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Habitat of juvenile Caribbean reef sharks, *Carcharhinus perezi*, at two oceanic insular marine protected areas in the southwestern Atlantic Ocean: Fernando de Noronha Archipelago and Atol das Rocas, Brazil

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Abstract

Habitat of juvenile Caribbean reef sharks, *Carcharhinus perezi* (Carcharhinidae), was identified using fishing surveys and capture of immature specimens at two Brazilian insular sites in the southwestern Atlantic Ocean, Fernando de Noronha Archipelago and Atol das Rocas. Standardized sampling at Fernando de Noronha indicated that parturition occurred from February to April and that a wide depth-range (at least 5–30 m) along the insular shelf was used by immature sharks throughout the year. The catch-per-unit effort of *C. perezi* was significantly higher inside than outside a marine protected area at this location, suggesting that these sharks are more common in parts of the reef least disturbed by human activities. More limited sampling at Atol das Rocas suggested that juvenile *C. perezi* occurred at similar depths and utilized similar substrate as sharks at Fernando de Noronha. These findings suggest that successful conservation and management of this economically important, protected species will need to include conservation of habitat around insular reef systems.
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Keywords: Caribbean reef shark; Juvenile habitat; Nursery area; Parturition; Reproduction; Marine protected area

1. Introduction

The Caribbean reef shark, *Carcharhinus perezi*, is among the most common top-predators associated with tropical reef ecosystems of the western Atlantic Ocean (Compagno, 1984). Endemic to this region, it ranges from North Carolina, Bermuda, and the east coast of Florida to southern Brazil, including the northern Gulf of Mexico and the Antilles (Garrick, 1982; Compagno, 1984; Jensen et al., 1995). *C. perezi* is exploited by fishers for its meat and fins (Bonfil, 1997; Chan and Shing, 1999), and has become the main species of shark-feeding ecotourism activities in the Bahamas and Caribbean (Compagno, 2002), generating important benefits for local economies. The Caribbean reef shark is a prohibited species that cannot be taken in U.S. federal waters (NMFS, 1999), and remains one of the least studied carcharhinid sharks. There are very few fisheries or demographic data for this species and management is generally lacking throughout much of its range (Castro et al., 1999). As with many other large sharks, there are concerns that the K-selected life-history strategy and reef habitat association of adults may make *C. perezi* highly susceptible to over-exploitation (Camhi et al., 1998; Musick et al., 2000), potentially threatening a burgeoning and otherwise likely sustainable ecotourism industry that generates local-community economic benefits in many developing nations of the tropical western Atlantic. Additionally, recent studies have indicated that a decline in the population of large apex predators (specifically including *C. perezi*) may have extensive effects on the ecological functioning of coral reef ecosystems (Bascompte et al., 2005).

An understanding of the location and characteristics of habitats utilized by juvenile sharks is a priority for effective conservation and fisheries management (Castro, 1993; NMFS, 1999).

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Cortes (2002) has suggested that enhancing survival of juvenile sharks is likely a critical step in recovering and sustaining exploited shark populations. Although efforts to locate and characterize habitat for juvenile sharks have increased, especially in large estuaries and along continental coastlines (Castro, 1993; Simpfendorfer and Milward, 1993; Camhi et al., 1998; Van der Molen and Caille, 2001; Heupel and Hueter, 2002), the habitat for *C. perezi* juveniles has only been described in Belize, Central America (Pikitch et al., 2005). Since reef-dwelling sharks of the tropical Pacific are known to breed in insular areas (Wetherbee et al., 1996, 1997), the limited records of habitat for *C. perezi* juveniles may be attributable to limited surveying of the elasmobranchs around insular areas of the tropical western Atlantic.

A report of a gravid female with near-term embryos (Gadig et al., 1996) and underwater observations of juvenile *C. perezi* (Sazima and Moura, 2000) in insular areas off northeastern Brazil suggest the presence of habitat for juveniles of this species in this region. This is also suggested by landings records from a shark fishery operating from 1992 to 1997 at the Fernando de Noronha Archipelago located off the coast of northeastern Brazil. Seventy percent of the archipelago's coastline was established as a marine protected area (MPA) in 1988 (Maida and Ferreira, 1997), and the shark fishery operating just outside the protected areas occasionally landed gravid *C. perezi*. Eighteen months of landings data included 498 *C. perezi*, representing 58% of the total shark catch (RCG, unpublished data). This fishery closed in 1997 after it became unprofitable relative to alternative marine ecotourism opportunities.

A better understanding of habitat use by juvenile *C. perezi* at Fernando de Noronha and elsewhere may provide important information for the conservation and management of this species, and broaden knowledge of the utilization of oceanic insular habitats by sharks. Here, we report on using standardized fishing surveys at two insular sites located in Brazilian waters, Fernando de Noronha and Atol das Rocas, to obtain information on use of these habitats by juvenile Caribbean reef sharks in terms of: (1) time of parturition, (2) seasonal patterns of juvenile abundance, (3) spatial distribution of juveniles around the archipelago in relation to depth and management zones, and (4) demographic population structure.

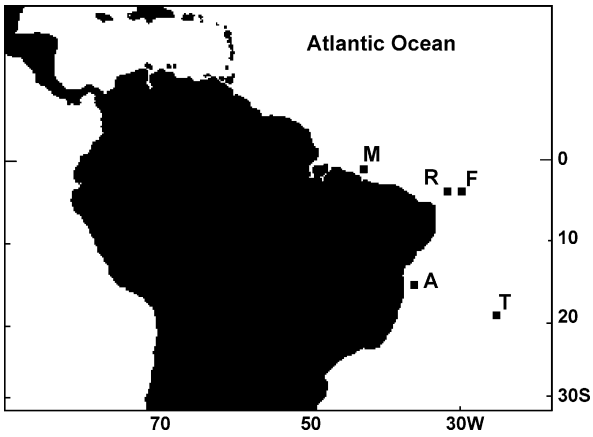

Fig. 1. Location of Fernando de Noronha Archipelago (F) and Atol das Rocas (R), distant 345 and 267 km, respectively, from the Brazilian northeastern coast. Other localities in the southwestern Atlantic Ocean where the occurrence of neonate or juvenile *Carcharhinus perezi* has been recorded: Parcel Manoel Luis, 86 km from the northern coast (M); Abrolhos Archipelago, 65 km from the northeastern coast (A); Trindade Island, 1160 km from the southeastern coast (T).

2. Methods

2.1. Study site

Fernando de Noronha Archipelago is located 345 km off the northeastern coast of Brazil, at 03° 51′S; 32°25′W, and consists of one large island and 19 small adjacent islets, totalling 26 km^2 (Figs. 1 and 4). About 70% of the main island and the coastline from shore to the 50 m isobath constitute a marine protected area (MPA) established in 1988. A large section, including the remaining portion of the main island to the 50 m isobath, is an Environmental Protection Area (EPA) designated for sustainable use where fishing and boat traffic are allowed. The climate is tropical with an average air temperature of 25.4 °C. Mean water temperature is 26–27 °C and mean salinity is 36‰ (Maida and Ferreira, 1997). Atol das Rocas is a marine protected area located 148 km to the west of Fernando de Noronha Archipelago at 03°52′S; 33°49′W (Figs. 1 and 2), and consists of an ellipsoid, calcareous algal reef covering approximately 5.5 km^2 with cli-

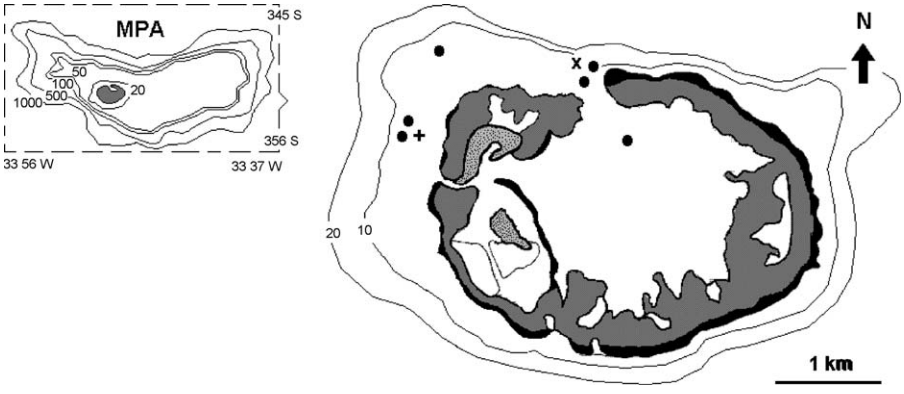

Fig. 2. Distribution of handline fishing sites and CPUE at Atol das Rocas. CPUE (sharks/h): (●) 0.3–0.5; (+) 0.5–1; (×) 1–2. Inset: dashed lines indicate the MPA limits that encompass the whole atoll shelf.

mate and sea conditions similar to the archipelago (Maida and Ferreira, 1997).

2.2. Fishing surveys

Bottom-set longlines (10 hooks) baited with tuna, *Thunnus* spp., and set for 1 h, were used in a preliminary survey of Fernando de Noronha in March and September 1999 (3% of total fishing effort). Several longline captured *C. perezi* were noticeably fatigued upon retrieval of the gear. Therefore to reduce capture stress on the sharks, all subsequent (97%) fishing effort at this location between March 2000 and February 2003 was conducted using single-hook handlines baited with similar sized pieces of grouper, *Cephalopholis fulva*, or jacks, *Carangoides* and *Caranx* spp. This handline method allowed quick recovery and release of captured sharks. From March 2001 to February 2003 fishing sites were randomly selected around the archipelago, and their geographic positions recorded with a handheld GPS (Garmin, Kansas). At each of these sites, two standard-sized, 14 0/0 J-hooks were fished simultaneously from a small skiff and fishing effort was calculated by recording the time the first hook was deployed to the time the last hook was removed. Catch per unit effort [CPUE = (sharks captured/h fishing)] was calculated at each site. The same fishing gear and methods were also employed in February-March 2000 at Atol das Rocas. A Student's *t*-test was used to compare mean CPUE between EPA and MPA fishing sites at Fernando de Noronha. In one case at Fernando de Noronha, a large (presumed adult female) *C. perezi* was sighted during standard sampling efforts and a non-standard, heavy handline with a 16 0/0 J-hook was deployed to catch it. This capture was not included in the CPUE analysis.

Immature sharks were categorized into their approximate early life-stage, defined on the basis of external morphology through a modification of Merson and Pratt (2001) and Stehmann's (2002) terminologies: "Neonates" included sharks with an open umbilicus; "Young-of-the-year" (age 0–1) were individuals with healed and visible umbilical scars; "Juveniles" (≥1 year old) were individuals with no visible umbilical scar and were under published size-at-maturity total lengths (152–168 cm for males and >200 cm for females; Compagno, 1984) Although rarely captured, presumed mature sharks were defined on the basis of length measurements, using size-at-maturity from Compagno (1984). Captured sharks were brought alongside the boat, examined for an umbilical scar, measured (fork length [FL] and total length [TL]), sexed, and marked with a nylon dart tag (Hallprint, South Australia) while in the water. All lengths reported in this study refer to TL unless otherwise noted. After the above work-up, sharks were quickly removed from the water, placed in a bag or on a stretcher and weighed with a handheld scale, and usually released within 5 min of being caught. To supplement data from Fernando de Noronha and Atol das Rocas, Brazilian university and museum collections were surveyed for immature *C. perezi* to identify other areas in the southwestern Atlantic where juveniles occurred.

3. Results

From 1999 to 2003, a total of 438.5 h of fishing effort was conducted in 182 sites around Fernando de Noronha Archipelago, focusing on its calmer leeward side, which was accessible and sampled during all months of the year (with the exception of December each year, when research activities were suspended). In Atol das Rocas, 34 h of fishing effort were expended in four sites along its calmer western reef front during February and March, 2000 (Fig. 2).

In Fernando de Noronha a total of 143 *C. perezi*, including 33 neonates, 56 young-of-the year, 51 juveniles, 2 presumed adult males (both captured on longlines), and one presumed adult female were captured along the insular shelf. Sampling at Atol das Rocas yielded 5 neonates (72–85 cm) and 11 young-of-the-year (up to 90 cm) specimens. A total of 140 *C. perezi* from Fernando de Noronha were sexed (82 females and 58 males), and specimens ranged in length from 71 to 224 cm (mean = 97.1 ± 22.7 cm), with males from 74 to 162 cm and females from 71 to 224 cm (Fig. 3A). Immature *C. perezi* were captured throughout the year, with the exception of December when there was no sampling effort. All 38 neonates from Fernando de Noronha and Atol das Rocas were captured between February and April, with peak CPUE at Fernando de Noronha in March (Table 1 and Fig. 3B). Neonates, young-of-the-year and

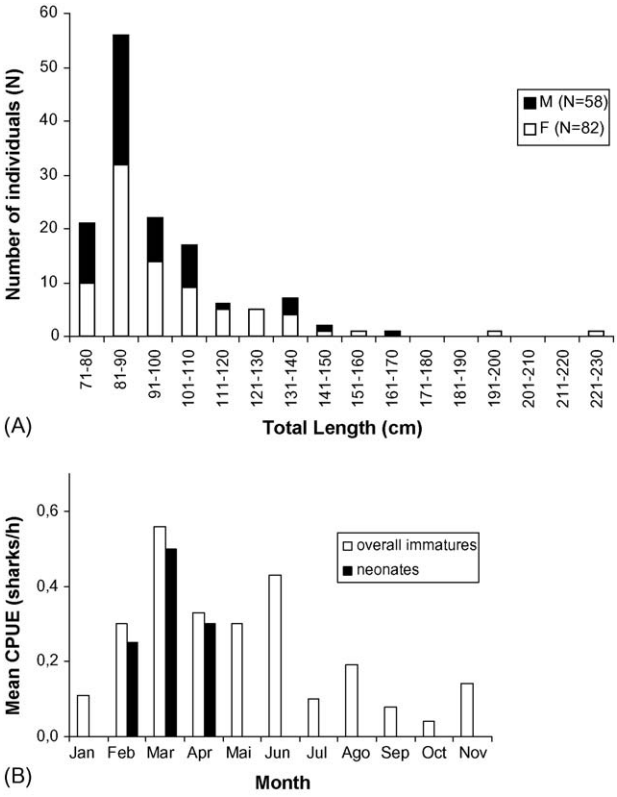

Fig. 3. (A) Length frequency distribution of *C. perezi* caught at Fernando de Noronha Archipelago between March 1999 and February 2003 ($N = 140$) solid bars = males; open bars = females. (B) Mean catch-per-unit effort (CPUE) of neonate (solid bars) and all immature (open bars) by month at depths of 5–30 m along the insular shelf of Fernando de Noronha.

Table 1
Mean effort per month (CPUE = number of sharks captured/h fishing) within the Fernando de Noronha Archipelago management areas from 2001 to 2003

	CPUE (total number of sharks)										
	January	February	March	April	May	June	July	August	September	October	November
EPA	0.04 (1)	0.08 (6)	0.10 (10)	0.16 (13)	0.05 (2)	0.0 (0)	0.0 (0)	0.04 (1)	0.0 (0)	0.0 (0)	0.0 (0)
MPA	0.06 (3)	0.20 (20)	0.25 (19)	0.17 (16)	0.21 (7)	0.43 (2)	0.06 (2)	0.15 (4)	0.08 (4)	0.04 (2)	0.14 (2)

EPA: environmental protection area; MPA: marine protected area. Numbers in parenthesis indicate the total number of sharks caught.

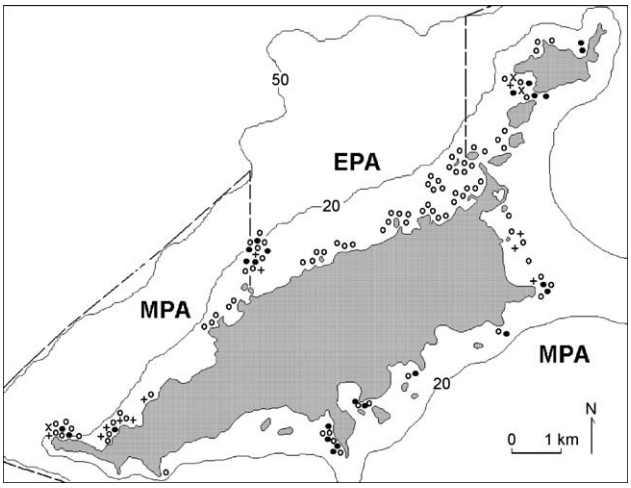

Fig. 4. Distribution of handline fishing sites and CPUE at Fernando de Noronha Archipelago. CPUE (sharks/h): (◯) 0; (●) 0–0.5; (+) 0.5–1; (×) 1–2. EPA: Environmental Protection Area. MPA: marine protected area. Dashed lines indicate boundary of the MPA.

juveniles were captured both at the leeward and windward sides of the archipelago at depths between 5 and 30 m (62% of captures between 10 and 20 m) over hard-bottom substrates. Five small *C. perezi* approximately 70–80 cm were observed chasing baitfish schools inside an intertidal pool at a depth of less than 40 cm in February 2003.

Standardized handline fishing at 148 sites around Fernando de Noronha between March 2001 and February 2003 resulted in the capture of *C. perezi* at 20.3% of the sites, with the CPUE per site ranging from 0 to 1.2 sharks/h (Fig. 4). Fishing effort was distributed among 69 sites in the EPA and 79 sites in the MPA. Mean CPUE in sites within the unprotected EPA (0.03 ± 0.12S.D.) was significantly lower than in the MPA (0.16 ± 0.30) (*t*-test, $P < 0.05$) (Table 1). When considering only the more accessible leeward side, fishing effort was distributed among 69 sites in the EPA and 50 sites in the MPA. Again, mean CPUE within the EPA (0.03 ± 0.12) was significantly lower than in the MPA (0.21 ± 0.33) (*t*-test, $P < 0.05$). All shark catches in the EPA were within 1-km of its western boundary with the MPA.

Examination of a number of Brazilian ichthyology collections revealed specimens of neonate and juvenile *C. perezi* from three insular locations[1] (see Fig. 1 for location): (1) one neonate female (89 cm) and four unsexed young-of-the-year sharks captured at Abrolhos Archipelago between 1997 and 1999, (2) three females and one male (81.5–94.5 cm) captured in 1996 at Parcel Manoel Luis, and (3) one neonate male (84.5 cm) and a juvenile female (142 cm) captured at Trindade Island in 1996 (Motta et al., 1999).

4. Discussion

Capture of neonate and young-of-the-year *C. perezi* at Fernando de Noronha Archipelago and Atol das Rocas coupled with examination of museum collections all indicate that juveniles of this species utilize nearshore waters of oceanic insular areas during their first few years of life. The importance of oceanic insular shelves for juvenile *C. perezi* is further supported by the rarity of captures of this species, particularly of small juveniles, in fisheries operating off Brazilian mainland waters or in the open ocean (Amorim et al., 1998; Gadig et al., 2000; Hazin et al., 1990, 2000). A habitat is considered a nursery if its contribution to the production of individuals that recruit to adult populations is greater than production from other habitats in which juveniles occur (Beck et al., 2001). However, since it is difficult to directly compare the recruitment potential of different shark habitats, the term "nursery area" is often used in the literature to describe geographically discrete parts of the species range where the gravid females deliver their young, and where the young spend their first weeks, months or years (Castro, 1993; Simpfendorfer and Milward, 1993; Camhi et al., 1998; Van der Molen and Caille, 2001; Heupel and Hueter, 2002). Although this type of presence/absence information is considered by some authors to be the lowest tier of knowledge for defining nursery areas (Beck et al., 2001), it is still an important first step towards defining and preserving essential habitat required for effective shark conservation and fisheries management. To acknowledge the difference between the strict, ecological definition of a nursery and simple presence/absence data for juveniles within a habitat, we suggest that these oceanic insular areas are currently best categorized as "juvenile habitat" for *C. perezi*, until further investigation confirms that they meet the strict ecological definition of a nursery area (Beck et al., 2001). Regardless of how these areas are defined, successful conservation of *C. perezi* in the southwestern Atlantic will require fisheries management and habitat conservation directed toward these insular reef-systems.

This study demonstrates that parturition takes place at Atol das Rocas and Fernando de Noronha at the end of the dry season (February to possibly late April) and that immature *C. perezi* are present within Fernando de Noronha Archipelago's insular shelf throughout most, if not all, of the year. This year-round

[1] Voucher specimens examined are deposited in the fish collections of Museu de Zoologia of Universidade de São Paulo (MZUSP) and Museu de Zoologia of Universidade Estadual de Campinas (ZUEC): MZUSP 53007, 53077, 60784, 60785, ZUEC 4980.

presence contrasts with results for juvenile sharks of subtropical and temperate regions, which often seasonally migrate from primary (i.e. where parturition takes place) to secondary nursery areas/juvenile habitat in geographically discrete locations (Castro, 1993; Merson and Pratt, 2001; Heupel and Hueter, 2002). The spatio-temporal overlap of multiple juvenile size classes, the year-round use of Fernando de Noronha, and the multi-year site-fidelity of juveniles tracked in a parallel telemetry study (Garla et al., 2006) all indicate that a seasonal migration from "primary" to "secondary" juvenile habitat does not occur in *C. perezi* at this site. This longer-term residency may be due to the relative remoteness of this reef or the comparatively minor seasonal environmental changes that occur in tropical insular reefs like Fernando de Noronha, particularly with regard to water temperature (Maida and Ferreira, 1997).

Juvenile *C. perezi* frequent a wide depth range at Fernando de Noronha, from pools in the intertidal zone to reef areas of up to 30 m depth, and were not uniformly distributed along the coastline. Locations with high CPUE were concentrated in particular areas within the MPA or very near its boundary, and only a few *C. perezi* were captured deep inside the EPA.

Juvenile *C. perezi* continue to be landed by fishers at Fernando de Noronha, mainly from Dois Irmaos Reef near the western boundary of the MPA. These results, coupled with data from our related automated telemetry study where none of 14 sharks carrying acoustic transmitters were detected within the EPA over a year-long period (Garla et al., 2006), suggest that immature *C. perezi* were generally uncommon within the EPA. The low abundance of *C. perezi* within this area may be a consequence of increasing anthropogenic disturbance over the past 4 years, especially boat traffic associated with the archipelago's main port, which may inhibit the shark's presence within the EPA. Another possibility is that the concentrated fishing effort that focused within the EPA following the establishment of the no-take MPA may have severely depleted juvenile *C. perezi* and/or their major prey species within this zone. Signs of ecological stress in the EPA have recently emerged as a huge increase in abundance of an urchin species (*Tripneustes ventricosus*), which has often been implicated as an effect of overfishing in marine systems (Roberts, 1995; McClanahan, 1997; Ruttenberg, 2001).

In conclusion, this study indicates that the early life-history of *C. perezi* is especially associated with the nearshore waters of several oceanic insular areas in the southwestern Atlantic. Parturition takes place at the end of the dry season and juveniles are year-round residents of the coast occupying depths from the intertidal zone to at least 30 m. Although research into the efficacy of MPA's for shark fisheries management and conservation is in its infancy (Chapman et al., 2005; Garla et al., 2006), catch data from Fernando de Noronha suggest that protected areas may support significant populations of juvenile reef sharks and can provide spillover of individuals to neighboring fisheries.

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