Caribbean Journal of Science, Vol. 46, No. 1, 29-38, 2010

Preliminary assessment of a possible lemon shark nursery in the Turks & Caicos Islands, British West Indies

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Abstract.—Juvenile lemon sharks, *Negaprion brevirostris*, were captured at shallow-water sites around South Caicos over a 16 month period. Capture and recapture rates were relatively low, and residency time appeared to be short, possibly indicating that South Caicos is just part of a larger nursery area. Nonetheless, the presence of neonates with fresh umbilical scars confirms that parturition did take place within the study area. It is suggested that the juvenile sharks utilise a larger activity space than in previously studied areas, and that this is facilitated by strong tidal movements over a large expanse of contiguous habitat.

Keywords.—Elasmobranch, nursery, gillnet, mangrove, tagging.

Introduction

The lemon shark *Negaprion brevirostris* is a large coastal shark with complex life-history traits, and is found in coastal waters of the western Atlantic, eastern North Atlantic, and eastern Pacific oceans (Compagno 1984). The species is exploited by commercial fisheries in the western Atlantic and eastern Pacific and is regarded as near-threatened (IUCN 2008). Like many carcharhinid species, female lemon sharks move inshore to specific pupping grounds to give birth, and the newborn sharks then utilise these shallow waters, where they form an important component of the ecosystem (Gruber 1982; Cortés and Gruber 1990).

Fisheries assessment and management should focus on the life stages being exploited, but should also include information on stages which have not yet been recruited to the fishery, and on habitat important to their survival (NMFS 2006). Therefore, studies on lemon shark nursery grounds are important for the conservation of the species. However, although a number of investigators have undertaken in-depth research on the biology and ecology of juvenile lemon sharks (e.g. Banner 1968; Gruber 1982; Schmidt 1986; Gruber et al. 1988; Cortés and Gruber 1990; Morrissey and Gruber 1993; Correan et al. 1995; Gruber et al. 2001; Freitas et al. 2006; Caviezel 2007; Wetherbee et al. 2007; DeAngelis et al. 2008), most studies have been limited to a small number of locations, which include southern Florida, Bimini Island in the Bahamas, and Atol das Rocas off the coast of Brazil. Despite its broad distribution, little is known about habitat utilisation by juvenile lemon sharks beyond these established study areas (Reyier et al. 2008).

Juvenile lemon sharks can be sighted close to the shore of South Caicos in the Turks & Caicos Islands, suggesting that this might be another nursery area for the species. The coastal areas of the island are largely undeveloped and most commercial fishing activity takes place further out on the Bank, focusing almost entirely on queen conch *Strombus gigas* and spiny lobster *Panulirus argus* (Vaughan 2004). The tourism industry within the Turks and Caicos Islands has been largely confined to the islands of Providencialis and Grand Turk, but the expansion of the industry into South Caicos threatens to alter the local marine environment through shore-based construction and increased recreational utilisation of its coastal waters. Recent studies have found evidence of negative anthropogenic impacts on local marine life (Schelten et al. 2006; Goreau et al. 2008). The present study was undertaken to investigate lemon shark utilization of the shallow waters around South Caicos so as to provide baseline information on lemon shark occurrence.

Materials and Methods

Study area

The Turks & Caicos Islands lie at the southernmost end of the Bahamian Archipelago, where they form two island groups: the Caicos Islands and the Turks Islands. The Caicos Islands is the larger of the two groups and consists of eight inhabited islands and a number of associated cays (Proctor and Fleming 1999). The main islands form a perimeter along the western, northern and eastern margins of the Caicos Bank, which ends abruptly and gives way to deep (> 2000 m) waters on all sides. The interior of the bank forms a shallow (circa 1 – 5 m deep) sandy-bottom environment which experiences a tidal range of *ca.* 1.5 m (AH, pers. obs.) and is host to a variety of vertebrate and invertebrate fisheries (Tewfick and Bene 2004; Vaughan 2004; Lockhart et al. 2006). The island of South Caicos is of particular interest as it is surrounded by a diverse array of habitat types and is home to most of the fishing industry. To the east of the island there is deep ocean; seagrass beds are sheltered by the reef crest in the south (East Bay); shallow sandy areas fringed with mangrove can be found in the west (John Dean Bay, Man-O-War Bush, Moxy Bush); and a sheltered sound penetrates the north-western coast (Bell Sound) (Figure 1).

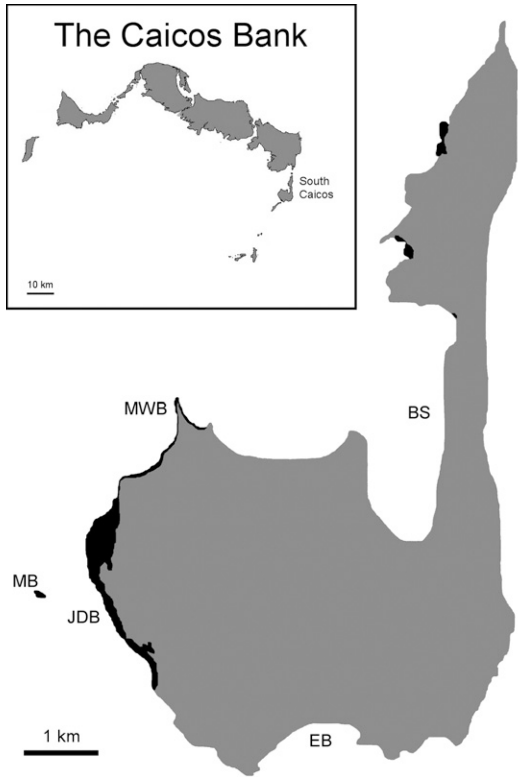

Fig. 1. Map of South Caicos showing study site locations: EB = East Bay, BS = Bell Sound, JDB = John Dean Bay, MB = Moxy Bush, MWB = Man-O-War Bush. Blackened areas indicate mangroves.

Data collection and analyses

Sampling was conducted between March 2005 and July 2006, and the primary study sites were chosen so as to encompass all of the main shallow-water habitat types around South Caicos (Figure 1). The Caicos Bank experiences a diurnal tide, but due to its shallow nature many parts of the Bank are submerged for only the latter part of each flood tide and the first part of each ebb tide. Most study sites, with the exception of Bell Sound, were therefore alternately exposed and submerged twice a day.

Sampling was conducted with two monofilament gillnets which were set in series, perpendicular to the shore, 1 - 3 times per week. Each net measured 50 m in length, 2 m in depth and had a square-mesh of 6.5 cm. The nets were generally set so as to experience one full tidal cycle (approximately three hours on the flood tide and three hours on the ebb tide at the shallow sites). On all other occasions the nets were set so as to experience an equal amount of flood and ebb tide in each sampling session. In all cases, sampling centred on the first high tide to occur after sunrise. When a sampling session commenced prior to sunrise, or concluded after sunset, the duration of daylight/night sampling was noted. Once the nets were set, water depth, temperature and salinity were measured hourly at the mid-point of the nets. The sampling personnel always remained close to the net – either on shore, or aboard a small skiff anchored near the end of the net. Captures were easily observed (visually and acoustically), and sharks were removed from the net immediately afterwards. Nonetheless, the nets were patrolled every 20 minutes to check for captures which may have gone unnoticed.

Once caught, sharks were removed from the net, measured to the nearest cm (precaudal, fork and total lengths) with the caudal fin aligned along the axis of the body, and weighed to the nearest 100 g with a spring balance. All length values reported here are total length (TL), and all means are reported ± standard error. The umbilical scar was identified as being open, closed or fully healed, and gender was assigned based on the presence or absence of claspers. A T-bar anchor tag (Floy Tag & Mfg Inc.) was inserted at the base of the first dorsal fin, after which the shark was moved through the water and released once fully revived. As the same gear configuration was used throughout the study, catch per unit effort (CPUE) was calculated as the number of sharks caught per hour of fishing. Seasons were designated as follows: spring (March, April, May), summer (June, July, August), autumn (September, October, November), winter (December, January, February).

The size frequency distribution of captured lemon sharks was tested for normality with the Anderson-Darling test, and the mean size of male and female sharks was compared with Student's t-test. The effects of moon-phase and photoperiod (day/night) on CPUE were assessed with the Kruskal-Wallis test and Mann-Whitney U-test respectively, while the relationship between CPUE and salinity/water temperature was investigated with the Spearman rank correlation in both cases. The relative condition of the sharks was determined using the equation $CF = W/L^b$ (King 1995), where CF is condition factor, W and L are the total weight and total length of the shark respectively, and b is the exponent from the length-weight relationship for the sample.

Results

Different depth ranges were recorded at the various study sites (Table 1), but the differences in mean depth were not significant (ANOVA, $n = 5$, $P > 0.05$). A total of 150 elasmobranch captures was made during 470 hours of sampling, over the course of the study, and comprised of 128 lemon sharks, 16 blacknose sharks *Carcharhinus acronotus*, three bonnethead sharks *Sphyrna tiburo*, two southern stingrays *Dasyatis americana* and one nurse shark *Ginglymostoma cirratum*. Non-elasmobranch captures occurred occasionally, consisting primarily of yellow fin mojarra *Gerres cinereus* and bonefish *Albula vulpes*. The mangrove-fringed areas west of the island (Man-O-War Bush, Moxy Bush and John Dean Bay) had the highest lemon shark catch rates, while the areas lacking mangroves had notably lower catches (Figure 2). When viewed from a

Table 1. Overview of study sites where gillnets were used to capture juvenile lemon sharks around South Caicos,

Location	Description	Depth range	Mean depth ± standard error
East Bay	Seagrass beds, fringed by sandy and rocky shore	4 – 130 cm	40.5 ± 2.9 cm
Bell Sound	Hard substrate, rocky shore, few mangroves	9 – 92 cm	40.2 ± 3.7 cm
John Dean Bay	Soft substrate, dense fringing mangroves	0 – 77 cm	38.7 ± 1.9 cm
Moxy Bush	Isolated mangle	0 – 88 cm	35.5 ± 1.5 cm
Man-O-War Bush	Soft and hard substrate, fringing mangroves	12 – 88 cm	43.5 ± 2.7

seasonal perspective, CPUE was variable and displayed an inverse trend to that of temperature (Figure 3); however, neither temperature nor salinity was correlated with CPUE (Spearman rank correlation, n = 108, P > 0.05 in both cases). Analysis also failed to reveal any effect of moon-phase or photoperiod (day/night) on CPUE (Kruskal-Wallis test, n = 120, P > 0.05; Mann-Whitney U-test, n = 120, P > 0.05 respectively).

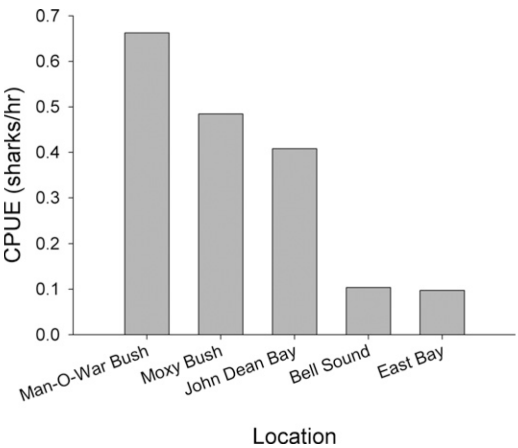

FIG. 2. Lemon shark catch per unit effort (CPUE) at different study sites around South Caicos.

Lemon sharks ranged in length from 60 - 125 cm, with a mean of 85.9 ± 1.2 cm. The size distribution was normal (Anderson-Darling test, n = 128, P > 0.05), and both sexes followed a similar size distribution pattern, although there was a more pronounced mode in the male distribution (Figure 4). Despite this, there was no difference in the mean size of male and female lemon sharks (t-test, n = 128, P > 0.05), and the overall sex ratio was 1.1:1 in favour of males. Most sharks had closed or fully healed umbilical scars; only five sharks captured during the latter half of June, all smaller than 66 cm, had open scars. In all five of the sharks, the scar exuded liquid when slight pressure was applied, indicating that the scars were fresh.

In relation to seasonality, significant differences in the size distribution of caught animals were observed (Figure 5). A positively skewed unimodal distribution was evident in spring, revolving around an 80 - 89 cm size-class mode. However, by summer this had shifted towards a bimodal distribution with a second peak occurring at the 60 - 69 cm

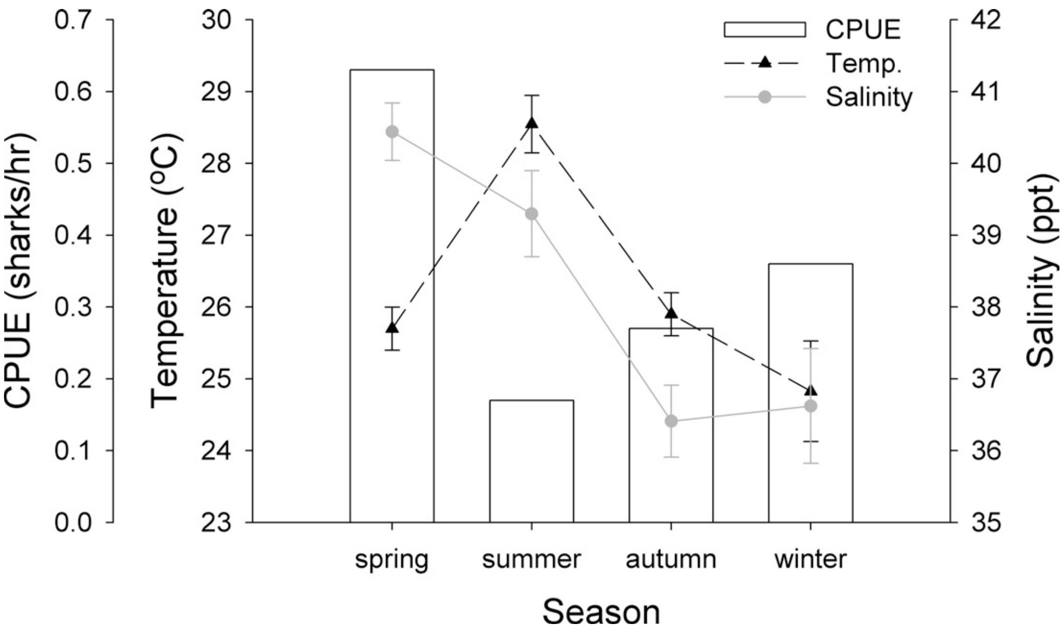

FIG. 3. Seasonal catch per unit effort, mean seasonal water temperature and mean seasonal salinity for shallow coastal waters around South Caicos during the present study.

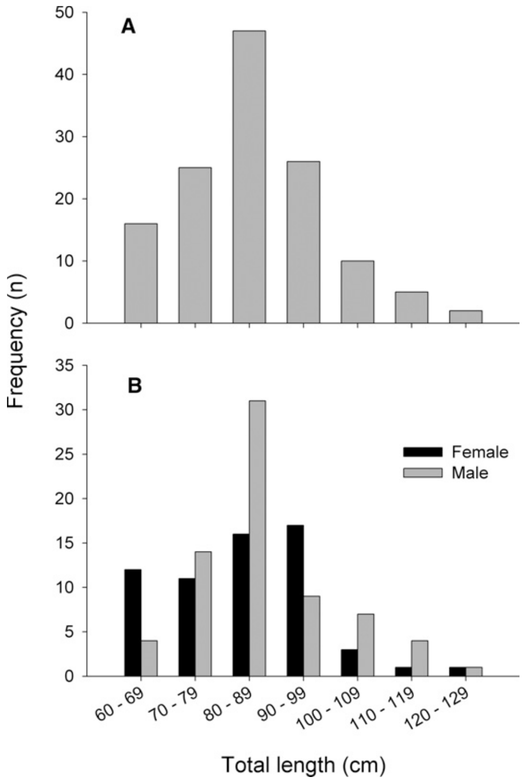

FIG. 4. Size distribution of lemon sharks from South Caicos: (a) sexes combined, (b) sexes separated.

size-class, indicating an influx of neonates. By autumn, the smallest size-class had disappeared, while a corresponding increase in the 70 - 79 cm size-class was observed, and by winter the size distribution was again unimodal. Moxy Bush, John Dean Bay and Man-O-War Bush all yielded broadly similar size distributions, with the exception that the largest size classes were absent from the latter. Bell Sound only yielded specimens smaller than 90 cm, primarily between 60 - 69 cm. In contrast, East Bay only yielded sharks larger than 80 cm (Figure 6).

Of the 128 lemon shark captures 28 were recaptures, giving a recapture rate of 21.9%. Fifteen of these recaptures were sharks that were only recaptured once, while four were double recaptures of two sharks at different times, and nine were triple recaptures of three different sharks. The maximum time at liberty was 202 days, while the maximum time at liberty between any two captures was 103 days. However, time at liberty was generally low, with a mean of 28.6 ± 5.5 days between captures, and a mean of 42.0 ± 11.2 days between initial capture and last recapture. Tag loss was evident in two other sharks, each of which had a clear puncture wound at the base of the first dorsal fin.

The majority of recaptures were made at the same site as the original capture. However, two of the sharks (96 cm and 86 cm TL) tagged in John Dean Bay were recaptured at Moxy Bush, one and ten days after their initial capture respectively. The former individual was captured for the second time 18 days later, again at Moxy Bush, and caught for the third time in John Dean Bay one month later. Another shark (87 cm TL), initially captured and tagged at Moxy Bush, was recaptured in John Dean Bay 15 days later.

All recaptures displayed positive growth, but only one shark was at liberty for a sufficient period of time to estimate the rate of growth, and this individual grew from 76 to 89 cm over 202 days, equating to an annual growth rate of 23.5 cm. Total weight ranged from 1.1 kg in a 62 cm shark to 9.4 kg in a 125 cm shark; mean weight was 3.4 ± 0.2 kg. The length-weight relationships were $y = 3E\text{-}06x^{3.098}$ for females ($R^2 = 0.916$), $y = 4E\text{-}06x^{3.048}$ for males ($R^2 = 0.923$), and $y = 3E\text{-}06x^{3.078}$ for the sexes combined ($R^2 = 0.918$). Data were log-transformed to test for differences in the slopes of the male and female length-weight equations, but no significant difference was found (t-test, n= 108, $P > 0.05$). The exponent from the combined equation was therefore used to calculate the condition factor (CF) for each shark. A Spearman-rank correlation determined that CF neither increased nor decreased with increasing TL (n = 108, $P > 0.05$). The possible impact of tagging on shark health was investigated by comparing CF at initial capture and at recapture, and analysis showed a mean decrease of 4.6 ± 2.6 %. The effect of the number of times a shark was captured on CF was also explored, but no relationship was found (Spearman rank correlation, n = 12, $P > 0.05$).

DISCUSSION

The lemon shark capture/recapture rate around South Caicos was low when

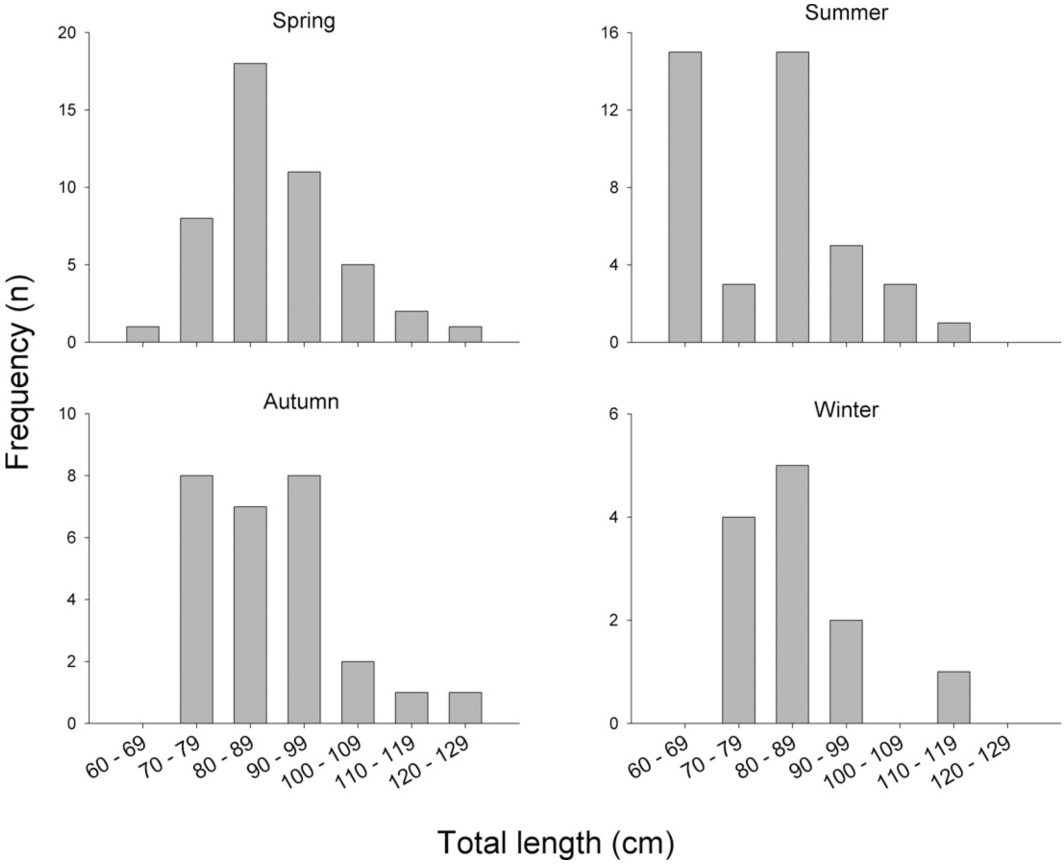

Fig. 5. Seasonal size distributions of lemon sharks from South Caicos.

compared to gillnet studies in Florida (Gruber 1982; Reyier et al. 2008), Bimini (Feldheim et al. 2002) and Atol das Rocas (Freitas et al. 2006). This could be indicative of a small resident population with high mortality and/or tag loss. Tag loss was clearly evident in the South Caicos sharks, but was confined to a very small number of animals, and it seems unlikely that recapture data were compromised in this regard. Mortality may have been high in the South Caicos sharks, as high rates of mortality have been observed in juvenile sharks previously (Manire and Gruber 1993; Heupel and Simpfendorfer 2002), but the fact that new, untagged sharks were encountered throughout the study suggests that additional factors were involved. A continual influx of new individuals, combined with the low rate of recapture, and limited time at liberty for recaptures, implies that the sharks had only a transient residency in the waters around South Caicos. Additionally, juvenile lemon sharks have been observed in adjacent areas – the shallow sand flats to the west, and along the mangrove-fringed coast of East Caicos to the north (A. C. Henderson, unpublished data). Therefore, it seems likely that the sharks encountered during the present study were only part of a larger, more dispersed population, which extended beyond the confines of the study area.

While usage of a large activity space would run contrary to the concept that juvenile sharks minimize their movements in order to conserve energy, some species have shown strong movement with tidal flow (Medved and Marshall 1983; Ackerman et al. 2000; Wetherbee and Rechisky 2000),

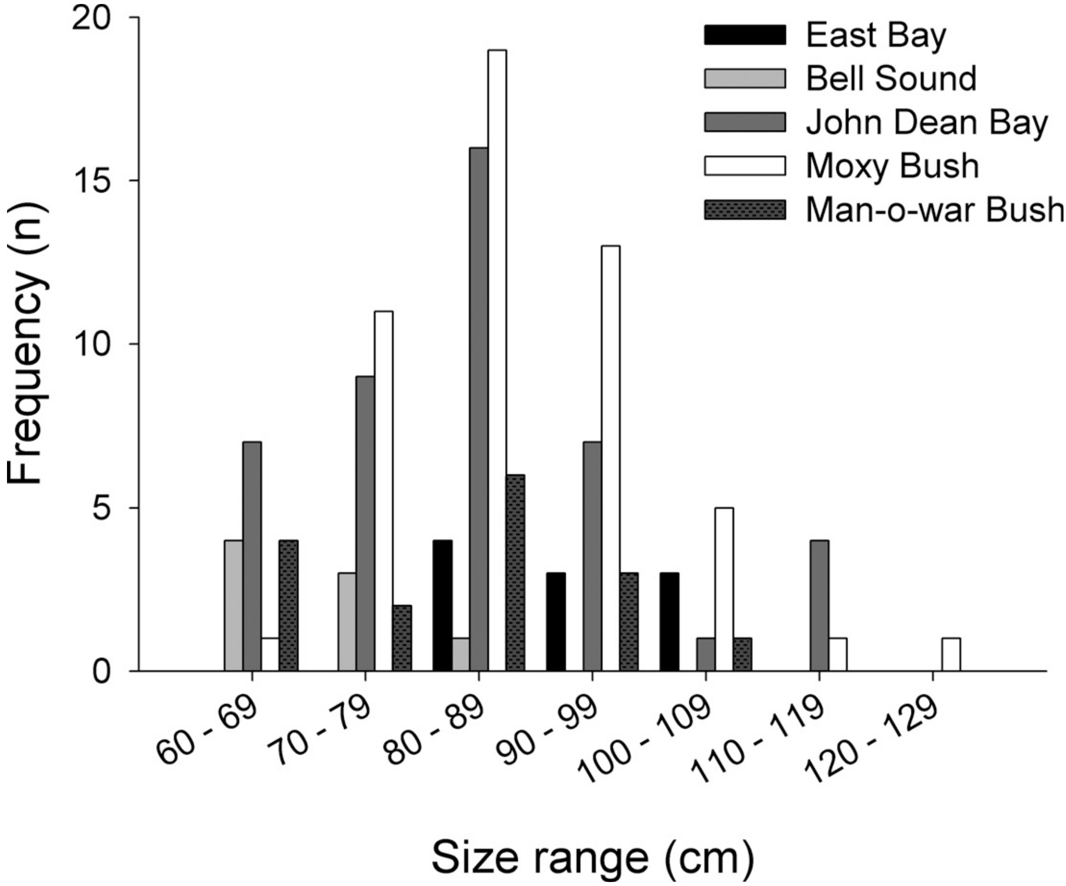

FIG. 6. Lemon shark size distributions from sampling areas around South Caicos.

and it has been suggested that this allows individuals to select specific habitats via tidal transport, thus conserving energy (Heupel and Simpfendorfer 2008). Additionally, although juvenile lemon sharks at Bimini, Atol das Rocas and the U.S. Virgin Islands remained site attached (Morrissey and Gruber 1993; Freitas et al. 2006; DeAngelis et al. 2008), those at Cape Canaveral in Florida displayed extensive movements (Reyier et al. 2008). The Caicos Bank experiences strong tidal currents and the sites with the highest CPUE in the present study (Man-O-War Bush, John Dean Bay and Moxy Bush) are all exposed to strong tidal movements, whereas the lowest CPUE sites (East Bay and Bell Sound) are more sheltered. Furthermore, the capture/recapture of sharks between Moxy Bush and John Dean Bay illustrates the mobility of the South Caicos sharks. These two locations are approximately 1 km apart, they are alternately upstream/downstream of each other depending on the tide (ebb or flood). While passive transport over parts of the Caicos Bank would provide juvenile lemon sharks with an extended forage base, utilisation of low-energy sheltered areas may be driven by predator avoidance rather than food availability (Heupel and Heuter 2002).

Environmental variables such as salinity and temperature have been related to shark movements (Grubbs et al. 2007; Heupel 2007; Reyier et al. 2008), although their degree of influence is sometimes unclear and may not be obvious in the presence of greater movement cues (Heupel and Simpfendorfer 2008). If shark movements on the Caicos

Bank were driven primarily by tidal movements, it would help explain the lack of any relationship between such variables and CPUE in the present study. However, variation in CPUE at South Caicos is consistent with some degree of seasonal shift in the sharks' spatial activities, and it seems likely that this would be driven by environmental cues, such as temperature, similar to the seasonal migratory behaviour of juvenile lemon sharks along the south-eastern coast of the United States (Reyier et al. 2008).

The term 'nursery' has been commonly applied to areas where juvenile sharks are recorded (Castro 1993; Holland et al. 1993; Constantini and Affronte 2003; Duncan and Holland 2006; Garla et al. 2006; DeAngelis et al. 2008), and its usage in the literature has been rather liberal (Heupel et al. 2007). The most recent definition suggests that, for an area to be identified as a nursery, sharks must be more commonly encountered there than in other areas; they must remain in, or return to, the area for extended periods; the area must be used repeatedly across years (Heupel et al. 2007). Although juvenile lemon sharks were present around South Caicos throughout the year, and their size distribution suggests that up to four year-classes were present (Brown and Gruber 1988), the transient nature of individuals around South Caicos and the occurrence of juvenile lemon sharks in adjacent areas dictates that South Caicos is only part of a larger, more expansive nursery ground. Nonetheless, the fact that open umbilical scars were observed on some of the sharks captured during the present study indicates that they were only recently birthed, and that parturition took place close by, intimating that South Caicos is a pupping area for lemon sharks.

The size range reported here differs somewhat from that of lemon sharks caught in nurseries at Bimini (Manire and Gruber 1991; Morrissey and Gruber 1993; Barker et al. 2005), Atol das Rocas (Freitas et al. 2006) Florida (Reyier et al. 2008) and the U.S. Virgin Islands (DeAngelis et al. 2008). While all studies have reported a similar minimum size (equating to the size at birth), sharks up to 150 cm TL and 149 cm PCL were recorded from Atol das Rocas (Freitas et al. 2006) and Florida (Reyier et al. 2008) respectively. A variety of size ranges have been reported from Bimini (Manire and Gruber 1991; Morrissey and Gruber 1993; Barker et al. 2005), but these were generally the result of an intended sampling bias, and the available information suggests that a wide size range of lemon sharks occur around Bimini (Gruber et al. 1988; Feldheim et al. 2002). This is in contrast to the present study, where only small juveniles (≤ 125 cm TL) were recorded. Larger lemon sharks (up to 180 cm TL) have, however, been observed and captured further afield on the Caicos Bank (A. C. Henderson, unpublished data). These larger sharks may have shifted their home range from the shallow coastal waters to the open sand flats, similar to lemon sharks at Bimini (Morrissey 1991). In the U.S. Virgin Islands, a smaller size range was observed, but the authors attribute this to fishing gear bias (DeAngelis et al. 2008).

While most of the South Caicos sharks were not at liberty for a sufficient amount of time to reliably estimate the mean growth rate, the shark which was recaptured after 202 days exhibited a growth rate similar to that previously reported for the species (Freitas et al. 2006). This suggests that the plastic T-bar anchor tags used in the present study did not affect growth to the extent that metal-headed dart tags did on lemon sharks in Florida Bay (Manire and Gruber 1991). Nonetheless, condition factor had declined in most of the recaptured sharks from South Caicos. While this could have been due to the tag, or the stress of capture, it could also have been caused by exogenous factors, as was suggested for the decrease in condition of juvenile lemon sharks along the south-eastern United States, and for juvenile scalloped hammerhead sharks *Sphyrna lewini* in Kāne'ohe Bay, Hawaii (Duncan and Holland 2006).

The results of the current study suggest that South Caicos may only form part of a larger nursery area, although further studies are required to confirm this. If, indeed, this is the case, then the development of South Caicos may only partially disrupt the sharks' activities, although the importance of South Caicos as a pupping ground within the nursery demands attention. Future research should focus on shark movements, the effects of tidal currents and environmental variables thereon, and the study area should be expanded to include all contiguous habitat.

Acknowledgements.—The authors gratefully acknowledge the logistical support of the School for Field Studies, particularly that of Dr. D. Wilson (Center Director, Center for Marine Resource Studies). We are also grateful to the Turks & Caicos Government (Department of Environment and Coastal Resources) for permitting us to undertake this research. We are especially indebted to all of the SFS students who assisted us in the field.

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