Nesting biology and conservation of the olive ridley sea turtle (*Lepidochelys olivacea*) in Brazil, 1991/1992 to 2002/2003

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This article presents biological data and an assessment of the conservation of the olive ridley sea turtle (*Lepidochelys olivacea*) population nesting in the States of Sergipe and Bahia, north-eastern Brazil, between 1991/1992 and 2002/2003. Projeto TAMAR-IBAMA (the Brazilian Sea Turtle Conservation Programme) maintains seven field stations in that region to monitor nesting activity over 339 km of beach. An increasing trend was observed in the estimated number of nests per nesting season: from 252 nests in 1991/1992 to 2606 in 2002/2003, an approximately 10-fold increase in 11 years. The available data and biological knowledge suggest that TAMAR's conservation efforts may have contributed to the significant increase in olive ridley nesting in Sergipe and Bahia; that increase is not only of regional importance, but also of significance at the western Atlantic level.

INTRODUCTION

The olive ridley sea turtle (*Lepidochelys olivacea*; in Portuguese: 'tartaruga-oliva', 'tartaruga-pequena' or 'tartaruga-comum') has a nearly circumglobal distribution in tropical waters (Márquez, 1990). This species is currently classified as Endangered by the International Union for the Conservation of Nature (IUCN, The World Conservation Union; Red List Standards & Petitions Subcommittee, 1996). In the eastern Atlantic, nesting by olive ridleys has been reported in Africa between Guinea-Bissau and Angola (Fretey, 2001). In the western Atlantic, this species has limited distribution and nests mainly in Suriname, French Guiana, and north-eastern Brazil (Fretey, 1999; Marcovaldi, 2001).

In Brazil, olive ridley nesting is concentrated in the State of Sergipe and the northern section of the State of Bahia (Figure 1). North of this region, a single olive ridley nest was recorded in April 2002 in the State of Ceará (Lima et al., 2003; Figure 1); nesting by olive ridleys is known to occur on the southern State of Alagoas coast (contiguous to the State of Sergipe; Figure 1), but no reliable information on the annual number of nests is available (Projeto TAMAR-IBAMA, the Brazilian Sea Turtle Conservation Programme, unpublished data, 2006). To the south of Sergipe and Bahia, a small number of olive ridley nests (1–4 per season) were recorded in the State of Espírito Santo (Marcovaldi & Marcovaldi, 1999; Figure 1). Other sea turtle species nesting in the States of Sergipe and Bahia are loggerheads (*Caretta caretta*), hawksbills (*Eretmochelys imbricata*) and, in small numbers, green turtles (*Chelonia mydas*) (Marcovaldi & Marcovaldi, 1999).

Projeto TAMAR-IBAMA (Marcovaldi & Marcovaldi, 1999) began working in Sergipe and northern Bahia in 1982,

initially at Pirambu (Sergipe) and Praia do Forte (Bahia) and later extended its activities to other sections of the coastline. When TAMAR started working in Sergipe, nearly all clutches were being collected for human consumption and local inhabitants indicated that no hatchlings had been
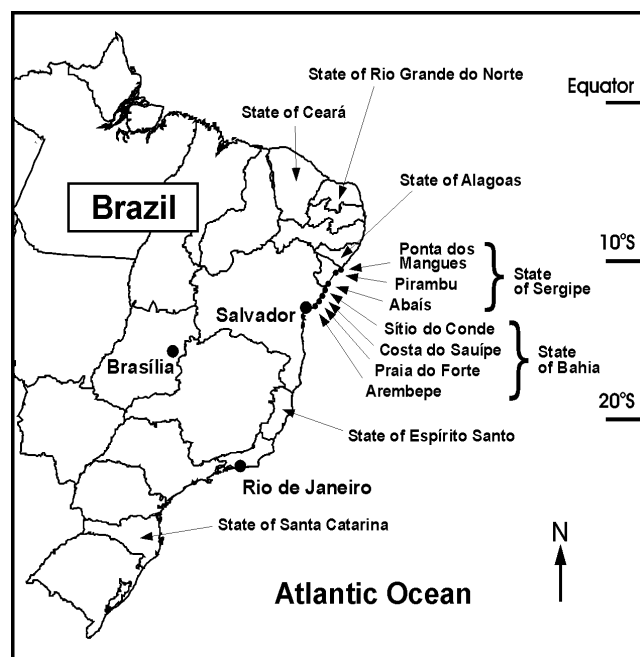
Figure 1. Map of Brazil, showing the location of the three TAMAR stations in the State of Sergipe and the four stations in the State of Bahia. Other Brazilian states mentioned in the text are also indicated.

seen for more than 15 years. In Bahia, human habitation was low and the beaches were not easily accessible, and nest poaching although prevalent was not as intensive as in Sergipe. It is interesting to note that although olive ridleys are known to form 'arribadas' (large nesting aggregations) on many beaches (Márquez, 1990), there are no observations, historical records or oral accounts by old fishermen of arribadas in the study area.

Today, TAMAR maintains seven field stations in Sergipe and northern Bahia to monitor nesting activity over 339 km of beach. Additionally, TAMAR since the beginning sought to incorporate the interests and needs of the coastal communities in its conservation work through various educational, economic and cultural activities. Given the intensive monitoring and conservation efforts of TAMAR in Sergipe and northern Bahia, the objectives of this article are to describe the population trend and reproductive biology of olive ridleys nesting in that region over 12 nesting seasons as well as to assess management practices and the relative importance of the Brazilian population.

MATERIALS AND METHODS

Study area and period

In the States of Sergipe and Bahia, TAMAR covers 339 km of beach between latitudes 10°31'S (the mouth of the São Francisco River, at the border between the States of Sergipe and Alagoas) and 12°28'S (Salvador, the State of Bahia capital) (Figure 1). In Sergipe, nesting activity is monitored at three TAMAR stations: Ponta dos Mangues (36 km), Pirambu (53 km) and Abaís (36 km), covering 125 km of beach (Figure 1); a central portion of Sergipe's coast measuring about 38 km, around Aracaju, the state capital, is not monitored—nowadays, a very small number of sea turtle nestings occur in that area, possibly as a result of anthropic actions. In Bahia, nesting is monitored at four TAMAR stations: Sítio do Conde (80 km), Costa do Sauípe (57 km), Praia do Forte (30 km) and Arembepe (47 km), covering 214 km of beach (Figure 1).

The northern part of the State of Bahia and the State of Sergipe are located within the tropical zone, with warm temperatures and a dry summer (climate Am in Koeppen's classification; De Blij & Muller, 1993). The coastline of Sergipe is composed of high energy beaches with an open, rock-free offshore approach. Beaches are backed by coastal sand dunes with lagoons located relatively close to the dunes in some areas. In northern Bahia, much of the coastline consists of sandy beaches with rocks and coral reefs located close to shore; the beaches are generally backed by coastal sand dunes and seasonal or permanent wetlands. Sand in the study area varies from coarse to fine grained, and from yellow to white in colour.

The nesting season for olive ridleys in Brazil is during the austral summer, from September to March, so each nesting season is denoted by a two-year code, e.g. 1994/1995. As nestings have been observed in all months of the year, a definite date is needed to mark the start of each season, which has been arbitrarily defined as 1 July. Although TAMAR began its activities in the study area in 1982, only data from 1991/1992 onwards are used, because of the availability of data for the whole study area only from that season. The

study period includes 12 nesting seasons, from 1991/1992 to 2002/2003.

Data collection

TAMAR's regular fieldwork is carried out from 15 September to 15 March. This period has been chosen because it has been TAMAR's experience (obtained from beach surveys), and common knowledge among local people, that the large majority of sea turtle nesting in the study area occurs in that period. Information on nestings occurring outside the regular monitoring period arrive only opportunistically to TAMAR; these nestings are assumed to be no more than 1–2% of the annual total.

Although TAMAR's goal has been to leave every nest *in situ*, clutches that were at risk from tidal inundation, predators, poaching (collection of eggs for human consumption), beach illumination, or habitat alteration were either transferred to open beach hatcheries or to another location on the beach. Hired fishermen, who worked under the supervision of TAMAR's biologists, surveyed the beaches every morning, located and counted nests laid the previous night, marked those that would incubate *in situ*, and collected those clutches that needed to be transferred to open beach hatcheries or to other sections of beach under the management of TAMAR's stations. In years with economic restrictions, some beaches with known low levels of poaching were simply monitored for numbers of nests laid with no relocation; on some of these beaches, the turtles' tracks and nesting attempts were erased, making it harder for the nests to be located. On these beaches, all clutches were left *in situ*, under TAMAR's protection, but no nest inventory was carried out after hatching; it is hypothesized that these nests most likely underwent normal incubation. Due to economic restrictions in some years, some areas under TAMAR's management were monitored only during part of a nesting season, and occasionally they were not monitored at all.

Date of laying and date of hatchling emergence were recorded for all nests on monitored beaches or in hatcheries. Nests monitored *in situ*, in the hatcheries or at the transferred location on the beach were excavated after emergence, to determine clutch size and number of live hatchlings. The clutch species was identified, if possible, by examining dead or live hatchlings in the nest. In this article, we also use data on clutches identified as belonging to other species or not identified to species when estimating the total number of olive ridley clutches in each season; more explanation follows below. All nesting data have been entered into TAMAR's standardized national database.

Nesting females were found mainly opportunistically on the beaches during regular fieldwork. Females encountered when nesting were tagged (monel tags, National Band and Tag Co., USA, style 681) and curved carapace length (CCL) and curved carapace width measurements were taken with flexible plastic tapes. Projeto TAMAR's field methodology has been described in detail by Marcovaldi & Laurent (1996) and Marcovaldi & Marcovaldi (1999).

Data analyses

To estimate the total number of olive ridley nests per season, data for each season were analysed at the level of individual beaches in Sergipe (12 beaches) because of

marked differences in the temporal coverage of monitoring on each beach. In Bahia, due to the nearly homogeneous temporal monitoring coverage among the beaches in the area under the management of each station, data for each season were analysed at the level of each TAMAR station, i.e. for all beaches combined for each station. The results for all individual beaches in Sergipe and stations in Bahia were then summed to estimate the total number of olive ridley nests in a season. The estimation method took into account the possible variation in the relative proportion of nests laid by the different sea turtle species on each beach or in each station area, as well as the varying temporal coverage among the different beaches and stations. All nests were used in this analysis, regardless of whether they were left *in situ*, transferred to a hatchery, or relocated to a different section of the beach. The procedure used to estimate the number of nests per season is described below.

For each beach or station, a crude estimate of the number of olive ridley nests in a season was determined. This estimate was the sum of the number of nests known to belong to olive ridleys and the number of olive ridley nests estimated from nests of unknown species that were recorded. To estimate the number of olive ridley nests from nests of unknown species, the number of nests of unknown species was multiplied by the ratio: number of olive ridley nests/number of nests of known species. The nests for which the species was known were regarded as a random sample of the total number of nests laid on the beach or in the station area.

A further correction was made: the crude estimate of olive ridley nests in a season was corrected for incomplete temporal monitoring of the beach or station. For the State of Sergipe, the following procedure was used: in each season, in the area under the management of each station, data on the temporal distribution of olive ridley nests from a reference beach (i.e. a beach on which monitoring was consistent throughout the nesting season) were used to correct for incomplete monitoring of the other beaches in the area in that season. In Sergipe, the three reference beaches were Pirambu (12 km in length), Abaís (12 km) and Ponta dos Mangues (8 km). Each of these beaches forms the central management section of each TAMAR station in Sergipe, and was consistently monitored in all seasons, providing the best available temporal distribution data of olive ridley nests. The temporal distribution, which was computed from the deposition date of all olive ridley nests on the reference beach, was assumed to be valid for all beaches in the area under the management of the particular station. To calculate a final estimate of the total number of olive ridley nests laid on a non-reference beach during the season, the crude estimate of olive ridley nests for the non-reference beach was divided by the proportion of olive ridley nests laid on the reference beach during the period of actual monitoring of the non-reference beach. Whenever a specific beach was not monitored in a given season, the number of nests laid on that beach for that season was estimated as the average of the estimated number of nests laid in the previous and following seasons; this happened only five times in a total of 144 beach years. For the State of Bahia, the above procedure was applied on a station by station basis, and for each station the complete temporal distribution of olive

ridley nests for the entire State of Bahia in the season was used as the reference distribution.

The above estimation procedure is, by construction, consistent in the sense that the estimated number of olive ridley nests in a beach (or station in Bahia) tends to the number of nests known to belong to olive ridleys as the number of nests of unknown species tends to zero and the actual period of monitoring of the beach (or station in Bahia) tends to the complete monitoring period of the reference beach (or of the entire State of Bahia).

An estimate of the variance of the estimate of the number of olive ridley nests laid on the beach or in the station in the season was obtained by nonparametrically bootstrapping (with 1000 resamplings) the entire estimation procedure for each beach or station outlined above (Efron & Tibshrani, 1993). In each season, an estimate $\hat{x}$ of the total number of olive ridley nests in the whole study area was obtained by adding the estimates obtained for each beach or station. An estimate $\hat{\nu}$ of the variance of $\hat{x}$ was obtained by adding the estimated variances for each beach or station, on the assumption that the data were obtained independently from each beach or station (Rice, 2007). An estimate $\hat{s}$ of the standard deviation of $\hat{x}$ was then obtained by taking the square root of $\hat{\nu}$, which allowed us to calculate a standard 95% normal confidence interval $[\hat{x} - 1.96\,\hat{s}, \hat{x} + 1.96\,\hat{s}]$ for the estimated number of olive ridley nests in the season (Efron & Tibshrani, 1993). Data were processed by a computer program written in CA-Clipper 5.2 (Computer Associates International, Inc., 1992), using TAMAR's data stored in Dbase files. The random number generator described by L'Ecuyer (1988) was used for the bootstrapping.

To determine clutch size, hatching success, and incubation period, only nests left *in situ* or moved to the hatchery were used; olive ridley nests relocated to another section of the beach (5.2% of all olive ridley nests) were not included in the analyses because of small sample size. Clutch size distribution was compared among seasons using the Kruskal–Wallis test (Rice, 2007). Average clutch size in Sergipe and Bahia in each season was compared to that in Suriname (Schulz, 1975) using the *t* test (Rice, 2007).

Hatching success was calculated as the percentage of eggs that produced live hatchlings, including live hatchlings encountered during nest excavation. *In situ* hatching success was compared among seasons using the Kruskal–Wallis test. Additionally, the hatching success of nests *in situ* and in the hatchery were compared in each nesting season using the Mann–Whitney test (Rice, 2007). Incubation period was calculated as the number of days between nest deposition and time of emergence of the first hatchling. *In situ* incubation period was compared among seasons using the Kruskal–Wallis test. Incubation period was compared between *in situ* and hatchery nests in each season using the Mann–Whitney test.

A test for trend on the number of nests per season was performed by means of the nonparametric nonseasonal Mann–Kendall test (Hipel & McLeod, 1994). Tests for trend of the clutch size distribution and CCL distribution along the seasons were performed by means of the nonparametric Jonckheere–Terpstra test (Hollander & Wolfe, 1999); only the first CCL measurement of each turtle in each season
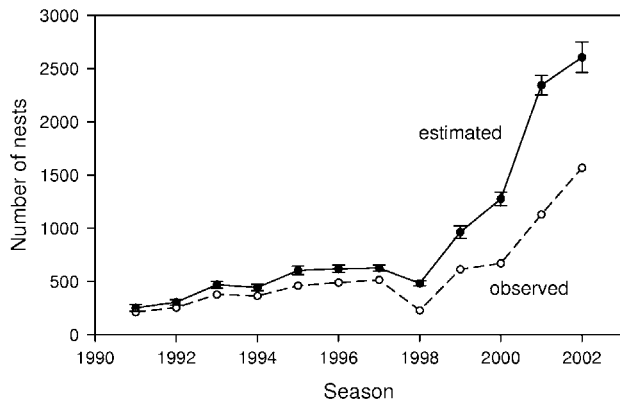
Figure 2. Observed (white points, N=6894) and estimated (black points, N=10,975) number of olive ridley nests in Sergipe and Bahia, 1991/1992 to 2002/2003. Error bars indicate 95% pointwise confidence intervals. The first year of each season is shown, e.g. 1992 = 1992/1993.
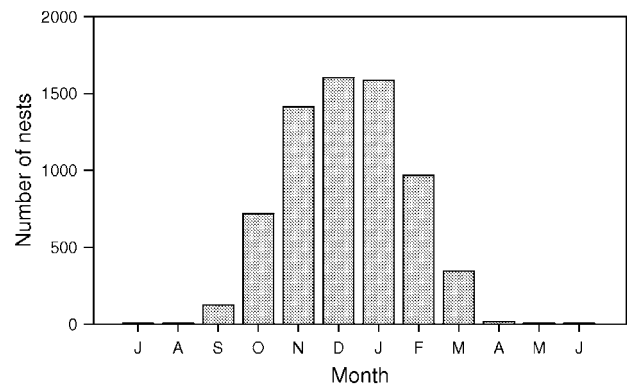
Figure 3. Number of observed olive ridley nests (N=6802) in Sergipe and Bahia by month, 1991/1992 to 2002/2003.

was included in the calculations (however, only the first measurement of each turtle, all seasons considered, was used to construct the complete CCL distribution). To assess the relationship between CCL and clutch size, a least squares linear regression was used (Rice, 2007). Statistical analyses were carried out with the softwares R 2.3.1 (R Development Core Team, 2006) and StatXact 4 (Mehta & Patel, 1998), with alpha (probability of type I error) = 0.05.

RESULTS

Temporal distribution of nests

An increasing trend was observed in the estimated number of nests per season, particularly after 1998/1999 (nonseasonal Mann–Kendall test, $P<0.0001$, N=10,996; Figure 2). The number of nests laid in 1991/1992 and in 2002/2003 was

estimated to be 252 and 2606, respectively, indicating an approximately 10-fold increase in 11 years.

Most (92.4%) of the observed nestings (N=6802) occurred between October and February; only 0.7% of the total number of observed nestings occurred between April and August (Figure 3). There are records of nests in all months of the year, but only in the 2002/2003 nesting season were there nests recorded in all months. Nesting occurs essentially at night; among 157 nestings which had the time of laying recorded, 93.6% occurred between 18:00 and 06:00 hours, and no nestings occurred between 09:00 and 15:00 hours.

Clutch size, curved carapace length and tagging data

The average CCL of nesting females was 73.1 cm (SE=0.24 cm, median=73.0 cm, range=62.5–83.0 cm, N=170). The CCL distribution was significantly different among

Table 1. *Percentage of olive ridley clutches (N=6896) and percentage of clutches of non-identified species (N=8752) left* in situ, *transferred to a hatchery or to another section of the beach, and the estimated percentage of olive ridley clutches among clutches of non-identified species, 1991/1992 to 2002/2003, Sergipe and Bahia. Sample sizes are within parentheses. TAMAR began transferring clutches to other sections of the beach in 1994/1995.*

	Species						Percentage of all clutches with species not identified estimated to have been laid by olive ridleys
	Olive ridley Management			Not identified Management			
Season	*In situ*	Hatchery	Beach	*In situ*	Hatchery	Beach	
1991/1992	3.3 (7)	96.7 (203)	0.0 (0)	70.7 (65)	29.3 (27)	0.0 (0)	12.1
1992/1993	3.1 (8)	96.9 (248)	0.0 (0)	36.9 (24)	63.1 (41)	0.0 (0)	12.6
1993/1994	23.9 (87)	77.0 (292)	0.0 (0)	72.4 (126)	27.6 (48)	0.0 (0)	15.6
1994/1995	14.5 (53)	81.9 (299)	3.6 (13)	31.9 (101)	50.8 (161)	17.4 (55)	14.7
1995/1996	9.1 (42)	85.7 (396)	5.2 (24)	39.6 (107)	33.7 (91)	26.7 (72)	18.3
1996/1997	10.0 (49)	81.6 (400)	8.4 (41)	61.2 (251)	19.0 (78)	19.8 (81)	20.3
1997/1998	17.5 (90)	77.3 (398)	5.2 (27)	74.9 (400)	13.1 (70)	12.0 (64)	22.0
1998/1999	25.3 (58)	71.2 (163)	3.5 (8)	58.9 (179)	24.7 (75)	16.4 (50)	14.3
1999/2000	25.9 (159)	68.1 (419)	6.0 (37)	85.6 (1081)	7.5 (95)	6.9 (87)	26.5
2000/2001	11.7 (79)	87.0 (587)	1.3 (9)	86.1 (1413)	9.3 (152)	4.7 (77)	25.5
2001/2002	15.6 (176)	82.7 (934)	1.8 (20)	81.1 (1698)	9.0 (189)	9.9 (208)	30.7
2002/2003	21.5 (338)	67.1 (1053)	11.4 (179)	75.0 (1189)	13.6 (216)	11.4 (181)	34.5

Table 2. *Hatching success and incubation period of olive ridley clutches left* in situ *and transferred to a hatchery, 1991/1992 to 2002/2003, Sergipe and Bahia. Values presented are mean ±standard error, range and sample size within parentheses.*

| Season	Hatching success			Incubation period		
	In situ	Hatchery	MW *P*-value	*In situ*	Hatchery	MW *P*-value
1991/1992	75.6 ±9.4 37.3–95.6 (7)	79.1 ±1.4 1.6–100 (203)	0.952	54.8 ±1.4 52–59 (5)	53.7 ±0.2 45–62 (198)	0.473
1992/1993	84.5 ±5.2 61.3–99.1 (8)	75.4 ±1.5 0.0–100 (247)	0.257	52.0 ±NA 52–52 (1)	51.6 ±0.2 45–69 (238)	0.821
1993/1994	80.3 ±2.8 0.0–100 (82)	81.1 ±1.1 0.0–100 (292)	0.299	49.8 ±0.3 41–57 (63)	50.4 ±0.1 46–61 (291)	0.055
1994/1995	81.5 ±3.1 3.5–98.0 (50)	83.5 ±1.0 0.0–100 (299)	0.735	50.0 ±0.3 47–55 (43)	51.3 ±0.2 47–94 (263)	0.001
1995/1996	84.4 ±2.9 0.0–98.9 (40)	75.2 ±1.0 1.0–100 (396)	0.001	51.2 ±0.5 46–59 (32)	51.2 ±0.2 44–61 (336)	0.945
1996/1997	85.2 ±2.2 24.0–100 (45)	79.5 ±1.0 2.5–100 (391)	0.019	50.4 ±0.4 46–56 (37)	51.0 ±0.1 46–71 (333)	0.113
1997/1998	81.4 ±2.1 0.0–98.9 (88)	74.0 ±1.1 0.0–100 (393)	<0.001	49.3 ±0.2 47–54 (49)	49.2 ±0.1 43–62 (359)	0.472
1998/1999	80.9 ±2.2 29.7–100 (57)	72.9 ±1.6 10.9–100 (160)	0.006	49.3 ±0.3 47–54 (28)	48.1 ±0.2 44–55 (98)	0.001
1999/2000	79.6 ±1.9 0.0–100 (147)	82.0 ±1.0 0.0–100 (403)	0.835	52.2 ±0.5 48–63 (46)	52.2 ±0.1 46–68 (342)	0.128
2000/2001	79.0 ±2.8 2.7–97.8 (66)	81.0 ±0.8 8.5–100 (544)	0.862	51.9 ±0.8 48–57 (10)	51.0 ±0.1 44–58 (493)	0.255
2001/2002	77.0 ±2.0 0.0–100 (158)	82.1 ±0.6 0.0–100 (825)	0.230	51.3 ±0.3 46–57 (50)	51.9 ±0.1 46–59 (767)	0.040
2002/2003	80.5 ±1.1 0.9–100 (286)	75.4 ±0.7 0.0–100 (969)	<0.001	50.8 ±0.5 46–72 (89)	50.1 ±0.1 44–75 (816)	0.660
Total	80.2 ±0.7 0.0–100 (1034)	78.7 ±0.3 0.0–100 (5122)		50.6 ±0.1 41–72 (453)	51.0 ±0.04 43–94 (4534)	

MW *P*-value = *P*-value of Mann–Whitney test comparing *in situ* and hatchery nests. NA, not applicable.

seasons; there was a decreasing trend in CCL over the years (Jonckheere–Terpstra test, *P*<0.001, N=174; Figure 4).

The average clutch size was 100.1 eggs (SE=0.29, median=102, range=4–182, N=6480). Clutch size distribution was significantly different among seasons; there was a decreasing trend in clutch size over the years (Jonckheere–Terpstra test, *P*<0.001, N=6480; Figure 4).

A positive relationship was found between clutch size and CCL (linear regression; r^2=0.072, *P*=0.004, N=111; Figure 5), although only 7% of the variation is explained.

Among 170 olive ridleys tagged between 1991/1992 and 2002/2003 on nesting beaches in Sergipe and Bahia, only eight turtles have been recaptured on the nesting beaches, three of them in the same season, and five turtles in subsequent years, with remigration intervals of 1 year (2 turtles), 3 years (1 turtle), 4 years (1 turtle) and 6 years (1 turtle); more data are needed to establish internesting and remigration intervals. Two olive ridleys tagged while nesting in Sergipe or Bahia were recaptured dead outside of the study area: (a) one turtle tagged in December 1993 in Abaís,
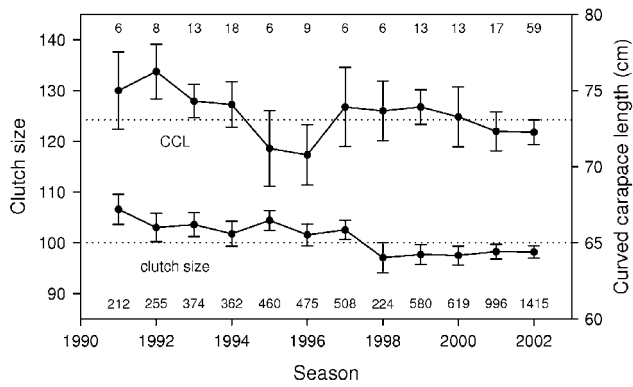
Figure 4. Average clutch size (N=6480) and average curved carapace length (CCL, N=174) by season for olive ridleys nesting in Sergipe and Bahia, 1991/1992 to 2002/2003. The first year of each season is shown, e.g. 1992=1992/1993. Error bars indicate 95% pointwise confidence intervals for the true average value. The upper dotted line indicates the average CCL for all seasons (=73.1 cm) and the lower one indicates the average clutch size for all seasons (=100.1 eggs). The upper row of numbers shows sample size for CCL by season, and the lower row shows that for clutch size.
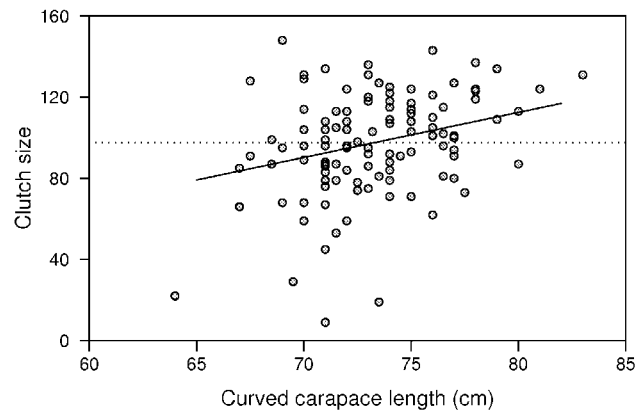
Figure 5. Clutch size by curved carapace length (CCL) of olive ridleys nesting in Sergipe and Bahia, 1991/1992 to 2002/2003 (N=113). The solid line is a linear regression (N=111); the points with the smallest (=64 cm) and largest (=83 cm) CCL were excluded from the linear regression computations, as they are relatively isolated from the main group of data and could have a relatively large influence on the results. The dotted horizontal line is the average clutch size (=97.5 eggs) of data points used in the regression.

Sergipe was found dead in January 1997 in Armação, State of Santa Catarina, southern Brazil (Figure 1; Marcovaldi et al., 2000); (b) one turtle tagged in January 1995 in Pirambu, Sergipe was found dead in January 1995 in Maceió, State of Alagoas (Figure 1; Marcovaldi et al., 2000). Furthermore, one olive ridley found dead in January 1996 just north of Salvador, Bahia (Marcovaldi et al., 2000) had been tagged in December 1990 in Abaís, Sergipe, but the initial tagging of this turtle occurred outside of the study period. No olive ridley tagged in Brazil has ever been recorded in another country.

Management practices

The percentage of olive ridley clutches that remained *in situ* each season ranged between 3.3 and 25.9%, and was always greater than 9.1% from 1993/1994 onwards; most of the clutches that were identified as belonging to olive ridleys were transferred to hatcheries (Table 1). However, among clutches that were not identified to species, the percentage that remained *in situ* was higher, and ranged between 31.9 and 86.1% between 1991/1992 and 2002/2003; among those clutches, the percentage that was estimated as belonging to olive ridleys increased along the seasons, from 12.1% in 1991/1992 to 34.5% in 2002/2003 (Table 1).

The overall average hatching success for *in situ* clutches was 80.2% (SE=0.7, median=88.7, range=0.0–100, N=1034; Table 2). *In situ* hatching success was not significantly different among seasons (Kruskal–Wallis test; H=11.04, P=0.440; N=1034; Table 2). The overall average hatching success for clutches relocated to a hatchery was 78.7% (SE=0.3, range=0.0–100, median=85.3, N=5122; Table 2). In five of the 12 seasons (between 1995/1996 and 1998/1999 and in 2002/2003), there was a significant difference between hatching success for *in situ* clutches and those transferred to a hatchery (Mann–Whitney test; P<0.05 in each season; Table 2); in each of these five seasons, the average *in situ* hatching success was higher than that of transferred clutches.

The overall average incubation period for *in situ* clutches was 50.6 days (SE=0.1, range=41–72, N=453; Table 2). *In situ* incubation period differed significantly among seasons (Kruskal–Wallis test; H=61.6, P<0.001, N=453; Table 2). The overall average incubation period for clutches relocated to a hatchery was 51.0 days (SE=0.04, range=43–94, N=4534; Table 2). In three of the 12 seasons (1994/1995, 1998/1999 and 2001/2002) there was a significant difference in the incubation period between *in situ* clutches and those transferred to a hatchery (Mann–Whitney test; P<0.05 in each season; Table 2). However, no clear pattern appears in these three seasons when comparing average incubation period between *in situ* and transferred clutches.

DISCUSSION

Population trend and biological parameters

Although marked inter-annual variability in nesting numbers is found in some sea turtle populations (Heppell et al., 2003), there was relatively little inter-annual variability in olive ridley nesting in Sergipe and Bahia, aside from the long-term trend (Figure 2). Together with the large increase in nesting numbers, this made it possible to detect a clear upward trend despite a relatively short time series.

Figure 2, which shows the estimated annual number of nests, also provides some information on the annual number of nesting females, as long as one takes into account the annual clutch frequency, which could vary among years. No reliable information is available in Brazil on the average olive ridley clutch frequency, which in Suriname is around 1.5–2 (Schulz, 1975). The average clutch frequency seems to be a relatively conservative, little varying characteristic for each sea turtle species (Van Buskirk & Crowder, 1994), so it is unlikely that variation in annual clutch frequency could explain to a large degree the approximately 10-fold increase in the estimated annual number of olive ridleys nests in Sergipe and Bahia between 1991/1992 and 2002/2003.

Most probably, the increasing trend in the estimated annual number of nests is nearly paralleled by an increasing trend in the annual number of nesting females.

Given the loss of the arribada and the observed decline in the annual number of nests in Suriname over the past 40 years and the uncertainty of nesting trends in French Guiana (Schulz, 1975; Hoekert et al., 1996; Fretey, 1999; Marcovaldi, 2001; Godfrey & Chevalier, 2004), the observed increase in olive ridley nests in Brazil is not only of regional importance, but also of significance at the western Atlantic level. A proper evaluation of the conservation status of the western Atlantic population would require an assessment of the distinctiveness between the Brazilian population and that nesting in Suriname/French Guiana, the two major nesting colonies in that part of the ocean (Fretey, 1999; Marcovaldi, 2001; Godfrey & Chevalier, 2004); however, this possible distinctiveness remains an open question, due to insufficient and/or contradictory information:

(1) the nesting seasons in Suriname/French Guiana and Brazil do not overlap: the Suriname population nests between May and July (Schulz, 1975) while the Brazilian population nests mainly between October and March (this study); this suggests adaptation by each population to local conditions over a long period of time (Godfrey & Chevalier, 2004).

(2) Mitochondrial DNA analyses have indicated little genetic segregation between Suriname and Sergipe, Brazil, but these results have to be interpreted cautiously because of the low mtDNA diversity observed in the Atlantic (Bowen et al., 1998).

(3) Tagging data: (a) to date, no olive ridley tagged in Brazil has been found elsewhere (this study), although there are a small number (<10) of records of olive ridley tagged in Suriname and later caught in north and north-eastern Brazil as far as the State of Rio Grande do Norte (Pritchard, 1973; Schulz, 1975; Figure 1); (b) one olive ridley incidentally captured in a fishing weir and tagged in Almofala, Ceará in March 1998 was found nesting in Sítio do Conde, Bahia in October 2003, just outside of the study period (Projeto TAMAR, unpublished data, 2006); (c) the very limited sample size from Brazil regarding turtles recaptured in different nesting seasons (this study) and the greater number of olive ridleys tagged in Suriname and later recaptured there in different seasons (Pritchard, 1973; Schulz, 1975) suggest some level of philopatry. Items (a) and (b) indicate a possible overlap between feeding grounds of Brazilian and Suriname/French Guiana populations.

More demographic and genetic data are needed to clarify the possible connections between Brazilian and Suriname/French Guiana populations. Genetic studies based on mtDNA indicate that there has been no evidence of female exchange between the western and eastern Atlantic populations despite the lack of genetic diversity (Bowen et al., 1998).

Olive ridleys in the North Pacific Ocean have been estimated to have a median age at sexual maturity of about 13 years, although there is a large uncertainty associated with this estimate; maturity could possibly occur between ten and 18 years (Zug et al., 2006). Kemp's ridleys (*Lepidochelys kempii*), which possibly have growth patterns similar to those of olive ridleys (Zug et al., 2006), have been estimated to mature

between ten and 20 years approximately (Chaloupka & Zug, 1997; Schmid & Witzell, 1997; Shaver, 2005). If similar maturity estimates apply to olive ridleys nesting in Brazil, then the recent increase in nesting in Sergipe and Bahia may be at least partly due to the nesting beach protection efforts of TAMAR in that area since 1982. When TAMAR began working in the region in 1982, nearly 100% of the clutches were collected in Sergipe; high intensity egg collections on nesting beaches have contributed to the decline of other sea turtle nesting populations (Chan & Liew, 1996; Hoekert et al., 1996). However, between 1991/1992 and 2002/2003 only about 1.5% of the clutches (of all species) laid in the study area were recorded as having been collected by humans (Projeto TAMAR, unpublished data, 2006), indicating a large increase in egg survivorship.

The decrease in clutch size and CCL along the seasons (Figure 4) could be due to the recruitment of new, presumably younger and smaller female turtles to the nesting population, that lay smaller clutches on average (Figure 5). However, other factors could be acting here:

(1) mortality of breeding adults, believed to be caused by shrimp trawling around the Sergipe coast, could play a role in an explanation for the apparent decrease in CCL, as has been suggested by Shanker et al. (2003) with regard to the decrease in CCL of olive ridleys nesting in Orissa, India. The Sergipe coast is an important shrimping area, where a sizeable trawling fleet operates, causing a great deal of interaction between sea turtles and trawl nets, frequently right in front of nesting beaches. Trawlers also operate along the northern Bahia coast; furthermore, coastal gill-nets are widely used in that area and are known to incidentally capture adult sized olive ridleys. Stranded dead olive ridleys, many of them of adult size, have been observed on beaches in Sergipe and northern Bahia, usually during the nesting season or just before (Thomé et al., 2003; T.Z. Serafini, personal communication, 2006), but this mortality has not been adequately evaluated yet. Continued monitoring of changes in turtle's size in the Brazilian olive ridley population may be worthwhile in addition to a quantitative assessment of the impact of shrimp fleets and other kinds of fishing gear.

(2) Small scale egg poaching could be involved in the apparent decrease in clutch size over the years. Almeida & Mendes (2007), analysing data from the State of Espírito Santo (Figure 1), showed that loggerhead clutches collected on the beach by local fishermen hired by TAMAR and later transferred to hatcheries had about 7–11 fewer eggs than clutches collected and transferred by TAMAR personnel; this difference, which is within the range of decline observed for olive ridley clutches in the present study (Figure 4), was attributed by Almeida & Mendes (2007) to the removal of some eggs for consumption by the hired fishermen before sending the clutches to the hatcheries. No analyses of this kind have been performed in Sergipe and Bahia.

Average olive ridley clutch size in Suriname in 1967 was 116 eggs (N=1154; Schulz, 1975), which is higher than the observed average clutch size in Sergipe and Bahia in each season (Figure 4). Taking summarized clutch size data from Schulz (1975) (SE=0.447), and running *t* tests to compare the average clutch size in Suriname in 1967 with that of Sergipe and Bahia in each season, significant differences for

all seasons were obtained ($P<0.001$ in each season). It is not possible to compare CCL measurements of the Brazilian nesting population with those of other populations in the Atlantic because of lack of published CCL data and/or of a formula to convert straight carapace length to CCL for olive ridleys in the Atlantic. Overall, good quality regional nesting and morphological data and more refined genetic analyses are needed to better understand olive ridley trends, distribution, and demographics in the western Atlantic.

Management methods

The hatching success of clutches transferred to hatcheries was significantly lower than that of clutches kept *in situ* in five seasons, and the incubation period was significantly different (either higher or lower) between clutches kept *in situ* and those transferred to hatcheries in three seasons. Sand temperature, hydric conditions, sand compaction and other micro-environmental factors could affect hatching success of clutches relocated to hatcheries (Ackerman, 1997), as well as egg movement during relocation (Limpus et al., 1979). The incubation period (and also the sex ratio of hatchlings) is largely dependent on nest temperature during incubation (Ackerman, 1997).

Sand temperatures at nest depth in open-air hatcheries managed by TAMAR were shown to be generally quite close to those in natural beaches at Praia do Forte, Bahia and also, to the south, at Comboios, State of Espírito Santo (Figure 1), but some differences did occur (Baptistotte et al., 1999; Naro-Maciel et al., 1999), so temperature could play a role in explaining differences in hatching success and incubation period between natural beaches and hatcheries in Sergipe and Bahia. However, no studies comparing hatching success or incubation period between *in situ* clutches and those relocated to hatcheries in relation to sand temperature or other environmental parameters have been carried out in Sergipe and Bahia yet; studies of this kind should be given priority in future researches in these states. With respect to the possible effect of egg movement during relocation on hatching success, TAMAR's field methodology acknowledges the importance of this topic and enforces that the movement of eggs be minimized and the spatial orientation of each egg be maintained as closely as possible during relocation, and also that relocation should take place in the shortest possible period of time. The analysis of data relating hatching success and incubation period to the conditions (period of time, possible movement of eggs) of the relocation of clutches to hatcheries will be the object of future research. TAMAR does attempt to leave as many clutches as possible *in situ*. However, given the numerous factors adversely impacting *in situ* clutches on several beaches, it is currently felt that relocation to hatcheries should be a management alternative.

Conclusions

The available data and biological knowledge suggest that TAMAR's conservation efforts may have contributed to the significant increase in olive ridley nesting in Sergipe and Bahia. There is no quantitative information about past (i.e. before 1980, when TAMAR started operating; Marcovaldi & Marcovaldi, 1999) levels of olive ridley populations in Brazil nor about their former geographical nesting range, so we cannot place the current level and geographical extent of olive ridley nesting in a proper historical perspective.

The collection of eggs, which occurred at a very high level before the establishment of TAMAR in Sergipe and Bahia in 1982, is currently essentially controlled. Among the known threats to olive ridleys in Brazil, incidental captures in trawl fisheries off the State of Sergipe coast and in fishing nets along the northern coast of Bahia are believed to be the most important (Thomé et al., 2003).

Shrimp trawl vessels of more than 11 m in length whose nets are retrieved by mechanical means (this category encompasses only part of the trawlers operating in Sergipe) are required by Brazilian law to use turtle excluder devices (TEDs). Furthermore, Brazil has signed and ratified the Inter-American Convention for the Protection and Conservation of Sea Turtles, which requires the use of TEDs by parties. Despite these rules, shrimp trawlers in Sergipe do not use TEDs for several reasons: (1) the cost of TEDs precludes their use; (2) fishermen believe that TEDs interfere with shrimp quantity and quality; and (3) law enforcement has been ineffective up to now.

TAMAR has worked, in partnership with governmental environmental agencies, towards the improvement and enforcement of laws requiring the use of TEDs and towards the development of TEDs suitable for the regional shrimp fishery, and has also worked towards the enforcement of local laws which forbid shrimping within a 3 nautical mile exclusion zone around nesting beaches (Thomé et al., 2003) and which establish seasonal closures to shrimp fishing. Besides that, TAMAR has sought several other ways to deal with the incidental capture of sea turtles in Sergipe and Bahia, often by working closely with trawler crews and net owners. Since 1993, TAMAR has maintained educational campaigns regarding the rehabilitation of turtles caught in nets (Marcovaldi et al., 2001). The development of economic alternatives, like oyster culture, is one of TAMAR's lines of action with regard to the threat posed by fishing (Marcovaldi & Thomé, 1999). However, much remains to be done. Protection on nesting beaches alone is not sufficient to ensure survival of sea turtle populations; demographic models have indicated that both increased survival at sea and higher egg survival rates are essential for maintaining populations (Heppell et al., 2003). Besides fishing, other lower level threats in the study area, sometimes due to the lack of proper law enforcement, include artificial lighting near nesting beaches, as well as construction and vehicle traffic on the beaches.

Sea turtles are slow-maturing long-lived animals, so long-term conservation actions are required to ensure the recovery of depleted populations (Bjorndal, 1999). We hope that continued conservation efforts in Brazil and in other countries will bring a bright future to olive ridleys in the Atlantic.

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