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Nesting Ecology and Conservation of the Loggerhead Sea Turtle (*Caretta caretta*) in Rio de Janeiro, Brazil

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ABSTRACT. – **Loggerhead turtle (*Caretta caretta*) nesting in the Southwest Atlantic has been monitored for decades, but information from northern Rio de Janeiro State (Brazil) has been lacking until now. In this study, we documented 11,086 nests laid between the 1992/1993 and 2010/2011 nesting seasons (∼1000 nests per season) and found significant variations in incubation period and hatching success among in situ and relocated nests. Because loggerhead nests in Rio de Janeiro are presumed to produce a large proportion of male hatchlings because of lower average incubation temperatures, this area is an important component of loggerhead population biology and conservation in Brazil and the southwest Atlantic region.**

The main sea turtle nesting sites in Brazil have been protected since 1980 by Projeto TAMAR-ICMBio (TAMAR), the Brazilian sea turtle conservation program (Marcovaldi and Marcovaldi 1999). In Brazil, sea turtles are fully protected by law and are included in the Brazilian Red List of Threatened Species (Machado et al. 2008; Santos et al. 2011). Loggerheads (*Caretta caretta*) are currently classified as Endangered globally by the International Union for Conservation of Nature (IUCN 2011).

The loggerhead turtle is the most common species nesting along the mainland coast of Brazil (Marcovaldi and Marcovaldi 1999) and likely constitutes one of the largest remaining loggerhead nesting populations in the world (Marcovaldi and Chaloupka 2007). The main nesting area of loggerheads along the Brazilian coast extends from Sergipe, northeastern Brazil, to the northern state of Rio de Janeiro, eastern Brazil (Marcovaldi and Chaloupka 2007), where TAMAR maintains the Bacia de Campos station (Fig. 1).

TAMAR started beach monitoring and nest protection at Bacia de Campos Station in 1992, covering 8 km. In 2004, fieldwork was extended to 100 km of nesting beaches. Currently, the Bacia de Campos station is responsible for the protection of approximately 1000 loggerhead nests per season. Moreover, TAMAR has extended its activities in the state, and in addition to beach monitoring and nest protection, it has implemented actions for environmental conservation and local community involvement.

The loggerhead turtle has temperature-dependent sex determination (TSD), by which embryonic sex is determined by incubation temperatures (Marcovaldi et al. 1997). Although nesting regions in northeastern Brazil largely produce female hatchlings (Marcovaldi et al. 1997), nests laid in the state of Espírito Santo, in southeastern Brazil, produce more male hatchlings, attributable to lower average incubation temperatures (Baptistotte et al. 1999). Given that Rio de Janeiro is south of Espírito Santo (and further from the equator) one may assume that loggerhead nests laid in this area also produce a large number of male hatchlings. However, analyses of hatchling sex ratios along this area are lacking.

This paper presents information on nesting loggerheads from the northern part of Rio de Janeiro State. We evaluated data from 19 nesting seasons, focusing on information from the last seven nesting seasons, which followed similar spatial and temporal patterns. Additionally, we present information on major threats, seasonal and spatial distribution of nestings, incubation periods, and hatching success along the study area.

METHODS

Study Area and Period. — The area monitored by the Bacia de Campos station consists of 100 km of continuous coastline in the northern part of Rio de Janeiro State, including three municipal districts: Campos dos Goytacazes, São João de Barra, and São Francisco do Itabapoana (Fig. 1). From 2001 to 2005 the monitoring area also included the municipal district of Quissamã, which hosts part of the Restinga de Jurubatiba National Park. However, areas with relatively higher nesting density were prioritized to ensure better conservation results. The station is located in the town of Farol de São Thomé (lat 22°02′31.83″S, long 41°02′58.74″W), district of Campos dos Goytacazes. The region is characterized by the ''resting'' habitat, which consists of low lying salt-tolerant vegetation on coarse sandy soils. Campos has a wet and dry tropical climate, with average annual temperatures between 20° and 32°C, and average annual rainfall of 1300 mm, unevenly distributed through the year (FEEMA 1993). The shoreface of the area is a high-energy coastal segment and plays a critical role in sediments transference.

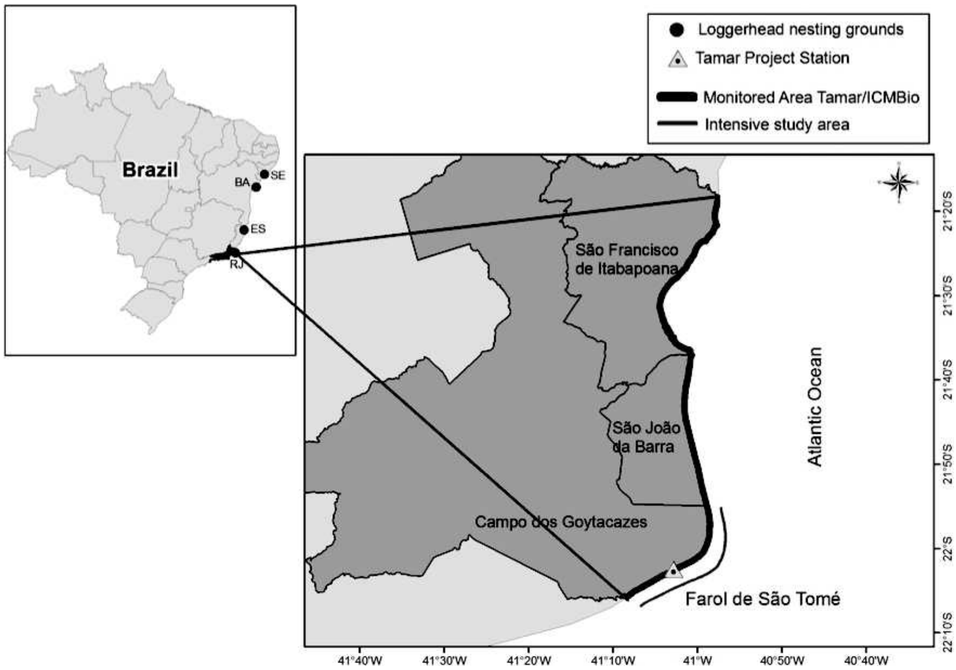

Figure 1. Map of the study area on the northern coast of Rio de Janeiro State. The thick black line shows the monitored area and the thin grey line indicates the Intensive Study Area (ISA) along the Farol de São Tomé beach. The map of Brazil on the left indicates the main nesting grounds for loggerheads located in the states of Sergipe (SE), Bahia (BA), Espírito Santo (ES), and Rio de Janeiro (RJ).

The loggerhead nesting season in Rio de Janeiro occurs during the austral summer, and most clutches are laid between September and March. Therefore, each nesting season is denoted by a two-year code (e.g., 2008/2009 [Marcovaldi et al. 2007]). The study period included the nesting seasons from 1992/1993 to 2010/2011; however, we focused on data from the last seven nesting seasons, which were obtained using standardized methods and effort. Moreover, nightly beach patrols were conducted during the 2004/2005 and 2008/2009 nesting seasons to tag nesting females, collect biometric data, and samples for genetic studies.

Data Collection. — From 2004/2005 to 2010/2011, a standard monitoring methodology was followed: the 100 km of monitored beach was divided into an Intensive Study Area (ISA) of 31 km and a Protection Area (PA) of 69 km to direct conservation efforts. The classification of a nesting area as either ISA or PA facilitates standardizing the monitoring methodology among all nesting areas on the Brazilian coast (Marcovaldi and Marcovaldi 1999).

Intensive Study Area (ISA). — An important characteristic of the ISA is the collection of data with full coverage such that all the information regarding nesting activities (i.e., incubation parameters, species identification, and hatching success) is fully captured. The ISA is located in the southern part of the study area, and it was patrolled by Tamar staff at least once daily during each nesting season. After nests were identified (track visualization and presence of eggs), clutches of eggs were either left in situ (I) or they were transferred (<100 m) to safe locations on the beach (B) or they were transferred to one of three open air hatcheries (H) located in the PAs. Nests were preferentially relocated in less than six hours or between 6 and 12 hrs after oviposition. The I and B nests, which were maintained on the beach, were covered with wire mesh grids to deter nest predators, such as crab-eating foxes (*Cerdocyon thous*) and domestic dogs, and they were marked with numbered wooden stakes, placed 100 cm away from the nests. The mesh size was large enough to allow hatchlings to pass through it during their emergence from the nest (Marcovaldi and Laurent 1996). After hatchling emergence, the nests were excavated within 24 hrs to identify the species (through the examination of dead hatchlings and embryos), to calculate hatching success, and to release hatchlings that could not exit the egg chamber by themselves. Hatching success was calculated by dividing the total number of live hatchlings (counted either directly or indirectly, by counting empty egg shells minus the number of dead hatchlings in the nest) by total clutch count (Marcovaldi and Laurent 1996). Incubation period was calculated as the number of days between clutch deposition and time of emergence of the first hatchlings (Marcovaldi and Laurent 1996).

Protection Areas (PAs). — The PAs included beaches located in the municipalities of São João da Barra and São Francisco do Itabapoana. These areas were patrolled daily by ''tartarugueiros'' (turtlers), who were local residents hired and trained by TAMAR (Marcovaldi and Marcovaldi 1999), working under direct supervision of the TAMAR staff. The management strategies used in the PAs were B, I, and H. Throughout the most recent seasons (2004/2005 to 2010/2011), three open-air hatcheries were maintained along these

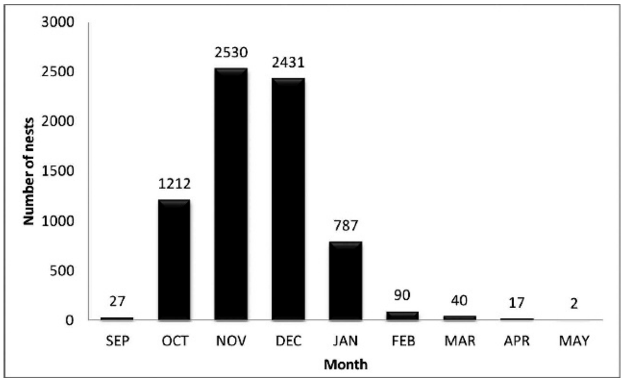

Figure 2. Number of observed loggerhead nests ($n = 7136$) in the northern region of the state of Rio de Janeiro, by month, from 2004/2005 to 2010/2011.

areas. From 2001/2002 to 2004/2005 the city of Quissamã was monitored as part of the PA. Because this area is a very low density nesting ground, the site is no longer monitored. The main difference between PA and ISA is that PAs are not considered high priority areas for data collection.

Night Patrols. — Continuous patrols were conducted nightly along 10 km in the southern area, between November and December 2004 and again between November and December 2008, by TAMAR station staff. Nesting females encountered were tagged with inconel metal tags (Style 681; National Band and Tag Co., Newport, KY) on the trailing edge of the front flippers and measured with a flexible tape during oviposition. Curved carapace length (CCL) was measured from the anterior point at midline (nuchal scute) to the posterior tip of the supracaudal scutes. Curved carapace width (CCW) was measured across the widest part of the carapace, perpendicularly to the longitudinal body axis (Marcovaldi and Laurent 1996).

Data Analysis. — Statistical comparisons of hatching success and incubation period among the seasons for in situ nests and among management practices in each season were carried out by means of nonparametric Kruskal-Wallis tests (Conover 1999), using the software R 2.15.0 (R Development Core Team 2012). In addition, post-hoc comparisons in each season for both hatching success and incubation period were performed with nonparametric Dunnett tests between in situ (I) nests, used as control, and relocated nests (B and H) using the package *nparcomp* of the R software (Konietschke 2011). Significance level for all tests was alpha = 0.05. Nests that were poached, predated, inundated, or otherwise destroyed were not included in the statistical analyses.

RESULTS

A total of 11,086 nests were laid between the 1992/1993 and 2010/2011 nesting seasons on the northern coast of Rio de Janeiro. The large majority of sea turtle nests in the area are loggerheads. Among 8216 nests with known species, 8205 (99.8%) were from loggerheads, three from olive ridleys, three from hawksbills, two from green turtles, and three from leatherback.

Table 1. Number of in situ nests (I), beach relocated nests (B), open air hatchery nests (H) per season, total number of nests per season (TN), days monitored (DM), and kilometer of beach monitored (km).

Nesting season	I	B	H	TN	DM	km
1992/1993	12	0	49	61	?[a]	8
1993/1994	5	0	75	80	?[a]	14
1994/1995	29	0	121	150	?[a]	53
1995/1996	12	0	247	259	?[a]	53
1996/1997	0	132	214	346	?[a]	53
1997/1998	0	0	64	64	45	53
1998/1999	10	0	48	58	11	53
1999/2000	0	0	78	78	114	53
2000/2001	11	148	87	246	138	60
2001/2002	32	419	379	830	150	153
2002/2003	0	113	668	781	180	120
2003/2004	75	35	887	997	150	120
2004/2005	159	117	637	913	151	120
2005/2006	284	322	321	927	150	122
2006/2007	307	276	238	821	150	74
2007/2008	210	256	554	1020	150	100
2008/2009	235	152	690	1077	211	100
2009/2010	275	157	324	756	212	69
2010/2011	373	203	1046	1622	212	100

[a] Unknown.

The loggerhead nesting season in the state of Rio de Janeiro extends from late September to March, with a peak in November and December (Fig. 2).

The mean annual number of nests laid between 2004/2005 and 2010/2011 was 1021 (SD = 288; range = 756–1622). The overall number of nests recorded per season since 1992 are shown in Table 1.

Between 2004/2005 and 2010/2011, hatching success for in situ nests was significantly different among the seasons (Kruskal-Wallis test, $p < 0.0001$). The annual average hatching success for in situ nests varied between 72.6% (in 2009/2010) and 80.9% (in 2007/2008). For each season between 2004/2005 and 2010/2011, hatching success was significantly different among I, B, and H nests (Kruskal-Wallis tests, $p < 0.005$ always). Nonparametric post-hoc tests showed that B and H nests had a significantly lower hatching success when compared to I nests in all seasons, except in 2006/2007 (Table 2). During that season, financial constraints limited the monitoring area and compromised the fieldwork; hence most I nests located within the PAs were not monitored until emergence. For relocated clutches, the annual average hatching success varied between 56.8% (in 2009/2010) and 81.4% (in 2006/2007) for B nests, and it varied between 61.2% (in 2005/2006) and 73.8% (in 2004/2005) for H nests (Table 2).

Between 2004/2005 and 2010/2011, incubation periods for in situ nests were significantly different among the seasons (Kruskal-Wallis test, $p < 0.0001$). The annual average incubation period for in situ nests varied between 54.7 d (in 2009/2010) and 66.8 d (in 2006/2007). For each season between 2004–2005 and 2010–

Table 2. Hatching success and incubation period for loggerhead in situ (I), beach relocated (B), and hatchery (H) nests from 2004/2005 to 2010/2011. Values are mean and sample size (*n*).

	Hatching success, % (*n*)				Incubation period, days (*n*)			
Season	I	B	H	*p*-value	I	B	H	*p*-value
2010/2011	78.01 (316)	68.77[a] (172)	64.64[a] (1015)	<0.0001	57.93 (299)	56.85[a] (165)	53.79[a] (1009)	<0.0001
2009/2010	72.59 (225)	56.76[a] (127)	62.10[a] (301)	<0.0001	54.7 (218)	56.18[a] (122)	51.94[a] (289)	<0.0001
2008/2009	75.03 (193)	61.05[a] (128)	65.83[a] (579)	<0.0001	64.76 (183)	67.32[a] (121)	61.33[a] (562)	<0.0001
2007/2008	80.88 (67)	60.16[a] (54)	61.91[a] (550)	<0.0001	59.57 (135)	59.07 (96)	54.92[a] (551)	<0.0001
2006/2007	78.92 (8)	81.37 (24)	65.03 (231)	0.0045	66.75 (39)	66.42 (45)	59.56[a] (231)	<0.0001
2005/2006	73.77 (76)	65.57[a] (62)	61.23[a] (280)	<0.0001	58.85 (116)	60.38 (99)	61.01[a] (294)	0.0007
2004/2005	78.03 (88)	66.22[a] (80)	73.8[a] (602)	<0.0001	60.43 (97)	61.15 (84)	59.09[a] (606)	<0.0001

[a] Significantly different from in situ (I) nests according to nonparametric Dunnett's post-hoc test.

2011, incubation period was significantly different among I, B, and H nests (Kruskal-Wallis tests, $p < 0.001$ always). Nonparametric post-hoc tests showed that H nests had a significantly lower incubation period when compared to I nests in all seasons, except in 2005/2006 (Table 2). Additionally, incubation period for B nests differed significantly from I nests in the 2008/2009, 2009/2010, and 2010/2011 nesting seasons. For relocated clutches, the annual average incubation period varied between 56.2 d (in 2009/2010) and 67.3 d (in 2008/2009) for B nests, and it varied between 51.9 d (in 2009/2010) and 61.3 d (in 2008/2009) for H nests (Table 2).

A total of 217 nesting females were tagged in Farol de São Thomé during the 2004/2005 and 2008/2009 nesting seasons. Over this period, the CCL was in the range of 86.5–114.5 cm (mean = 100.5, median = 100, SD = 5.7,) and the CCW was in the range of 80.5–105.0 cm (mean = 91.8, median = 91.5, SD = 4.7).

DISCUSSION

Reis et al. (2009) identified the loggerhead nesting population in Brazil as genetically distinct from other aggregations around the world. Evidence shows that the colonization of Brazilian rookeries probably occurred from the southern United States stock and that it possibly followed a north to south route along the Brazilian coastline, influenced by the warm Brazil Current. Furthermore, within Brazil two subpopulations have been identified, Rio de Janeiro/Espírito Santo nesters (southern stock) and Bahia/Sergipe nesters (northern stock) (Reis et al. 2009). These findings highlight the importance of the conservation of loggerhead rookeries at both the southern and northern parts of their nesting range in Brazil.

Variations in body size among different populations may be directly influenced by geographic location (Van Buskirk and Crowder 1994). Nesting loggerheads in Brazil and Florida have similar straight carapace lengths (Tiwari and Bjorndal 2000). In contrast, the Mediterranean loggerhead population comprises smaller individuals when compared to other populations (Margaritoulis et al. 2003). The mean CCL calculated for loggerheads nesting in Rio de Janeiro State is similar to the mean values reported for loggerheads nesting in Espírito Santo State (102.7 cm, $n = 198$; Baptistotte et al. 2003) and Bahia State, Brazil (102.8 cm, $n = 176$; Marcovaldi and Laurent 1996; 101.2 cm, $n = 29$; Tiwari 1998).

Hatching success for in situ nests was significantly greater than for relocated (H and B) nests (Table 2). The relocation of nests either to safe locations on the beach or into hatcheries is a conservation technique used for reducing threats to sea turtle eggs and hatchlings. It has been shown, however, that clutch relocation may significantly affect incubation conditions, thus modifying the hatching success (Eckert and Eckert 1990), hatchling fitness (Reece et al. 2002), or hatchling sex ratio (Mrosovski and Yntema 1980). According to Limpus et al. (1979) and Miller (1997), hatching success of transferred nests may be affected by rotation of the eggs during the relocation process, and the effect of egg movement increases greatly with time after oviposition (Baptistotte et al. 2003). Other factors, such as climate conditions and nest distance to the sea also appear to have some effect on the emergence pattern (Adam et al. 2007) and incubation periods (Marcovaldi and Laurent 1996).

Incubation periods for H nests were significantly shorter when compared with those of I and B nests (Table 2). This result is probably related to the exposure of the H nests to higher temperatures that increased metabolic rates of the embryos. Sea water has receded dramatically in Farol de São Thomé, increasing noticeably the distance between the water edge and the hatchery, which could possibly contribute to higher sand temperatures of H nests. This conclusion is of great concern, considering that sexual differentiation in sea turtle embryos is dependent on incubation temperature (Marcovaldi and Laurent 1996). Therefore, appropriate measures that emulate natural conditions (i.e., cooling the nests with shading or irrigation), which are based on the successful experience of all other hatcheries maintained by TAMAR along the coast, are currently being taken. TAMAR aims to leave every nest in situ. However nest relocation is sometimes necessary to mitigate threats such as regular inundation by tides, degradation of nesting habitat, artificial lighting, and uncontrolled beach use (Mortimer 1999; Garcia et al. 2003). Hatcheries should be appropriately managed such that relocated nests have incubation conditions as close as possible to in situ nests (Baptistotte et al. 2003).

Brazil is a large country with a wide range of weather conditions and significant temperature variation along the coast. Therefore, Brazilian sea turtle nesting populations are exposed to different nesting beach temperatures, which directly affect the hatchling sex ratio attributable to temperature-dependent sex determination (Marcovaldi et al. 1997). Loggerhead nests laid in Bahia produce a majority of female hatchlings (89%–98%), whereas in Espírito Santo, the reported rates for female hatchling production are lower (53%–70%) (Marcovaldi et al. 1997; Baptistotte et al. 1999). Although there are no direct data available on hatchling sex ratios in Bacia de Campos, it is likely that this area produces a large proportion of males. This is because it is located south of Espírito Santo and, thus, is expected to experience lower average sand temperatures. Therefore, hatchling production from Bacia de Campos likely contributes males to the larger Brazilian loggerhead metapopulation and, hence, contributes to the conservation value of loggerhead nesting in the state of Rio de Janeiro (Mrosovsky 1988).

Baptistotte et al. (1999) suggested that females produced in warmer areas mate with males that hatch on beaches further south. Therefore, long-term conservation of the Brazilian loggerheads requires protection of all rookeries in Brazil to ensure an appropriate gender composition.

Conservation Implications. — Loggerhead nesting in Brazil is confined largely to four states, including Rio de Janeiro, making Bacia de Campos an important rookery for this species in the south Atlantic (Marcovaldi and Chaloupka 2007). However, the northern coast of Rio de Janeiro also has one of the most productive oil and gas fields in Brazil (namely, Bacia de Campos). According to Jablonski (2008), most of the oil (85%) and natural gas (59%) produced in Brazil derive from offshore fields, largely concentrated in Bacia de Campos. Seismic surveys, as well as oil drilling, production, transportation, and refining, have the potential to cause serious impacts on sea turtle populations and their habitats (Holdway 2002). Oil spills, toxin exposure, pathogen pollution, and ingestion of marine debris are examples of potential human-induced contamination of the marine environment (Lutcavage et al. 1995; Love et al. 2003). Unplanned coastal development, destruction and alteration of nesting habitats, unsustainable tourism, and incidental bycatch in fishing gear are other threats to sea turtle populations along the northern coast of Rio de Janeiro.

Sea turtles have survived large climate fluctuations throughout history attributable to their great ability to adapt. However, the average temperature on Earth has been changing rapidly, in a short time frame, as a result of global warming (Hughes 2000). Extreme weather and climate change may cause sex ratio imbalances that could threaten population persistence or limit population growth (Hawkes et al. 2009). Additionally, with an increase in global temperatures, loggerheads may shift their nesting range to higher latitudes to reduce possible feminization. This has apparently occurred in the past, when warmer temperatures in interglacial periods facilitated the expansion of loggerheads into higher latitudes (Bowen et al. 1993). Therefore, the protection of Bacia de Campos nesting grounds may be crucial to assure sex ratio balance in loggerhead populations in Brazil.

It is relevant to reinforce that protection of sea turtles on nesting beaches alone is not sufficient to ensure their survival (Crouse et al. 1987). Understanding factors impacting juvenile survivorship, recruitment and others is critical for the conservation of populations. In addition to the environmental protection activities, TAMAR has aimed to incorporate human and social issues into all its initiatives, involving local communities in its conservation efforts (Marcovaldi et al. 2005).

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