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Shark scavenging and predation on sea turtles in northeastern Brazil

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Abstract. Large sharks have the potential to help structure ecosystem dynamics through top-down impacts on their prey, including sea turtles. Studies of interactions between large sharks and sea turtles, however, are practically nonexistent along the Brazilian coast. Between September 2002 and May 2011 we examined 655 sea turtles – including green turtles *Chelonia mydas* (n = 607), olive ridleys *Lepidochelys olivacea* (n = 10), hawksbills *Eretmochelys imbricata* (n = 33), and loggerheads *Caretta caretta* (n = 5) – that stranded on Paraíba coast, northeastern Brazil. A total of 63 green turtles (10.4%), two olive ridleys (20.0%) and one hawksbill (3.0%) had shark-inflicted bites. Most bites could not be definitively attributed to scavenging or attacks on living turtles, but the presence of healed shark bites and freshly bleeding bites suggests that some attacks occurred pre-mortem. Bite characteristics suggest that tiger sharks *Galeocerdo cuvier* were responsible for most bites that could be identified to a particular species. Within green turtles, the only species with sufficient sample size, the probability of carcasses having been bitten increased with carapace length but did not vary across seasons and years. However, there was spatial variation in the probability of a carcass having been bitten by sharks. Our estimates of the minimum proportion of turtles attacked while alive (∼4%) and bitten overall are similar to other areas where shark-turtle interactions have been studied. Turtles likely are an important food for tiger sharks in northeastern Brazil, but further studies are needed to determine the relative frequencies of scavenging and predation.

Keywords: Behavior, *Galeocerdo cuvier*, mesoconsumer, predation, top predators.

Introduction

Sea turtles have generally been considered to be largely immune to predators once they reach large body sizes (i.e. large juveniles and adults). Recent studies, however, suggest that predators of adult and large juvenile turtles – particularly sharks – can influence their behavior (e.g., spatial distributions) and may be important in influencing turtle population sizes in spite of low rates of predation (see Heithaus et al., 2008 for a review).

Worldwide, white (*Carcharodon carcharias*), bull (*Carcharhinus leucas*) and tiger (*Galeocerdo cuvier*) sharks are known predators of sea turtles (Heithaus et al., 2008). Of these, tiger sharks are the most common sea turtle predator, and sea turtles make up a large proportion the diets of large tiger sharks in numerous locations (e.g., Witzell, 1987; Lowe et al., 1996; Simpfendorfer, Goodreid and McAuley, 2001; see Heithaus et al., 2008). This, and the finding that green turtles show tiger shark predation risk-sensitive foraging behavior (Heithaus et al., 2007), has led several authors to suggest turtle population sizes may be at least partially regulated by shark predation and predation risk (e.g., Witzell, 1987; Simpfendorfer, Goodreid and McAuley, 2001; see Heithaus et al., 2008 for a review).

Unfortunately, little is known about diets and behavior of large coastal sharks in Brazilian waters. However, both tiger and bull sharks occur in these waters and are potential threats to sea turtles. Tiger sharks, due to their larger body sizes and specialized dentition (e.g., Motta and Wilga, 2001), likely are a greater threat

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to turtles than bull sharks (e.g. Heithaus et al., 2008). Adult tiger sharks are more common in northeastern Brazil, and consume whale carcass in large proportions (e.g., Bornatowski et al., 2012).

Five species of sea turtles are encountered in coastal waters of Brazil (Mascarenhas, Gonçalves and Zeppelini, 2005). Green turtle *Chelonia mydas* (IUCN Red List Status "Endangered"), nesting is concentrated on oceanic islands of Brazil, such as Trindade, Atol das Rocas and Fernando de Noronha Archipelagos, although nesting may also occur along the northeastern coast of Brazil (Marcovaldi and Marcovaldi, 1999; Almeida et al., 2011). Although nesting beaches only cover a limited area, the entire Brazilian coast serves as a foraging ground for juveniles and adults (Sales, Giffoni and Barata, 2008; Proietti et al., 2009; Almeida et al., 2011). The hawksbill turtle *Eretmochelys imbricata* (IUCN Red List Status "Critically Endangered") nests along the northeastern coast of Brazil from Bahia to Rio Grande do Norte coasts (Marcovaldi, Santos and Lopez, 2011). Juvenile and adult foraging grounds occur off the northeastern coast (Sales, Giffoni and Barata, 2008; Marcovaldi, Santos and Lopez, 2011). The olive ridley turtle *Lepidochelys olivacea* (IUCN Red List Status "Vulnerable") nests between the Alagoas and Bahia coasts in northeastern Brazil, and juveniles and adults occur in oceanic and coastal areas from southern to northern of Brazil (Silva et al., 2007). Finally, loggerhead turtles *Caretta caretta* (IUCN Red List Status "Endangered") nest primarily on the Bahia and Sergipe coasts in northeastern Brazil (Marcovaldi and Marcovaldi, 1999; Santos et al., 2011), and juveniles and adults forage throughout Brazilian waters in oceanic and coastal areas (Santos et al., 2011).

Despite the possibility that sharks could impact turtle populations there remain major gaps in our understanding of shark-sea turtle interactions and the importance of shark predation on adult sea turtles in general. Of interest are studies of a wider range of turtle species and from a greater geographic range than previous studies. For example, along the Brazilian coast studies of shark-turtle interactions are lacking with the exception of one record of tiger shark predation on a hawksbill turtle, *Eretmochelys imbricata* (Gasparini and Sazima, 1995). Here, we conduct the first systematic investigation of shark-sea turtle interactions (predation or scavenging) in Brazilian waters based on analyses of eight years of turtle stranding data in northeastern Brazil.

Material and methods

We obtained information on stranded turtles between the beaches of João Pessoa (7°08′S and 34°48′W) and Cabedelo (7°01′S and 34°49′W), Paraíba, northeastern Brazil from Projeto Tartarugas Urbanas, a regional Sea Turtle Stranding and Salvage Network (fig. 1).

The project's Sea Turtle Stranding and Salvage Network (SOS Turtles) is a regional network of trained biologists that document sea turtles that are found stranded in the state of Paraiba. Live turtles are taken to rehabilitation facilities and dead turtles are often salvaged for necropsy and study. From September of 2002 and May 2011 the beaches were monitored daily, with additional information on turtle strandings provided by the public. Because of incomplete yearly records, analyses only included data from 2003 to 2010.

For each stranding event, date, species, location, curved carapace length (CCL) and curved carapace width (CCW) (Wyneken, 2001), carcass condition, and information on external anomalies (e.g., fisheries interactions, propeller damage, fibropapillomas, epibionts and shark and other injuries/bites) were recorded. We considered marks to have been inflicted by sharks if turtles were missing large portions of the body (limbs, head and carapace), if they were crescent-shaped, or if tooth marks were present. Any injuries that could have been caused by anthropogenic interactions were not considered to be inflicted by sharks. Most bites could not be definitively attributed to scavenging or attacks on living turtles, but the presence of healed shark bites and freshly bleeding wounds suggests that some attacks occurred pre-mortem. All observations were made by one of the authors (R. Mascarenhas), ensuring consistency in data.

The total length of the attacking shark was estimated for only eight turtles that showed visible teeth marks and/or measurable bite circumferences. These estimates were based on total length-bite circumference or total length-interdental distance (IDD) relationships generated by Lowry et al. (2009). Finally, we determined the portions of the turtle's body that had been consumed (e.g. loss of head, number of flippers lost).

The potential species of attacking shark was determined when possible. Sharks from the genus *Carcharhinus*

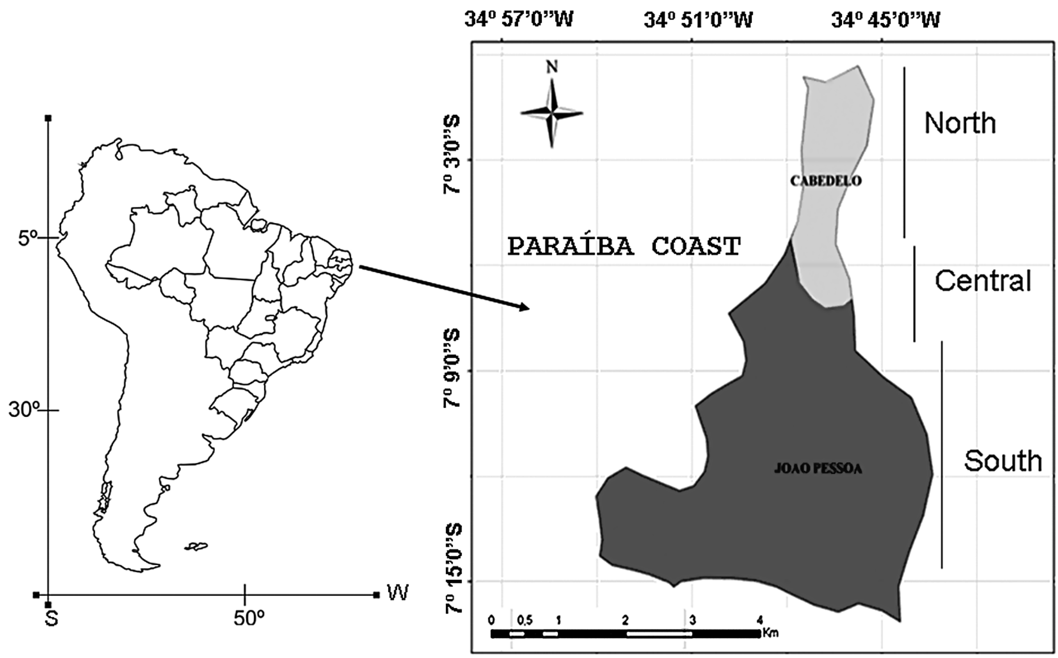

Figure 1. The study was conducted in two municipalities (João Pessoa and Cabedelo) of northeastern Brazil, south-western Atlantic. We subdivided the study area into three regions (north, central and south).

(e.g., *Carcharhinus leucas*, *C. obscurus*) have jaws that are crescent-shaped with numerous pointed teeth, the cutting edges of the teeth overlap, and they tend to make a clean, smoother cut. On the other hand, tiger sharks have widely spaced and much broader teeth that are the same size in the upper and lower jaws and produce slashing bites (Long and Jones, 1996; Heithaus, 2001).

We used logistic regression to determine the effects of season, year and CCL on the probability that stranded green turtles (the only species with sufficient sample sizes) had been bitten by sharks either before or after death. Also, logistic regression was used to examine whether there was spatial variation in the probability of a carcass having been bitten across three regions (north, central and south) of the Paraíba coast (fig. 1).

Results

A total of 655 stranding turtles (54 alive and 601 dead) were recorded (mean = 77 ± 13 SD per year) (table 1) including 607 green turtles

Table 1. Turtle stranding data obtained from September 2002 to May 2011 in northeastern Brazil. F, female; M, male; UN, unidentified sex.

Stranding (year)	*C. mydas*			*E. imbricata*			*L. olivacea*			*C. caretta*		
	F	M	UN	F	M	UN	F	M	UN	F	M	UN
25 (2002)	7	3	15	–	–	–	–	–	–	–	–	–
64 (2003)	38	12	12	1	–	–	–	1	–	–	–	–
76 (2004)	44	12	18	–	–	–	1	–	–	1	–	–
86 (2005)	33	11	39	–	–	1	–	1	–	–	1	–
78 (2006)	26	8	40	–	–	3	–	1	–	–	–	–
61 (2007)	22	11	21	4	–	2	–	1	–	–	–	–
59 (2008)	23	7	27	–	1	1	-	–	1	–	–	–
93 (2009)	40	20	19	7	3	1	2	–	1	–	–	1
96 (2010)	49	17	17	6	2	–	–	1	–	1	–	1
16 (2011)	10	2	4	–	–	1	–	–	–	–	–	–
Total	292	103	212	18	6	9	3	5	2	2	1	2

Table 2. Location of bites on green turtle carcasses (n = 54) across classes. Class 1: 20-39 cm; class 2: 40-59 cm; class 3: 60-79 cm; class 4: 80-99 cm; class 5: 100-120 cm. Data obtained from 2003 to 2010 in northeastern Brazil. For eleven individuals, data on wounds and turtle size were not collected.

Bite marks location(s)	Class 1 (n = 4)	Class 2 (n = 15)	Class 3 (n = 7)	Class 4 (n = 11)	Class 5 (n = 17)	Total
Forelimb	–	(3) 20%	–	(2) 20%	–	(5) 9.7%
Hindlimb	–	(2) 13%	–	–	(2) 13%	(4) 7.7%
Anterior and posterior limbs	–	(1) 6%	–	(2) 20%	(2) 13%	(5) 9.7%
Head and limbs	(2) 50%	(5) 33%	(7) 100%	(5) 50%	(6) 38%	(24) 48%
Head	(2) 50%	(4) 27%	–	(1) 10%	(4) 25%	(11) 21.1%
Marks in carapace	–	–	–	–	(2) 13%	(2) 3.8%

Figure 2. Live-stranded green turtle (90 cm curved carapace length) with amputated right foreflipper, in northeastern Brazil. This figure is published in colour in the online version.

Figure 3. A crescent-shaped wound in the foreflipper of a green turtle caused by a tiger shark, in northeastern Brazil. This figure is published in colour in the online version.

from 12.4 to 127.5 cm CCL (mean ± SD = 59.5 ± 24 cm), 33 hawksbills from 26.3 to 94.3 cm CCL (mean ± SD = 52 cm ± 22 cm), 10 olive ridleys from 58.8 to 68.0 cm CCL (mean ± SD = 64.1 ± 5.2 cm) and five loggerheads from 42.0 to 109.0 cm CCL (mean ± SD = 81.5 ± 35 cm). Sixty six of these turtles (10.1%) had shark-inflicted wounds: 63 green turtles (10.4%), two olive ridleys (20.0%) and one hawksbill (3.0%). Sample sizes were insufficient to test for interspecific differences in bite probabilities. Green turtles with evidence of shark bites ranged from 28.0 to 117.6 cm CCL (n = 57; mean ± SD = 79.2 ± 27.2 cm). The other two species with bite marks – *L. olivacea* and *E. imbricata* – had CCLs of 73.6 cm and 86 cm, respectively.

The vast majority of turtles surveyed had stranded dead, and it was impossible to determine whether they were killed by predators or scavenged after death. However, it appears that a number of the individuals that stranded dead were attacked while alive. One of 41 (2.4%) live-stranded green turtles had evidence of pre-mortem shark bites (fig. 2). So did one of the three live-stranded olive ridley turtles. None of the 10 live-stranded hawksbills had evidence of being bitten by sharks. Two of the turtles that had stranded dead had amputated but healed forelimbs suggestive of a shark predation attempt. In addition, eight green turtles (1.4%) that stranded dead had shark-inflicted bite marks that were still bleeding.

The majority of injured turtles were missing heads and limbs (n = 25). Turtles missing only heads (n = 11) were the second most common (table 2). Of the carcasses with bite marks (n = 65), 46.2% were in state of advanced decom-

Table 3. Estimated lengths (TL) of eight tiger sharks that had bitten green turtles based on average interdental distances (IDD) and bite circumferences (estimates based on relationships in Lowry et al., 2009). CCL, curved carapace length.

Turtle CCL (cm)	IDD (mm)	Bite circumference (mm)	TL shark estimated (cm)
89	–	340	250
97.5	–	420	300
93	–	470	330
97	–	410	290
105	22	–	320
84	20	–	290
47.1	–	420	300
53.7	–	290	220

position, 32.3% were moderately decomposed, 12.3% were fresh with bleeding bite marks and 6.2% were only body parts. Of the 32 turtles where an attacking sharks species could be determined, all appeared to be tiger sharks (fig. 3). Based on measurements of bite circumference and interdental distances (IDD), the size of tiger sharks that had bitten turtles ranged form 220 to 330 cm TL (table 3). Within green turtles, there was no temporal (season and year) variation in the probability that turtles stranded with shark bites (table 4), but the probability that a stranded turtle had at least one bite increased with turtle body size (table 4, fig. 4). Also, there was significant spatial variation in the probability of a bite on a green turtle carcass. A higher proportion of carcasses had been bitten in the southern area of the study site than the central or northern region (fig. 5).

Discussion

Most information on sea turtle-shark interactions (scavenging or predation) comes from analysis of shark stomach contents (Heithaus et al., 2008). Here, although not the primary objective of the sea turtle stranding research program, we used stranding data to gain insights into shark-turtle interactions in Brazilian waters.

Sharks are the most important predator of large juvenile and adult sea turtles and only re-

Table 4. Results of a logistic regression model exploring the factors influencing the probability of a green turtle having a wound. Non-significant interactions were removed from the final model. Bold type indicates significant values. CCL, curved carapace length.

Source	DF	L-R ChiSquare	Prob > ChiSquare
Season	3	0.30520994	0.96
CCL	**1**	**27.83219**	**<0.0001**
Year	7	13.755609	0.056
Region	**2**	**10.748114**	**0.005**

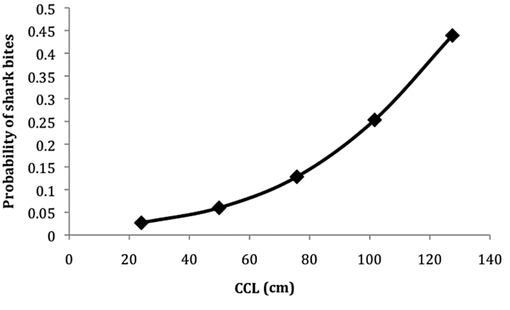

Figure 4. Size-related variation in predicted probabilities of a stranded green turtle having a shark bite based on logistic regression. CCL, curved carapace length.

cently has the potential importance of predation been considered in detail (see Heithaus et al., 2008). Although there are limited data on tiger shark diets in Brazilian waters (see Gasparini and Sazima, 1995; Shibuya, Rosa and Gadig, 2005; Bornatowski, Robert and Costa, 2007), turtles are an important component of the diets of individuals >250 cm total length in many locations around the world (e.g., Lowe et al., 1996; Simpfendorfer, Goodreid and McAuley, 2001; Heithaus et al., 2008). The frequency of bites on stranded turtles suggests that they also likely are important food sources for at least tiger sharks in Brazilian waters.

The frequency of green turtles with bite marks increased with turtle size. Although turtles would be expected to accumulate wounds over the course of their lives, relatively few stranded turtles bore healed wounds. It is possible that sharks selectively target large individuals, but it is more likely that this relationship is due to differences in the probability that small turtles are ingested whole, whether as carcasses

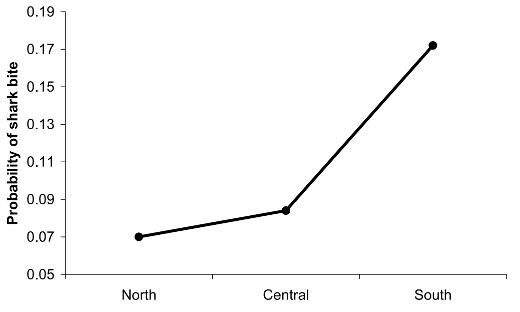

Figure 5. Regional variation in predicted probabilities of a stranded green turtle having a shark bite based on logistic regression.

or if attacked while alive (e.g. Heithaus et al., 2008). Indeed, Gasparini and Sazima (1995) recorded a whole hawksbill turtle (34 cm CCL) in the stomach of a tiger shark of *ca*. 250 cm TL in northeastern Brazil and whole small green turtles have been found in tiger sharks in other areas of the world (C. Simpfendorfer, pers. comm.).

Interestingly, the probability that a stranded green turtle had been scavenged or bitten pre-mortem varied across the study area. The probability that a carcass had bites was nearly twice as high in the southern portions of the study area. The reasons for this difference are not immediately apparent but warrant further investigation. There are no reefs near shore in the southern regions, which may increase the probability of a carcass stranding with bite marks.

The frequency of bitten turtles in northeastern Brazil (10.0%) is comparable to studies in other areas of the world (e.g., Heithaus et al., 2002; Chan, 2004; Balaz, 2006; Chaloupka et al., 2008) (table 5). One difficultly in interpreting patterns of shark-inflicted bites and other wounds among studies is attributing bites to those that were the cause of turtle death (or pre mortem) and those that were scavenging events. In the Gulf of Mexico, 35.1% of nesting Kemp´s ridley turtles had healed carapace damage and three (8.0%) had rear flipper damage, but was impossible determined if injuries were from shark bites, boat collision, or propeller cuts (Witzell, 2007). In Shark Bay, Australia, bite marks frequencies were determined for living turtles captured by hand (Heithaus, Frid and Dill, 2002; Heithaus et al., 2005). The rate of shark-inflicted injuries to green turtles (*ca.* 8%) was higher than our minimum estimates of pre-mortem attacks on stranded turtles in Brazil (2.4%). Shark predation on turtles, however, has been observed several times in Brazil. In the Abrolhos Archipelago, also northeastern Brazil, a tiger shark of *ca.* 250 cm total length was observed chasing a green turtle about 45 CCL cm (R.B. Francini-Filho, pers. comm.). In the same Archipelago, a tiger shark was observed eating a leatherback turtle alive. Both anterior limbs of the turtle had been removed (L. Wedekin, pers. comm.). Therefore, it is possible that we underestimated the actual rate of unsuccessful shark attacks on turtles in Brazil.

Although our study suggests that shark-sea turtle interactions may be important for both predator and prey in Brazilian waters, future studies at sea are needed to determine the fre-

Table 5. Comparison across multiple studies of bite frequencies. LK, *Lepidochelys kempii*; LO, *Lepidochelys olivacea*; CM, *Chelonia mydas*; CC, *Caretta caretta*; EI, *Eretmochelys imbricata*.

Locality	Species	Total with bite marks (pre or post mortem)	Proportion attacked alive	Reference
Texas, EUA	LK	2.3%	–	Shaver, 1998
Tamaulipas, Mexico	LK	35.1%*	–	Witzell, 2007
Hawaii, EUA	CM	~3.0%	–	Balazs, 2006
Hawaii, EUA	CM	2.7%	–	Chaloupka et al., 2008
North Carolina, EUA	CM	<0.1%	–	Chan, 2004
Shark Bay, Australia	CM, CC	–	CM ~ 8.0%, CC > 60%	Heithaus et al., 2002
Northeastern Brazil	EI, LO, CM	EI 3.0%, LO 20.0%, CM 10.4%	LO 33.0%, CM 2.4%	Present study

* It was not possible to distinguish injury from shark bites, boat collisions, and propeller cuts.

quency of shark-turtle interactions, the possible influence of sharks on sea turtle behavior and populations, and the relative importance of sea turtles (both dead and alive) as a source of food for sharks. Because both sharks and sea turtles can play important roles in marine ecosystems and have significant economic and cultural value (Bjorndal and Jackson, 2003; Heithaus et al., 2005; Nakaoka, 2005; Ferretti et al., 2010; Lal et al., 2010), such studies are important for understanding the dynamics of coastal marine ecosystems in Brazil.

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