*Chelonian Conservation and Biology*, 2019, 18(1): 75–81
doi:10.2744/CCB-1343.1


# Long-Range Movements and Growth Rates of Brazilian Hawksbill Turtles: Insights from a Flipper-Tagging Program

ARMANDO J.B. SANTOS[1,*], C. BELLINI[2], LUIS F.W. BORTOLON[1], BARB OUTERBRIDGE[3], DARREN C. BROWNE[4], ALEXSANDRO SANTOS[5], ANNE MEYLAN[6,8], PETER MEYLAN[7,8], BERENICE M.G. SILVA[9], JUÇARA WANDERLINDE[10], EDUARDO H.S. LIMA[11], CECILIA BAPTISTOTTE[12], AND MARIA A. MARCOVALDI[5]

[1]*Fundação Pro-Tamar, Fernando de Noronha, Pernambuco, Brazil [armando@tamar.org.br; luisfwb@hotmail.com];*
[2]*Centro Nacional de Proteção e Pesquisa das Tartarugas Marinhas (Projeto TAMAR), Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), Parnamirim, Brazil [claudio.bellini@icmbio.gov.br];*
[3]*Bermuda Aquarium Museum and Zoo, 40 North Shore Road, Flatts FL 04, Bermuda [bcouterbridge@gov.bm];*
[4]*Barbados Sea Turtle Project, Department of Biological and Chemical Sciences, University of the West Indies, Cave Hill Campus, St. Michael, Barbados [dazbo_b@yahoo.com];*
[5]*Fundação Pro-Tamar, Mata de São João, Bahia, Brazil [alex@tamar.org.br; neca@tamar.org.br];*
[6]*Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 100 8th Avenue S.E., St. Petersburg, Florida 33701 USA [anne.meylan@myfwc.com];*
[7]*Natural Sciences, Eckerd College, 4200 54th Avenue South, St. Petersburg, Florida 33711 USA [meylanpa@eckerd.edu];*
[8]*Bermuda Aquarium Museum and Zoo, 40 North Shore Road, Flatts FL 04, Bermuda (Research Associate);*
[9]*Fundação Pro-Tamar, Ubatuba, São Paulo, Brazil [bere@tamar.org.br];*
[10]*Fundação Pro-Tamar, Florianopolis, Santa Catarina, Brazil [ju@tamar.org.br];*
[11]*Fundação Pro-Tamar, Itarema, Ceará, Brazil [eduardo.lima@tamar.org.br];*
[12]*Centro Nacional de Proteção e Pesquisa das Tartarugas Marinhas (Projeto TAMAR), Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), Vitória, Brazil [cecilia.baptistotte@icmbio.gov.br]*
**Corresponding author*

ABSTRACT. – **The understanding of developmental and reproductive migrations of sea turtles is essential for effective protection and conservation efforts. Flipper tags remain a valuable method for detecting movements and migrations because they are cost-effective and conspicuous, allowing the detection of a tagged animal by any person worldwide. Here we report 13 flipper-tag recoveries for Brazilian hawksbill (*Eretmochelys imbricata*) turtles that augment the body of information on the migratory nature of this species and provide new growth-rate data.**

Until the 1980s, in contrast to other marine turtle species, hawksbills (*Eretmochelys imbricata*) were believed to be nonmigratory (Witzell 1983). In recent decades, data from tagging programs and new technologies, such as molecular genetics and satellite telemetry, have led to the realization that hawksbills also regularly undertake long-distance developmental and reproductive migrations (Meylan 1982, 1999; Blumenthal et al. 2009; Horrocks et al. 2011; Marcovaldi et al. 2012).

Hawksbill turtles are classified as Critically Endangered by both the International Union for the Conservation of Nature and the Brazilian Red List of Threatened Species (Mortimer and Donnelly 2008; Marcovaldi et al. 2011). In Brazil, hawksbill turtles are only known to nest on the mainland. Major rookeries occur along the northern coast of Bahia (Marcovaldi et al. 2007) and the southern coast of Rio Grande do Norte (Santos et al. 2013); however, a small number of nests are also recorded in Ceara (Lima 2002), Northern Rio Grande do Norte (Farias et al. 2016), Paraiba (Mascarenhas et al. 2004), Pernambuco (Moura et al. 2012), Alagoas (Bonfim et al. 2013), Sergipe (Marcovaldi et al. 2007), and Southern Bahia (Camillo et al. 2009). Juveniles are distributed along the north and northeastern coasts and, less frequently, along the south and southeastern coast of Brazil (Marcovaldi et al. 2011), with major foraging grounds located in the Fernando de Noronha Archipelago and Rocas Atoll (Sanches and Bellini 1999; Fig. 1). Records of foraging grounds also exist near the islands of Trindade (TAMAR database, unpubl. data, 2018, www.projetotamar.org.br), São Pedro e São Paulo, Abrolhos Archipelago (Pedrosa and Verissimo 2006; Proietti et al. 2012), and Arvoredo (Reisser et al. 2008; Proietti et al. 2012).

Feeding aggregations consist mostly of animals originating from Brazilian rookeries (Bahia and Rio Grande do Norte), but may also include individuals from African and Caribbean rookeries (Proietti et al. 2014). Satellite telemetry was used to identify adult foraging ranges of 5 females from the nesting beach in northern Bahia; they were found to forage along the eastern coast of Brazil, along the continental shelf, within coastal reef ecosystems (Marcovaldi et al. 2012).

A long-term capture–mark–recapture study conducted by ProjetoTAMAR-ICMBio, the Brazilian national sea turtle conservation program, has been underway since 1982 (Marcovaldi and Marcovaldi 1999). The program focuses primarily on nesting sites, but since 1989, it also has included foraging areas. Brazil has $>$ 8000 km of coast, along which 25 Tamar stations have been established in 9 states covering $\sim$ 1100 km. Here we report on 13 flipper-tag recoveries for Brazilian hawksbill turtles that augment the body of information on the


**Figure 1.** Movements of 13 Brazilian hawksbills (*Eretmochelys imbricata*) based on tag recoveries (see Table 1). Eight represent "within-life stage" movements. Cases 1–7 were tagged as immatures in developmental habitat that were subsequently recaptured or recovered as immatures > 250 km away from the tagging site. Case 8 is an adult female tagged on the nesting beach and recaptured at a foraging area. Cases 9–13 show nesting beach locations for 5 individuals originally tagged as juveniles in Atol das Rocas, Brazil.

migratory nature of this species and generate growth rates for individuals from the southern Atlantic.

*Methods*. — At the islands Fernando de Noronha and Atol das Rocas, researchers made in-water captures by hand using snorkel or SCUBA, whereas along the mainland, researchers collaborated with coastal fishers to recover turtles from bycatch. A national educational campaign called "Marked to Live," which explains the importance of reporting tagged turtles, has greatly increased the range from which tags have been reported in the country.

Each captured or incidentally captured turtle was identified to species and double-tagged (one tag on the trailing edge of each foreflipper) with monel tags from 1989 to 1994 and inconel tags from 1995 onward (Style 681, National Band and Tag Co, USA). The change from

monel to inconel tags was due to the higher rate of loss of monel tags compared with inconel for hawksbills in Fernando de Noronha (Bellini et al. 2001). Researchers measured curved carapace length (CCL) to the nearest 0.1 cm with a flexible plastic tape from the nuchal notch to the posterior tip of the supracaudal ($CCL_{n\text{-}t}$ of Bolten 1999). We assigned maturity class to each turtle based on the mean size of nesting hawksbill turtles in Brazil (92 cm CCL; Santos et al. 2010; Soares et al. 2017). We considered all turtles smaller than this size to be putatively immature, whereas we considered those equal to or larger than this size to be adults. For hawkbills at Fernando de Noronha, size-at-first-capture varied from 28 to 84 cm CCL, with a mean of 44.4 cm ($n$ = 503 turtles) indicating that, although a few adults may be present, this site is predominantly inhabited by immature turtles (C.B. et al., unpubl. data, 2018).

We calculated maximum recapture intervals (MRI) using the difference in duration between the initial tagging date and the final recapture date. We calculated mean annual growth rates by dividing the difference in CCL (centimeters) by the MRI (years). We calculated distance moved for recaptures as straight-line measurements between the 2 sites, considering the most direct path by water (avoiding crossing land), using Google Earth (Google Inc, USA).

*Results*. — In Table 1, we report 13 cases of long-range movements ($>$ 250 km) that can be considered developmental and/or reproductive migrations that were detected by returns of flipper tags originally applied in Brazil. Eight of these (cases 1–8) occurred within a single life stage (7 developmental migrations of immatures and 1 reproductive migration of an adult), and 5 (cases 9–13) included a life-stage transition from immature to adult (Table 1; Fig. 1). We also present information on the capture site, size at first capture, date of first capture, and growth rate (when possible) for each turtle (Table 1).

In the present report, we have added to the literature (Marcovaldi and Filippini 1991; Bellini et al. 2000; Grossman et al. 2007) 7 new cases involving movements of immature hawksbill turtles tagged in Brazil that could be considered developmental migrations. Six occurred within Brazilian waters and involved travel distances of 400 to 2045 km (Table 1; Fig. 1). In the seventh case, the turtle travelled 5193 km from Atol das Rocas to Bermuda, in the northwestern Atlantic Ocean (Table 1; Fig. 1). These developmental migrations occurred over periods of 2.1 to 11.2 yrs (mean 7.3 yrs; SD = 2.8 yrs). We also recorded a reproductive migration of 1516 km that occurred over a 3-mo interval (case 8; Table 1; Fig. 1).

Five of the records reported here span the transition in life history stages from an immature stage on an immature-dominated foraging ground (developmental habitat) to the mature, adult stage on the nesting beach (Table 1; Fig. 1). These turtles initially were tagged at an average size of 63.2 cm CCL, and then later were seen on a nesting beach at an average size of 91.4 cm CCL. In all 5 cases, maturity was confirmed by the observation of reproductive activity on a nesting beach. Four were turtles nesting in Brazil, at distances of 270 to 1389 km from the developmental site where researchers first tagged them. Case 12 involved an individual that nested $\geq$ 4 times in 2 nesting seasons in Barbados, a minimum distance of 3415 km from her original capture site in Brazil in what was presumed to be a developmental habitat.

*Discussion*. — Records of sea turtle movements occurring within the same life stage are more frequently reported than movements of individuals that have transitioned from one life stage to the next. The former includes the reproductive migrations of breeding males and females (Van Dam et al. 2008; Horrocks et al. 2011) and the developmental migrations of immature turtles traveling between developmental sites (Meylan 1999). For Brazilian hawksbills, even these within-life-stage movement records are scarce. To date, the only published case has been a trans-Atlantic crossing by a juvenile hawksbill turtle that travelled from Atol das Rocas, Brazil, to Dakar, Senegal, in 6 mo, a straight-line distance of 3680 km (Marcovaldi and Filippini 1991).

Transitions from one life stage to another (e.g., immature to breeding adult) for hawksbill turtles have rarely been reported (Bjorndal et al. 2008; Ordoñez Espinosa et al. 2010). For 2 previous Brazilian records, nesting was not confirmed (Bellini et al. 2000; Grossman et al. 2007). Two hawksbill turtles, tagged as juveniles in Fernando de Noronha, were recaptured in Corisco Bay in West Africa. One was reported from Gabon (Bellini et al. 2000) and the other from Equatorial Guinea (Grossman et al. 2007). They had each travelled a straight-line distance of $\sim$ 4670 km. The fishermen who captured them described them as adult females, but no confirming data accompanied these reports.

The CCL of nesting hawksbill turtles in southern Rio Grande do Norte, Brazil, varies between 74 and 102 cm (mean, 91 cm; TAMAR, unpubl. data, 2018); only 3.7% are $>$ 100 cm. In northern Bahia, where extensive hybridization with the loggerhead turtle (*Caretta caretta*) is known to occur (Lara-Ruiz et al. 2006), CCL of hybrids varies between 98 and 113 cm (mean, 103.7 cm), while for hawksbills (nonhybrids) CCL varies between 78 and 100 cm (mean, 92.3 cm; Soares et al. 2017). In case 13, the nesting female was 103.2 cm CCL, which is larger than the range known for nonhybrids. This raises the possibility that this individual was a hybrid, which if true, would be the first record of an *Eretmochelys-Caretta* hybrid at a developmental aggregation in the Brazilian islands (Proietti et al. 2014).

We believe that all 5 of the turtles in cases 9–13 were immature when last seen at the Atol das Rocas. However, the individual in case 9 was 78 cm CCL when she was tagged, which is above the minimum size (74 cm; TAMAR, unpubl. data, 2018) of adult females seen on Brazilian nesting beaches. She also was recaptured within the offshore developmental site for the next 2 yrs and grew

**Table 1.** Summary of capture histories for 13 individual hawksbill turtles; only first and last captures are shown. Cases 1–8 are considered within life-stage movements, 9–13 are juveniles later encountered nesting. Fernando de Noronha, Atol das Rocas, and Bermuda are offshore island locations. Ilha Anchieta is a coastal island, < 1 km distant from the mainland; other Brazilian sites are located in the mainland. CCL = curved carapace length; PE = Pernambuco; BA = Bahia; RN = Rio Grande do Norte; SP = São Paulo; SC = Santa Catarina; CE = Ceará; ES = Espírito Santo.

| Case[a] | Tags | Location | Record | Date | CCL (cm) | Maximum recapture interval (yrs) | Growth rate (cm/yrs) | Straight distance (km) |
|---|---|---|---|---|---|---|---|---|
| 1 | BR45573<br>BR45574 | Atol das Rocas, RN, Brazil, 3.86357°S, 33.80204°W | Foraging ground | 23 Jul 05 | 46 | 7.4 | 3.8 | 1073 |
| | | Subaúma, BA, Brazil, 12.25259°S, 37.78065°W | Stranded | 29 Dec 12 | 74 | | | |
| 2 | BR37482<br>BR37483 | Fernando de Noronha, PE, Brazil, 3.80754°S, 32.38503°W | Foraging ground | 22 Nov 04 | 46 | 6.3 | 1.3 | 400 |
| | | Baía Formosa, RN, Brazil, 6.37899°S, 34.99050°W | Stranded | 03 Apr 11 | 54 | | | |
| 3 | BR51685<br>BR51686 | Ilha Anchieta, SP, Brazil, 23.55646°S, 45.06862°W | Bycatch | 15 Dec 06 | 56.5 | 2.1 | — | 470 |
| | | São Francisco do Sul, SC, Brazil, 26.26102°S, 48.51715°W | Stranded | 29 Jan 09 | — | | | |
| 4 | BR19563<br>BR19564 | Fernando de Noronha, PE, Brazil, 3.86033°S, 32.40100°W | Foraging ground | 31 Jan 99 | 39 | 6.8 | — | 835 |
| | | Almofala, CE, Brazil, 2.95070°S, 39.78071°W | Lobster net | 30 Nov 05 | — | | | |
| 5 | BR44886 | Atol das Rocas, RN, Brazil | Foraging ground | 14 Jan 08 | 36 | 8.2 | 3.9 | 695 |
| | BR44887 | Almofala, CE, Brazil, 2.83777°S, 39.95573°W | Coastal fisheries | 09 Mar 16 | 68 | | | |
| 6 | BR21186 | Fernando de Noronha, PE, Brazil | Foraging ground | 26 Oct 01 | 35 | 11.2 | 3.2 | 2045 |
| | BR21187 | Anchieta, ES, Brazil, 20.78211°S, 40.57671°W | Stranded | 26 Dec 12 | 70.7 | | | |
| 7 | BR45595 | Atol das Rocas, RN, Brazil | Foraging ground | 01 Jan 06 | 40 | 9.3 | 3.0 | 5193 |
| | BR45596 | Bermuda, 32.36744°N, 64.65788°W | Bycatch | 22 May 15 | 68.2 | | | |
| 8 | BR28014<br>BR28015 | Praia do Forte, BA, Brazil, 12.54729°S, 37.98353°W | Nesting site | 06 Apr 03 | 92 | 0.3 | 0 | 1516 |
| | | Almofala, CE, Brazil, 2.5628°S, 39.4885°W | Foraging ground | 03 Jul 03 | 92 | | | |
| 9 | BR26441 | Atol das Rocas, RN, Brazil | Foraging ground | 20 Oct 02 | 78 | 9.3 | 1.2 | 1389 |
| | BR26442 | Ilhéus, BA, Brazil, 14.8244°S, 39.02461°W | Nesting beach | 05 Mar 12 | 89.2 | | | |
| 10 | BR17946 | Atol das Rocas, RN, Brazil | Foraging ground | 15 Apr 03 | 64 | 8.9 | 3.3 | 305 |
| | BR17947 | Baía Formosa, RN, Brazil, 6.32841°S, 35.03223°W | Nesting beach | 21 Mar 12 | 93.6 | | | |
| 11 | BR15551 | Atol das Rocas, RN, Brazil | Foraging ground | 12 Apr 96 | 63 | 18.9 | 1.0 | 270 |
| | BR17649 | Malembá, RN, Brazil, 6.15676°S, 35.09800°W | Nesting beach | 11 Mar 15 | 81 | | | |
| 12 | BR45537 | Atol das Rocas, RN, Brazil | Foraging ground | 23 Feb 05 | 56 | 10.5 | 3.3 | 3415 |
| | BR45538 | Boardwalk Beach, Barbados, 13.06503°N, 59.56156°W | Nesting beach | 23 Jun 15 | 90.2 | | | |
| 13 | BR45575 | Atol das Rocas, RN, Brazil | Foraging ground | 02 Aug 05 | 55 | 10.5 | 4.6 | 1183 |
| | BR45576 | Itacimirim, BA, Brazil, 12.62558°S, 38.04595°W | Nesting beach | 29 Jan 16 | 103.2 | | | |

[a] 1 = Recaptured twice within the developmental area: 8 May 2006 (52 cm), 14 January 2008 (65 cm). Found dead with signs of fishing gear on the left hind limb. 2 = Recaptured within the developmental area 7 times, always at the same location: 15 June 2005 (46 cm), 19 September 2008 (51 cm), 1 October 2008 (51 cm), 25 August 2009 (51.5 cm), 15 May 2010 (52.5 cm), 8 July 2010 (52.6 cm), and 16 November 2010 (53.5 cm). No indication of cause of death. 3 = First captured as bycatch in a pound net (coastal fishery). Found dead with the carapace broken, probably caused by a propeller or boat collision. 4 = Killed in an illegal lobster net. 5 = Recaptured as bycatch in a pound net (coastal fishery). The turtle was healthy and released with both tags in good condition. 6 = Recaptured within the developmental area 13 times, always at the same location: 28 March 2002 (36 cm), 16 December 2002 (38 cm), 7 February 2003 (39 cm), 14 August 2003 (40 cm), 5 October 2005 (51 cm), 24 February 2006 (53 cm), 29 October 2007 (60 cm), 13 November 2007 (60 cm), 3 October 2008 (64.5 cm), 30 July 2009 (67.1 cm), 27 October 2009 (67.8 cm), 4 May 2010 (69.8 cm), and 7 March 2011 (70.2 cm). No indication of cause of death. 7 = Left hind limb was observed to be broken at the time of the first capture. Recapture as bycatch on hook and line; turtle was admitted into the rehabilitation program of the Bermuda Aquarium Museum and Zoo for hook removal, retagged, and released 15 d later. The injured limb had not healed properly but the turtle was in good body condition, suggesting that the turtle was not in Bermuda as a result of drifting there after being injured. Small numbers of immature hawksbills are known to be resident on the Bermuda Platform (Meylan et al. 2011); this individual was within the size range of immature turtles previously reported from Bermuda. 8 = Recaptured by fisherman snorkeling at a FAD (Fishing Aggregating Device). 9 = Recaptured within the developmental area twice, always at the same location: 1 June 2003 (79 cm) and 30 December 2004 (82 cm). 10 = Recaptured within the developmental area twice, always at the same location: 25 March 2005 (72 cm) and 15 November 2005 (72 cm). 11 = Recaptured within the developmental area twice, always at the same location: 18 January 1997 (68 cm) and 11 September 1997 (71 cm). 12 = Additional nesting occurred at Dover Beach (13.06503°N, 59.56156°W), Barbados, 24 August 2015, 31 July 2017, and 16 August 2017.

to 82 cm (growth rate of 1.8 cm/yr). However, it is clear from other studies that hawksbills larger than the minimum size at maturity for females can still be immature (Meylan et al. 2011). The capture site, Atol das Rocas, is a well-known developmental site for hawksbill turtles (Bjorndal et al. 2016). In none of the 5 cases reported here was the individual observed back at Atol das Rocas after being observed on a nesting beach. This is consistent with the idea that the adult foraging range is geographically separate from developmental habitat for hawksbills in Brazil. The fact that no known adult has been captured at Atol das Rocas is further evidence that this site serves as a developmental site rather than an adult foraging site.

Hawksbill turtles at the 2 island foraging sites (Fernando de Noronha and Atol das Rocas) depart from their developmental habitats at a range of sizes. Cases 1–8 suggest that many individuals leave while they are immature. However, others remain until they approach maturity (case 9). Thus, the transition to reproductive maturity probably takes place on other foraging areas in most cases, although it may occasionally take place at these 2 sites. Further research, including the use of laparoscopy, would be required to confirm whether some individuals mature at these sites (see Meylan et al. 2011).

Age-at-maturity for hawksbills has been estimated to be 20–40 yrs (Meylan and Donnelly 1999). In the Bahamas, a juvenile hawksbill turtle with 48.1-cm SCL was seen nesting 9.3 yrs later (Bjorndal et al. 2008). Transition from juvenile to nesting adult was also reported for a hawksbill tagged as a small immature (26.1-cm SCL) in Puerto Rico that nested in Panama 15 yrs later (Ordoñez Espinosa et al. 2010).

For animals that may migrate over vast areas, a variety of detection methods must be used. Flipper tags are still very valuable for studying sea turtles because they are cost-effective and conspicuous, allowing the detection of a tagged animal by any person worldwide. Although flipper tags can have a higher rate of loss than passive integrated transponders (PITs), they should still be used even when other marking methods are applied (van Dam and Diez 1999).

Individuals that have washed ashore dead or alive-but-injured always raise some questions concerning their origin: were they living at the place where they were found stranded, or did they drift there after being injured? For cases 1, 2, 3, and 6, the turtles may have died far from where they were found stranded (Fig. 1), which means they may not have been living at or near the point of tag recovery.

This report contributes to the understanding of some of the priority research questions for immature turtles addressed by Wildermann et al. (2018). Specifically, our report brings new insight concerning the connectivity among developmental sites and nesting beaches for hawksbills in the Atlantic, and adds to the growing evidence that the hawksbill turtle regularly makes long-range migrations at multiple life stages. Thus, it highlights the importance of international agreements and policies that aim to increase the protection of this Critically Endangered species. Additionally, observed growth rates suggest that maturation in Brazilian hawksbills varies among individuals and may require $> 2$ decades.

*Acknowledgments.* — The Pro-TAMAR Foundation is among the institutions responsible for implementing conservation actions under the National Action Plan For The Conservation Of Sea Turtles - NAP ICMBio/MMA. Projeto TAMAR is officially sponsored by Petrobras. Biodiversity authorization and information system (SISBio) issued data collection license 42760. We acknowledge that safe animal handling practices were used. We are grateful to Guilherme Maurutto for making the maps and for distance calculations. We also thank the field workers who contributed to the data collection. We thank IMA (Instituto Mamiferos Aquaticos) for the report of a tagged nesting hawksbill turtle in Ilhéus, Bahia, Brazil, and the staff of the Bermuda Museum Aquarium and Zoo (BAMZ) for their efforts to maintain a comprehensive sea turtle stranding network.

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*Received*: 2 July 2018
*Revised and Accepted*: 4 February 2019
*Published Online*: 13 June 2019
*Handling Editor*: Jeffrey A. Seminoff