Vol. 21: 25–32, 2013
doi: 10.3354/esr00505

ENDANGERED SPECIES RESEARCH
Endang Species Res

Published online June 20

FREE ACCESS

Northeast Brazil shows highest hawksbill turtle nesting density in the South Atlantic

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ABSTRACT: To date, hawksbill turtle *Eretmochelys imbricata* nesting in Brazil has been estimated by recording clutch numbers. To better address conservation assessments and more reliably estimate the number of females, the Projeto TAMAR-ICMBio initiated a mark and recapture program of nesting females to gather data on critical parameters such as clutch frequency and remigration interval. The study area on the southern coast of Rio Grande do Norte was divided into 2 data-recording efforts: index (IA) and protected (PA) areas. Overall, 243 nesting hawksbill turtles were tagged along 42 km of nesting beach; 153 of these were within the 4 km area of intensive tagging. We estimated a remigration interval of 2.1 yr and a clutch frequency of between 2.3 and 2.6 clutches per female. Furthermore, the number of active breeding females was estimated to be between 705 and 791. The average number of clutches per kilometer was 21.1 in the IA and 20.7 in the PA (although some sections were as high as 37.5 and 48.5 nests km^{-1}, respectively). This represents the highest density of hawksbill clutches per kilometer found so far for the South Atlantic, and highlights the importance of southern Rio Grande do Norte for the conservation of the Critically Endangered hawksbill turtle.

KEY WORDS: Brazil · Clutch frequency · Conservation · *Eretmochelys imbricata* · Remigration interval

INTRODUCTION

Hawksbill turtles *Eretmochelys imbricata* are distributed throughout tropical areas of the Atlantic, Indian and Pacific Oceans (Witzell 1983, Márquez 1990). They are probably one of the most exploited marine turtle species worldwide, as their keratin-rich scutes (traditionally known as tortoiseshell or 'bekko') have been used traditionally to make jewelry and in art crafts (Meylan 1999, Mortimer & Donnelly 2007). Their harvest has contributed to a global decline in hawksbill numbers over the past few decades (Meylan & Donnelly 1999); however, the number of individuals has presumably been declining for many centuries (McClenachan et al. 2006). Consequently, hawksbill turtles are currently classified as Critically Endangered by both the International Union for the Conservation of Nature and the Brazilian Red List for Threatened Species (Marcovaldi et al. 2011).

The analysis of population trends in long-lived marine organisms, such as hawksbill turtles and other sea turtle species, is challenging and requires information on annual nesting abundance over long

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time frames. Long-term data sets allow for more accurate estimates of biological parameters such as clutch frequency and remigration intervals, which are critical to estimates of a population's conservation status (Richardson et al. 2006). Biological parameters can vary among populations, and require accurate and consistent data collection methods at local scales.

In Brazil, 2 major hawksbill nesting sites have been identified on the coastlines of northern Bahia and southern Rio Grande do Norte (Marcovaldi et al. 2007). Smaller numbers of nests also occur in the states of Sergipe (Marcovaldi et al. 2007), Paraíba (Mascarenhas et al. 2004), Pernambuco (Moura et al. 2012) and southern Bahia (Camilo et al. 2009; see Fig. 1). However, current nesting surveys of Brazilian hawksbills rely entirely on the number of clutches per season, which alone is insufficient to determine the number of nesting females that visit a specific beach per season. To gain this understanding, more detailed information on clutch frequency and remigration intervals is required (see Mascarenhas et al. 2004, Marcovaldi et al. 2007, Camilo et al. 2009).

In the state of Rio Grande do Norte, Projeto TAMAR-ICMBio, the Brazilian sea turtle conservation program, initiated nesting beach surveys during the 2003/2004 nesting season; in these surveys the number of clutches was determined. In addition, mark and recapture efforts using flipper tags applied to nesting hawksbill turtles began in 2004/2005, with the goal of estimating the number of nesting turtles in the region. Here, we present the first analyses of the data gathered on the southern coast of Rio Grande do Norte, Brazil, during 8 nesting seasons.

MATERIALS AND METHODS

Study site

The study area was located in northeastern Brazil, in the southern section of the state of Rio Grande do Norte (Fig. 1). We divided the surveyed areas into index areas (IA) and protected areas (PA).

Index area (IA)

Nine kilometers of beaches were monitored within the municipality of Tibau do Sul (06. 190121° S, 35.084720° W), ca. 45 km south of the city of Natal (Fig. 1). The landscape consists of cliffs, interspersed with dunes, and narrow bands of beaches. Intensive tagging efforts (IT) were focused on the southernmost 4 km, while nest inventory data were collected along the entire 9 km of monitored beach (Fig. 1).

Protected area (PA)

After the establishment of the IA, adjacent beaches were gradually included from 2004/2005 onwards (Table 1). The whole PA combined is ca. 33 km in length and was patrolled daily from 1 November to 30 May for each season. Nest inventories and random tagging of turtles were done opportunistically (methods were the same as for the IA; see following subsection). Night patrols were carried out using a 4 × 4 all-terrain-vehicle (ATV).

Nesting activity

Morning patrols were conducted daily to record nest numbers, from 15 September until the hatching of the last nest for each nesting season. In 2008/2009, after 5 seasons of very low nesting activity during September and October (Fig. S1 in the Supplement at www.int-res.com/articles/suppl/n021p025_supp.pdf), the patrolling protocol of the nesting season survey was changed to begin daily morning patrols on 1 November, with 3 patrols per week in October. The early start of patrols during the initial years of this study was due to prior experience of the team at higher latitudes in Brazil, where the nesting season occurs earlier. Nest locations were marked with stakes to confirm emergence and to identify nesting species. To estimate the number of hawksbill clutches, we added the number of clutches identified as hawksbills to an estimation of the unidentified observed clutches that were considered to be most likely from hawksbills. Even without direct observation, for each area, we assumed that the ratio of *Eretmochelys imbricata* clutches among unidentified clutches was the same as that of identified clutches. We used the following equation for this: estimated hawksbill clutches = observed hawksbill clutches + *ph* unidentified clutches, where *ph* is the probability of a turtle in the studied area being a hawksbill; *ph* is estimated as the ratio between the number of clutches identified as hawksbills and the total number of observed clutches identified as other species. Unidentified clutches occurred when: total hatchling emergence had occurred, where only empty egg

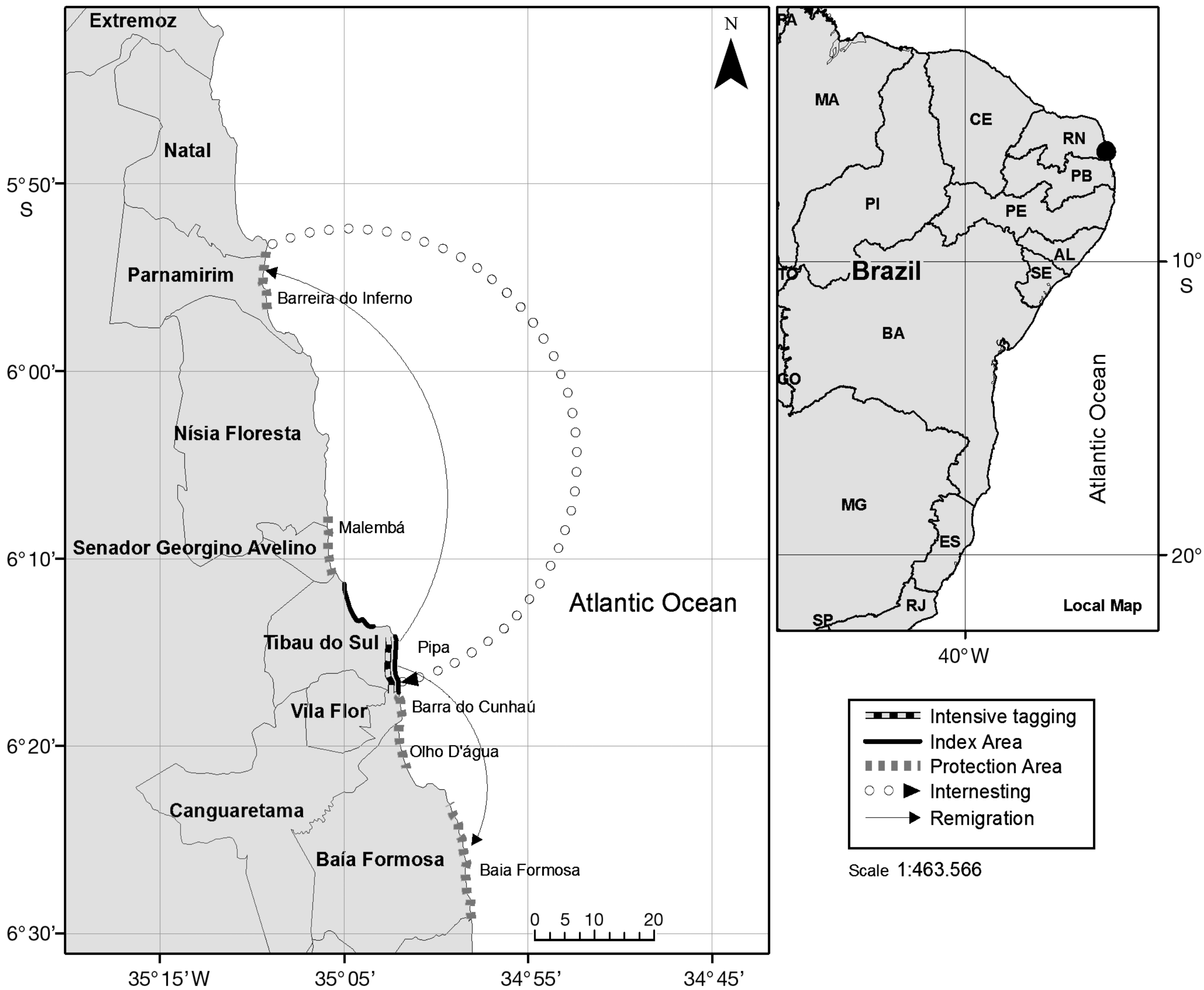

Fig. 1. Patrolled area of 42 km length situated on the southern coast of the state of Rio Grande do Norte, northeastern Brazil. The PA includes 5 sections: Baia Formosa (15 km long), Olho D'água (4 km), Barra do Cunhaú (2 km), Malembá (6 km) and Barreira do Inferno (6 km). The municipalities' are also labeled. Right panel: the states on the Atlantic coast of Brazil are shown: Ceara (CE), Rio Grande do Norte (RN), Paraiba (PB), Pernambuco (PE), Sergipe (SE) and Bahia (BA). Recaptures outside the tagging section are also presented, with arrows pointing to the recapture site: 1 potential internesting interval around 45 km southward, 12 d after the previous sighting; and 2 remigration intervals (2 yr for both) with tagging site distances of 42 km (northward) and 20 km (southward)

shells remained in the nest; no eggs hatched (embryo absence); clutches were destroyed by predators or another sea turtle, or erosion; as well as missing locations. The spatial density of hawksbill clutches (clutches km^{-1}) was calculated by dividing the estimated number of clutches by the length of the beach (km). The average clutch density (i.e. number of clutches km^{-1}) was calculated as the ratio between the total numbers of clutches for all sites divided by the total area monitored (Tables S1 & S2 in the Supplement at www.int-res.com/articles/suppl/n021p025_supp.pdf).

Tagging effort

All the females encountered were tagged with inconel metal tags (No. 681 National Band and Tag Company), attached anterior to the most proximal scale of both front flippers. Turtles retaining tags were designated 'remigrants', while untagged turtles that presented no tag scars were considered as 'first-tagged'. The presence of tag scars was also recorded. Random tagging (RT), defined as the sporadic patrols to encounter nesting hawksbill turtles, was conducted during the 2004/2005 and

Table 1. Patrolled sections in the protected area

Section	Coordinates	Municipality	Beach length (km)	Patrols started
Barra do Cunhaú	06.300115° S, 35.031890° W	Canguaretama	2	2004/2005
Olho D'água	06.369390° S, 35.006720° W	Baía Formosa	4	2004/2005
Barreira do Inferno	05.901970° S, 35.155610° W	Parnamirim	6	2005/2006
Baía Formosa	06.36625° S, 35.0038333° W	Baía Formosa	15	2005/2006
Malembá	06.1453° S, 35.09825° W	Senador Georgino Avelino	6	2010/2011

2005/2006 nesting seasons (as described for PAs). IT, that is the uninterrupted night-long patrols, was conducted from 10 December to 15 April during the 2006/2007 to 2010/2011 nesting seasons. Each IT was conducted along a 4 km beach section (Fig. 1), with the entire section traversed every 40 min, starting at 19:00 h and ending at 04:30 h. From 2004/2005 to 2006/2007, patrols to detect females on the beach were conducted on foot; from 2007/2008 to 2010/2011, a 4 × 4 ATV was used.

Internesting interval and clutch frequency

The calculation of these parameters enabled us to estimate the number of females nesting within the area. Analysis of internesting interval and clutch frequency occurred from 2006/2007 onwards, when IT effort began. The internesting interval is the number of complete days (24 h) between subsequent egg-laying events. We calculated observed clutch frequency (OCF) as the number of times a given female was observed nesting in a season. We calculated estimated clutch frequency (ECF) as the number of clutches that a given female had most likely laid, considering internesting intervals and potential internesting intervals (related to false crawls) to provide additional information beyond the observed value. The terminology 'potential internesting interval' was used under the assumption that even though the turtle was not directly observed nesting, there likely was a nesting event (see Santos et al. 2010). For internesting intervals in excess of 20 d, it was assumed that unobserved nesting event(s) had occurred, where the number of clutches added was the internesting interval divided by the average internesting interval, as in Johnson & Ehrhart (1996). In the cases where the last emergence was a false crawl, we used the potential internesting interval to estimate additional clutches.

Number of females

The number of females nesting within a season was estimated using 2 methods: (1) by dividing the total number of nests in the nesting season with the greatest spatial cover by ECF and (2) by applying the same ratio of average number of females and clutches observed in the intensive tagging area to the nesting season with greatest spatial cover. In order to obtain an estimation of the number of active breeding females, we multiplied the number of females nesting within a season, obtained from each of the methods described above, by the average remigration interval.

Data analyses and mapping

We chose to use Kruskal-Wallis rather than ANOVA because the former does not require the assumption of normality, a condition that is not fulfilled for most data in this study. Statistical analyses were performed using the R program (R Development Core Team 2008). All maps and calculations of distance between marking and recapturing sites were obtained with ArcGis 9.3. Each distance was measured as a straight line between 2 points.

RESULTS

Nesting activity

Five sea turtle species nested along the IA during the study period: hawksbill, green turtle *Chelonia mydas*, loggerhead *Caretta caretta*, olive ridley *Lepidochelys olivacea* and leatherback *Dermochelys coriacea*. A total of 1554 nests were recorded; of these 1246 were identified to species, with hawksbill nests comprising 98% (N = 1222; Table S1). As IA has an equivalent spatio-temporal effort during our study, the number of estimated hawksbill clutches

(Table S1) was used to analyze abundance and annual variation. Statistical analyses show that the number of clutches in the IA was stable through time, oscillating around 190 clutches per nesting season (F = 0.66; df = 7; p = 0.45; Fig. 2).

During the study period, the PA was progressively extended up to 33 km in length (see 'Materials and methods'). Out of 2362 nests recorded, 426 were identified to species; hawksbill nests accounted for 97.4% (N = 415; Table S2).

Tagging effort

Overall, 243 nesting hawksbill turtles were tagged within the 42 km-long patrolled area, 66.3% within the IA (153 females in the IT and 8 females tagged outside this area) and 33.7% within the PA (see Table S2 in the Supplement). Focusing on the IT site, 153 individual females were documented; of these, 100 females were seen in 1 nesting season, 37 were seen in 2, 14 were seen in 3, and 2 were seen in 4 seasons. The average remigration interval was 2.10 ± 0.51 yr (N = 68; range = 0.84 to 3.98 yr). Hawksbills without tags and with the presence of tag scars appeared only once during the study period. Out of 524 recaptures, 13 turtles were found retaining a single tag, generally after 1 remigration interval. In addition, 8 double-tagged turtles had at least 1 tag replaced.

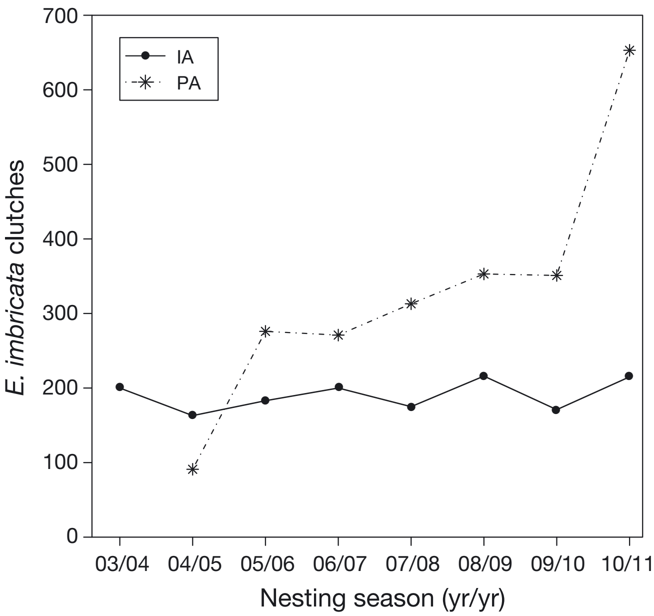

Fig. 2. *Eretmochelys imbricata*. Clutches on the southern coastline of Rio Grande do Norte, Brazil, in 8 nesting seasons of data collection. The intensive study area (IA) fluctuates around an average of 190 clutches yr^{-1} (F = 0.66; df = 7; p = 0.54). The rise in clutch numbers in the protection area (PA) is related to the gradual increase in patrolled areas over the years (see Table 1)

Internesting interval and clutch frequency

The interval between 2 consecutive successful nesting events varied from 12 to 56 d. However, 85% of the distribution had an interval of between 12 and 20 d. We assumed that internesting intervals in excess of 20 d were caused by at least 1 unobserved nesting event and, thus, focused analyses on the period from 12 to 20 d. There were no differences in internesting intervals between nesting seasons (Kruskal-Wallis: chi-squared = 3.36; df = 5; p = 0.65). Average internesting interval was 15.0 ± 1.5 d (N = 163; median = 15 d; range = 12 to 20 d). The average OCF was 2.0 nests (N = 190), OCF ranged from 1 to 6 nests, and OCF = 1 accounted for 54.1% of all values (Fig. S2 in the Supplement). The average ECF using Method 1 was 2.3 nests (N = 200); it ranged from 1 to 6 nests, and ECF = 1 accounted for 49.7% of all cases, which included 10 turtles that were observed making false crawls. The average ECF for remigrant turtles was 2.4 ± 1.22 clutches $female^{-1}$ (range = 1 to 5; N = 35), which is significantly higher (p = 5.96×10^{-5}; F = 3.77; df = 70) than the average ECF for first-tagged turtles which was 1.3 ± 0.44 clutches $female^{-1}$ (range = 1 to 4; N = 37). The average ECF using Method 2 was 2.6 nests (average number of females = 39.6 females $season^{-1}$ and average number of clutches = 102.2 clutches $season^{-1}$). Therefore, we performed statistical tests using the last 2 seasons (2009/2010 and 2010/2011) in order to increase the reliability of our analysis.

Number of females

The nesting season of 2010/2011 was selected because it had the greatest spatial coverage. In total, 376 female turtles, as estimated by Method 1, nested across the 42 km of nesting areas during this season. As the remigration interval is 2.1 yr, we obtained an estimate of 791 actively breeding females. When using Method 2 we found that 335.6 females nested during this season, with ca. 704.7 active breeding females for the entire study area. We thus estimate the number of actively breeding females to be between 705 and 791.

DISCUSSION

Nesting activity

Although the 5 sea turtle species found in Brazil have been recorded nesting on the southern coast of Rio Grande do Norte, the preponderance of hawksbill turtles *Eretmochelys imbricata* (98%) in this area reveals a different pattern from that observed in Bahia (800 km further south; Fig. 1), where the loggerhead turtle *Caretta caretta* is the most common nesting turtle species, representing 54.8% of occurrences from 1999 to 2002 (see Lara-Ruiz et al. 2006, Marcovaldi & Chaloupka 2007). Most nesting occurrences of hawksbill turtles were recorded in Paraiba (Mascarenhas et al. 2004; 105 km further south; Fig. 1) and Pernambuco (Moura et al. 2012; 250 km further south; Fig. 1), which are contiguous with our study site. In contrast, despite intensive sea turtle nesting patrols in Sergipe since 1982 (540 km further south; Fig. 1), hawksbill turtle clutches there are scarce (Marcovaldi et al. 2007). These distributional patterns may indicate that the main aggregations of nesting hawksbill turtles in Brazil are spatially separated. Genetic investigations are underway to better understand the population structure.

The annual number of hawksbill clutches on the southern coast of Rio Grande do Norte appears to be stable; however, data for only 8 consecutive nesting seasons were monitored, too short a monitoring period to allow robust conclusions. The increasing trend reported by Marcovaldi et al. (2007) for Brazilian hawksbills was noted in the states of Bahia and Sergipe, but remained undetected for the southern coast of Rio Grande do Norte, where the historical series of data still need to be explored to identify trends. Detailed density distributions (hawksbill clutches per kilometer) for each nesting season and section are available in Tables S1 & S2. Considering the total extent of the area patrolled and the number of hawksbill clutches within this area, the number of clutches per kilometer was 19.3, 15.3 and 3.3 in Paraiba (Mascarenhas et al. 2004), Pernambuco (Moura et al. 2012) and southern Bahia (Camilo et al. 2009), respectively. In addition, although there are about 1500 hawksbill clutches each year along 214 km of nesting beaches in northern Bahia, the distribution is not homogenous, with concentrations as high as 31.6 clutches km^{-1} in the most dense areas (Projeto TAMAR-ICMBio unpubl. data). So we conclude that the densities at our study site are the highest in Brazil and in the South Atlantic, as the only suitable nesting environment for hawksbill turtles in the Southwest Atlantic is found in Brazil, and reports of hawksbill nesting along the coast of Africa are scarce (Hutchinson et al. 2008).

Tagging effort

Tag scars were only found on 1 untagged individual, and records of tag replacement or of only a single tag being attached accounted for 4% of all recaptures. Around 50% of the females from a given annual cohort were recaptured after 2 yr, which corresponds to the average remigration interval. The detection of bias due to tag loss is still undetermined, as the mark and recapture program has not been carried out for a sufficient period of time to determine how long tags normally remain on a flipper. The use of passive integrated transponder tags would help to better understand this source of bias.

Internesting interval and clutch frequency

Around 50% of the females nested only once during the study period; the average OCF and ECF were 2 and 2.3 (see ECF in Table 2), respectively. Beggs et al. (2007) excluded turtles that nested just once for the calculation of ECF (4.1); if we had used the same methodology, we would have obtained an ECF of 3.5. For Guadeloupe, French West Indies, the ECF estimate was 2 clutches female^{-1}; underestimation was concluded, due to the limited coverage of the survey (Kamel & Delcroix 2009). Clutch frequency in Jumby Bay, Antigua, was 4.5, with a pronounced mode of 5 (Richardson et al. 1999). Remigrant turtles laid more clutches than first-tagged turtles, in agreement with Mortimer & Bresson (1999) and Beggs et. al (2007). Behavioral differences in nest site fidelity between individuals, within and among nesting seasons, influence individual detectability and, consequently, the females that are likely to renest within a small range of km will probably present a raised ECF. Turtles probably also nest outside of the surveyed area; we detected 1 female renesting 45 km northward (Fig. 1). Tucker (2010) demonstrated by satellite telemetry that actual clutch frequency and nest site fidelity are higher than the same values obtained by beach tagging efforts for loggerhead turtles. Increase in tagging effort in adjacent areas, coupled with satellite tagging, will enhance detection of realistic clutch frequencies and the range of nest site fidelity.

The additional method that we explored (Method 2) produced an ECF of 2.6 (Table 2). Method 2 was an

Table 2. Estimated clutch frequency (ECF) and remigration interval according to location

Location	ECF	Remigration interval (yr)	Source
Pipa, Brazil[a]	2.3/2.6	2.1	Present study
Cuba	1.45 ± 0.07	2.4 ± 0.5	Moncada et al. (2010)
Yucatan, Mexico[a]	2.1/4.8	2	Garduño-Andrade et al. (1999)
Seychelles	3.6	2/3	Mortimer & Bresson (1999)
Seychelles[a]	2.4/2.6	3	Allen et al. (2010)
Guadeloupe, French West Indies[a]	2.3/2.7	2.24 ± 0.47	Kamel & Delcroix (2009)
Milman Island, Australia	2.5	3.4 ± 0.62	Dobbs et al. (1999)
Antigua	4.5	2.69	Richardson et al. (1999)
Barbados	4.1	2.5 ± 0.8	Beggs et al. (2007)

[a]Both values are given for locations where 2 methodologies were considered for the clutch frequency estimation

attempt to deal with the presumed underestimation of ECF due to the limited coverage at our site. If the ECF is lower than the actual clutch frequency, the number of reproductive females is higher than assessed, so accuracy in determing the ECF is essential for population assessments.

Conclusions and conservation outcomes

The northern section of our study area, Barreira do Inferno, has been protected by the Brazilian Space Agency (full protection) since 1965; this area is adjacent to the capital of Rio Grande do Norte (Natal; Fig. 1). The area of Malembá and the whole IA are part of a natural protected area (Bonfim-Guarairas); however, this area is not afforded full protection, and no management plan has been implemented here. The rest of the areas are not protected. Coastal development is perhaps the main concern, currently accelerated by unplanned tourism activities, which result in vehicle traffic, obstacles for nesters and hatchlings (such as parasols and chairs), artificial light and buildings close to the shoreline. Despite anecdotal evidence of rare events of poaching and slaughtering of turtles (Table S2), these threats are not a major concern. The challenge today is to protect the nesting beaches through participation in coastal management councils and through proposing zones for protected areas. The goal of this paper is to provide key information to the Brazilian authorities to ensure that important hawksbill nesting areas are protected and considered by the tourism and development industry.

Acknowledgements. We thank Projeto TAMAR, a conservation program of the Brazilian Ministry of the Environment, affiliated with ICMBio (the Brazilian Institute for Biodiversity Conservation — Instituto Chico Mendes) and co-managed by Fundação Pró-TAMAR. We also thank Santuário Ecológico de Pipa, Centro de Lançamentos da Barreira do Inferno, David Hasset, Paulo Barata, Ricardo Feitosa, Claudius Monte, Guilherme Maurutto, Luis Felipe, Milagros Lopez, Valdenir Andrade, Mariana Fuentes, Ricardo Azevedo, Daphne Wrobel and all field volunteers. We are also grateful to the anonymous reviewers and editor who much improved the manuscript. Data collection was authorized by ICMBio, through Special License Number 14122, issued by the Biodiversity Authorization and Information System (SISBIO).

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Editorial responsibility: Jeffrey Seminoff, La Jolla, California, USA

Submitted: August 17, 2012; Accepted: February 26, 2013
Proofs received from author(s): June 6, 2013