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Incidental catch of sea turtles by the Brazilian pelagic longline fishery

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*This paper presents data on the incidental catch of sea turtles in both the Brazilian exclusive economic zone and adjacent international waters (both areas are located mainly in the south-western Atlantic) by Brazilian commercial pelagic longliners targeting swordfish, tuna and sharks. Data were obtained by on-board observers for 311 trips carried out in 2001–2005, totalling 7385 sets and 11,348,069 hooks. A total of 1386 sea turtles were incidentally captured in the five years (some of them were considered dead at capture): 789 loggerheads (*Caretta caretta*), 341 leatherbacks (*Dermochelys coriacea*), 45 green turtles (*Chelonia mydas*), 81 olive ridleys (*Lepidochelys olivacea*) and 130 of unknown species. Taking into account the distribution of the fishing effort in the study area and the incidental catch of sea turtles, four regions were highlighted for the analyses: Zone 1 is located off the northern Brazilian coast; Zone 2 is located off the central Brazilian coast; Zone 3 is the region off the southern Brazilian coast; and Zone 4, located in the open sea almost totally within international waters, is the region around a chain of undersea mountains known as the Rio Grande Rise (Elevação do Rio Grande). There is no information on the origin (nesting areas) of the captured olive ridleys, but there is some evidence, obtained through genetic and demographic analyses, that loggerheads, leatherbacks and green turtles inhabiting the open ocean around Brazil originate from nesting areas in several countries. Together with the fact that the south-western Atlantic is fished by longliners again from several countries, this places the conservation of sea turtles in that part of the ocean in an international context. Some conservation actions carried out by Brazil concerning the interaction between pelagic longlines and sea turtles in the study area are described.*

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INTRODUCTION

The incidental catch in coastal and oceanic fisheries is an important threat to sea turtles, causing the injury or death of a considerable number of turtles and bringing losses to fishers due to lower productivity and damage to the gear (National Research Council, 1990; Hall *et al.*, 2000; Lewison *et al.*, 2004). Incidental catches are a matter of special concern at the present time, as six out of the seven extant species of sea turtles—the leatherback (*Dermochelys coriacea*, Vandelli, 1761), the green turtle (*Chelonia mydas*, Linnaeus, 1758), the loggerhead (*Caretta caretta*, Linnaeus, 1758), the hawksbill (*Eretmochelys imbricata*, Linnaeus, 1766), the olive ridley (*Lepidochelys olivacea*, Eschscholtz, 1829), and the Kemp's ridley (*Lepidochelys kempii*, Garman, 1880)—are currently classified as either Endangered or Critically Endangered by the World Conservation Union (IUCN, formerly the International Union for Conservation of Nature and Natural Resources; IUCN, 2007).

Research on the incidental catch of sea turtles by pelagic longlines has been conducted, especially in the North Atlantic (Witzell, 1984, 1999; Ferreira *et al.*, 2001, 2003), in the Pacific (Balazs & Pooley, 1994; Lewison *et al.*, 2004) and in the Mediterranean (Aguilar *et al.*, 1995; Gerosa & Casale, 1999). Relatively few studies have been performed until now in the South Atlantic (Barata *et al.*, 1998; Achaval *et al.*, 2000; Kotas *et al.*, 2004; Pinedo & Polacheck, 2004; Carranza *et al.*, 2006). Lewison *et al.* (2004) and Lewison & Crowder (2007) provided overviews of the impact of pelagic longlines on sea turtles.

Pelagic longlines have been used in Brazil since 1956, when some Japanese longline vessels were chartered by a Brazilian company based in Recife, state of Pernambuco (Hazin *et al.*, 1998). The first longline vessels in Brazil targeted tuna (*Thunnus* spp.) and used multifilament longlines (Hazin *et al.*, 2002). In 1994, part of the fleet based in Santos, state of São Paulo, targeting the swordfish (*Xiphias gladius*, Linnaeus, 1758), started to use monofilament longlines, baited with squid and light sticks (Amorim *et al.*, 2002). The improved results achieved with the new gear enhanced its quick adoption throughout the Brazilian longline fleet, and since 1997 that fleet, targeting swordfish, tuna (mainly *Thunnus albacares*, Bonnaterre, 1788, *T. alalunga*, Bonnaterre, 1788 and *T. obesus*, Lowe, 1839) and sharks (mainly *Sphyrna* spp., *Carcharhinus* spp., *Prionace glauca*, Linnaeus, 1758, and *Isurus oxyrinchus*, Rafinesque, 1810), has largely been operating with monofilament longlines (Chinese chartered vessels which operated until 2006 in the Brazilian exclusive economic zone (EEZ) from the port of Recife, state of Pernambuco, used a different kind of longline, in which

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monofilament segments alternated with multifilament segments, and part of the longline fleet based in Itaipava, state of Espírito Santo, fishing in more coastal waters over the continental platform, use multifilament longlines (Coluchi *et al.*, 2005)). Currently, the main ports used by the longline fleet in Brazil are: Belém (state of Pará; code P1 in Figure 1), Natal (Rio Grande do Norte; P2), Cabedelo (Paraíba; P3), Recife (Pernambuco; P4), Itaipava (Espírito Santo; P5), Santos (São Paulo; P6), Itajaí (Santa Catarina; P7) and Rio Grande (Rio Grande do Sul; P8).

Five species of sea turtles are found in Brazil: leatherback, loggerhead, green turtle, olive ridley and hawksbill (Marcovaldi & Marcovaldi, 1999). At the end of 2001, Projeto TAMAR (TAMAR), the national Brazilian sea turtle conservation programme (Marcovaldi & Marcovaldi, 1999), put into action a national plan for the reduction of incidental catch of sea turtles in Brazilian fisheries (Marcovaldi *et al.*, 2002), which includes the continued assessment of the level of incidental catches of sea turtles by pelagic longlines. The objective of this paper is to present an overview of the situation regarding the incidental catch of sea turtles by the Brazilian commercial pelagic longline fishery in the Brazilian EEZ and adjacent international waters for the five year period between 2001 and 2005. The article focuses on the following questions: (i) what is the distribution of the longline fishing effort in the study area?; (ii) which species of sea turtles interact with pelagic longlines in that region?; (iii) what are the rates of incidental catch of sea turtles by species?; (iv) which size-classes of sea turtles are incidentally captured for each species?; and (v) are there any areas where the interaction between sea turtles and pelagic longlines is more intense or of greater concern in regard to the conservation of sea turtles?

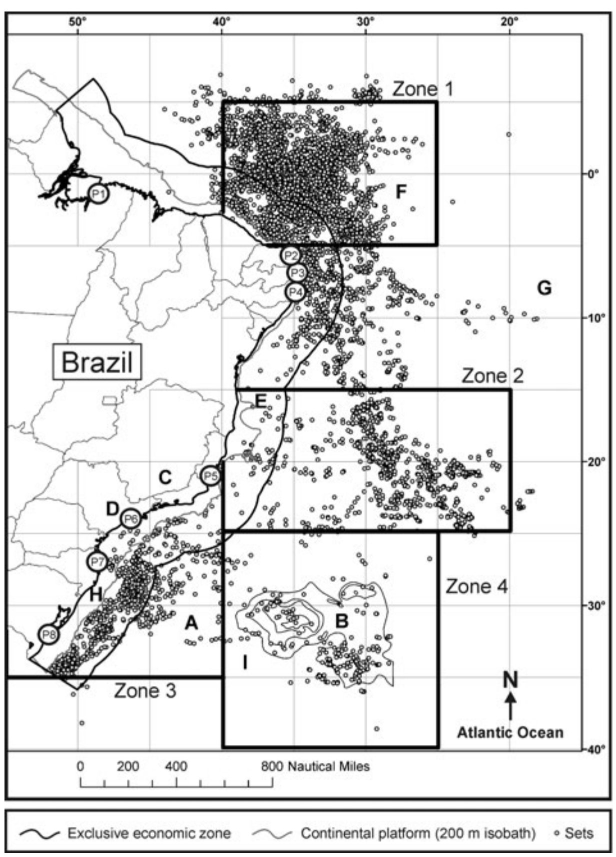

Fig. 1. Map of Brazil and the part of the Atlantic Ocean around it. Each small circle indicates the location of a pelagic longline set in the sample. The main ports used by the Brazilian commercial pelagic longline fleet are indicated by codes P1 to P8 placed inside circles located on the coastline (to relate the codes to the ports' names, see Introduction). The four Zones that have been highlighted for the analyses are delimited by black borders (see Results). Inside Zone 4 isobaths are shown indicating the location of the Rio Grande Rise. Some quadrants of 5° of latitude and 5° of longitude mentioned in the text are tagged by letters A to I (see Materials and Methods)

MATERIALS AND METHODS

The Brazilian commercial longline fleet is composed of both Brazilian-owned and foreign chartered vessels, and incidental catches of sea turtles by the two kinds of fleet have been analysed together in this study. Differences in longline fishing techniques (size of vessels, target species, kind of pelagic longline, number of hooks per set, type of hook and bait, etc.) were not considered in this article, and here all pelagic longline activities by the Brazilian commercial fleet targeting swordfish, tuna and sharks were considered as a whole.

Recently, Brazilian legislation (Decree No. 4810, 19 August 2003) has been approved which requires that observers be placed on-board foreign chartered vessels, but no law requires observers on-board the Brazilian-owned fleet. However, with the cooperation of fishing industry managers, captains and crew, some trips by Brazilian-owned longline vessels have been monitored by on-board observers of TAMAR and partner institutions, generating data for the fishing sector and research studies. Accordingly, in this study we present data on the incidental catch of sea turtles collected by observers on-board both Brazilian-owned and foreign chartered commercial vessels in the period between 2001 and 2005. The study area, which includes both waters in the Brazilian EEZ and international waters, is essentially the part of the Atlantic Ocean between latitudes 10°N and 40°S and between longitudes 15°W and 55°W (Figure 1). Most of that area is located within the south-western Atlantic, but a relatively small part is within the north-western Atlantic.

In this study data are presented: (i) on the total fishing effort performed by the Brazilian longline fleet each year, measured by the total number of hooks used by the fleet; and also (2) on the fishing effort in the trips that make up the sample, that is, the trips which were monitored by observers on-board some longline vessels; that effort is also measured by the total number of hooks used in these trips (Table 1). Unless explicitly stated otherwise, in the analyses to follow the expression 'fishing effort' will always mean the total number of hooks in the sample. Furthermore, all information on the number of captured turtles, capture rates and size of the turtles refers to the sample, not to the whole fleet.

For each trip in the sample, the number of longline sets, as well as the date, geographical position (latitude and longitude) of the vessel at the start of each set and the number of hooks deployed in each set, were recorded. In the statistical analyses, data from 2001–2005 were pooled, that is, they were not analysed separately by year, so the analyses do not address possible annual, seasonal or other temporal variation in the fishing effort and/or incidental catch of sea turtles. Data were

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Table 1. Number of vessels and hooks in the Brazilian longline fleet and number of vessels, trips and hooks in the sample by year, 2001–2005. Some information is presented separately for Brazilian-owned and foreign chartered vessels.

Year	Brazilian longline fleet		Sample			
	Vessels (Brazilian-owned/ chartered)	Hooks	Vessels (Brazilian-owned/chartered)	Trips (Brazilian-owned/chartered)	Hooks (Brazilian-owned/chartered)	Hooks used in the sample as a percentage of the number of hooks used by the whole fleet
2001	123 (55/68)	17,163,003	4 (4/0)	6 (6/0)	81,361 (81,361/0)	0.47
2002	129 (55/74)	10,073,499	5 (5/0)	8 (8/0)	123,800 (123,800/0)	1.24
2003	119 (55/64)	4,619,819	6 (4/2)	7 (5/2)	177,270 (73,558/103,712)	3.85
2004	89 (55/34)	8,853,851	38 (7/31)	114 (9/105)	4,379,278 (91,379/4,287,899)	49.5
2005	99 (61/38)	12,605,815	36 (4/32)	176 (10/166)	6,586,360 (388,105/6,198,255)	52.3
Total		53,315,987		311	11,348,069	

analysed by quadrants of 5° of latitude and 5° of longitude, although most of the results are presented by Zones, which are large areas of the ocean (groupings of 5° by 5° quadrants) defined by geographical characteristics (see Results). Some quadrants mentioned in the text are (southernmost/westernmost coordinates): A = 35°S 45°W, B = 35°S 35°W, C = 25°S 45°W, D = 25°S 50°W, E = 20°S 40°W, F = 5°S 30°W, G = 10°S 20°W, H = 30°S 50°W and I = 35°S 40°W (Figure 1). The catch-per-unit-of-effort (CPUE, number of turtles caught/1000 hooks) in the sample was calculated separately for each sea turtle species.

Data on the total fishing effort performed by the Brazilian longline fleet each year, measured by the total number of hooks used, were obtained from ICCAT's (International Commission for the Conservation of Atlantic Tunas) TASK II data set (available from ICCAT, Calle Corazón de María 8, 28002 Madrid, Spain; http://www.iccat.es). ICCAT's data originate from Brazil's own data on the total fishing effort. However, considering that: (i) the total fishing effort (the total number of hooks) obtained from the Brazilian longline fleet come from the vessels' own log books; and (ii) according to the authors' experience, many times the number of hooks is not correctly recorded in the log books, or it is not even recorded, we believe that for some or all years the total fishing effort is underestimated. Nevertheless, these are the best data available on the total fishing effort by the Brazilian longline fleet, and we believe they give us at least an order of magnitude estimate of the actual total fishing effort.

Whenever on-board observers were trained by TAMAR to measure turtles and identify the species, the curved carapace length (CCL, nuchal notch to posteriormost tip of carapace; Bolten, 1999), and condition (i.e. if the animal was alive or dead) of the turtles at capture were recorded; animals with no apparent movement were considered dead (although they may have been alive but comatose). Some of the live turtles incidentally caught were tagged on the proximal part of the trailing edge of both of the front flippers with inconel tags (National Band and Tag Company, Newport, KY, USA; style 681; Balazs, 1999); leatherback turtles were tagged on the hind flippers, following standard TAMAR procedure (Thomé *et al.*, 2007). To compare the CCL of captured green, loggerhead and leatherback turtles to carapace length data found in the literature, whenever necessary published straight carapace lengths (SCLs) were converted to CCLs by using the formulae in Teas (1993).

Geographical data were processed by means of the software ArcView 8.2 (Minami, 2000). CPUEs were compared by means of Fisher's exact tests, and CCLs were compared by means of Kruskal–Wallis tests (Zar, 1996). Statistical tests were carried out with the software R 2.4.1 (R Development Core Team, 2006); alpha = 0.05 (probability of a type I error).

RESULTS

Data were obtained for a total of 311 trips (38 trips by Brazilian-owned commercial vessels and 273 trips by foreign chartered commercial vessels) between 2001 and 2005, corresponding to 7385 sets and 11,348,069 hooks (Table 1; Figure 1). The number of hooks in the sample (the fishing effort) increased from 81,361 in 2001 (all of these hooks were set by Brazilian-owned vessels), amounting to 0.47% of the total number of hooks used by the Brazilian longline fleet in that year, to 6,586,360 hooks in 2005 (388,105 hooks set by Brazilian-owned vessels and 6,198,255 hooks by foreign chartered vessels), amounting to 52.3% of the total number of hooks used in that year (Table 1).

Taking into account the distribution of the fishing effort in the study area and the incidental catch of sea turtles, four regions, Zones 1, 2, 3 and 4, were highlighted for the analyses (Figure 1): Zone 1 is located off the northern Brazilian coast; Zone 2 is located off the central Brazilian coast, and includes two chains of undersea mountains, the Vitória–Trindade chain (20–21°S 29–38°W) and the Abrolhos chain (16–18°S 35–38°W); Zone 3 is located off the southern Brazilian coast; and Zone 4, located in the open sea, is the area around a chain of undersea mountains known as the Rio Grande Rise (Elevação do Rio Grande, 31°00′S 34°30′W), located approximately 600 nautical miles off the southern Brazilian coast. Each of the four Zones includes both waters

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Table 2. Areas, number of vessels, number of hooks in the sample, fishing effort density in the sample (hooks per square nautical mile), number of captures, catches-per-unit-effort (CPUEs) (turtles/1000 hooks) and condition of the turtles at capture (dead or alive) by Zone and species, 2001–2005. The number of vessels is presented separately for Brazilian-owned and foreign chartered vessels.

Zone	Approximate area, square nautical miles	Number of vessels in the sample (Brazilian-owned/chartered)	Number of hooks in the sample (per cent of total)	Hooks per square nautical mile	Loggerhead		Leatherback		Green		Olive ridley		Species unknown
					Captures (A/D/NR)	CPUE	Captures (A/D/NR)	CPUE	Captures (A/D/NR)	CPUE	Captures (A/D/NR)	CPUE	Captures (A/D/R)
Zone 1	528,000	24 (0/24)	7,400,215 (65.2%)	14.0	9 (6/0/3)	0.0012	84 (48/3/33)	0.0114	28 (16/2/10)	0.0038	71 (28/10/33)	0.0096	86 (33/7/46)
Zone 2	711,000	20 (3/17)	1,257,795 (11.1%)	1.8	17 (3/1/13)	0.0135	44 (16/0/28)	0.0350	4 (1/0/3)	0.0032	3 (1/1/1)	0.0024	6 (1/2/3)
Zone 3	448,000	18 (13/5)	1,099,920 (9.7%)	2.5	458 (421/17/20)	0.4164	168 (155/2/11)	0.1527	9 (9/0/0)	0.0082	2 (2/0/0)	0.0018	10 (10/0/0)
Zone 4	810,000	13 (6/7)	344,350 (3.0%)	0.4	300 (286/11/3)	0.8712	26 (25/1/0)	0.0755	0	0.0000	0	0.0000	6 (6/0/0)
Outside of the four Zones		35 (3/32)	1,245,789 (11.0%)		5 (2/2/1)	0.0040	19 (10/0/9)	0.0153	4 (3/0/1)	0.0032	5 (4/0/1)	0.0040	22 (9/0/13)
Total		110 (25/85)	11,348,069 (100%)		789		341		45		81		130

A, alive; D, dead; NR, condition not recorded.

in the Brazilian EEZ and international waters, but Zone 4 is almost wholly within international waters (Figure 1).

The area where the highest fishing effort was recorded was Zone 1, with 7.4 million hooks (65.2% of the total number of hooks in the sample in the five years); this is also the area with the highest fishing effort density, 14.0 hooks per square nautical mile in the five years. Zones 2 and 3 had approximately the same fishing effort (about 1.1–1.3 million hooks) and fishing effort density (about 1.8–2.5 hooks per square nautical mile). The lowest fishing effort (0.34 million hooks) and fishing effort density (0.4 hooks per square nautical mile) were observed in Zone 4. Outside of the four Zones there occurred 11.0% of the fishing effort (Figure 1; Table 2). Although there are sufficient data to calculate the percentage that the fishing effort in the sample represents of the total fishing effort by the whole Brazilian commercial longline fleet in the whole study area in each year (Table 1), there are no data on the total number of hooks used by the whole fleet in each of the above described Zones in the study period, so it is not possible to calculate the percentage that the sample's fishing effort in each Zone represents of the total fishing effort (i.e. by the whole fleet) there.

A total of 789 loggerheads were incidentally caught in the five years. Although there were captures of loggerheads in all latitudes between 10°N and 40°S, most (97.9%) of them occurred at latitudes equal to or to the south of 20°S, despite the much higher fishing effort in Zone 1 (Table 2; Figure 2). Loggerhead CPUEs were significantly different among the four Zones (Fisher's exact test, $P < 0.0001$; Table 2); the highest loggerhead CPUEs were observed in Zone 3 (0.4164/1000 hooks) and mainly in Zone 4 (0.8712/1000 hooks). In the region of Zone 4 between latitudes 30°S and 35°S, right over the Rio Grande Rise (three 5° by 5° quadrants; Figure 2) there occurred 88.7% of all loggerhead captures in Zone 4 and 33.7% of the loggerhead captures in the whole study; the CPUE for that region was 1.1550/1000 hooks (fishing effort = 230,308 hooks). Some 5° by 5° quadrants in Zones 3 and 4 had particularly high loggerhead CPUEs: quadrant A (in Zone 3, adjacent to Zone 4) had the highest loggerhead CPUE among all quadrants in this study, 2.1668/1000 hooks (fishing effort = 37,383 hooks), and quadrant B (the central quadrant of Zone 4) had a CPUE of 1.4163/1000 hooks (fishing effort = 132,036 hooks).

A total of 624 loggerheads were measured; most of them (97.3%) were captured in Zones 3 and 4 (Table 3). Their CCL ranged between 39 and 103 cm; other loggerhead CCL summary statistics are presented in Table 3 for the whole study area and also by Zone. Among the measured loggerheads, 95.5% had CCL equal to or smaller than 70 cm, a value (i) smaller than the minimum CCL of 71 cm reported by López-Jurado *et al.* (2003) for loggerheads nesting between 1998 and 2001 in the Cape Verde Archipelago, Africa, (ii) smaller than the minimum size of 83 cm of loggerheads nesting in Brazil between 1982/1983 and 1999/2000 (Kotas *et al.*, 2004), and (iii) also smaller than the minimum carapace sizes (converted to CCL whenever necessary) described by Dodd (1988) for other nesting populations in the Atlantic. Loggerhead CCL was significantly different among the four Zones (Kruskal–Wallis test, $P < 0.0001$, $N = 624$), and was higher in Zones 1 and 2 than in Zones 3 and 4 (Table 3).

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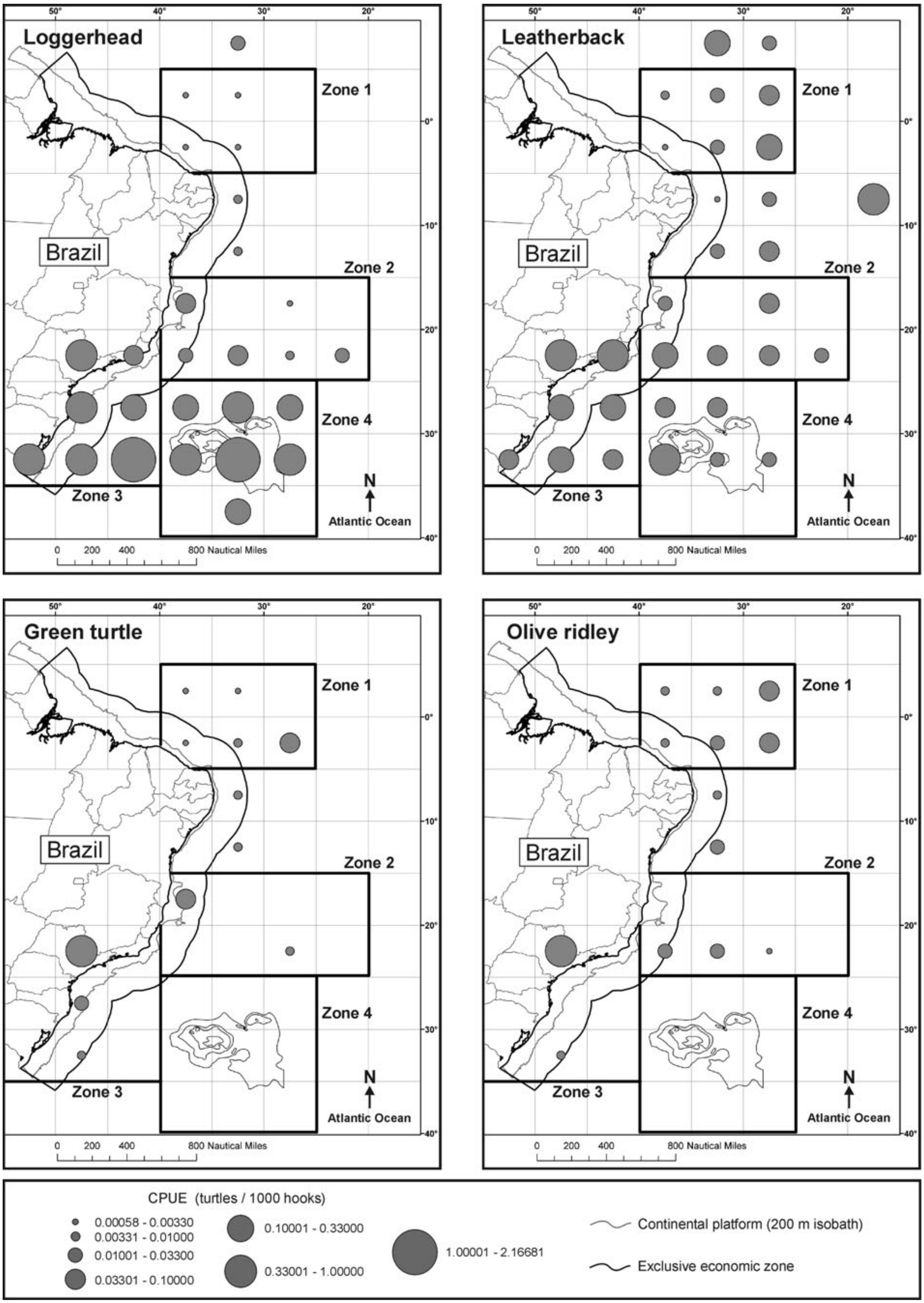

Fig. 2. Catch-per-unit-of-effort (CPUE) in the sample by quadrants of 5° of latitude and 5° of longitude, by sea turtle species. Inside Zone 4 isobaths are shown indicating the location of the Rio Grande Rise.

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Table 3. Number of loggerhead and leatherback turtles measured and tagged, and curved carapace length data (cm) by species, by Zone, 2001–2005.

Zone	Loggerhead					Leatherback				
	Measured (tagged)	Min and Max	Mean (SD)	Median	Quantiles 0.10 and 0.90	Measured (tagged)	Min and Max	Mean (SD)	Median	Quantiles 0.10 and 0.90
Zone 1	3 (0)	59–72	65.3 (6.5)	65.0	59–72	27 (0)	50–170	116.4 (34.7)	125.0	60–150
Zone 2	14 (1)	55–103	70.8 (13.4)	66.5	59–95	8 (0)	80–170	117.5 (31.5)	100.0	80–170
Zone 3	410 (229)	39–98	58.2 (7.3)	57.5	50–67	14 (8)	127–194	155.2 (22.7)	155.5	130–185
Zone 4	197 (168)	39–103	57.0 (7.4)	56.0	48–67	3 (1)	90–140	119.7 (26.3)	129.0	90–140
All four Zones	624 (398)	39–103	58.1 (7.7)	57.0	50–67	52 (9)	50–194	127.2 (34.7)	130.5	80–170

Min, minimum; Max, maximum; SD, standard deviation.

A total of 341 leatherbacks were incidentally captured. Leatherbacks were caught in all latitudes between 10°N and 35°S (Table 2; Figure 2). However, leatherback CPUEs were significantly different among the four Zones (Fisher's exact test, $P < 0.0001$; Table 2); the highest leatherback CPUEs were observed in Zone 3 (0.1527/1000 hooks) and in Zone 4 (0.0755/1000 hooks). The highest leatherback CPUEs in the study were observed in quadrants C (CPUE = 0.9763/1000 hooks; fishing effort = 33,800 hooks) and D (CPUE = 0.7050/1000 hooks; fishing effort = 2837 hooks), both located in Zone 3 close to the coast of the states of São Paulo, Rio de Janeiro and Espírito Santo (Figure 1), but it should be observed that the fishing effort in quadrant D was quite small. Quadrant G (not belonging to any of the four Zones; Figure 1) had a relatively high leatherback CPUE (0.4916/1000 hooks), but that was due to the capture of just one turtle with a quite small fishing effort (2034 hooks).

A large number of leatherbacks, 21 turtles, were captured in just one set (29°47′1″S 47°32′1″W; 1100 hooks) in quadrant H of Zone 3 (Figure 1) on 8 August 2001 by the vessel *Yamaya III* (based in Itajaí, state of Santa Catarina; Figure 1), targeting swordfish (*Xiphias gladius*), tunas (*Thunnus spp.*) and sharks (*Sphyrna* spp., *Carcharhinus* spp. and *Prionace glauca*). In that set, sea surface temperature was 22.8°C, but the kinds of hooks and baits were not recorded. These 21 leatherbacks, which amounted to 12.5% of all leatherbacks captured in Zone 3 (Table 2), were all released alive. A large number of leatherbacks, 19 turtles, were also captured in just one set (30°31′40″S 35°28′58″W; 1400 hooks) in quadrant I of Zone 4 (Figure 1) by the vessel 'Camburi' (based in Santos, state of São Paulo; Figure 1) on 12 May 2002. That vessel was targeting the same kind of fish as the 'Yamaya III'. In that set, sea surface temperature was 23.0°C, the bait was the Argentine short fin squid (*Illex argentinus*, Castellanos, 1960), but there was no record of the kind of hooks. The 19 leatherbacks were all released alive to the sea; they amounted to 73.1% of all leatherbacks captured in Zone 4 (Table 2).

A total of 52 leatherbacks were measured (Table 3); their CCL ranged between 50 and 194 cm; other leatherback CCL summary statistics are presented in Table 3 for the whole study area and by Zone. Leatherback CCL was significantly different among the four Zones (Kruskal–Wallis test, $P < 0.01$, N = 52), and was highest in Zone 3 (Table 3). A total of 19 measured leatherbacks (36.5% of the measured leatherbacks in the sample) had CCL equal to or smaller than 124 cm, the minimum CCL of leatherbacks nesting in the Atlantic (Thomé *et al.*, 2007). A total of 15 leatherbacks (28.8% of the leatherbacks that were measured in the sample) had CCL equal to or smaller than 101 cm, the carapace size (converted to CCL) reported by Eckert (2002) at which a shift in habitat by leatherbacks from warmer tropical waters to higher latitude colder waters might occur. Among these 15 small leatherbacks, 9 turtles were found in Zone 1 (CPUE = 0.0012/1000 hooks), 5 in Zone 2 (CPUE = 0.0040/1000 hooks) and 1 turtle was found in Zone 4 (CPUE = 0.0029/1000 hooks); the CPUEs for these small leatherbacks were significantly different among Zones 1, 2 and 4 (Fisher's exact test, $P = 0.039$), and were highest in Zone 2.

A total of 45 green turtles were incidentally caught in the five years; there were captures of green turtles between latitudes 5°N and 35°S, but no green turtles were caught in Zone 4 (Table 2; Figure 2). Green turtle CPUEs were not significantly different among the four Zones (Fisher's exact test, $P = 0.142$; Table 2). A total of 31 green turtles were measured; their CCLs ranged between 27 and 90 cm, but 30 green turtles (96.8%) had CCL equal to or smaller than 75 cm. Other green turtle CCL

Table 4. Number of green turtles and olive ridleys measured and tagged, and curved carapace length data (cm) by species, by Zone, 2001–2005.

Zone	Green					Olive Ridley				
	Measured (tagged)	Min and Max	Mean (SD)	Median	Quantiles 0.10 and 0.90	Measured (tagged)	Min and Max	Mean (SD)	Median	Quantiles 0.10 and 0.90
Zone 1	18 (0)	27–72	53.7 (12.1)	55.0	30–70	48 (0)	36–80	52.5 (9.8)	52.5	41–63
Zone 2	4 (1)	39–90	63.3 (23.4)	62.0	39–90	3 (1)	35–64	51.7 (15.0)	56.0	35–64
Zone 3	9 (6)	34–75	44.9 (12.9)	39.0	34–75	1 (1)	59–59	59.0 (–)	59.0	59–59
Zone 4	–	–	–	–	–	–	–	–	–	–
All four Zones	31 (7)	27–90	52.4 (14.7)	50.0	36–72	52 (2)	35–80	52.6 (9.9)	53.5	41–63

Min, minimum; Max, maximum; SD, standard deviation.

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summary statistics are presented in Table 4 for the whole study area and by Zone. Among the 31 measured green turtles, 28 (90.3%) had CCL smaller than 73.5 cm, the minimum CCL of green turtles nesting in the Atlantic (Hirth, 1997; conversion from SCL to CCL was performed whenever necessary). Green turtle CCL was not significantly different among Zones 1, 2 and 3 (Kruskal–Wallis test, $P = 0.092$, $N = 31$).

A total of 81 olive ridleys were incidentally caught in the five years. Most (90.1%) of the olive ridleys were caught between latitudes 10°N and 10°S, where 73.3% of the total number of hooks in the sample (Table 1) were deployed; the olive ridley CPUE for the region between latitudes 10°N and 10°S (0.0088/1000 hooks) is significantly higher than the CPUE concerning the study area outside of that region (0.0026/1000 hooks) (Fisher's exact test, $P < 0.001$). Olive ridley CPUEs were significantly different among the four Zones (Fisher's exact test, $P < 0.001$; Table 2); the highest olive ridley CPUE was observed in Zone 1, and no olive ridleys were caught in Zone 4 (Table 2; Figure 2). A total of 52 olive ridleys were measured, and their CCLs ranged between 35 and 80 cm; other olive ridley CCL summary statistics are presented in Table 4 for the whole study area and by Zone. Among the 52 measured olive ridleys, 44 (84.6%) had CCL equal to or smaller than 62.5 cm, the minimum CCL of nesting females in the states of Sergipe and Bahia, where the large majority of olive ridleys nesting in Brazil occur; there are no other CCL measurements for olive ridley populations nesting in the western Atlantic and no published formulae to convert SCL to CCL for olive ridleys in the Atlantic (da Silva *et al.*, 2007). Olive ridley CCL was not significantly different among Zones 1, 2 and 3 (Kruskal–Wallis test, $P = 0.808$, $N = 52$).

In this study, some mortality was observed at capture for each sea turtle species incidentally caught (Table 2).

DISCUSSION

The fishing effort (number of hooks in the sample) has increased since 2001, and mainly since 2004 (Table 1), as a set of institutions (Universidade Federal Rural de Pernambuco (UFRPE; state of Pernambuco), Universidade do Vale do Itajaí (Univali; state of Santa Catarina), Instituto Albatroz (based in Santos, state of São Paulo), Núcleo de Educação e Monitoramento Ambiental (NEMA; Rio Grande, state of Rio Grande do Sul) and TAMAR) managed to place an increasing number of observers on board the Brazilian commercial longline fleet through the years, mainly as the result of the law, effective from 19 August 2003, which requires observers on-board foreign chartered vessels. The much higher proportion of fishing effort in Zone 1 (Figure 1; Table 2) is partly due to the facts that: (i) the foreign chartered vessels operating in that Zone, based in Natal, Cabedelo and Recife, usually spend a much longer period of time at sea (often about two months) than Brazilian-owned vessels (which typically spend about 20–25 d at sea); and (ii) the foreign chartered vessels typically use 2000–2500 hooks per set, while Brazilian-owned longliners typically use 1000–1300 hooks per set. Furthermore, as observers have been required by law on-board foreign chartered vessels since 19 August 2003, a relatively large amount of data were generated from that date on concerning these vessels. On the other hand, as Brazilian-owned vessels are not required by law to have observers on-board, the presence of observers on these vessels depended on special arrangements with fishing companies and crew, and so only some trips by these vessels had an observer on board. Table 2 shows the number of foreign chartered vessels and Brazilian-owned vessels in the sample by zone.

Among the five species of sea turtles that occur in the South Atlantic Ocean (loggerhead, leatherback, green turtle, olive ridley and hawksbill), to our knowledge only the hawksbill has never been reported as incidentally caught by longlines in that region. However, in the North Atlantic, three hawksbills were reported as caught in longline gear in 1992–1999 (National Marine Fisheries Service Southeast Fisheries Science Center, 2001). Ulloa-Ramirez & González-Ania (2000) also reported the capture of hawksbills by longlines in the Gulf of Mexico.

There are few reports of interactions between olive ridleys and longlines in the south-western Atlantic (Serafini *et al.*, 2002; Pinedo & Polacheck, 2004; Carranza *et al.*, 2006). In the present study, data on the incidental capture of 81 olive ridleys are presented. The fact that the olive ridley CPUE for the region between latitudes 10°N and 10°S is significantly higher than the CPUE concerning the study area outside of that region, and that, among the four Zones, the highest olive ridley CPUE was observed in Zone 1, suggests that the part of the ocean around the northern region of Brazil is a preferential habitat for olive ridley turtles. A small number of olive ridleys (about 1 turtle per year on average between 1994 and 2003) have been incidentally captured in fishing weirs or stranded at Almofala, state of Ceará, northern Brazil, within Zone 1, where TAMAR maintains a station (Projeto TAMAR, unpublished data, 2007), and an olive ridley nest was recorded there in 2002 (Lima *et al.*, 2003), but there is no further information on the distribution or ecology of olive ridleys in the region around northern Brazil. The olive ridley CPUE found in Zone 1 (0.0096 turtles/1000 hooks; Table 1) was significantly lower than that reported for olive ridleys incidentally captured by longlines in the Gulf of Guinea (0.38 turtles/1000 hooks; Carranza *et al.*, 2006) (Fisher's exact test, $P < 0.00001$).

The available data seem to indicate that both adult and juvenile olive ridleys were caught in longlines, although most of them should be juveniles (Table 4). At Almofala, state of Ceará, the olive ridleys which were incidentally captured in fishing weirs or stranded in the period between 1994 and 2003 had CCLs both smaller and larger than 62.5 cm, the minimum CCL of nesting females in the states of Sergipe and Bahia (da Silva *et al.*, 2007; Projeto TAMAR, unpublished data, 2007). There is no information on the origin (nesting areas) of the olive ridleys incidentally captured in this study. In the western Atlantic, the main nesting areas for olive ridleys are located in Suriname, French Guiana, and north-eastern Brazil, in the states of Sergipe and Bahia, but olive ridleys nest also in the eastern Atlantic in Africa (da Silva *et al.*, 2007).

The green turtle was the species with the lowest number of interactions with longlines. No green turtles were caught in Zone 4, but there was no significant difference in green turtle CPUEs among the four zones. Green turtle displacements have been recorded between north-eastern Brazil, a feeding area for green turtles, and the Caribbean region, Suriname/French Guiana and Ascension Island (United Kingdom) (Pritchard, 1973; Mortimer & Carr, 1987; Lima *et al.*, 2003). Although there was a relatively small number of green turtles

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reported from Zone 2 (Table 2), we consider that it is important to monitor the longline fleet in that region on a continued basis, as Trindade Island, the main nesting site for green turtles in Brazil and one of the main nesting sites in the Atlantic for that species, is located there (Moreira *et al.*, 1995).

The captured green turtles were generally juvenile or subadult animals. One green turtle caught approximately 160 nautical miles from Trindade Island had a CCL of 90 cm; that CCL, although smaller than the CCL of green turtles nesting on Trindade Island (minimum CCL = 101.0 cm, N = 465, data from 1982–1995; Moreira *et al.*, 1995), is well into the range of CCLs of nesting green turtles found in the Atlantic, where several rookeries with a relatively large annual number of green turtle nestings are found, mainly the one at Tortuguero (Costa Rica) (Hirth, 1997; Bjorndal *et al.*, 1999). Naro-Maciel *et al.* (2007) showed through genetic analyses based on mitochondrial DNA (mtDNA) that juvenile green turtles found at Almofala, state of Ceará, and at Ubatuba, state of São Paulo in south-eastern Brazil, originate largely from Ascension Island (United Kingdom) but also possibly from several other rookeries in the Atlantic, mainly Tortuguero (Costa Rica), Matapica (Suriname), Aves Island (Venezuela) and Trindade Island (Brazil).

The loggerhead turtle is the species with the highest estimated number of interactions with pelagic longlines all over the world (Lewison *et al.*, 2004). In the present study, the greatest loggerhead CPUE was observed in Zone 4 (0.8712/1000 hooks). Although the fishing effort (the number of hooks) in that Zone represented only 3% of the total effort, the loggerhead turtles captured in that region corresponded to 38% of the total number of loggerheads caught in the five years. In the south-western Atlantic, Achaval *et al.* (2000) found an average loggerhead CPUE of 1.18/1000 hooks in 9 trips by two Uruguayan longline vessels. Pinedo & Polacheck (2004) obtained a similar loggerhead CPUE (approximately 1.2 turtles/1000 hooks) in 41 sets (12,870 hooks) carried out by a Brazilian research vessel operating around southern Brazil. Kotas *et al.* (2004), monitoring 3 trips (34 sets and 33,650 hooks) by Brazilian commercial longline vessels operating in 1998 in Brazilian and international waters in the south-western Atlantic, found a loggerhead CPUE of 4.31/1000 hooks, which can be considered to be a very high CPUE; that CPUE is significantly higher than that found in this study for Zones 3 and 4 combined (a comparable region of the sea), 0.5248/1000 hooks (Fisher's exact test, $P < 0.00001$). Loggerhead CPUEs in the South Atlantic seem to be generally higher than those found in the North Atlantic. In the north-western Atlantic, Witzell (1999) found a loggerhead CPUE of 0.0751/1000 hooks; around the Azores, Ferreira *et al.* (2001) found a loggerhead CPUE of approximately 0.27/1000 hooks.

Zone 4 is the same region where Barata *et al.* (1998) found some of the highest CPUEs ever recorded for loggerheads worldwide (24.5/1000 hooks and 13.6/1000 hooks in each of two sets). That Zone is located exactly around the Rio Grande Rise (Elevação do Rio Grande; Figure 1), a region where depth ranges between 300 and 4000 m. Areas around seamounts are commonly good fishing grounds, being frequently visited by the tuna purse-seine fleet (Ariz *et al.*, 2002) and by longline vessels. The Rio Grande Rise is reported by some longline captains from Itajaí, state of Santa Catarina, and Santos, state of São Paulo, as a region where many sea turtles are incidentally caught. The relatively high CPUEs recorded in this study and by Barata *et al.* (1998) in the region around the Rio Grande Rise (Zone 4) suggest that that region is inhabited by relatively large numbers of loggerheads, and the fact that juvenile loggerheads are commonly found there (Table 3; Kotas *et al.*, 2004) suggests that that region could possibly be an important developmental habitat for that species. Further research on the occurrence of sea turtles in that region is clearly an urgent need.

Comparing the CCLs of the captured loggerheads with the CCLs of loggerheads from other populations in the Atlantic (see Results), it is possible to infer that most (about 95%) of the loggerheads incidentally caught were likely juvenile or subadult turtles. However, loggerheads of adult size were caught in all Zones (Table 3). The loggerhead is the species of sea turtle nesting in largest numbers on mainland Brazil (Marcovaldi & Marcovaldi, 1999). A genetic analysis (by means of mtDNA) of loggerhead turtles (N = 42) incidentally caught by the Brazilian commercial longline fleet in the south-western Atlantic (Brazilian and international waters between latitudes 30°S and 35°S approximately) indicated that only 45% of the captured turtles came from Brazilian nesting beaches; the other 55% came from unknown nesting areas, located possibly in Africa or even in the Indian Ocean (Soares, 2004). Loggerheads caught in longlines in the western North Atlantic were in the small juvenile to subadult size-range (Watson *et al.*, 2005).

The CPUE for leatherbacks in Zones 3 and 4 combined (0.1343/1000 hooks; Table 1) is significantly lower than the leatherback CPUE recorded by Kotas *et al.* (2004) for approximately the same area in the south-western Atlantic (0.59/1000 hooks) (Fisher's exact test, $P < 0.00001$). However, the CPUE for leatherbacks in those two Zones combined is significantly higher than the CPUE found by Witzell (1999) for leatherbacks in the North Atlantic, which was equal to 0.0710/1000 hooks (Fisher's exact test, $P < 0.00001$). The two quadrants where the largest leatherback CPUEs were observed were located in Zone 3, close to the coastline (quadrant C: CPUE = 0.9763/1000 hooks, and quadrant D: CPUE = 0.7050/1000 hooks), but there were captures of leatherbacks in all quadrants of Zone 3. In Zone 4 (leatherback CPUE = 0.0755/1000 hooks), a total of 26 leatherbacks were caught; however, 19 of them were caught in a single set (see Results).

No genetic analyses have been performed of the leatherbacks incidentally caught by the Brazilian longline fleet, which could contribute to clarify the natal origin of these turtles. Barata *et al.* (2004) present some information on the possible origin of leatherbacks stranded in southern Brazil; some of these strandings could possibly be the result of longline operations in the open ocean. These authors advance a demographic analysis that, by comparing the estimated average annual number of turtles nesting in the only known nesting area in Brazil (located in the state of Espírito Santo; Thomé *et al.*, 2007) to the estimated average annual number of strandings in southern Brazil, suggests that the Brazilian leatherback nesting area could not possibly be the sole source of the turtles stranded on the southern Brazilian coast. In the Atlantic, leatherbacks nest mainly in French Guiana and Suriname in South America, Trinidad in the southern Caribbean, and Gabon and Congo in western Africa, but there are other smaller rookeries in the Caribbean (Barata *et al.*, 2004). Furthermore, satellite telemetry data indicate that leatherbacks nesting in eastern South Africa can enter the South Atlantic (Hughes *et al.*, 1998; G.R. Hughes, personal

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communication, 2002). Recently, Billes *et al.* (2005) reported that four leatherback females flipper-tagged on nesting beaches in Gabon, western Africa, were found in the south-western Atlantic (three turtles in Brazil and one in Argentina), providing the first evidence of leatherback movement from Africa to South America. One of these four records was made by an observer on-board a Brazilian commercial longline vessel located within the Brazilian EEZ off the state of Rio Grande do Sul coast, which shows that leatherbacks from populations other than the Brazilian one are in fact interacting with longline fisheries around Brazil.

Leatherback populations in the Pacific are considered to be threatened with extinction, and recent studies indicate that fishing (in large measure with longlines) is at present one of the main reasons for the rapid decline of leatherback populations in that ocean (Spotila *et al.*, 2000; Lewison *et al.*, 2004). Modifications in fishing practice and closure of some areas to longline fishing have been proposed and/or implemented in the Pacific to deal with that situation (Lewison *et al.*, 2004).

Although a number of sea turtles were considered dead at capture in this study, the actual mortality of these animals due to the incidental catch in longlines may be higher than that observed at capture, due to factors such as wounds caused by hooks removed from turtles on-board, embedded hooks and lines, and the stress caused by the capture itself, as pointed out by Kotas *et al.* (2004); this situation can bring great uncertainty to the estimates of mortality for sea turtles incidentally captured in longlines (Balazs & Pooley, 1994; Eckert, 1994). In the present study, the turtles incidentally captured, and consequently at risk of death due to the capture, were often either relatively large juveniles or adult animals, with a relatively large reproductive value for their populations (Crouse *et al.*, 1987).

To obtain a clearer picture regarding the impact of Brazilian longliners on sea turtles, more detailed analyses would be necessary. Data on longline operations by seasons of the year, kind of fishing gear, target species (tuna, swordfish, sharks, etc.) and fishing grounds, as well as data on oceanographic, climatic and ecological factors, would be required to better understand the occupation of that part of the ocean by sea turtles, the spatial and temporal distribution of longline operations, and the impact of the longline fishery on sea turtles. These types of analyses would provide a more thorough basis for the proposal of conservation actions. Nevertheless, we believe that the information presented in this study already makes clear that the interaction between sea turtles and pelagic longlines within the Brazilian EEZ and adjacent international waters does occur at a level that raises some concern, given both the conservation status of the sea turtles species inhabiting that part of the ocean and the extent of longline operations in that area by vessels not only from Brazil but also from several other countries (Kotas *et al.*, 2004).

Besides the collection of data on the interaction between longline fishing and sea turtles, in order to form a database on this matter, some other actions are in progress in Brazil, partly in partnership with neighbour countries (mainly Uruguay), concerning the conservation of sea turtles in relation to longline fishing in the south-western Atlantic: (i) since 2003, when the south-western Atlantic Sea Turtle Specialist Group (the ASO network) was created (Fallabrino *et al.*, 2004), Brazil and Uruguay have adopted a joint, 'transboundary' approach to the analysis of sea turtle bycatch by longline vessels based in these two countries operating in that part of the ocean (Domingo *et al.*, 2006). Considering that sea turtles are migratory animals, this cooperative approach should provide a better understanding of the relationship between sea turtles and the longline fishery in the south-western Atlantic and should allow more effective conservation actions in that part of the ocean; (ii) since November 2004, TAMAR, partly supported by the National Oceanic and Atmospheric Administration of the United States government (NOAA) and in partnership with some Brazilian fishing companies, has been testing 10° offset, 18/0 circular hooks as substitutes for the 9/0 J hooks traditionally used by the largest part of the Brazilian longline fleet targeting swordfish, tuna and sharks (Swimmer *et al.*, 2006). This research, which parallels research by other countries on the same topic (Gilman *et al.*, 2006), aims for the employment by the longline fleet of fishing gear less threatening to sea turtles; the experiments which have been performed by longliners based in Santos and Itajai operating to the south of latitude 23°S, are expected to be finished by the end of 2007; and (iii) since August 2003, the presence of observers on board foreign chartered vessels has been mandatory. TAMAR has participated in all observer training courses (which are organized by Universidade Federal Rural de Pernambuco, Universidade do Vale do Itajaí, Núcleo de Educação e Monitoramento Ambiental and Instituto Albatroz, and are financed mainly by the Brazilian federal government, but also by municipal governments, universities and international non-governmental organizations), providing the trainees with the knowledge necessary to correctly identify the sea turtle species, to record data in the appropriate forms, and also to adequately handle and release sea turtles incidentally caught by the longline vessels.

Sea turtle conservation in relation to longline fishing in the south-western Atlantic (as in other oceans) is truly an international problem, calling for international cooperation (Trono & Salm, 1999; Crowder, 2000), inasmuch as (i) there is some evidence that sea turtles inhabiting the south-western Atlantic originate from nesting areas in several countries, and (ii) that part of the ocean is fished by longline vessels again from several countries. Brazil's conservation actions in the open ocean, which could have influence on the fate not only of turtles originating from Brazilian beaches but also of those originating from nesting beaches in other countries, are in accord with international agreements established by Brazil and also with recommendations by international organizations concerned with fishing policies and their impact on sea turtles. Brazil is a member of the International Commission for the Conservation of Atlantic Tunas (ICCAT), which issued in 2003 a resolution encouraging the parties to share information on the relationship between sea turtles and ICCAT fisheries and to take measures to diminish the impact of these fisheries on sea turtles (ICCAT Resolution 03-11; ICCAT, 2006). A technical consultation on the relationship between sea turtle conservation and fisheries, held in Thailand at the end of 2004 by the Food and Agriculture Organization of the United Nations (FAO), of which Brazil is a member country, issued a series of recommendations on the conservation of sea turtles in relation to fisheries (FAO, 2005). Brazil has also signed and ratified the Inter-American Convention for the Protection and Conservation of Sea Turtles, which has, in the Third Conference of the

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Parties, held in 2006, issued a resolution urging the parties to take actions concerning the reduction of adverse impacts of fisheries on sea turtles (resolution CIT-COP 3-2006-R2; Convención Interamericana para la Protección y Conservación de las Tortugas Marinas, 2006).

The actions which have already been taken by Brazil, some of them partly in partnership with neighbour countries, should represent first steps towards the conservation of sea turtles with regard to the threats posed by the pelagic longline fishery. Much has yet to be done.

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