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MARINE MANAGEMENT

NURSERY GROUNDS OF BLACKTIP SHARKS (CARCHARHINUS LIMBATUS) IN MANGROVE-FRINGED BAYS IN THE CENTRAL PART OF THE GALAPAGOS ARCHIPELAGO

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Nursery grounds of blacktip sharks (*Carcharhinus limbatus*) in mangrove-fringed bays in the central part of the Galapagos Archipelago

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Mangrove forests are areas of great ecological value and provide numerous ecosystem services (Bennett & Reynolds, 1993; Clough, 1993). These sites are characterized by having high primary and secondary productivity, as well as the presence of a large number of microhabitats, which play a major role in the life cycle of many aquatic species (Beck *et al.,* 2001). Globally, mangrove-fringed bays have been shown to serve as nursery grounds for a large number of bony fish and sharks, and to provide a rich source of food and protection against predation (e.g., Robertson & Duke, 1987; Simpfendorfer & Milward, 1993; Ashton *et al.*, 2003; Knip *et al.,* 2010).

Under the current zoning scheme of the Galapagos Marine Reserve (GMR), the majority of bays with mangrove forests are listed as subzones for extractive use or fishing (2.3), thus they are visited frequently by fishermen to catch mullet (Mugilidae) and bait for high seas fishing (Andrade & Murillo, 2002; Murillo *et al.*, 2004; Peñaherrera-Palma, 2007). While sharks are protected throughout the GMR (Subsecretaría de Recursos Pesqueros, 1989), their wide distribution makes them susceptible to permitted fishing activities. Sharks are the top predators in the food chain and have a critical role in maintaining the health of marine ecosystems (Myers *et al.,* 2007). They also have a high economic value as one of the biggest attractions for dive tours in the GMR (Espinoza & Figueroa, 2001; Peñaherrera *et al.,* 2013).

In order to provide key information to ensure the proper management of fisheries and the protection of sharks, the Galapagos National Park Directorate (GNPD) began a process of identification and monitoring of essential shark habitats within the GMR. Based on observations by fishermen, four mangrove bays of San Cristóbal Island were studied and a surprising abundance of juvenile blacktip sharks (*Carcharhinus limbatus*) were found (Llerena, 2009). Since these results demonstrated the existence of nursery areas for this species, the GNPD established permanent monitoring in mangrove-fringed bays in southeastern Santa Cruz Island, with the goal of identifying other potential nursery grounds for sharks. In addition, the GNPD collaborated on other satellite projects in the central area of the Archipelago (Jaenig, 2010; Hirschfeld, 2013).

This article summarizes the most important results of the monitoring project on the nursery grounds for blacktip sharks in the GMR, compares the results to similar studies, and reviews management implications as they relate to the current coastal zoning scheme.

Methods

According to Heupel *et al.* (2007), three criteria are needed to identify an area as a nursery ground for sharks: i) sharks are found more often in the area than in other areas; ii) sharks tend to remain in the area or return for extended periods; and iii) the area or habitat is used repeatedly by sharks over the years. To determine if these criteria exist and to understand how juvenile blacktip sharks use mangrove bays, different types of monitoring were implemented using experimental fishing and acoustic telemetry (Table 1).

Table 1. Classification of separate information sources used for analysis.

Type of monitoring	Source	Location	Study site	Study period
Experimental fishing				
Systematic monitoring	GNPD	Santa Cruz (southeast)	Garrapatero, Saca Calzón, Punta Rocafuerte and Tortuga Bay	January 2010 - December 2012
Seasonal monitoring	Llerena (2009)	San Cristóbal (central-northwest)	Cerro Brujo, Manglecito, Puerto Grande, Rosa Blanca and Tortuga	January - April 2009
	Jaenig (2010)	Santa Cruz (northwest)	Bahía Borrero, Caleta Tortuga Negra, El Edén and Venecia	November 2009 - March 2010
Random monitoring		Baltra (south)	Itabaca Channel	Random monitoring in April 2012 and March, April, May, June, July 2013
		Fernandina (east)	Puerto Copiano and Punta Mangle	
		Isabela	Bahía Elizabeth, Caleta Negra, Cartago Chico 1, 2, 3, 4, 5, Cartago Grande 1, 2, Piedras Blancas, Poza de los Tiburones, Puerto Las Tablas and Punta Albermarle	
		San Cristóbal	Puerto Grande	
		Santiago	La Bomba, Poza de las Azules and northeastern Santiago	
Acoustic telemetry				
Continuous monitoring	Hirschfeld (2013)	San Cristóbal	Puerto Grande	April - August 2012 and November 2012 - February 2013

The experimental fishing monitoring methodology (seasonal, systematic, and random) was standardized by Llerena (2009). It is based on bottom-setting a gill net, similar to those used by artisanal fishermen, for one hour in the inner areas of the bays (details in Llerena *et al.,* 2011). Results are expressed as CPUE (catch per unit effort), representing the number of individuals captured during each sampling hour for each gill net set (ind/h*net). This provides a measure of the relative species abundance, which can then be compared between studies. The most important difference among the three types of monitoring is time of execution, with systematic monitoring involving the greatest duration and scientific rigor (monthly samplings at each site for three consecutive years). Seasonal monitoring was conducted for one or two contiguous seasons, while random surveys were completed on one or two occasions in the central, southern, and western parts of the Archipelago (Table 1).

Acoustic telemetry was used to evaluate daily behavior and site fidelity of eight blacktip sharks captured in Puerto Grande, San Cristóbal. Each shark was monitored continuously for up to 45 hours, using a small boat and special equipment (Hirschfeld, 2013).

Results

A total of 972 blacktip shark juveniles were caught and released alive during the systematic monitoring carried out in southeastern Santa Cruz, with a rate of 312 individuals per year and an average of 5.6 ind/h*net. The number of sharks registered by site was highly variable, with catches of 0 to 39 ind/h*net, but their constant presence throughout the study provides evidence that the four zones studied are areas preferred by this species. The relative abundance of sharks was significantly higher during the warm season than in the cold season (Figure 1a). The differences observed in the size structure of the sharks caught provides evidence of the birth of new individuals in the areas sampled, a situation that can be seen clearly when analyzing the total length (cm) and the presence of an umbilical scar of each shark (Figure 1b and c). During the hot season, the average total length of sharks was ~68 cm, due to a greater number of neonates (recently born sharks with the umbilical scar still open) and young-of-the-year (semi-enclosed scar). The opposite situation was observed in the catches recorded in the cold season, where the average total length was significantly greater (~72.4 cm) due to the dominance of juveniles (with no umbilical scar).

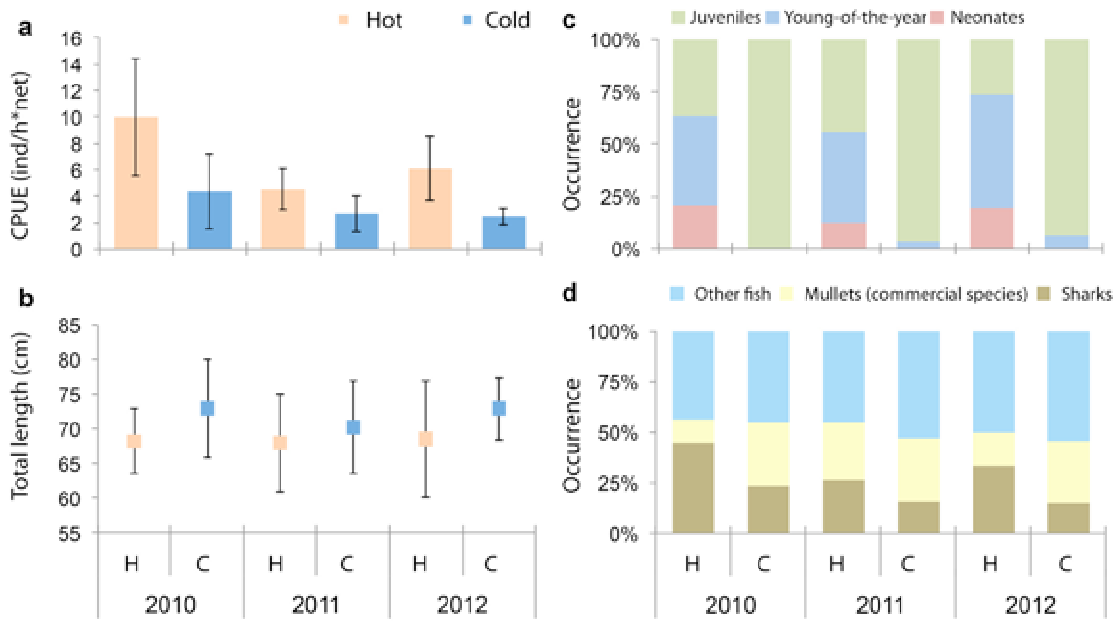

Figure 1. Differences between the hot (H) and cold (C) seasons for the four sites sampled in relation to: a) average relative abundance using CPUE (catch per unit of effort); b) average total length; c) percentage of occurrence of neonate sharks (with open umbilical scar), young-of-the-year (semi-open scar), and juveniles (closed scar), and d) percentage of occurrence of juvenile blacktip sharks, Mugilidae (black- and yellow-tailed mullets), and other boney fish with little or no commercial value.

Observations in this study are similar to those from studies carried out in Hawaii and Florida, where it is suggested that changes in abundance and size may be a product of new births in the warm season and then a high mortality of newborn sharks during their first weeks of life due to predation, malnutrition, or fishing (Heupel & Hueter, 2002; Heupel & Simpfendorfer, 2002; Carlson *et al.*, 2004), and/or from the migration of individuals to other areas of the island following the masses of warm water with the change of season (Heupel, 2007). Causes for inter-annual variations in the relative abundance of this species are unknown. These fluctuations in abundance could be part of normal cyclical processes of reproduction (eg., Lucifora *et al.*, 2002; Meyer *et al.*, 2009), food availability (e.g., Ramirez-Macias *et al.*, 2012), or even a response to changes in oceanographic conditions (e.g., Froeschke *et al.*, 2010).

Juvenile blacktip sharks can be very common in catches using gill nets. Black- and yellow-tailed mullet (higher commercial value species) equaled 10-38% of the catches. However, blacktip sharks can vary between 15-45% in catches, which indicates a higher incidence of the protected species than species with commercial value.

Results of systematic monitoring indicate patterns and trends of the presence and abundance of juvenile sharks that can be compared with other studies (Table 2). While data from the study of Llerena (2009) are restricted to the warm season, the pattern of catches for Puerto Grande, Manglecito, and Tortuga resembles the pattern observed in the systematic monitoring sites. A similar situation was reported for Caleta Tortuga Negra, Venecia, and El Edén in northwestern Santa Cruz, where the greatest relative abundance of sharks with a length under the average were recorded, as well as the presence of neonates during the hot season versus the cold season (Jaenig, 2010). These comparative results of both seasonal and systematic monitoring show that there is a seasonal pattern of use of these areas, which occurs every year.

How long do sharks remain? Do they always use the same areas?

Based on the conventional marking used in the systematic monitoring in Santa Cruz and the continuous monitoring on San Cristóbal, it was determined that certain sites are preferred over adjacent areas (see study sites in Table 1). During the systematic monitoring, a number of marked sharks were re-captured in the same site, and others in bays nearby or adjacent to the initial capture site (Figure 2), similar to that reported by Jaenig (2010). This behavior was observed in greater detail through the acoustic telemetry monitoring (Hirschfeld, 2013). That study showed that the movements of juveniles of this species are concentrated in the inner areas of the mangrove bays, especially neonates, which did not move outside the shallow bays (Figure 3, Table 3). It also showed that the area used is considerably larger than the size of the bay, but that the excursions outside the bay occur primarily at night.

Table 2. Comparison of averages of abundance, length, and composition (N = neonates; YY = young-of-the-year, and J = juvenile) between systematic monitoring and seasonal monitoring in the hot (H) and cold (C) seasons.

Location	Abundance (ind/h*r)		Total length (cm)		Composition (%)						Source
					C			H			
	C	H	C	H	N	YY	J	N	YY	J	
Systematic monitoring											
Santa Cruz – southeast	5.6	3.0	68.3	72.4	32	35	33	0	2	98	This study
Seasonal monitoring											
San Cristóbal – central-northwest	3.3	---	69.5	---	39	0	62	---	---	---	Llerena 2009
Santa Cruz - northwest	8.1	6.1	69.7	84.0	42	47	11	0	0	100	Jaenig 2010

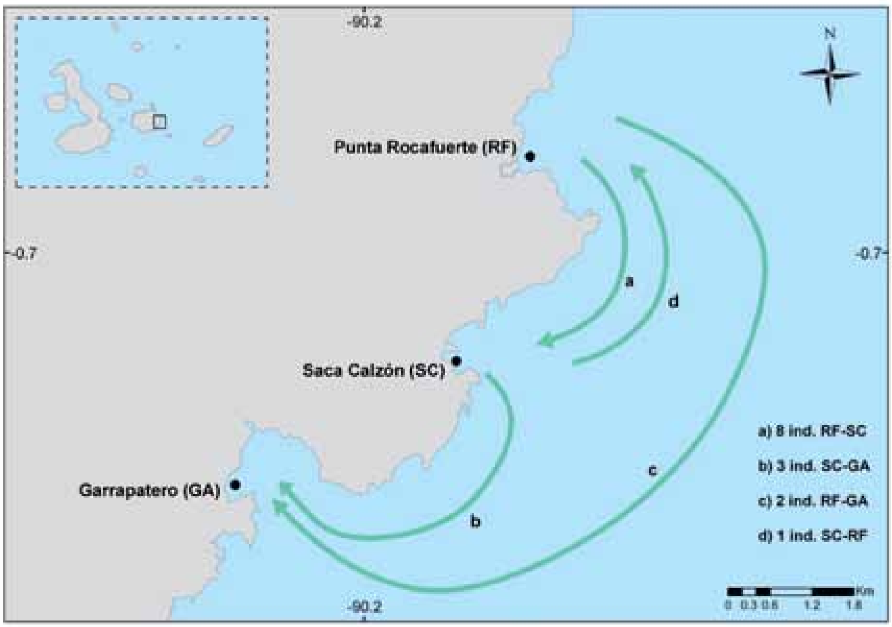

Figure 2. Connectivity map obtained from the conventional marking of juvenile blacktip sharks in the systematic monitoring carried out in southeastern Santa Cruz.

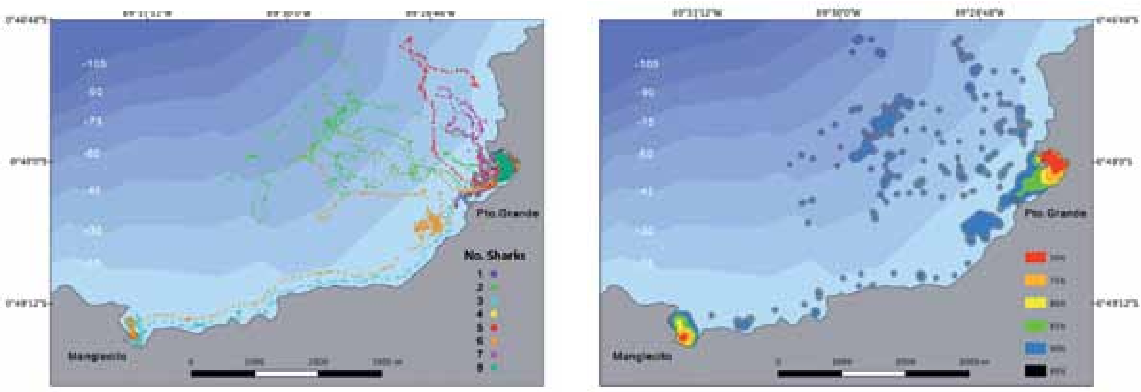

Figure 3. a) Distribution patterns of eight blacktip shark juveniles tracked continuously in Puerto Grande, San Cristóbal. b) Areas used calculated from the concentration of points during monitoring. Red indicates areas where the largest number of sharks was detected.

The results clearly show that the study sites are critical habitats for the early stages of life of blacktip sharks. However, these areas represent only a small fraction of all mangrove-fringed bays in the GMR. For this reason, random surveys were executed in different sites of the Archipelago to identify potential nursery grounds (Table 4, Figure 4). At least one shark was captured at 50% of the 20 sites monitored randomly, so these sites have been categorized as potential nursery areas. However, the remaining sites have been classified as places that should be included in future monitoring, in order to be able to determine if the absence of catches was the product of natural variability.

Table 3. Morphology and movement patterns of eight sharks monitored using acoustic telemetry in Puerto Grande, San Cristóbal, during months in 2012 and 2013 (N = neonate, YY = young of the year).

Shark number	Sex	Age class	Tracking time (h)	Total distance (km)
1	Male	YY	45	38.3
2	Female	YY	35	46.8
3	Female	YY	27	13.6
4	Female	N	42	27.1
5	Female	YY	45	27.1
6	Female	YY	42	27.8
7	Male	YY	40	23.6
8	Male	N	34	20.8

Conclusions and recommendations

Monitoring of 34 coastal sites in the GMR occurred during a period of three years and eight months. Of these sites, 79% were located in subzones of Extractive Use or Fishing (2.3), 12% in the Protection subzone (2.1), and 9% in the No Extractive Use or Tourism subzone (2.2). Based on the criteria of Heupel *et al.,* (2007), this study identified the existence of nine confirmed and 11 potential nursery areas for blacktip sharks. Of these, only 25% are found in Protection or Non-extractive Use subzones, all on Santa Cruz Island.

However, this study and others analyzed here have examined fewer than half of the mangrove bays within the GMR. There are a large number of coastal areas with similar characteristics, such as southeastern Isabela Island, where there are large tracts of mangrove forests that were identified as potential nursery grounds but were not studied due to lack of resources. We recommend that future studies be expanded to include such sites in order to understand the status of all nursery grounds in Galapagos.

The results of this study show the importance of nursery grounds for the birth of blacktip sharks during the hot season, and their subsequent growth within the bay during the cold season. Movement data for this species within, outside, and between bays show the extent of the area used by juvenile blacktip sharks within the bays and the importance of maintaining connectivity between adjacent bays.

Coastal areas surrounded by mangroves have great biological importance not only for sharks but also for many species of commercial interest to the community (Beck *et al.,* 2001). Several of the monitored sites are used by fishermen who use gillnets to catch target species such as mullets. The results show that there is a high chance that approximately a quarter of the catch (~ 25%) is composed of juvenile blacktip sharks, especially if the fishing is carried out during the hot season, which could have an impact on this species over the long term.

We recommend that the results of this study identifying nursery grounds of juvenile sharks be incorporated into the re-evaluation of the current coastal zoning of the GMR, and that these areas be included in the category of Non-Extractive Use or Protection. The protection of these areas will not only ensure that shark populations remain stable, but will also help ensure a healthy marine ecosystem that will benefit other marine species including those of high commercial value (e.g., mullet).

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Table 4. Variation in CPUE (catch per unit effort) by season (Hot = H; Cold = C) registered for each site using bottom-gill nets, and the category assigned (nursery ground = NG; possible nursery ground = PNG; area with insufficient data (ID), and areas not identified as rearing areas (NI). In addition the categories of each site sampled using the current zoning scheme, including Protection sub-zone (2.1), No Extractive Use or Tourism subzone (2.2), and Extractive Use or Fishing subzone (2.3).

Island	Study site	No. of samples	CPUE		Category	Sub-zone	Fig. 4 code
			H	C			
Systematic monitoring							
Santa Cruz	Garrapatero	51	4.7	3.3	NG	2.2	1
	Punta Rocafuerte	50	7.6	3.2	NG	2.3	2
	Saca Calzón	52	6.0	4.0	NG	2.3	3
	Tortuga Bay	26	4.2	1.5	NG	2.2	4
Seasonal monitoring							
San Cristóbal	Cerro Brujo	2	0.0	---	NO	2.3	5
	Manglecito	4	3.9	---	NG	2.3	6
	Puerto Grande	5	4.1	---	NG	2.3	7
	Rosa Blanca	1	0.0	---	ID	2.3	8
	Tortuga	4	2.0	---	PNG	2.3	9
Santa Cruz	Bahía Borrero	1	---	0.0	ID	2.3	10
	Caleta Tortuga Negra	20	4.7	9.5	NG	2.2	11
	Canal (Cerro Dragón)	7	0.0	0.0	NO	2.1	12
	El Edén	14	9.3	2.7	NG	2.1	13
	Venecia	19	10.2	---	NG	2.1	14
Random monitoring							
Baltra	Itabaca Channel	1	0.0	---	ID	2.3	15
	Itabaca Channel north	1	0.0	---	ID	2.3	16
Fernandina	Puerto Copiano	1	0.8	---	PARA	2.3	17
	Punta Mangle	1	0.0	---	ID	2.3	18
Isabela	Elizabeth Bay	1	---	---	ID	2.1	19
	Caleta Negra	1	0.0	---	ID	2.3	20
	Cartago Chico 1	1	32.0	---	PNG	2.3	21
	Cartago Chico 2	1	30.0	---	PNG	2.3	22
	Cartago Chico 3	1	1.9	---	PNG	2.3	23
	Cartago Chico 4	1	0.0	---	ID	2.3	24
	Cartago Chico 5	1	9.4	---	PNG	2.3	25
	Cartago Grande 1	1	---	3.4	PNG	2.3	26
	Cartago Grande 2	1	---	0.0	ID	2.3	27
	Piedra Blanca	1	0.0	---	ID	2.3	28
	Poza de los Tiburones	1	0.0	---	ID	2.3	29
	Puerto Las Tablas	1	22.3	---	PNG	2.3	30
	Punta Albermarle	2	0.7	---	PNG	2.3	31
San Cristóbal	Puerto Grande	2	3.8	3.3	PNG	2.3	7
Santiago	La Bomba	1	0.0	---	ID	2.3	32
	Poza de las Azules	1	1.5	---	PNG	2.3	33
	Santiago noreste	1	0	---	ID	2.3	34

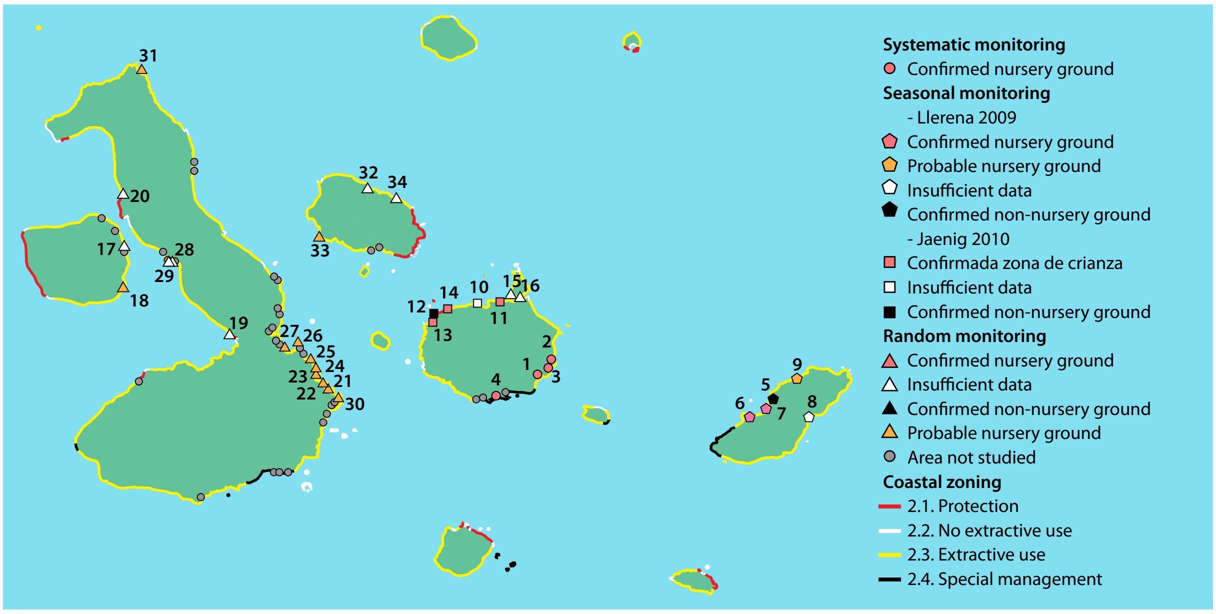

Figure 4. Distribution of mangrove-fringed bays in the GMR evaluated during this study, and the coastal zoning. The category "confirmed nursery ground" is denoted in red, "probable nursery ground" in orange, "area with insufficient data" in white, and "confirmed as non-rearing area" in black. Areas that were not studied are indicated in gray.

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