Photo: Elizabeth Knight

Identification of rearing areas for blacktip sharks *Carcharhinus limbatus* in the mangrove stands of coastal San Cristóbal Island

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Sharks fill a vital ecological role within marine ecosystems as a top predator (Stevens *et al.*, 2000). They help eliminate dead and weak animals from the water, impeding the spread of disease and strengthening the genetic structure of populations (Galván *et al.*, 1989).

The current status of shark populations in the Galapagos Marine Reserve (GMR) is unknown. However, they are under strong pressure from illegal fishing in spite of the prohibition of shark fishing (Reyes and Murillo, 2007). In Galapagos sharks are a symbol of the marine biodiversity and at least five shark species (reef whitetip shark *Triaenodon obesus*, whale shark *Rhincodon typus*, hammerhead shark *Sphyrna lewini*, Galapagos shark *Carcharhinus galapagensis*, and the silky shark *Carcharhinus falciformis*) represent an important tourism resource in the GMR, especially for dive trips (Reyes and Morillo, 2007). Knowledge of shark biology and ecology in the coastal zones is critical for effective management and conservation.

This study examines the different species of juvenile shark that use certain coastal zones of San Cristóbal Island for rearing. These data will help to establish a baseline for these areas and to promote similar studies in the rest of the archipelago to improve management in all coastal areas of the GMR.

Shark rearing areas

Gravid females of many shark species travel to specific rearing areas to give birth to their young or deposit eggs on the sea floor.

The young spend the first part of their lives where they are born, making these areas critically important to shark populations (Springer, 1967; Castro, 1993). Rearing areas can be relatively closed or open to the sea, but are usually located in the shallow, highly-productive coastal zones, where the newborn can find abundant food and protection from larger sharks (Simpfendorfer and Milward, 1993; Bonfil, 1997; Carlson, 1999). These areas can be identified through observations of gravid females, neonates, and young-of-the-year (Bonfil, 1997). This study focused on evaluating five sites in San Cristóbal to determine if they are rearing areas for sharks.

Critical habitats for the protection of sharks

Shark populations can be limited by the number of rearing areas with adequate habitat (Springer, 1967). Knowing the location of the rearing areas is important to ensure adequate protection for these species and to evaluate possible human impacts in these areas (Skomal, 2007).

A variety of factors, such as increased fishing effort, inadequate fishing regulations, and the degradation of important rearing areas in coastal habitats, estuaries, and fresh water, has resulted in a decline in shark populations in various regions of the world (Camhi *et al.*, 1998). Ecosystems such as mangroves are both ecologically and biologically important, given that they stabilize coasts, protect the inland terrain, and provide habitat for many bioaquatic species (Reserva Nacional de Investigación Estuarina Bahía de Jogos, online). These ecosystems have high biodiversity with very high primary productivity, maintaining a complex trophic network that includes nesting areas for birds, and feeding, rearing, and protective zones for reptiles, fish, crustaceans, and mollusks (MacNae, 1968).

Management and conservation of critical habitats for reproduction and rearing in the waters off San Cristóbal through fishing closures and/or the establishment of protected zones is vital to ongoing reproductive processes (Anislado and Robinson, 2001). These sites have similar habitat characteristics and are surrounded by mangroves (Figure 1a), primarily the red mangrove (*Rhizophora mangle*). The roots of the mangroves provide a refuge from predators for juvenile sharks and young of other fish species (Figure 1b).

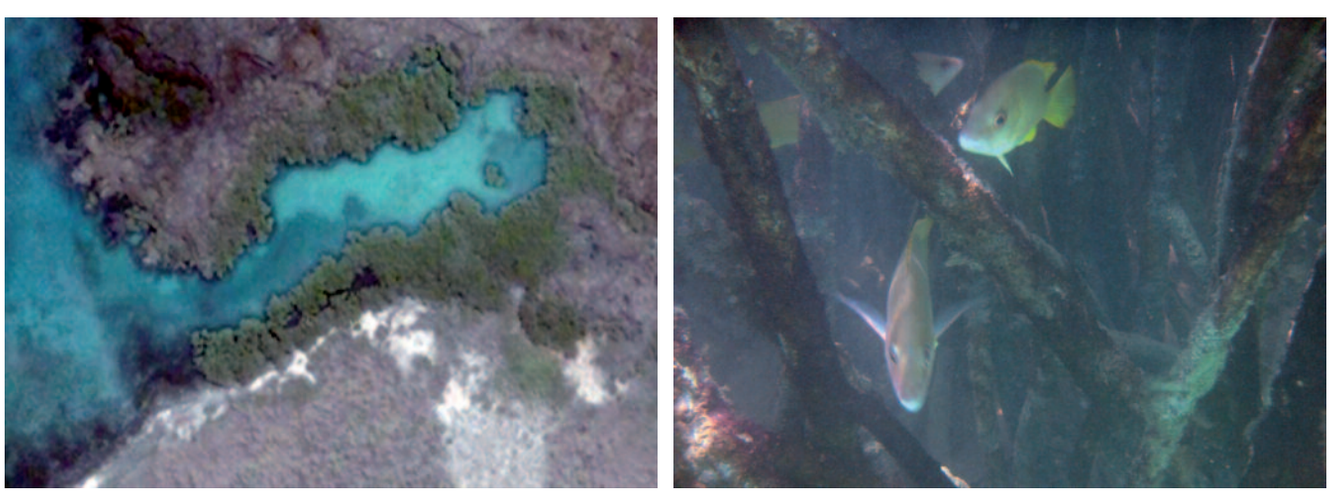

Figure 1. (a) Aerial view of the Tortuga study area surrounded by red mangrove (*Rhizophora mangle*); (b) Juvenile fish among the roots of the mangroves.

Study areas

This study was completed in five mangrove areas in the coastal zone of San Cristóbal: Tortuga, Cerro Brujo (the mangrove area), Puerto Grande, Manglecito, and Bahía Rosa Blanca (Figure 2). At all sites, sharks were fished using gill nets, locally known as "trasmallo lisero" and generally used in Galapagos for fishing mullets. The number of neonate and one-year-old sharks captured was recorded.

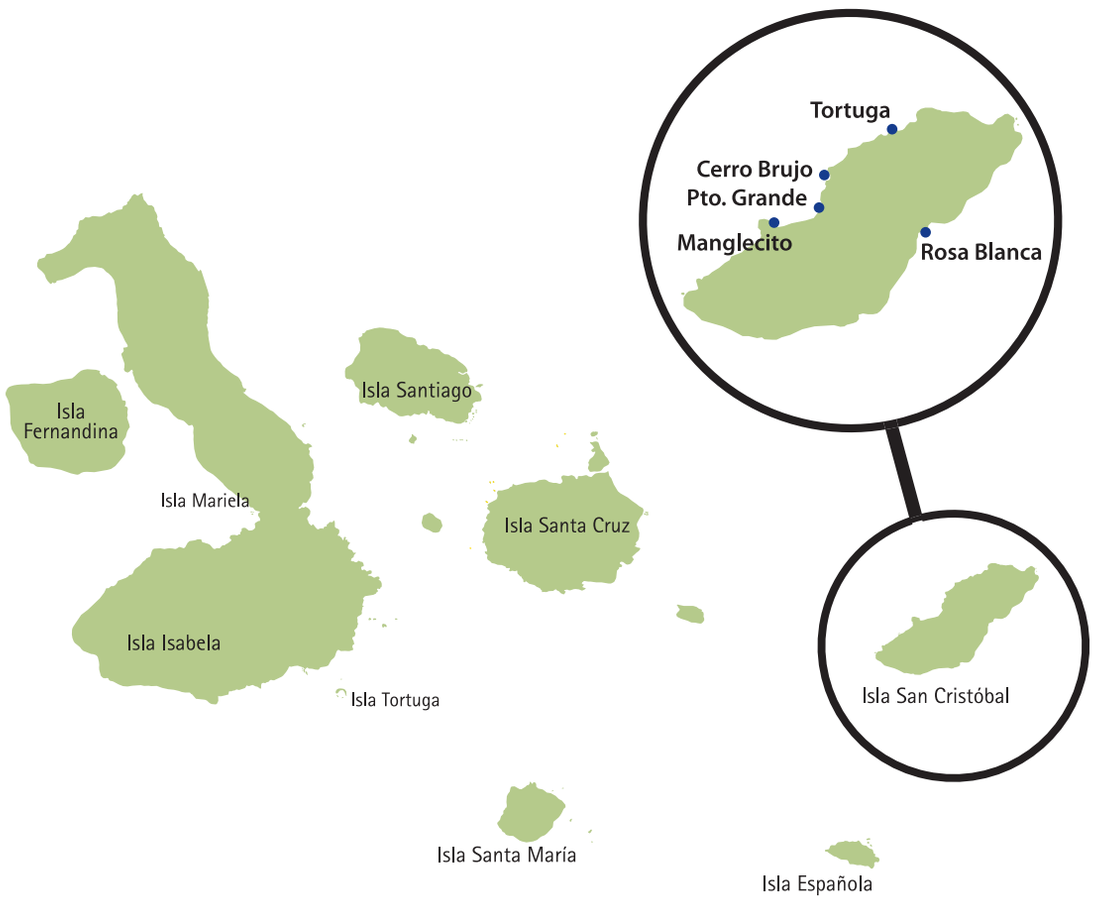

Figure 2. The Galapagos Islands with details of San Cristóbal Island and the five coastal study areas: Tortuga, Cerro Brujo (mangrove area), Puerto Grande, Manglecito and Bahía Rosa Blanca.

Methods

From May to December 2008, direct observations were made via snorkeling to detect and count sharks in the five study areas. In January, February, and April of 2009, six additional field trips were conducted to capture juvenile sharks using a gill net with 3-inch holes measuring 100 m x 3.5 m. The net was located at the entrance of each study area during one hour.

The captured sharks were immediately freed from the net and brought onboard where weight, measurements (total length, furcal length, and standard length), sex, and species were recorded. The state of the umbilical scar was also noted as either open or partially closed, to determine the shark's stage of development (Figure 3).

Figure 3. (a) Blacktip shark with an open umbilical scar (neonate); (b) Blacktip shark with a partially closed umbilical scar (young-of-the-year).

Results

Nineteen blacktip sharks were observed at Tortuga and Bahía Rosa Blanca and 23 reef whitetip sharks (both juveniles and adults) were spotted in the mangrove areas of Manglecito, Bahía Rosa Blanca, and Cerro Brujo (Table 1). Using the gill net, 52 neonates and one-year-old juvenile blacktip sharks were captured at Tortuga, Puerto Grande, and Manglecito; one neonate hammerhead shark was caught in Puerto Grande. This indicates that this fishing method is more efficient for studying these two species, especially the blacktip shark.

Table 1. Number of the three species of shark observed and captured in each study area in San Cristóbal.

Methodology	Species	Study Area					
		Tortuga	Cerro Brujo	Puerto Grande	Manglecito	Rosa Blanca	Total
Observed	Blacktip shark	9	0	0	0	10	**19**
	Reef whitetip shark	0	17	0	2	4	**23**
	Hammerhead shark	0	0	0	0	0	**0**
Captured	Blacktip shark	9	0	29	14	0	**52**
	Reef whitetip shark	0	0	0	0	0	**0**
	Hammerhead shark	0	0	1	0	0	**1**
	Total	18	17	30	16	14	**95**

In terms of neonates and one-year-olds, the species most often caught was the blacktip shark, which was observed in three of the study areas (Table 2). In January, the number of neonates was greater than the number of one-year-olds in both Puerto Grande and Manglecito, but not at Tortuga. In February, on the other hand, the number was nearly the same and they were present in Puerto Grande, Manglecito, and also Tortuga. In April, there were no neonates caught in any of the study areas, while the most one-year-olds were captured in Puerto Grande.

Table 2. Number of blacktip shark neonates and young-of-the-year captured at three of the study areas between January and April 2009.

Study Area	Month	Neonates	Young-of-the-year
Tortuga	January	0	0
	February	5	2
	April	0	2
Puerto Grande	January	6	1
	February	2	0
	April	0	20
Manglecito	January	5	0
	February	2	6
	April	0	1
TOTAL		20	32

The results suggest that blacktip sharks probably give birth in the first months of the year. For example, at Tortuga in February, young with a total length (TL) of 65 cm and a portion of their umbilical cord attached were captured (Figure 5), indicating that they had been born only a few days earlier. More frequent sampling is needed throughout the year to confirm this finding.

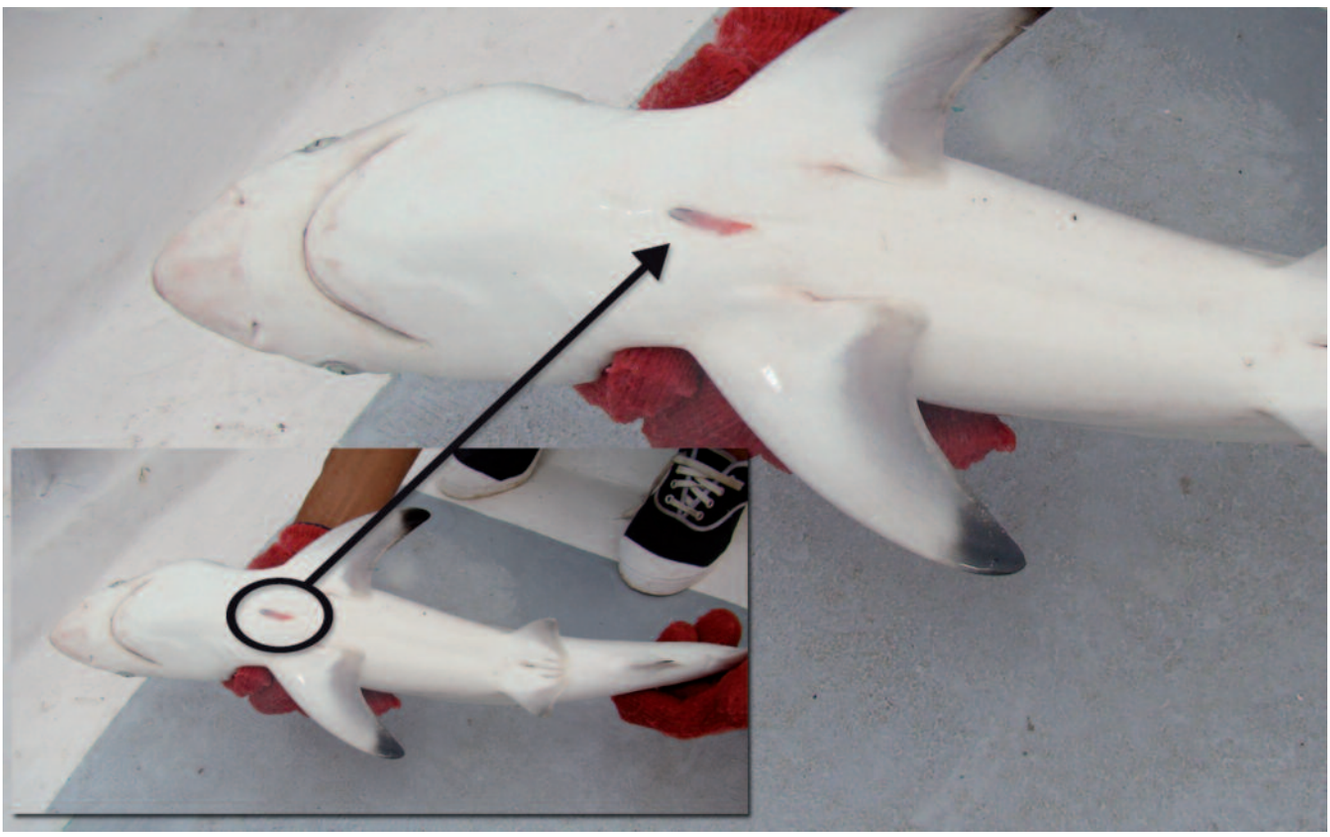

Figure 5. Blacktip shark neonate of 65 cm total length (TL), captured at Tortuga, showing in the circle the umbilical cord, indicating that it was born a few days before.

Other fauna in the five study areas

The number and species of fish observed using both methods confirm that the five mangrove areas possess a high abundance and diversity of species typically found in coastal bays (Allen *et al.*, 1995; Grove and Lavenberg, 1997; Humann and Deloach, 2003; Molina *et al.*, 2005), such as black-tailed mullet (*Xenomugil thoburni*), yellowfin mojarra (*Gerres cinereus*), golden-eye grunt (*Haemulon scudderii*), and blackspot porgy (*Archosargus pourtalesii*). The majority of these species remain in these areas during their juvenile stage.

Species of rays and fish were observed in all five study areas, with the greatest diversity of species at Tortuga and Manglecito, followed by Bahía Rosa Blanca, Puerto Grande, and finally Cerro Brujo (Table 3).

Conclusions and recommendations

The mangrove areas of Tortuga, Puerto Grande, and Manglecito of San Cristóbal are rearing areas for blacktip shark, with 98% of captured sharks being blacktip neonates and young-of-the-year. The remaining 2% were hammerhead sharks. Gill nets were more effective for collecting data on recently born sharks than direct observation.

It is evident that juvenile blacktip sharks prefer mangrove areas. The lack of observations of adult sharks suggests that they do not frequent these zones.

Additional studies are needed throughout the year to determine other characteristics of the population dynamics of blacktip sharks and other species, including movement patterns and growth rates. It is also necessary to determine if juvenile sharks use other types of habitats in the coastal zone of the GMR.

Table 3. Diversity of accompanying wildlife species in the five study areas of San Cristóbal, by presence/absence.

Species		Study Area				
Common Name	**Scientific Name**	**Tortuga**	**Cerro Brujo (Mangroves)**	**Puerto Grande**	**Manglecito**	**Rosa Blanca**
Blackspot porgy	*Archosargus pourtalesii*			X		
Yellowtail surgeonfish	*Prionurus laticlavius*	X		X		X
Yellow-tailed damselfish	*Stegastes arcifrons*	X	X	X	X	X
Milkfish	*Chanos chanos*				X	
Marbled goby	*Eleotrica cableae*	X	X	X	X	X
Bigeye jack	*Caranx sexfasciatus*	X			X	
Black-tailed mullet	*Mugil galapagensis*				X	
Thoburn's mullet	*Xenomugil thoburni*	X	X	X	X	X
Yellowfin mojara	*Gerres cinereus*	X			X	X
White salima	*Xenichthys agassizi*	X				
Brown-striped snapper	*Xenocys jessiae*	X				
Yellow-tailed snapper	*Lutjanus argentiventris*	X				X
Pacific dog snapper	*Lutjanus novemfasciatus*	X				X
Panamic sergeant major	*Abudefduf troschelii*	X	X	X	X	X
Spotted eagle ray	*Aetobatus narinari*				X	
Stingray	*Dasyatis brevis*	X	X	X	X	X
Grunt	*Orthopristis spp.*				X	
Golden-eye grunt	*Haemulon scudderii*	X	X			
Galapagos thread herring	*Opisthonema berlangai*			X	X	
Bullseye puffer	*Sphoeroides annulatus*	X	X	X	X	X
Yellow-tailed grunt	*Anisotremus interruptus*				X	
TOTAL		**14**	**7**	**9**	**14**	**10**

The gill net was effective for capturing both neonate and juvenile sharks that live in mangrove areas. The five study areas are all designated as fishing zones within the GMR zoning system and are regularly used by fishermen. This suggests that a continued incidence of capture of juvenile sharks and other protected species (i.e., rays) in nets may be occurring (Figure 6).

Based on the results of this research, we recommend that additional studies be carried out in San Cristóbal and other islands to determine the fishing methods and regulations that will help to protect shark rearing areas. The gill net used in this study resulted in a high incidence of capture of neonate and juvenile sharks. Its use by fishermen over the long-term could cause unintentional deterioration of these ecosystems. We recommend the reevaluation of the current zoning of important rearing areas and the establishment of protected zones in mangrove stands. The creation of protected zones for shark rearing would improve the management of these habitats, and also protect and conserve juvenile sharks and other species.

Figure 6. Eagle ray (*Aetobatus narinari*) captured incidentally in the gill net in Manglecito.