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Photo of a hawksbill (left) and loggerhead (right) hatchling. While these turtles are similar in color, both species can also appear much darker. Note their differences in shape. See pages 9-12 (J. Wyneken photo).

Articles

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Editors:

Kelly R. Stewart
The Ocean Foundation
c/o Marine Mammal and Turtle Division
Southwest Fisheries Science Center, NOAA-NMFS
8901 La Jolla Shores Dr.
La Jolla, California 92037 USA
E-mail: mtn@seaturtle.org
Fax: +1 858-546-7003

Matthew H. Godfrey
NC Sea Turtle Project
NC Wildlife Resources Commission
1507 Ann St.
Beaufort, NC 28516 USA
E-mail: mtn@seaturtle.org

Managing Editor:

Michael S. Coyne
SEATURTLE.ORG
1 Southampton Place
Durham, NC 27705, USA
E-mail: mcoyne@seaturtle.org
Fax: +1 919 684-8741

On-line Assistant:

ALan F. Rees
University of Exeter in Cornwall, UK

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Continued Light Interference on Loggerhead Hatchlings Along the Southern Brazilian Coast

P.H. Lara[1], D. Torres de Almeida[1], C. Famigliettia[2], A. Romano[2], J. Whelpley[2] & A. Byun[2]
[1]Projeto TAMAR-ICMBio, Rua Francisco Soares de Souza, n 29 Farol de São Thomé,
Campos dos Goytacazes, RJ, CEP 28140-000, Brazil (E-mail: daniella@tamar.org.br);
[2]Department of Biology, Fairfield University, 1073 North Benson Rd, Fairfield CT, 06824 USA (E-mail: sbyun@fairfield.edu)

The loggerhead sea turtle (*Caretta caretta*) is the most abundant nesting turtle species known to visit the beaches of Brazil during the September to March nesting season (Marcovaldi & Chaloupka 2007). Like other marine turtles, coastal development and activities may threaten the existence of sustainable wild populations (Chaloupka & Limpus 2001; Limpus & Limpus 2003). The establishment of the Brazilian Sea Turtle Conservation program Projeto TAMAR in the early 1980s has positively impacted the survival and recovery of sea turtles through the development of community-based monitoring programs of nesting activity and the protection of nests from predators and poaching (Baptistotte *et al.* 2003; Marcovaldi *et al.* 2005). Despite improvements, continued threats from coastal development continue to escalate the risk for loggerhead turtles through increased coastal and ocean activities, loss of nesting sites, and light pollution (Lima *et al.* 2012). Artificial light pollution is a significant contributor to hatchling mortality (Witherington 1997). Sea turtle hatchlings typically emerge from underground nests at night and immediately begin crawling toward the sea. Visual cues direct the hatchlings away from the land and toward the ocean (Lohmann *et al.* 1997); hatchlings instinctively orient towards the lowest, brightest horizon – typically seaward (Salmon *et al.* 1992). Lights from coastal development (*e.g.*, street and hotel lamps) are typically brighter than the horizon and disrupt the natural orientation cues of hatchling, resulting in hatchling misorientation (moving in the wrong direction) or disorientation (the inability to orient in any one constant direction) (Lorne & Salmon 2007). Hatchlings must enter the water quickly to minimize threats from predation, dehydration, and exhaustion (Witherington & Martin 2000). The negative effects of artificial lighting on the seaward orientation of hatchlings have been well documented (Salmon 2003; Tuxbury & Salmon 2005; Witherington & Bjorndal 1991; Witherington 1991) and have resulted in measures to eliminate or minimize the problems associated with coastal lighting (Witherington & Martin 2000).

Based on mtDNA analysis, the loggerhead population in Brazil is subdivided into lineages, a northern group which includes the rookeries of Sergipe and Bahia and a southern group, which is subdivided into the rookeries of Espírito Santo and Rio de Janiero state (Shamblin *et al.* 2014). The northern coast of Rio de Janeiro state is particularly important for conservation efforts due to lower average sand incubation temperatures, which produces a larger proportion of male turtles (Marcovaldi *et al.* 1997). These nesting beaches play a key role in the health of loggerhead populations in the southwestern Atlantic region by maintaining an appropriate gender composition (Lima *et al.* 2012). Rapid coastal development poses a challenge to protecting these populations, especially in important nesting areas that were previously undeveloped. To minimize the effect of artificial lights on emerging hatchlings, Projeto TAMAR collaborated with the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). Together, they submitted an ordinance in 1995 that prohibited any light source with a light intensity greater than 0 lux (lux is a measure of light intensity defined as one lumen per square meter) on the beach between the line of maximum low tide to 50 m above the line of the largest pre-tide of the year (spring tide) in the states of Rio de Janeiro, Espirito Santo, Bahia, Sergipe, Alagoas, Pernambuco and Rio Grande do Norte. When nest monitoring began in Farol de São Thomé, a town in the district of Campos dos Goytacazes in northern Rio de Janeiro state during the 1990s, the urban center was already well established. At that time, it was decided that the best management option was to relocate any nests in established nesting areas with coastal lights exceeding the ordinance limit to a local hatchery maintained by Projeto Tamar in the town of Farol de São Thomé. Any nests not deemed to be vulnerable are left *in situ*.

Along the beach near Farol de São Thomé, we categorized three areas according to the degree of development: Urbanized (U), Expanding Development (ED), and Non-Developed (ND). We measured the light intensity in each of these three areas and confirmed light intensities of 0 lux in all three locations in compliance with the 1995 ordinance established by IBAMA current regulations. Although readings of 0 lux in non-developed areas were expected, given the number of street lamps in developed and urbanized areas, our results of 0 lux was surprising. We suspected that the 0 lux readings in the latter two areas were misleading and actually a limitation of standard light intensity measurement. To determine whether artificial lights in urbanized and expanding areas were having a negative effect on seaward orientation of hatchlings (despite these 0 lux readings), we compared the orientation of hatchlings at each of these two beach areas (U and ED) with the orientation of hatchlings from a non-developed area (ND).

Three areas along the beach of Farol de São Thomé were chosen as test locations based on the degree of their development (Fig. 1). The first location, U, was situated within the city itself and characterized by a number of hotels, roads, stores and beach kiosks (Fig. 2a). The second location, ED, is situated about 5 km from downtown and lacks the commercial buildings found at the first site but does have a number of homes, roads and one beach kiosk that opens only during daylight hours (Fig. 2b). The third site, ND, was located about 10 km from town and had no houses or any other obvious signs of human activity (Fig. 2c).

In each of these areas, light levels were measured at the high tide mark and in the general area where loggerhead turtles were known to nest. Light intensity was measured using both an Extech Foot Candle Luxmeter 401025 and a DrMeter Digital Illuminance/Light Meter LX1330B. The Extech and DrMeter Digital Light meter both gave similar readings. To minimize redundancy in our results, we report the light intensity readings taken using the DrMeter Digital

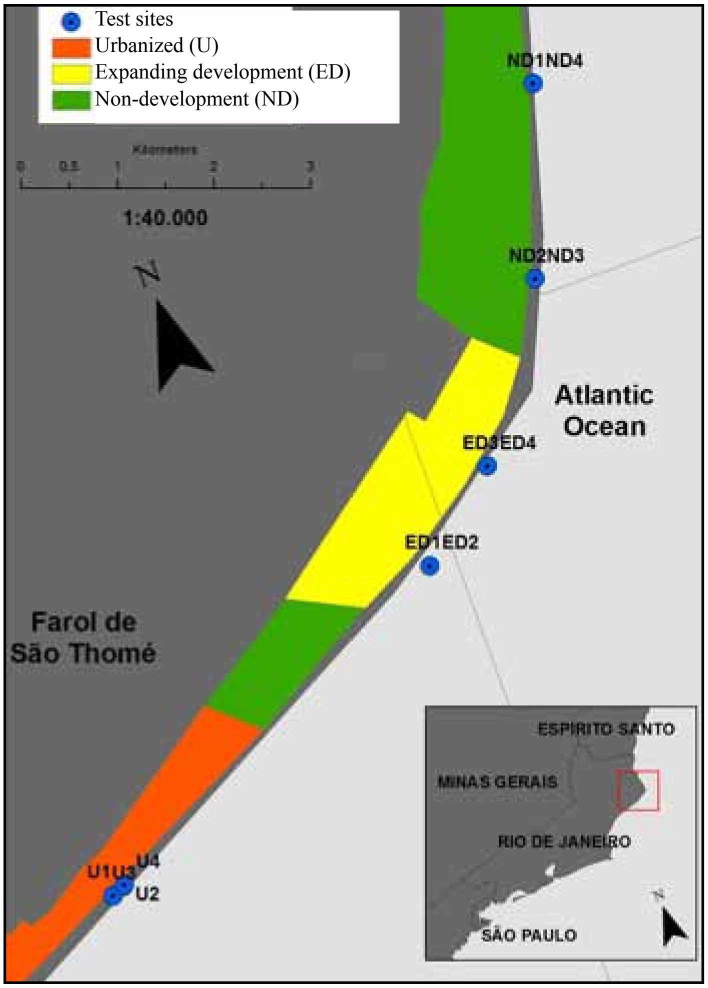

Figure 1. Location of the 12 test sites along the beach of Farol de São Thomé. The region is subdivided into three main areas: red: urbanized (U), yellow: expanding development (ED) and green: non-developed (ND). In each area, we had four independent test sites.

light meter. Light intensity was determined by taking measurements in five different directions in relation to the street: 0°, 90°, 180°, 270°, and directly overhead. The total light intensity reading at each site was determined by taking the sum of these five measurements (Table 1). Only two of the 12 test sites showed lux readings greater than 0 (ED 1 = 0.1 lux, and U3 = 1.3 lux). This discrepancy may have been due to ephemeral events such as the headlights from nearby passing cars. In general, all locations were in compliance with current government regulations of beach light intensities of 0 lux.

On the afternoon before the tests, nests at the Projeto TAMAR hatchery were assessed as to their likelihood of hatchling emergence that night based on the date a nest was laid and a sinking appearance at the sand surface (an indicator of hatching). Nests were then excavated and in order to prevent hatchlings from observing any light upon emergence, we placed cardboard boxes fitted with a downward pointing hose for aeration over each nest. Hatchlings were collected into Styrofoam® boxes under a heavy blanket to prevent light exposure to the animals. Between 8:00 pm and 10:30 pm, we randomly collected 20 hatchlings from each nest and immediately transported them to each of the three test sites. The time of hatchling collection varied depending upon when they actually emerged from the nests. A total of 12 nests, four for each test site, were excavated.

To assess the effects of artificial lights on the seaward orientation of loggerhead hatchlings, we used a two-meter circular pitfall arena, as described by Witherington & Bjorndal (1990). The circular trench was 15 cm deep/15 cm wide and subdivided into eight compartments as shown in Fig. 2. Each test was conducted between 8:30 pm and 12:00 am at three separate locations on the beach, each characterized by different levels of artificial light as described above: urbanized, expanding development, and non-developed. Four independent tests were conducted in each of these three locations resulting in a total of 12 tests. The GPS coordinates of each of the 12 test sites were recorded, as well as the weather conditions, based on the INMET Meterological Station (Code Name A620) located within Farol de São Thomé (lat -22.04°, long: -41.05°). For all tests the temperature remained fairly constant, between 27 and 31 °C. Although most tests were conducted during the new moon, some of the tests in the non-developed area were conducted between new and waning gibbous moons due to a lack of hatchlings from the TAMAR hatchery.

At each test site, the circular pitfall arena was constructed. The location of the pitfall was carefully chosen so that hatchlings would have an unobstructed view of both the road and the sea. The sand in the center of the circular pitfall was smoothed out to remove all footprints and other markings so we could track the movement of the hatchlings and also to prevent them from getting trapped in any indentations. All personal lights were turned off. Hatchlings were then placed in the center of the circle and allowed to disperse for 5 minutes. After this time had elapsed, all hatchlings were recovered.

Test	Time	Road	Sea	Middle
U1	21:00	19	0	1
U2	22:00	16	4	0
U3	21:30	19	1	0
U4	21:00	16	0	4
U total		70	5	5
ED1	21:05	9	11	0
ED2	21:40	0	18	2
ED3	20:54	4	16	0
ED4*	21:05	7	14	0
ED total		20	59	2
ND1	0:00	0	19	1
ND2	21:23	2	18	0
ND3	21:32	0	20	0
ND4	22:07	1	19	0
ND total		3	76	1

Table 1. Number of hatchlings found in each pitfall compartment.Hatchling orientation was tested at three locations: urbanized (U), expanding development (ED), and non-developed (ND). After five minutes of dispersal, the number of hatchlings in each compartment was recorded. Hatchlings that did not fall into one of the compartments were recorded as remaining in the middle.*In this test, 21 hatchlings rather than 20 were inadvertently collected.

Figure 2. A: Urbanized location (U1). There are many homes, shops, hotels and beach kiosks that occupy the beachfront. B: Expanding development location (ED1). There are some neighborhoods that have become established here with one beach kiosk (not open in the evening). C: Non-developed location (ND1). There is no development in this area. The non-developed area represents a dark, pristine beach. Photos by P. Lara.

Those that did not fall into one of the eight pitfall compartments were recorded as remaining in the middle of the arena.

To evaluate the movement of hatchlings in response to artificial lights on the road, we combined compartments 1, 2, 7, and 8 to represent the road portion of the pitfall arena and compartments 3, 4, 5, and 6 to represent the seaward portion (Fig. 2). We did not count the hatchlings that remained in the middle of the arena because it could not definitively be determined whether this lack of movement was caused by disorientation or their specific physical condition. We then totaled all hatchlings found in the seaward and road pitfalls for all of the four replicate tests for each of the three locations (Table 2).

We compared the proportion of hatchlings found orienting toward the sea and to the road in urban, expanding development, and non-development areas using a two-tailed two proportion Z test. We found that in urbanized and expanding development test sites, 6.2% (5/80) and 72.8% (59/81) of hatchlings oriented toward the sea respectively (Fig. 3). These were found to be significantly different (U vs. ED, $z = 8.6$, $p << 0.01$). Seaward orientation of loggerhead hatchlings in each of these two areas was also shown to be significantly different from seaward orientation in non-developed test sites, where 95% of hatchlings demonstrated seaward orientation (76/80) (U vs. ND, $z = 11.23$, $p << 0.01$; ED vs. ND, $z = 3.82$, $p << 0.01$).

Test	Time	0°	90°	180°	270°	Overhead	Total Lux
U1	21:00	0	0	0	0	0	0
U2	22:00	0	0	0	0	0	0
U3	21:30	0.7	0.3	0	0.3	0	1.3
U4	21:00	0	0	0	0	0	0
ED1	21:05	0.1	0	0	0	0	0.1
ED2	21:40	0	0	0	0	0	0
ED3	20:54	0	0	0	0	0	0
ED4	21:05	0	0	0	0	0	0
ND1	0:00	0	0	0	0	0	0
ND2	21:23	0	0	0	0	0	0
ND3	21:32	0	0	0	0	0	0
ND4	22:07	0	0	0	0	0	0

Table 2. Light intensity readings taken at each test site in urbanized (U), expanding development (ED), and non-developed (ND) areas. Five readings were taken at each test site. 0° represents the light intensity coming from the road. 90° represents the light intensity to the right. 180° represents the light intensity coming from the sea horizon. 270° represents the light intensity coming from the left of the road. Overhead represents the light intensity coming from directly above. Light intensity at each location was determined by the sum of these five measurements.

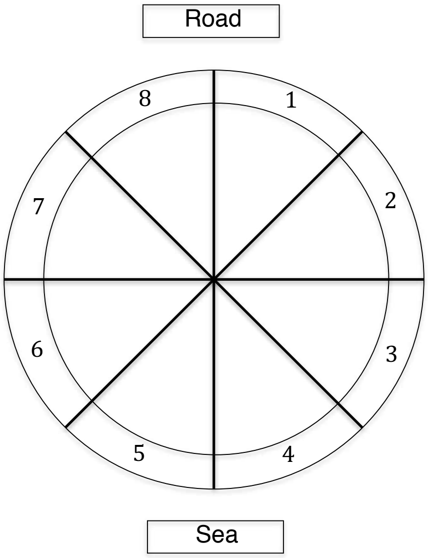

Figure 3. Diagram of the circular pitfall area. Hatchlings were placed in the center of the circle and allowed to disperse for 5 minutes. Hatchlings that reached the pitfalls fell into one of eight compartments. Compartments 1, 2, 7 and 8 were combined to make up the road half of the arena. Compartments 3, 4, 5, and 6 were combined to make up the sea half of the arena.

To assess the potential impact of hatchling orientation in response to artificial light at each of these three test locations, we determined the total number of nests (nests left *in situ* and nests translocated to the hatchery) at each of these locations over a period of two nesting seasons (2009 - 2010 and 2010 - 2011; Fig. 4). Based on these data, we estimated the total number of hatchlings in areas immediately adjacent to our test sites (Table 3). In the urbanized, expanding, and non-developed locations, this translated to a stretch of 4, 3, and 4 km of beach respectively. From these data, it is clear that the highest nest density (82.3 nests/km) occurs in the area of expanding development. Based on our data, we estimate that 93.8% (100% - 6.2%) and 27.2% (100% - 72.8%) of hatchlings could potentially become misoriented. Without conservation efforts (*e.g.*, nest relocation) we estimate that in urban and expanding development areas, about 15,000 (15,975 X 93.8%) and 5,500 (20,756 X 27.2%) (respectively) misoriented hatchlings moved toward the road over a two-year period. In the non-developed areas, we estimate that the number was much lower, at about 600 hatchlings. These data are particularly troubling as the highest loggerhead turtle nest densities occur in areas where there is currently rapid urban expansion.

Test site	Nests laid in 2009-2011	Number of hatchlings	Nest density (nests/km)
Urbanized	200	15975	50
Expanding Development	247	20756	82.3
Non-developed	190	14793	47.5

Table 3. Total number of nests and hatchlings at each test site along the beach of Farol de São Thomé during two consecutive nesting seasons 2009 - 2010 and 2010 - 2011.

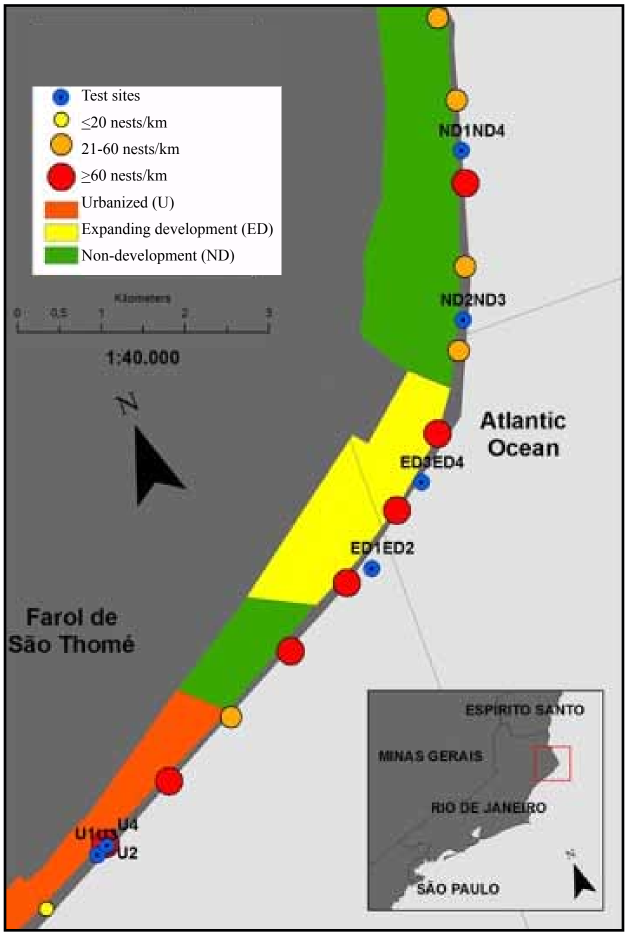

Figure 4. Loggerhead nest density of urbanized (U), expanding development (ED), and non-development (ND) areas. The 12 test sites (U1-U4, ED1-ED4, ND1-ND4) are also marked on the map. The urbanized and expanding development areas have the highest nest densities.

Given the numbers of hatchlings at this particular location between 2009 - 2011, we estimate that almost 9,600 hatchlings per year in a 3 km stretch of nesting beach will be in danger of becoming disoriented and/or misoriented and will face associated threats if this area reaches levels of development comparable to those seen in urbanized areas. As loggerhead populations make a gradual recovery in terms of population size, Projeto Tamar projects that the number of nests along this stretch of beach will increase, potentially endangering even more hatchlings in the future. Although there are laws protecting nesting areas from light effects our investigations show that the advance of the urban area of the town of Farol de São Thomé is a real threat for misorientation of hatchlings.

Our findings indicate that the lighting policy implemented by IBAMA in 1995 does not sufficiently protect loggerhead hatchlings from the dangers of misorientation and that current development procedures require significant modification. While moving or translocating eggs in ED and U areas to a local hatchery is possible, it is not ideal from a conservation management standpoint due to the potential for egg damage and possible alteration of population sex ratios (Byun *et al.* unpublished data). Studies of the effects of translocation in this area need to be conducted. Appropriate hatchery management will likely require comparisons of hatchery nests and in situ nests in a control area where eggs incubate and hatch under natural, undisturbed conditions.

With the rapid ongoing commercial expansion and urbanization of the southern Brazilian coast, it is imperative that new development strategies be implemented. These new strategies must include preserving naturally dark beach habitat for loggerhead nesting populations and a cessation of urban developers from focusing on maintaining 0 lux light levels when planning coastal communities. However, relying strictly on maintaining 0 lux light levels as we have demonstrated is not an effective measure on impacts to hatchling turtles. We suspect that standard equipment for measuring light levels such as the DrMeter Digital Illuminance/Light Meter LX1330B are not capable of detecting the extremely low light levels which loggerhead hatchlings are able to detect. As such, the lighting policy, while good in theory, is not effective in practice. Although translocation of eggs into a hatchery is possible, the expected increase in the number of nests over the next ten to twenty years makes translocation as a sole management strategy untenable. Simple measures such as structures to hide light sources (Witherington 2000) combined with landscaping projects designed to use vegetation to block artificial lights will likely be helpful in protecting hatchlings in southern Brazil.

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Identification of a New Nesting Beach in Mersin, Turkey: Nesting Activity of Green and Loggerhead Sea Turtles Over 6 Nesting Seasons (2009 - 2014) at Davultepe Beach

Serap Ergene[1], Mahmut Ergene[1], Aşkın Hasan Uçar[1], Cemil Aymak[2] & Yasemin Kaçar[1]
[1] Sea Turtle Application and Research Center, Mersin University 33290, Tece Campus, Mersin, Turkey (E-mail:askinhasanucar@gmail.com); [2]Bulancak Vocational and Technical Anatolian High School, 28300, Bulancak, Giresun, Turkey

There are 21 important nesting grounds for both *Caretta caretta* (loggerhead) and *Chelonia mydas* (green) sea turtles along the Mediterranean coasts of Turkey (Türkozan & Kaska 2010) (Fig.1). Five of these nesting beaches (from west to east: Anamur, Göksu Delta, Alata, Davultepe 100. Yıl, Kazanlı) are located in Mersin province. On 24 August 1988, 8 sea turtle nests were found on Davultepe 100. Yıl Beach (Baran & Kasparek 1989) (henceforth "Davultepe"). In 2006, 23 nests were reported on this same beach (Ergene 2006). In subsequent studies, Davultepe was found to be one of the most important nesting sites for green turtles, and also has a small number of loggerhead turtle nests laid annually (Ergene *et al*. 2010; 2012a, b; Ergene 2014).

Davultepe is located between Kandak Stream (36°43′446″ N, 34°30′336″ E) in the northeast and Onur Resort (36°42′535″ N, 34°28′410″ E) in the southwest of Mersin, totals 2.8 km in length, and includes Davultepe public beach, the picnic area and Gümüşkum Natural Park. The Gümüşkum Natural Park, designated on 7 November 2011, is 1.8 km long and located between Kandak Stream in the northeast and Kuğu Resort (36°43′008″ N, 34°29′290″ E) in the southwest. It is administered by Mersin Sea Turtle Rescue, Rehabilitation and Information Center in Gümüşkum Natural Park of Davultepe 100. Yıl Beach, and the Republic of Turkey Ministry of Forestry and Water Affairs, 7th Regional Directorate, Section of Mersin. The basic threats facing sea turtles and their nests at Davultepe are human impacts, including boardwalks constructed along the coast, light pollution, sand removal, and predation.

The populations of green and loggerhead sea turtles nesting on Davultepe Beach was investigated over 6 nesting seasons (2009-2014). In the 2009, 2010 and 2011 nesting seasons, the study area was limited to the 1.8 km of beach in the natural park, and in 2012, 2013 and 2014 we surveyed an additional 1 km section ending at the Onur Resort. All field observations were conducted between July and October and data were collected by teams of 5 or 6 people (researchers and students). Surveys were conducted daily, in the early morning, to find the tracks made by turtles the previous evening. During patrols, all nesting and non-nesting emergences, nest predation, and hatchling emergences were investigated and recorded. Each track was examined in detail to determine whether or not there was a nest. If there was no nest, it was recorded as a "non-nesting emergence." Nest locations were recorded and measurements were taken. All observed nests were protected against predation with wire cages that included warning signs, and coordinates were taken by means of a Global Positioning System (GPS). Then all turtle tracks in the area were obscured so they were not counted twice. The nests were excavated one week after the first emergence of hatchlings. The total number of eggs was calculated by counting unhatched eggs and hatched shell fragments. Davultepe, with a predominantly green turtle population and intensive public beach use, had some nests that were lost due to human activity or which had only empty shells and whose late embryos could not be seen; these were originally classified as "possible green turtle nests." Possible nests were later classified as either green of loggerhead turtle nests, based on further information including the nest distance from the sea, depth, proximity to vegetation, and the experience of the researchers.

Observed nest numbers increased from 2009 to 2012 and decreased in 2013 and 2014 (Table 1). Researchers also determined the most suitable nesting area, which was the better protected and more sheltered 1.8 km beach at the Gümüşkum Natural Park of Davultepe (Table 1).

The full 2.8-km study area was surveyed in the 2012, 2013 and 2014 nesting seasons and on the 1-km section which was outside

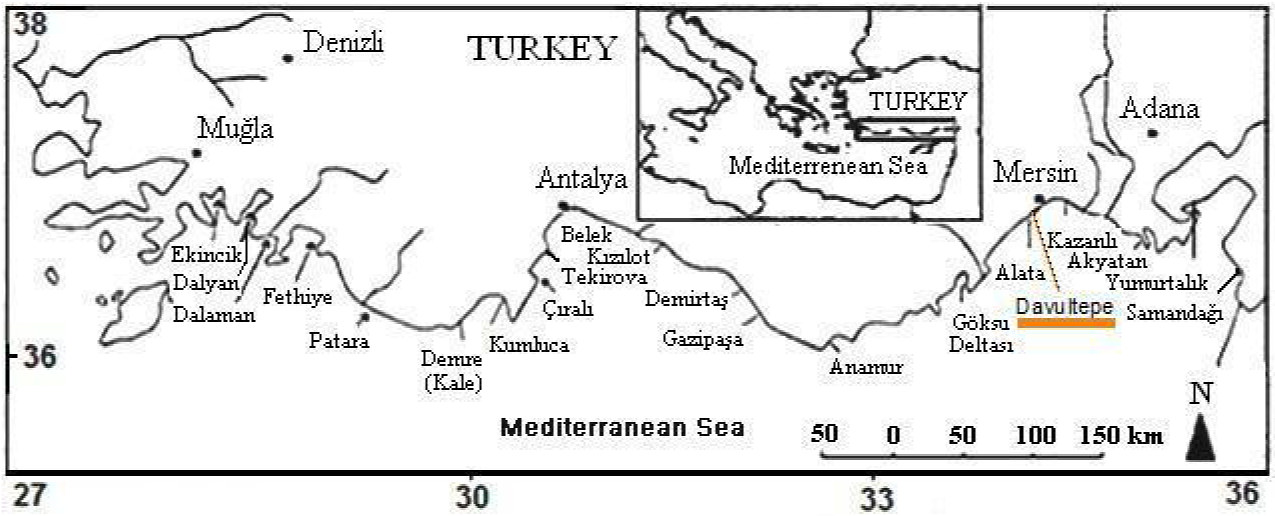

Figure 1. The important nesting areas of Turkey, including Davultepe beach (underlined in orange).

Nesting Season	2009[a]	2010[b]	2011[b]	2012[b,c]			2013[c]			2014[d]		
Beach surveyed (km)	1.8	1.8	1.8	1.8	1.0	2.8	1.8	1.0	2.8	1.8	1.0	2.8
Green turtle nests	68	76	95	148	24	172	114	21	135	73	13	86
Green hatchlings reaching the sea	3,652	4,318	6,887	11,447			10,096			6,909		
Loggerhead nests	4	2	6	4	0	4	8	3	11	2	0	2
Loggerhead hatchlings reaching the sea	281	105	375	291			549			67		
All nests	72	78	101	152	24	176*	122	24	146	75	13	88
Green turtle nests/km	37.8	42.2	52.8	82.2	24	61.4	63.3	21	48.2	40.6	13	30.7
All nests/km	40	43.3	56.1	84.4	24	62.9	67.8	24	52.1	41.7	13	31.4

Table 1. Sea turtle nests and hatchlings reaching the sea on Davultepe Beach between 2009-2014. Sources of data: [a]Ergene *et al*. (2010); [b]Ergene *et al*. (2012a,b); [c]Ergene (2014); [d]this study. *Does not include two nests found outside study area (see text).

the western border of the Gümüşkum Natural Park of Davultepe, a total of 61 nests (24 nests in 2012; 24 nests in 2013 and 13 nests in 2014) were recorded, with an annual mean of 20.3 nests (Table 1). Therefore, if the full, 2.8-km study area had been surveyed in the 2009, 2010 and 2011 nesting seasons, the total number of observed nests would likely have been higher.

A total of 632 green turtle nests were recorded. Excluding the unhatched nests and some nests whose locations were lost without excavating due to intense public beach use, we calculated that 43,309 green turtle hatchlings reached the sea from 509 nests (39 nests in 2009; 49 nests in 2010; 83 nests in 2011; 150 nests in 2012; 114 nests in 2013 and 74 nests in 2014; see Table 1). We calculated that 1,668 loggerhead hatchlings reached the sea from 29 nests recorded and excavated during six consecutive nesting seasons (2009–2014) on Davultepe (Table 1). The highest number of hatchlings reaching the sea occurred in 2012, the year with the highest nest numbers (Table 1). Also in 2012, two sea turtle nests were discovered on the beach in front of the summer buildings, outside the western border of Davultepe. Locations of those two nests were lost without determining their species due to intense public beach use. These two nests were not included to the calculation of nests/km because they were outside the borders of the beach studied. Several other nests were found outside the borders of the beach by the research team after they were informed by people, but are not reported here.

Casale & Margaritoulis (2010) estimated the average number of loggerhead nests laid annually in the entire Mediterranean was 7,200 nests. Türkozan & Kaska (2010) estimated the annual number of loggerhead nests in Turkey was 769-3521, similar to the earlier estimate of 1,366 loggerhead nests/season in Turkey by Margaritoulis *et al*. (2003). We recorded between 2 - 11 loggerhead nests per season on Davultepe, with an annual mean of 4.8 nests, during six consecutive nesting seasons (2009–2014). On Davultepe, the number of loggerhead nests is low.

We observed between 68 - 172 green turtle nests annually during six consecutive nesting seasons (2009–2014) on Davultepe, with an annual mean of 105.3. The highest number of green turtle nests on Davultepe occurred in 2012, with 172 nests recorded in the 2.8 km-beach sector. This corresponds to a density of 61.43 nests/km, which compares favorably to the other important nesting beaches for green turtles on the East Mediterranean coasts of Turkey; Davultepe ranks fifth (Table 2).

Estimates of the total number of green turtle nests laid in Turkey vary. Kasparek *et al*. (2001) estimated the annual number of green turtle nests in the Mediterranean as 350 - 1750. Canbolat (2004) estimated that the mean annual number of green turtle nests laid the coast of Turkey was 647.6, varying between 391 and 910 while Kaska *et al.* (2005) reported 700 - 1150 green turtle nests being laid each year in Turkey. Subsequently, Türkozan & Kaska (2010) estimated the annual green turtle nests laid on the beaches of Turkey between 452-2051. Using the values of Türkozan & Kaska (2010), the maximum and minimum nesting numbers on Davultepe constituted 15% and 8.4% of the recorded range of total nests along the Turkish coast (Table 3). The nesting numbers on Davultepe are also in proportion to the range of numbers of total

Nesting beaches	Akyatan[a]	Samandağ[b]	Alata[c]	Sugözü[d]	Kazanlı[e]	Davultepe [f]
Max. no. of nests	735	1172	198	213	856	172
Beach length (km)	21.7	14	3	3.4	4.7	2.8
Max nests/km	33.8	83.7	66	62.6	182.1	61.4

Table 2. Comparison of the important nesting areas for *Chelonia mydas* on the eastern Mediterranean coasts of Turkey. [a]Aureggi *et al.* (2000); Kasparek *et al.* (2001); [b]Sönmez (2013) [c]Ergene *et al.* (2012c); [d]Canbolat *et al.* (2005); [e]Ergene *et al.* (2013); [f]Ergene *et al.* (2012a,b); Ergene (2014); this study.

	Published range of green turtle nest numbers	Proportion of annual green turtle nests on Davultepe Beach[e] relative to annual nests laid in Turkey and the Mediterranean
Turkey	391- 910[a]	17.4% - 18.9%
	700-1150[b]	9.7% - 15%
	452-2051[c]	15% - 8.4%
Mediterranean	350-1750[d]	19.4% - 9.8%

Table 3. The proportion of minimum and maximum nest numbers on Davultepe beach between 2009-2014 to the range of annual nest numbers given for Turkey and the Mediterranean. Data sources: [a]Canbolat (2004); [b]Kaska *et al.* (2005); [c]Türkozan & Kaska (2010); [d]Kasparek *et al.* (2001); [e]Ergene *et al.* (2010; 2012a,b); Ergene (2014); this study.

nests on the Turkish coasts in Canbolat (2004), Kaska *et al.* (2005) and those in the Mediterranean in Kasparek *et al.* (2001) (Table 3).

Casale & Margaritoulis (2010) defined any nesting beach in the Mediterranean containing > 40 nests as a major nesting site for green sea turtles. On Akyatan Beach in Beach, the average annual number of nests (362) constituted approximately 25% of the overall nesting in the Mediterranean between the 2006 and 2011 nesting seasons (Yılmaz *et al.* 2015). During six consecutive nesting seasons (2009 – 2014), green turtle nests at Davultepe (mean = 105.3 nests/year) constituted 7% of the green turtle nesting potential for the entire Mediterranean. Other important nesting beaches for Mediterranean green turtles outside of Turkey include beaches in Latakia, Syria (Rees *et al.* 2010), and in North Karpaz and Alagadi in Cyprus (Casale & Margaritoulis 2010).

Türkozan & Kaska (2010) suggested that the exploration of two nesting sites at Sugözü and Alata Beaches may reveal significant nesting by green turtles, thus changing the current status of green turtles in the Mediterranean. Now we can add our new data from Davultepe, demonstrating the importance of this nesting beach for this species in the Mediterranean. Although sea turtle activity in Turkey has been studied for many years, there is still the potential to discover new significant nesting areas. Davultepe is an important example of this. The fact that Davultepe includes a 1.8-km section within Gümüşkum Natural Park offers a great opportunity for future protection and conservation of sea turtles.

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The Evolution of Hatchling Morphology

Michael Salmon[1], Megan Reising[1] & Seth Stapleton[2]
[1]Department of Biological Sciences, Florida Atlantic University,
Boca Raton, Florida 33431, U.S.A. (E-mail: salmon@fau.edu; megan.reising17@gmail.com)
[2]Jumby Bay Hawksbill Project, St. John's, Long Island, Antigua, West Indies (E-mail: seth.stapleton@gmail.com)

Marine turtles combine contrasting life history characteristics. As adults they are K-selected animals that are large, powerful swimmers with few enemies and high probabilities of survival (Heppell *et al.* 2003). However, they show more r-selected characteristics during reproduction as each female produces hundreds to thousands of hatchlings but few of these survive to become adults. Such high mortality is typical of the dispersal stages of many migratory organisms (Dingle 2013). These observations suggest that hatchlings should be under strong selection pressure to evolve traits that provide even a small survival advantage.

One such trait that is consistently evident is their strong migratory drive: in most marine turtles, post-emergence hatchlings show a "frenzy" period of enhanced activity, much like the well-known *Zugunruhe* (migratory "restlessness") hyperactivity shown by migratory birds. These highly specialized and rigidly programmed behavioral tendencies have rendered hatchling turtles (as well as migratory birds) ideal subjects for experiments to identify orientation cues (for review, see Lohmann *et al.* 2003), and to explore differences in migratory strategies among populations or species (Wyneken *et al.* 2008; Chung *et al.* 2009; Salmon *et al.* 2009).

While these behavioral discoveries are both important and fascinating, hatchling morphology, another obvious trait that could impact hatchling migratory survival, has been largely ignored. It is well known that the hatchlings of marine turtle species differ in size, shape and color. What is less understood is why such differences exist and what benefits they confer. These characteristics are often described, routinely measured, and faithfully reported in the published synopses on each species. But with few exceptions, they are rarely considered again other than in contexts such as life history studies (*e.g.*, van Buskirk & Crowder 1991). Our goal here is to compare and contrast the morphological differences between two closely related species (Naro-Maciel *et al.* 2008): hawksbills (*Eretmochelys imbricata*) and loggerheads (*Caretta caretta*; cover photograph). We then present a general hypothesis that relates those differences to presumed survival advantages. We suggest that many features of hatchling morphology probably have evolved for just that reason.

Our data come from measurements made in 2012 on naturally emerging hawksbills sampled from nests at Jumby Bay, Antigua, West Indies, and from naturally emerging loggerheads during the same year from nests in Boca Raton, Florida, U.S.A. We measured straight carapace length (SCL), straight carapace width (SCW), mass, and rear flipper area (RFA). RFA in mm^2 was calculated using the program Image J from scaled photographs of hatchlings. Sample sizes were 79 hawksbill hatchlings from 8 nests and 84 loggerhead hatchlings from 9 nests, except for loggerhead RFA/SCL, which was based on 40 hatchlings from 8 nests.

Our measurements confirm that hawksbills are on average smaller than loggerheads as they are significantly shorter in SCL and lighter in mass (Fig. 1, left two columns). The two species also differ in proportions that may be considered independently of their differences in size. Hawksbills are narrower for their length than loggerheads (SCL/SCW; Fig. 1, third column). We also determined that hawksbill rear flippers are proportionally larger in area, given the length of each species (based on RFA/SCL; Fig. 1, right column). Hawksbill average RFA (155.6 mm^2 $\pm$ 25.6 SD) is also absolutely larger than average loggerhead RFA (131.4 mm^2 $\pm$ 15.5 SD; $t = 5.82$), $p < 0.0001$). How might differences such as these provide a survival advantage?

We hypothesize that the survival advantages accrue both before and after emergence from the nest. In the Caribbean, where most hawksbills nest, females select sites near to or under a canopy of vegetation (Kamel 2013; Fig. 2) whereas in Florida, where most loggerheads nest, females select sites on the open beach between the

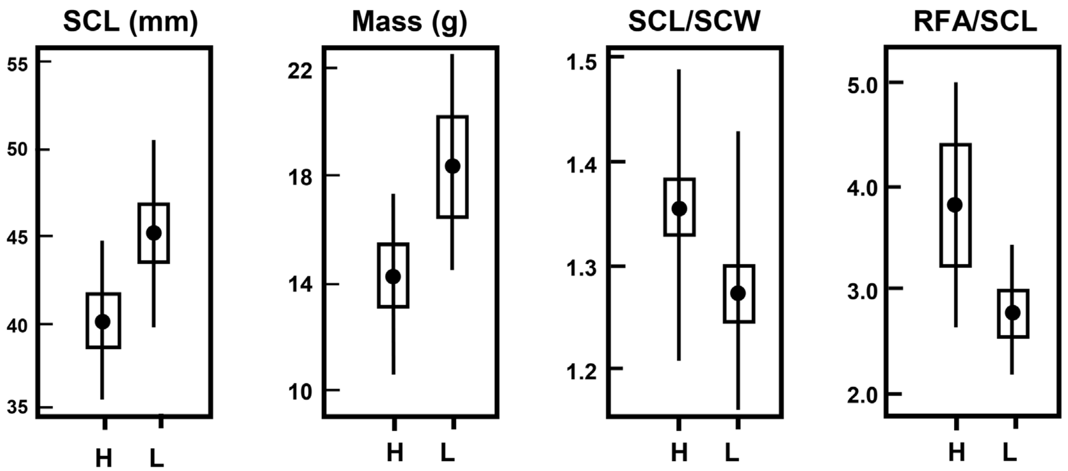

Figure 1. Morphological comparisons between Antigua hawksbill (H) and Florida loggerhead (L) hatchlings from the 2012 nesting season. Plots show the mean (filled circle), first standard deviation (box) and range (vertical line) of the measurements. All the comparisons are significantly different by a two-tailed T-test (at $p < 0.001$ or 0.0001). Abbreviations are: SCL=straight line carapace length in mm; SCL/SCW=SCL divided by straight line carapace width in mm; and RFA/SCL, rear flipper area in mm^2 divided by straight line carapace length in mm.

Figure 2. Above, left: hawksbill hatchling crawling toward the sea. Note its narrow body shape. Above, right: nest under vegetation and surrounded by a screen to collect the hatchlings after an emergence. Below, excavated egg chamber showing its invasion by roots. (M. Reising, photos).

dune and the mean extent of high tide (Witherington *et al.* 2006). Hatchling loggerheads rarely must contend with the invasion of plant roots into the egg chamber. That is not the case with hawksbills where such invasions often occur (Fig. 2) and may select for smaller hatchlings. Animals that dig through substrata containing a labyrinth of obstructions benefit not only from being smaller but also by possessing a more rounded, cylindrical shape in cross section like an earthworm or a mole, or in this case a hawksbill, both because less soil must be displaced to make forward progress and because a barrel-shaped body is less likely to be impeded by small spaces between solid or (in areas thick with plant roots) filamentous obstructions (Dunn 2006; www.stuartsumida.com). Sea turtles have the advantage of digging their way upward as a group but even so, individual hawksbill hatchlings must often negotiate their way through a maze of plant roots. Larger rear flippers should enable each turtle to exert greater upward pressure where that force is necessary. Broader rear flippers may also enable the turtles to more efficiently compact loosened sediment behind them as they progress upward toward the surface.

After they emerge a smaller more cylindrical body shape and broader rear flippers may assist by expediting their crawl through a forest floor containing a maze of vines, leaves and branches (Fig. 2).

Morphological characteristics may also confer survival advantages once the turtles begin migrating offshore. Hawksbill hatchlings are unusual in this respect. Behavioral studies from Malaysia show that after entering the sea, hawksbills initially swim with vigor using their most efficient front-flipper gait: powerstroking. Within an hour, swimming activity rapidly declines by ~ 30 % and rear-flipper kicking takes over as the dominant mode of locomotion (Chung *et al.* 2009). Even though this mode of locomotion is less efficient, the possession of larger rear flippers should allow the hatchlings to distance themselves further from shallow water areas with their abundance of predators. After about 3 hours, the turtles are almost completely inactive and probably drift offshore with the prevailing currents. The result is slower progress away from shallow water and its abundance of predators than other species. However, this escape strategy may render the turtles more difficult to detect by predators, especially those sensitive to prey movement.

In contrast, the dominant swimming gait shown by loggerheads (and hatchlings of all other species) after entering the sea is powerstroking, as confirmed by both laboratory (Wyneken 2003) and field (Witherington 1995) observations. In most populations, powerstroking persists for many hours or even days.

We hope that these observations and suggestions inspire others to further explore possible relationships between hatchling morphology, ecology, behavior and survival. Much also remains to be learned by considering what happens next in their life histories - that is, how small and still vulnerable neonates change in shape during early growth. The results reported here, in previous studies on hatchlings (*e.g*., Wyneken *et al.* 1999), and on the morphology of young juveniles (Salmon & Scholl 2014; Salmon *et al.* 2015) suggest that shape change is common and accomplished by allometric (disproportionate) growth between the limbs and the body. We now need to better understand the functional significance of these diverse growth and form patterns in terms of their costs and benefits to each species.

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Tag Returns of Adult Green Turtles from Florida's Headstart Program (1971-1988)

Carrie L. Keske[1], Dean A. Bagley[1,2], Anne B. Meylan[3], Cody R. Mott[1], Michael J. Bresette[1], Llewellyn M. Ehrhart[1,2] & Katherine L. Mansfield[2]

[1]Inwater Research Group Inc., 4160 NE Hyline Dr., Jensen Beach, Florida 34957, USA (E-mail: ckeske@inwater.org; cmott@inwater.org; mbresette@inwater.org); [2]Department of Biology, University of Central Florida, 4000 Central Florida Blvd, Orlando, FL 32816, USA (E-mail:dean.bagley@ucf.edu; lmehrhart@att.net; kate.mansfied@ucf.edu); [3]Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 100 8th Avenue Southeast, St. Petersburg, FL 33701,USA (E-mail: anne.meylan@myfwc.com)

From 1971 to 1988, the Florida Department of Natural Resources (FDNR, now Florida Fish and Wildlife Conservation Commission) conducted an experimental headstart program for Florida green turtles (*Chelonia mydas*). The program was initiated by Ross Witham prior to any organized statewide sea turtle nesting beach surveys, at a time when green turtle nest totals in the state were unknown. The first statewide nesting data were not collected until 1979 and those surveys indicated a total of 62 green turtle nests for that year (Meylan *et al.* 1995). Witham theorized that by raising green turtles in captivity and releasing them at a larger size, the high initial mortality rate associated with predation could be offset (Huff 1989). The hope was that the turtles that received a headstart would return to Florida beaches to nest and lead to an increase in the green turtle nesting population in Florida.

Clutches of green turtle eggs were collected from beaches on the central to southeast coast of Florida and incubated in Styrofoam® coolers at FDNR's field office in Jensen Beach, Florida. Once hatched, green turtles were reared at various facilities around the state for up to a year before being tagged and released. This program was initiated before temperature-dependent sex determination was clearly understood, and there were concerns in later years that the headstarted turtles may have been incubated at temperatures predicted to produce only males (Huff 1989). These concerns and the lack of any evidence that headstarted turtles came back to nest on Florida beaches led to the termination of the program in 1988.

Throughout the course of the headstart program, there were over 18,000 green turtle hatchlings reared for tagging and release (Huff 1989). The size range of most of these turtles at release was 16.0 cm - 35.0 cm (SCL - Straight Carapace Length, notch-to-tip). All were flipper-tagged with a single Monel or Inconel tag (National Band and Tag Co., Newport, Kentucky, Style No. 1005, Size No. 49 and Style No. 41005, Size No. 681) (Witham & Futch 1977). Most turtles were released on the beach; however, near the end of the project, some were released at sea or in coastal lagoons.

Identified by their original flipper tags, six headstarted green turtles have been observed in Florida waters or on beaches as adults since the termination of the program (Table 1). The first (PPG413) was a 91.7 cm SCL male (tail length = 39.0 cm) captured in 2002 at the St. Lucie Nuclear Power Plant intake canal on Hutchinson Island, Florida. The second (PPV502) was a female found in August 2002 nesting in the Archie Carr National Wildlife Refuge (ACNWR) in Melbourne Beach, Florida, during nesting surveys conducted by the University of Central Florida (UCF). This turtle was encountered again, nesting on the same beach in August, 2014. Three other headstarted females were encountered by UCF on the ACNWR beach - in 2005, 2008 and 2012. Two of these, PPG346 and PPN642, did not lay eggs and their activities were recorded as non-nesting emergences. Female turtle PPG637 nested successfully in June of 2012. In 2008, a headstarted adult male was found by UCF when a green turtle mating pair washed up on the beach long enough for the tag number to be documented. All six turtles hatched between 1985 and 1987, and were released between 1986 and 1988. Four of the six were released offshore, rather than from the beach. Females subsequently encountered on the nesting beach were between 15 and 24 years of age.

The recaptures reported here provide evidence that at least some of the 18,000 turtles reared as part of Florida's green turtle headstart program survived to reach reproductive maturity. Tag loss (Reisser *et al.* 2008; McNeill *et al.* 2013), the use of a single tag at release, the small number of nighttime surveys and tagging projects during green turtle nesting season on Florida beaches, and the generally lower probability of seeing males, likely contributed to the low

Tag Numbers	Release date	SCL at Release (cm)	Release Location	Offshore or Beach release	Recovery Date	SCL at Recapture (cm)	Recovery Location	Years at Large	Sex
PPG413	6/16/1987	32.2	Jensen Beach, FL	Beach	6/13/2002	91.7	St. Lucie Nuclear Power Plant, Jensen Beach, FL	15	M
PPV502	7/1/1988	17.4	Gulf Stream, 24 -32 km east of St Lucie Inlet, FL	Offshore	8/7/2002; 8/14/2014	99.0 (2014)	Melbourne Beach, FL (ACNWR)	14 / 26	F
PPG346	1/16/1988	22.9	South of Everglades National Park Ranger Station at Turkey Key, FL	Offshore	7/6/2005	99.3	Melbourne Beach, FL (ACNWR)	17	F
PPN642	3/21/1988	36.4	Offshore, 1.6 km north of Ft. Pierce Inlet, FL	Offshore	7/28/2005	N/A	Melbourne Beach, FL (ACNWR)	17	F
PPA425	7/11/1986	N/A	Stuart Beach, Stuart, FL	Beach	6/4/2008	N/A	Melbourne Beach, FL (ACNWR)	22	M
PPG637	6/2/1988	29.9	Howard Park, Tarpon Springs, FL	Offshore	6/6/2012	N/A	Melbourne Beach, FL (ACNWR)	24	F

Table 1. Headstarted turtle release and tag recovery information for green turtles (Chelonia mydas) recovered as adults in Florida.

(0.03%) rate of recapture. However, the extent to which these factors influenced the recapture rate is unknown. In any case, the data reported here are too few to offer insight regarding the success or failure of the headstarting project. The practice of headstarting sea turtles was terminated in Florida in 1988 and is now not allowed under Florida's Administrative Code Rule 68E-1.

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Tracks created by female loggerhead sea turtle after emerging from the sea to nest on Shackleford Banks, Cape Lookout National Seashore, North Carolina, USA. Photo by M. Godfrey.

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