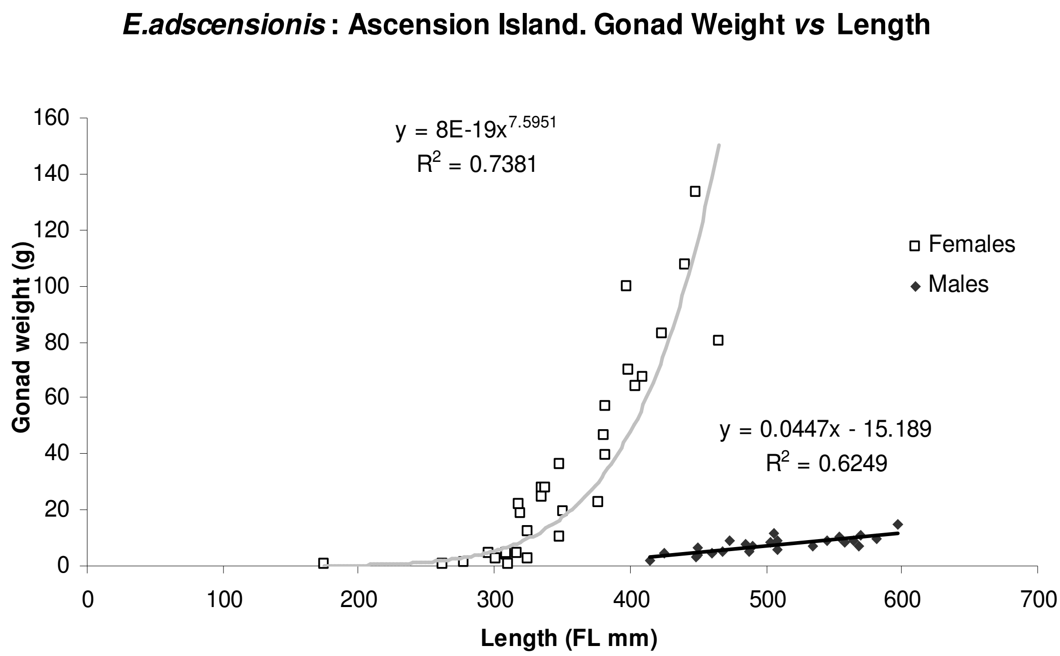

Figure 28: Ascension Is. Plot of gonad weight (ovaries and testes) on length.

Figure 29: Ascension Is. Gonad weight (ovaries and testes) plotted on to male and female growth curves

*Histological analysis***:** Histological examination of grouper gonads provided valuable confirmatory evidence of the reproductive biology of this species. The gonads of *E.*

adscensionis are elongate organs lying in the upper region of the abdominal cavity. Sectioning the gonads to provide crosswise (transverse) sections illustrates the internal structure. As is typical of many groups of reef fish the section of the ovary shows that the eggs (oocytes) are contained in folds of tissue, the lamellae, that hang down into the ovary cavity, the lumen. This structure can be seen in Fig 30 in which developing oocytes of various maturity stages can be seen within the lamellae. The presence of oocytes of different maturity stages suggest that *E. adscensionis* is a serial spawner, spawning a number of times during a seasonally restricted reproductive period. The testes were far smaller than the ovaries but showed a similar pattern of internal structure in which the spernmatogenic tissue is situated in lamellae that hang into a lumen (Fig 31). Spermatogenesis occurs throughout the lamellae producing mature sperm that accumulates in ducts in the wall of the testis. The structure of the testis may be interpreted in terms of its previous existence as an ovary. A comparison of Figs 30 & 31 shows the basic structural similarities between the ovary and the testis. Fig 32 shows the structure of a gonad in which sex reversal is taking place. The low power illustration shows the typical gonad structure. The high power illustration shows the lamellae filled with developed spermatogenic tissue but with the remnants of the female identity in the form of regressing oocytes. The internal process of sex reversal in which the oocytes are absorbed and spermatogenic tissue develops can be very rapid and accomplished in less than two weeks.

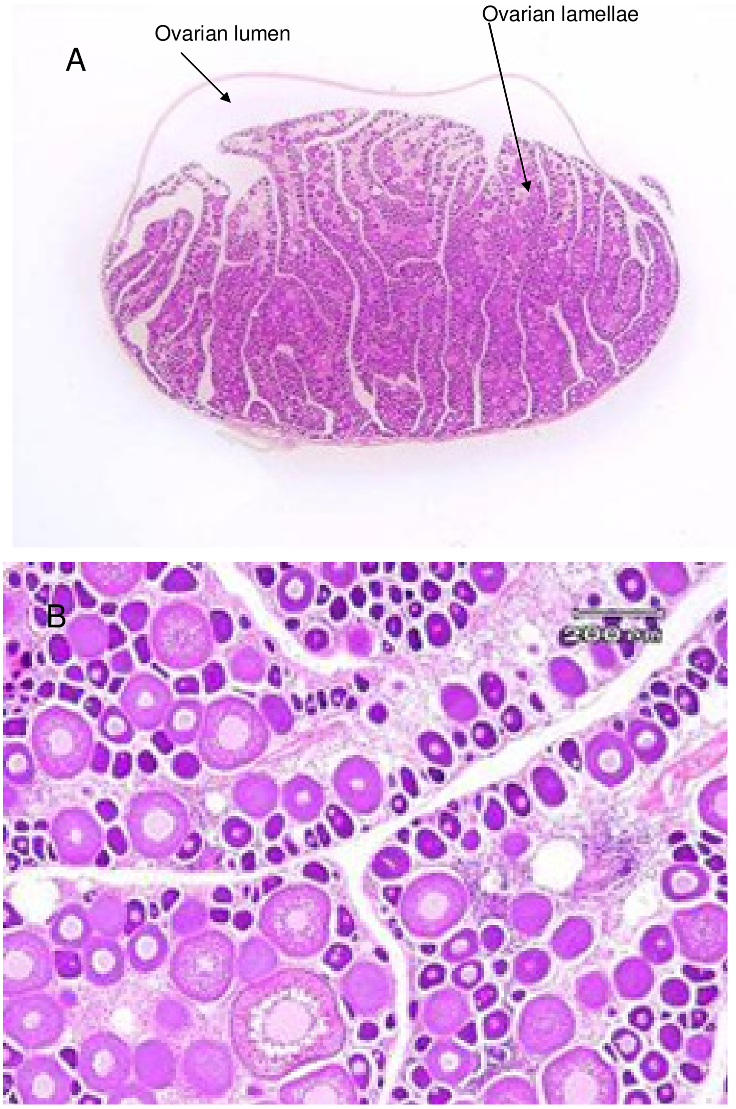

Figure 30: Transverse section of ovary of immature *E.adscenionis* 324 mm and 4 years from Ascension Island. (**A**) Whole ovary showing characteristic ovarian lamellae and lumen. (**B**) High power view of same section showing oocyctes in different stages of development.

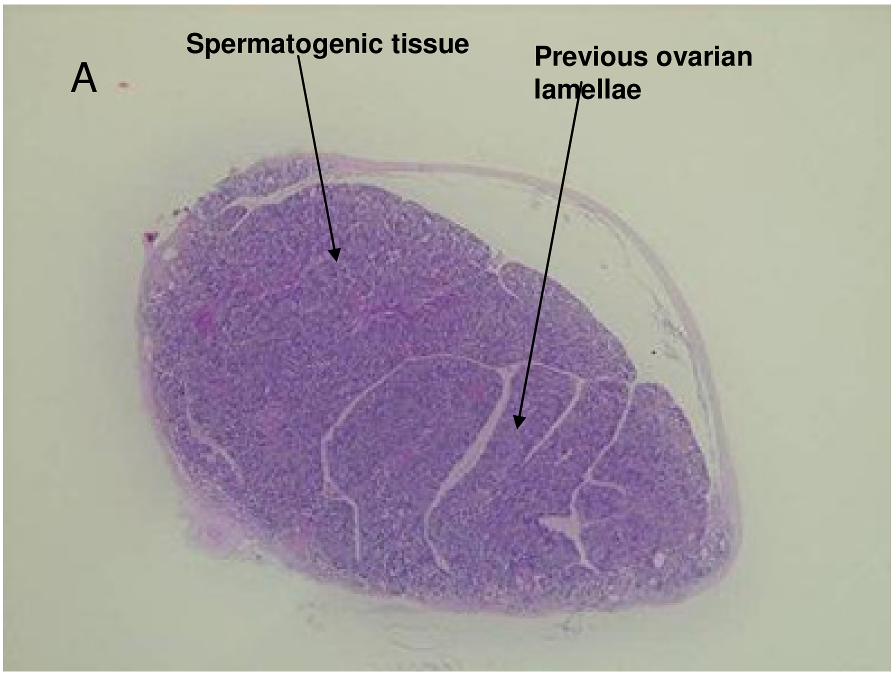

Figure 31: Transverse section of mature testis *E.adscenionis* 425 mm and 7 years from

Ascension Island. (**A)** Whole testis showing previous ovarian structures. (**B)** High power view of same section showing active spermatogenesis with mature sperm in peripheral ducts.

Thus the histological analysis helped confirm the pattern of ovary maturation identified by the plot of ovary weight against fish size (Fig 28) and confirmed that sex reversing was occurring in both *E adscensionis* populations.

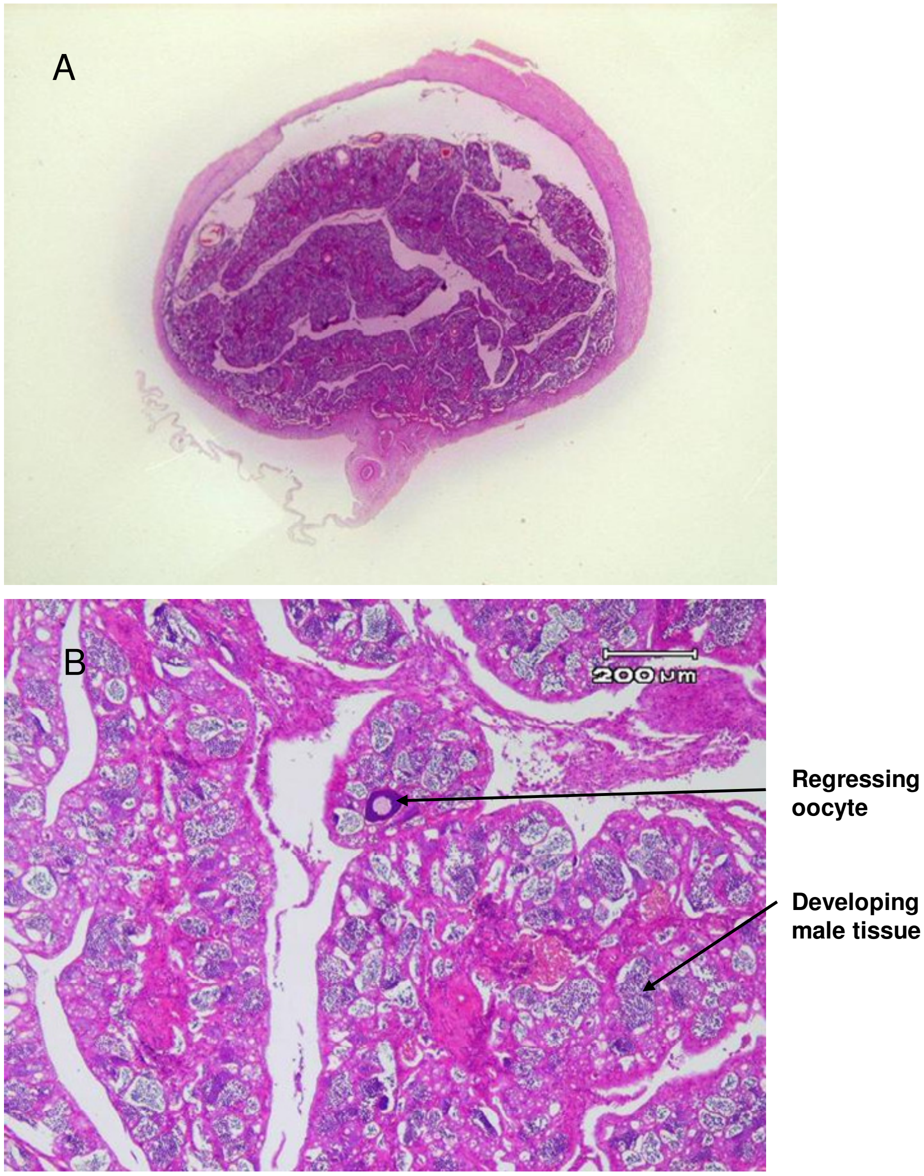

Figure 32: Transverse section of the gonad *E.adscensionus* 470 mm and 8 years from Ascension undergoing sex reversal. (**A)** Whole gonad showing typical ovarian structure but with male tissue. (**B)** High Power of the same section showing developing spermatogenic tissue and remnant oocytes**.**

Comparative life spans of St Helena and Ascension Island reef fish: St Helena island lies 1200 km to the south of Ascension and on average experiences a 3°C difference in mean water temperature. Previous studies (see Choat and Robertson 2002, Robertson et al 2005) have identified a consistent latitudinal trend in age structure in reef fishes with maximum age of the population increasing with increasing latitude (i.e. decreasing water temperature). From this relationship our expectation was that Jack at St. Helena would, under natural circumstances, consistently achieve a greater maximum age than at Ascension. However the preliminary information indicated that fishing pressure differed between the islands and if the St Helena fishery targeted large individuals there was a strong possibility that the age distribution would be truncated. Similar maximum ages at both islands could be the result of a strong fishing pressure directed against larger individuals at St Helena. Our predictions concerning the maximum ages of groupers on each island are as follows. i) If the populations were undisturbed we would expect the St Helena groupers to follow the natural trend observed in other reef fishes with the colder water St Helena populations achieving greater maximum ages than those at Ascension; ii) If the St Helena populations are subject to greater fishery effort than the Ascension populations we would expect these older individuals to be removed so that the populations on both islands had similar maximum ages. This is based on the observation that grouper fisheries invariably remove the larger and older members of the populations first.

It is not possible to reconstruct the St Helena grouper populations as they were before fishing commenced. However we can compare a range of populations and closely related species that occur on both islands to determine if the expected pattern of St Helena populations having a greater maximum age than Ascension populations occurs. Accordingly we analysed the age structure and growth patterns of four species of reef fishes that maintain populations at both St. Helena and Ascension Islands and occupy the same habitat and depth range as groupers. These were the endemic parrot fish *Sparisoma strigatum* (Rockfish), the surgeon fish *Acanthurus bahianus* (Shitty trooper), widespread in the tropical Atlantic, the blenny *Ophiblennius atlanticus* (Devilfish), also widespread in the tropical Atlantic, and two very closely related sister-species of damselfish *Stegastes* (Bastard Cunning Pilots) *S sanctaehelenae* (endemic to St. Helena) and *S lubbocki* (endemic to Ascension).

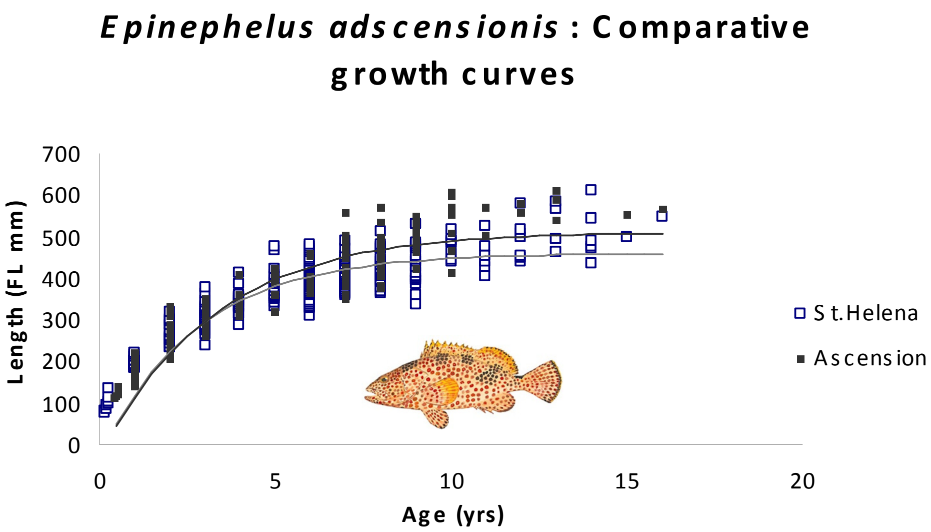

Figure 33: Growth curves and age distribution of *E.adscensionis* (Jack) populations from St.Helena and Ascension Islands.

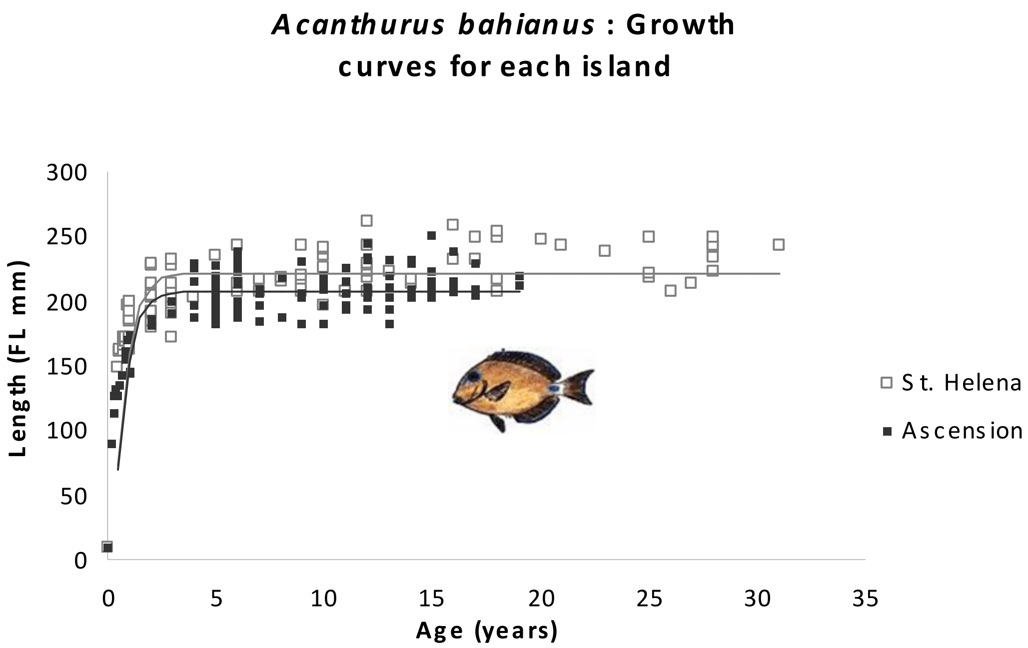

Figure 34: Growth curves and age distribution *A.bahianus* (Shitty Trooper) populations from St.Helena and Ascension Islands.

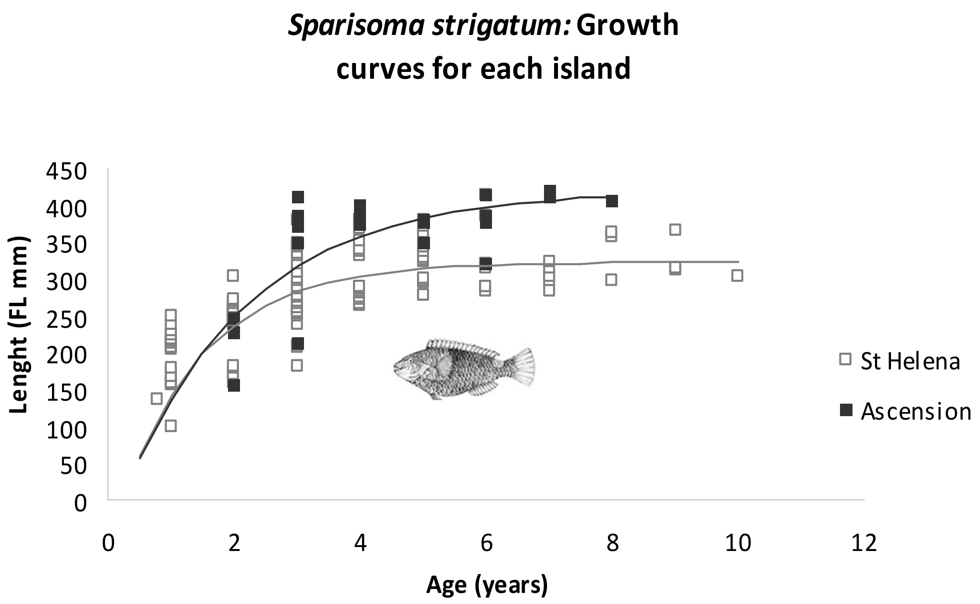

Figure 35: Growth curves and age distribution *S.strigatum* (Rockfish) populations from St.Helena and Ascension Islands.

The growth curves for each island population for each of these species are shown in Figs 34 to 37. In each instance the maximum ages of the St.Helena populations of these ecologically distinct species was greater (in three of the pairs significantly so) than those from Ascension. This contrasts strongly with the grouper populations (Fig 33). The graphs also illustrate another consistent aspect of reef fish ecological performance. Differences in life span are consistently great at high as compared to low latitudes which suggests they are conforming to some fundamental factors that drive reef fish population biology. This is especially clear in two abundant but unrelated groups, the surgeon fishes *Acanthurus bahianus* (Fig 34) and the pomacentrids *S.sanctaehelenae* and *S.lubbocki* (Fig 36) in which the life spans of the St Helena populations are at least 40% greater than those of Ascension. However growth rates do not vary consistently. This is shown in these examples in which the Ascension Rockfish are faster growing than their St Helena counterparts whereas the opposite effect is seen in the *Stegastes* (Figs 35 36). A summary of the main differences between St Helena and Ascension populations is provided in Table 8

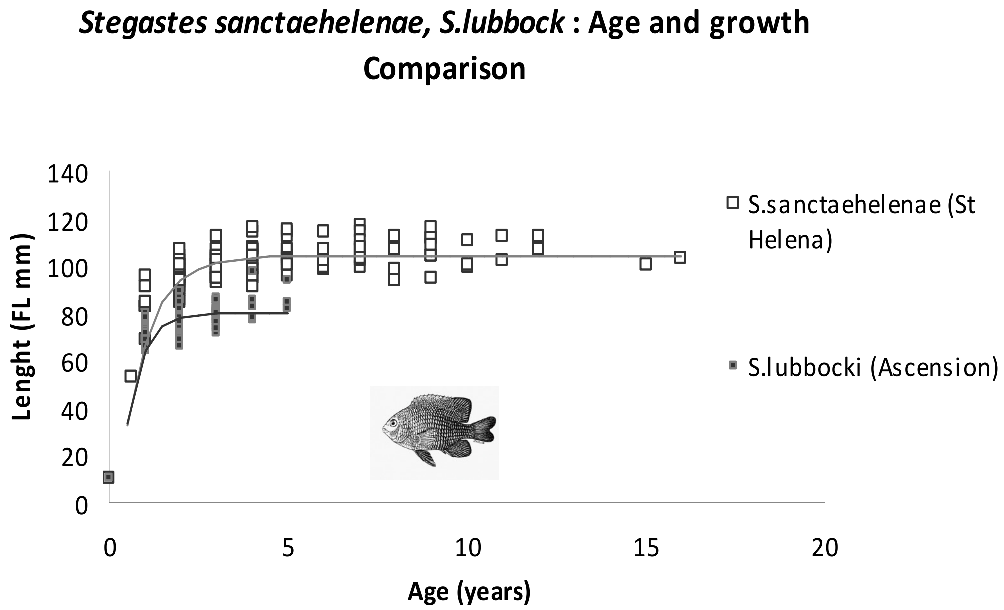

Figure 36: Growth curves and age distribution of *S.sanctaehelenae* and *S.lubbocki* sister species of Bastard Cunning Pilots from St.Helena and Ascension Islands.

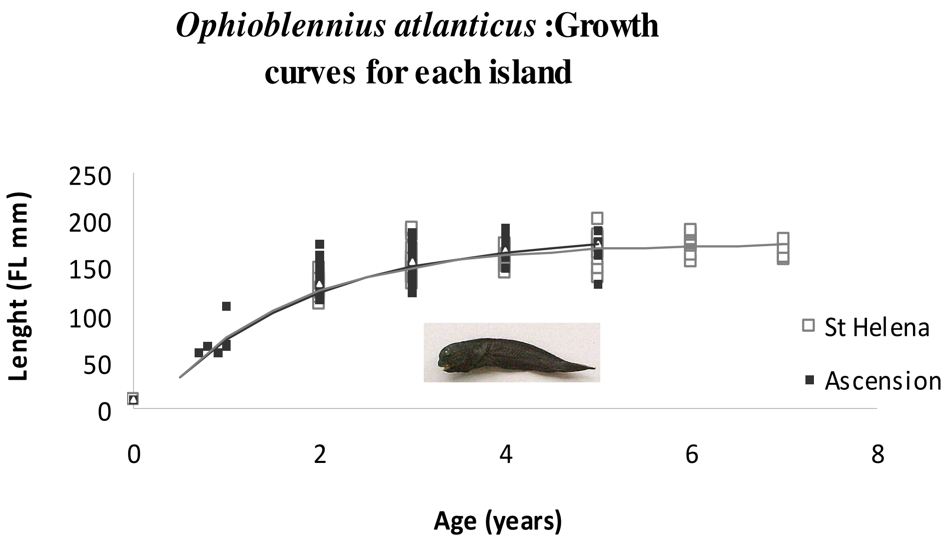

Figure 37: Growth curves and age distribution *O.atlanticus* (Devil Fish) from St.Helena and Ascension Islands.

Table 8: Summary of demographic trends for St Helena and Ascension populations of four species of reef fish

SPECIES	ASCENSION	ST HELENA	INTER-ISLAND DIFFERENCE
Shitty Trooper ***Acanthurus bahianus***			
Maximum size cm	25 cm	26 cm,	Similar
Asymptotic size cm	20.5 cm	22 cm	St Helena slightly higher
Longevity Years	19 years	32 years	**St Helena much longer lived**
Rockfish ***Sparisoma strigatum***			

Maximum size cm	41 cm	40 cm	Similar
Asymptotic size cm	40 cm	30 cm	Ascension greater size
Longevity Years	8 years	10 years	**St Helena longer lived**
Barstard Cunning Pilots Different but closely related species at each island	***Stegastes lubbocki***	***Stegastes sanctaehelenae***	
Maximum size cm	9.2 cm	11.8 cm	St Helena higher
Asymptotic size cm	8.0 cm	10.5 cm	St Helena higher
Longevity Years	5 years	16 years	**St Helena much longer lived**
Devilfish *Ophioblennius atlanticus*			
Maximum size cm	18 cm	20 cm	Similar
Asymptotic size cm	17.5 cm	17.5 cm	Similar
Longevity Years	5 years	7 years	**St. Helena longer lived**.

Biological Summary

Firstly the grouper *E.adscensionis* achieves its greatest recorded abundance at these two mid Atlantic islands. The biological characteristics of grouper populations are summarized in Table 9 which emphasizes the differences between the two islands. The most important differences are in the abundance patterns with the average density of groupers at Ascension being nearly three times that recorded at St Helena. In both cases the density of groupers is reduced close to centers of human access to the coast although this is much greater at St Helena. In terms of size and age the averages and maximum values obtained were surprisingly similar for each island which was also reflected in the similar growth and mortality rates. One small but consistent difference was that groupers on Ascension achieved a larger size due largely to a faster growth rate in older individuals. Both populations displayed very similar relationships between size and weight. However as growth rates differ between the islands it takes longer for a St Helena grouper to achieve the same weight as an Ascension grouper. A difference was also seen in deep and shallow water populations from St Helena where deeper water groupers had a lower weight for a given size than shallow water groupers.

Table 9: Summary of the ecological features of grouper populations for each island.

BIOLOGICAL VARIABLE	ASCENSION ISLAND	ST. HELENA ISLAND	INTER-ISLAND DIFFERENCE?
Density Average	7.8	2.9	**Ascension distinctly higher**
Density Maximum	23	10	**Ascension distinctly higher**
Density Reduced near habitation?	yes	yes	**St Helena stronger reduction**
Density Range in Caribbean sites	0.02-1.5		**Much lower than either island**
Size Max size (cm)	61	61	**Same**
Size Asymptote (cm)	55	48	**Ascension slightly higher?**
Size Frequency distribution	Small, Medium & Large	Mostly medium	**Ascension more evenly distributed Censuses & collections show same pattern**
Size Reduced near habitation?	Yes	Yes	**St Helena - stronger reduction**
Size Modal value from census counts	32cm	30cm	**No biologically significant difference**
Growth rate	Older fish continue growth, at faster rate	Older fish continue growth, but at slower rate	**Older fish continue to grow, but more slowly at St Helena**
Condition (length/weight exponent) Depth effect?	3.2 No data	3.2 Deeper - poorer condition	**Same**
Age Maximum longevity (yrs) Average top 10%	16 11.1	16 12.3	**Same** **No biologically significant difference**
Age Frequency distribution	Bimodal, many young fish	Unimodal, few young fish	**Ascension more evenly distributed**
Age Modal value for adults	7-8	6-7	**St Helena younger**
Mortality Adult rate	-0.40	-0.39	**No biologically significant difference**
Reproduction Size at sex change	12% of small fish	63% of small fish	**St Helena distinctly smaller**
Reproduction Age at sex change	37% of young fish	67% of young fish	**St Helena distinctly younger**
Sex ratio	63% female	33% female	**Distinctly fewer females at St Helena**

In both populations there is strong evidence of a protogynous mode of sexual development with all individuals commencing life as females and transforming to males by sex-reversal at approximately 5 to 8 years of age. There is evidence of significant differences between the two populations in terms of the schedule of sex reversal and the dynamics of male recruitment. The average age and size at which sex change occurs is much younger and smaller at St Helena. Consequently the sex-ratio in small groupers is biased towards males in St Helena so there are relatively few reproductive females compared to Ascension Island. Finally the similar life spans and maximum ages of groupers on the two islands is unusual when compared to other reef fish species with which they were compared.

It is important to take into consideration that these effects of fishing were detected after a period of 6-7 years of relatively low commercial catch levels. Sustained higher catch levels than occurred during that period likely will be manifest in stronger negative effects on abundance and demography of the Jack at St Helena.

Impacts of fishing and management implications

The initial impression of the status of grouper populations was that they are abundant and healthy with higher numbers per unit area of reef then at any other place on their broad geographical range. However there are clear signs of the impact of fishing on the St Helena population. Even if the harvesting of groupers is considered to be modest it is unlikely that this will decrease in the future and improved access to St Helena will inevitably lead to greater fishing impacts as has been the case in every island grouper population that has been studied. The following sections summarize the evidence for fishing impacts and identify approaches to the future monitoring and management of grouper populations on St Helena.

Evidence of overfishing.

Overview:

Are groupers as a group especially vulnerable to overfishing? This has a bearing on the future of the St. Helena grouper fishery. To put this fishery into context we consider the results of a recent IUCN workshop (Workshop for Global Red List Assessments of Groupers, Sadovy 2007) that took place 7-11 February, 2007, at the University of Hong Kong to determine the status of the 161 currently recognized species. Many groupers are commercially important and assessments to date on a subset of species suggest that the group might be particularly vulnerable to fishing. Of the species assessed 25% showed evidence of serious overfishing. Assessments were required on a global scale that considered species over their whole distributional range, rather than at individual localities as we did with *E adscensionis.*

A number of the findings are highly relevant to the St.Helena grouper fishery. The majority (>60%) of groupers assessed were Indo-Pacific species with wide geographical distributions. Of the 20 species placed in the most endangered categories 80% represented groupers from the tropical Atlantic or areas such as the East Pacific, Azores, the northwestern Pacific or the Galapagos Islands. Such areas support a relatively low diversity of reef fishes, many with fairly localized distributions. The groupers present represent some of the few species that are commercially valuable and have been targeted in local fisheries. Island populations were found to be especially vulnerable. Historical records indicate that many of these species were previously abundant which is why fisheries developed in the first place.

At present the St Helena grouper stock appears to be healthy as the Jack occurs at relatively high densities and with large individuals being well represented at many of the sites surveyed. However there is also clear evidence of fishing impacts. A matter of concern is that many of the grouper species in the Atlantic that have been severely depleted by overfishing, commenced as abundant populations in low diversity fish assemblages on island habitats where the absolute extent of reef habitat is relatively small.

The degree of predictability of replenishment of St Helena grouper populations by recruitment from planktonic larval sources is unclear. Genetic studies (Carlin et al 2003) demonstrate a high degree of similarity between southern Atlantic populations of

E.adscensionis. The results could indicate either extensive genetic connectivity between widely distributed populations or a history of large fluctuations in recruitment success and population size. At present it is not possible to distinguish between these alternatives. However the possibility of large, long-term natural fluctuations in grouper numbers and the relatively small area and extremely isolated nature of the St Helena subtidal habitat are of concern in the context of maintaining a sustainable fishery. As St. Helena is exposed to the variability of the south Atlantic ocean ecosystem fluctuations in the numbers of fish recruiting from larval populations is a strong possibility.

The main conclusion from a survey of grouper populations that share the same habitat and distributional features as *E.adscensionis* is that despite their apparent abundance such populations are vulnerable to over-fishing (Sadovy 2007). When considering the sustainability of reef fish populations it is important to note that every grouper population that has been subject to a targeted fishery has shown significant declines in numbers and catch rates over time.

***Summary of evidence of fishing impacts on St. Helena grouper populations*:**
There are four categories of evidence that are indicative of impacts of fishing**.**

Comparison of mean abundances between islands: A total of 230 underwater survey counts on St Helena (134) and Ascension (96) showed that groupers on St Helena reefs are only one third as abundant as those on Ascension reefs.

*Abundance and size-structure within each island***:** On St Helena reefs grouper abundance increases with distance from Jamestown on both the north and west coasts. Sites adjacent to Jamestown supported only 20% of the numbers of groupers found on the more distant north and southwest coasts. These low abundance sites were dominated by small groupers and no individuals in the largest size range were recorded. The grouper populations on Ascension showed no trend of reduction in abundance with proximity to human activity, although the most populated locality, Georgetown docks was dominated by very small groupers and had relatively few large individuals. Note that we identified these differences in 2006, after 6-7 years of relatively low catch rates by the commercial fishery (Fig 6) might have allowed some recovery by grouper population from previously higher levels of fishing.

Dynamics of male recruitment through sex-change in grouper populations: Like almost all species of groupers *E.adscensionis* is a protogynous hermaphrodite with males recruited into the population by the sex-reversal of mature females. In such species flexibility in the age and size at which females change sex is the norm. In both Ascension and St Helena populations the maximum age of females was 10 years, with all individuals between 10 and 16 years (the maximum age) being males. However, St Helena females tend to undergo sex-reversal at an earlier age than those on Ascension and at a rate that has biased the sex ratio there strongly towards males. Such changes in the schedule of sex-reversal in protogynous fishes are often associated with removal of large males from the population. A reasonable explanation for the striking differences in the sex ratio and pattern of male recruitment between the two islands is that fishing is removing larger and reproductively dominant males from the St Helena population resulting in a shift of sex-reversal to younger age classes.

Overall, fishing appears to have affected the grouper population at St Helena in several ways: (1) It has reduced overall densities; (2) it has reduced longevity; and (3) by leading to early induction of sex-change it has indirectly removed the largest females from the population and biased the sex-ratio towards males. The largest females in any fish species invariably are much more fecund than small females. Since females are both smaller and only half as abundant (relative to the abundance of males) at St Helena as at Ascension, and the absolute abundance of fish at St Helena is only ~40% that at Ascension, and there are relatively fewer large, highly fecund females at St Helena, fishing likely has reduced the biomass of females at St Helena to only ~10-20% that at Ascension. These multiplicative effects of the current fishing regime likely have strongly reduced egg production by the St Helena stock, production on which the long-term maintenance of that stock is entirely dependent.

Maximum ages of St .Helena groupers: In populations of reef fish that extend across significant latitudinal gradients those in higher latitudes and exposed to cooler temperatures are often of greater size and exhibit greater life spans than those from lower and more tropical latitudes. This is characteristic of a number of species including Indo-Pacific groupers. While we would have predicted greater life-spans in the higher latitude St.Helena populations it was found that the age structure of larger individuals were almost identical to those of the more tropical Ascension. We argue that the larger older populations on St Helena have been removed by fishing. To examine this in more detail we examined the life spans on conspecific and sister species of unfished species of reef-fish from unrelated groups that occur on both islands. All four species examined showed strong evidence of greater life spans in the St Helena as compared to the Ascension populations (Table 9). This evidence provided by four unrelated groups of fishes with differing habits and population dynamics strongly suggests that the latitudinal location of St .Helena relative to Ascension is sufficient to generate differences in the life-span of the grouper in the absence of a fishing effect.

In combination these observations demonstrate a lower population density of groupers on St Helena reefs, reduced numbers and sizes of groupers adjacent to the main population centre, sex-reversal to males by smaller and younger females and reduced numbers of large, highly fecund females compared to the situation at Ascension and an unexpected similarity of size and age structure between the islands despite their north/south separation by 1200km.The most parsimonious explanation accounting for the differences between St Helena and Ascension grouper populations is the fishing pressure generated by the 7 fold higher human population on St Helena relative to Ascension and the existence of a commercial fishery at St Helena but not Ascension.

These observations beg two questions;1) can it be demonstrated that increasing the catch rate will result in further declines in numbers and sizes of St Helena groupers; 2) what is the most effective way to monitor the populations of groupers and control fishing to ensure longer-term sustainability of the populations.

The St Helena grouper; are numbers changing? Consideration of monitoring options.

The issue: The core issue is to monitor grouper populations so as to detect changes in numbers and size that can be traced to fishing effects. There are two problems. Firstly fisheries, which naturally seek the best return, will focus on areas of high fish abundance. If fishery landing data are the sole source of information this will not give an accurate picture of changes in grouper populations. Secondly fish populations frequently vary due to natural causes. It is important to distinguish changes in numbers that reflect fishing from those attributable to natural causes.

We identify four possible sources of change.

Impacts of fishing: Expressed as reduction in the numbers and average size of groupers. This will be most pronounced if fishing targets large individuals.

Natural variation in recruitment: Most fish populations show fluctuations in numbers that can be traced to changes in the number of larvae that replenish adult populations. The causes are associated with changes in the oceanic systems that support and transport larvae to the adult habitat. This may be especially important for St Helena due to its isolation and exposure to the variable South Atlantic ocean environment. This is likely to become a more important source of variation if the South Atlantic oceanic ecosystem shows systematic changes over time due to long term climate change.

Changes to grouper habitats: Changes to shallow water habitats often associated with sedimentation or pollution may impact on the survival and recruitment of small groupers, which we found only in shallow, sheltered sites, sites that coincidentally are adjacent to areas suitable for human shore-based developments.

Changes to adult mortality patterns: This concerns episodes of unusually high adult mortality often occurring over short time periods. There have recently been examples of both fish and marine invertebrate deaths associated with viral and bacterial infections.

Monitoring and management.

For St Helena the major issue will be monitoring of numerical trends such that changes due to fishing are not confounded with natural changes in grouper numbers. It is unlikely at this point that changes to grouper habitats and to adult mortality patterns due to disease will be major issues.

Monitoring options.

1) *Continue monitoring of grouper catches but expand the scope of that monitoring from total weight of grouper per year to obtain annual estimates of both the number and size of groupers.*

Pros: Relatively simple and inexpensive procedure that provides summaries of catch rates and changes in the size of groupers being caught. In addition to collection of size and weight data from catch samples collection of otoliths will provide a source of information on grouper ages. A sample of 100 otoliths collected each year would allow monitoring of changes in age structure of the fished population. It has also been shown that the weight of otoliths can provide a useful approximation of grouper age (Fig 16).

Cons: Monitoring of populations that is based exclusively on fishery returns has been shown to provide overly optimistic assessments of the abundance of the target fish. . This is due to the high level of skill shown by many fishers in locating areas of high abundance that give the best return for fishing effort even though the total population may be declining. Thus estimates of fish abundance based on fishery data generally lag behind estimates based on fishery independent methods. This was a factor in the collapse of the Newfoundland cod fishery.

2) *Establish a system that allows fisher- independent estimates of grouper numbers over time: Non fishing areas with appropriate control (fished) sites.*

The St Helena habitat and grouper distribution patterns would allow implementation of a direct count monitoring program using Underwater Visual Census (UVC) techniques in areas both closed and open to fishing through an annual count program.

Pros: This approach will provide direct estimates of numbers of groupers in fished and unfished areas. With an appropriate design it is possible to detect and distinguish the impacts of fishing from changes in grouper populations driven by natural variation in recruitment and morality rates. Implementation of this approach at other locations has provided sound evidence of fishing impacts on grouper populations and a framework for equitable management practices.

Cons: Areas must be clearly designated and marked and compliance to non-fishing regulations maintained. This requires the legislation to mandate fishing closures by area, the legislative and social machinery to ensure compliance, the resources required for ongoing management, and the acceptance of management measures by the fishers. Although this is likely to be difficult to initiate, especially *de novo,* the record shows that marine protected areas that prohibit fishing have been consistently successful in allowing management agencies to gauge the impact of fishing and to develop equitable policies regarding levels of fishing. Moreover marine protected areas are now established over a large number of nations that maintain fisheries for reef species.

Marine protected areas; no-fishing reserves.

There is now a vast and readily accessible literature relating to the subject of no-fishing marine protected areas. This cannot be summarized in this report. However syntheses of the impact of reserve protection on reef fish stocks demonstrates that on average reserves generate strong positive effects for the biomass, density, species richness, and size of organisms within their boundaries. There is also emerging evidence that spillover of adults into nearby unprotected waters is a general phenomena associated with large reserves. Studies of the relative benefit of partial protection (e.g. size and bag limits) versus full protection (systems of no-take reserves) show that, on average, greater responses by fish populations are likely to be found for fully protected areas. A summary of the economic benefits provided by marine reserves and a summary of some of the relevant literature is provided by Balmford et al (2004).

A recent case history (Russ et al 2008) illustrates a number of these points. A series of large (5-10 km^2) no-fishing reserves and their adjacent control areas were established over the fringing reefs of three island sites on the Great Barrier Reef. Because closing these areas to fishing had been socially and politically controversial, it became imperative to assess the effectiveness of these reserves. In that study the densities of groupers of the genus *Plectropomus,* the major target group of the GBR line fishery were monitored. The monitoring design was as follows. No-fishing areas comprising a minimum of three sites at each island location plus control sites of similar area were monitored for grouper densities using UVC belt transects at the same time as the reserves were established. Each site within the protected area and each control site was then monitoring 1.5 to 2 years after the reserve had been established. The results are illustrated in Fig 38 . After 1.5 to 2 years of protection the density of the target groupers at two islands had increased significantly (60%) relative to the densities recorded from the protected site at the start of reserve protection while no detectable change was recorded at the sites open to fishing. At the 3rd island site grouper numbers declined in both the protected and control areas. This was associated with an episode of severe coral bleaching which impacted on both the protected and control sites. In all three cases the numbers of groupers in the protected areas increased relative to the control areas over the 1.5 to 2 year period. There are two messages here. Firstly the reserves rapidly generated detectable and substantial benefits through increased grouper densities. Secondly when a natural event of habitat change (severe coral bleaching) impacted on grouper numbers the experimental design allowed natural events to be separated from fishing effects.

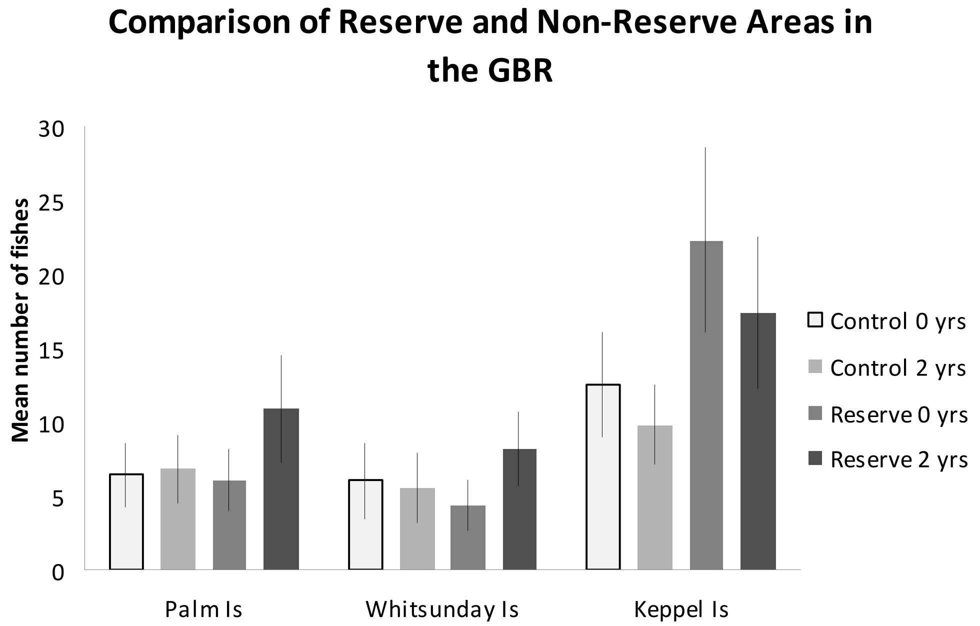

Figure 38: Mean number of groupers of the genus *Plectropomus* 1000m^{-2} in a system of marine reserves protected from fishing with equivalent control areas open to fishing over a two year period at three island groups in the Great Barrier Reef Marine Park. Data from Russ et al (2008).

In current best-practice systems operating on the Australian Great Barrier Reef and off the coast of California, USA, 30% of the suitable habitat is now included in non-fishing reserves. Those systems have expanded to that level over periods of several decades following intial establishment of small reserves. On these grounds we advocated the establishment of at least 3 no-fishing marine protected areas on the northern and western coasts of the island with adjacent control areas of similar dimensions. The minimal linear dimension for each reserve area should be 1 km, preferably 2 km, extending from MLW 100m seaward. Although the reserve size advocated is relatively small compared to those monitored in the Caribbean and the Indo-Pacific the most realistic approach is to commence with smaller reserves, monitor these over two years to assess their effects and expand their scope if positive results are obtained. Reserves should be established in places that are easy to monitor and visible to the public eye as publicity helps policing.

Two additional aspects of concern:

Deep water populations as a sustainable resource on St Helena: Most of the current fishery on St. Helena targets groupers between 30-50m. This is well beyond the depths (5-20m) over which the diving survey (which revealed evidence of fishing impacts) took place. If the fishery operates at a deeper level to what extent can the differences in abundance and size structure be attributed to fishing pressure? Firstly almost all reef fisheries initially start in shallow water and gradually move deeper in order to maintain a good catch return. It is possible that the patterns recorded from shallow water represent the historical impacts of fishing episodes in shallow water augmented by continued recreational and subsistence fishing in areas close to Jamestown.

A more important aspect of the deeper water fishery is that not only is increased effort required to harvest groupers from deeper water but the return will be less than that obtained from shallow water fishing Due to the difference in condition the return by weight for a hundred 50 cm grouper harvested from deep water (220 kg) will be 18% less than that obtained from shallow water (267 kg). Moreover the difference is likely to be greater from a fishery perspective as there will be greater proportional loss from muscle tissue (the fillets) than the skeletal system or viscera with depth. In addition due to the slower growth rate recorded from deeper water groupers it would take 3 years longer for deep water groupers to reach 440mm (the average catch size) compared to those from shallow water. At present we have no way of estimating the abundances of groupers at depths great than 20m but it is clear that the returns to fishery in terms of weight of landed groupers would be greater from shallow as opposed to deeper water.

Spawning behaviour: We are largely ignorant of the spawning behaviour of groupers on both islands, however it is a certainty that some form of aggregate spawning occurs (Tables 5 & 6). Groupers are most vulnerable to fishing during periods of aggregation for spawning. Investigation of spawning behaviour is a priority for the management of the fishery as targeting spawning aggregations invariably leads to rapid declines in grouper fisheries (Sadovy 2007). A common pattern among reef fishes is for spawning seasons to be shorter at higher-latitude sites (Robertson 1991). In that case we would expect the St Helena grouper population to have a shorter spawning season than the Ascension population. Indeed, the fact that we found ripe females at Ascension but not at St Helena supports the existence of such a latitudinal pattern. A shorter spawning season by a species that aggregates to spawn could increase its susceptibility to overfishing. Hence it is essential to establish the basic spawning biology of grouper at both St Helena and Ascension.

Recommendations

Given the evidence of fishing impacts on the St Helena grouper population we make the following recommendations.

- It is anticipated that fishing pressure will increase following air access to St Helena. In the face of evidence of current fishing impacts no increase in the catch rates of groupers in the commercial fishery be permitted.
- That total catch rates of groupers be recorded on a monthly basis with monitoring of a subsample for size and weight so that any changes in the average size of harvested groupers over time would be detected. In addition it is recommended that a sample of 100 otoliths covering the fished size range of grouper be collected on an annual basis.
- A system of a minimum of 3 no-fishing reserves be established, with each reserve including at least one km of coastline and extending seawards to the 100m depth profile, these reserves to be established on the north and west coasts of the island. These reserves and adjacent control (fished) areas with similar dimensions be monitored thereafter on an annual basis for grouper abundance and size structure, to assess their effects and provide such information to both fishers and regulators.

- Given the fact that most groupers form spawning aggregations it is also recommended that a program to determine the nature, location, seasonality and frequency of spawning in St Helena groupers be instituted as a part of a management plan for this species.
- A minimum size limit of 35 cm total length, 1 kg weight be imposed to enable most females to reach 6 years of age and live through at least one spawning season. This could be accomplished through a combination of (i) rejection of smaller fish by the fish factory and (ii) experimental fishing to determine the minimum hook size that largely eliminates hooking of fish smaller than that size by commercial fishers.
- Divide coastline into 1 km blocks to determine the geography of the intensity of fishing around the entire island. This would help determine overall levels of fishing intensity and identify natural reserves (heavy weather zones) and assist in the planning of the disposition of reserves

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