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

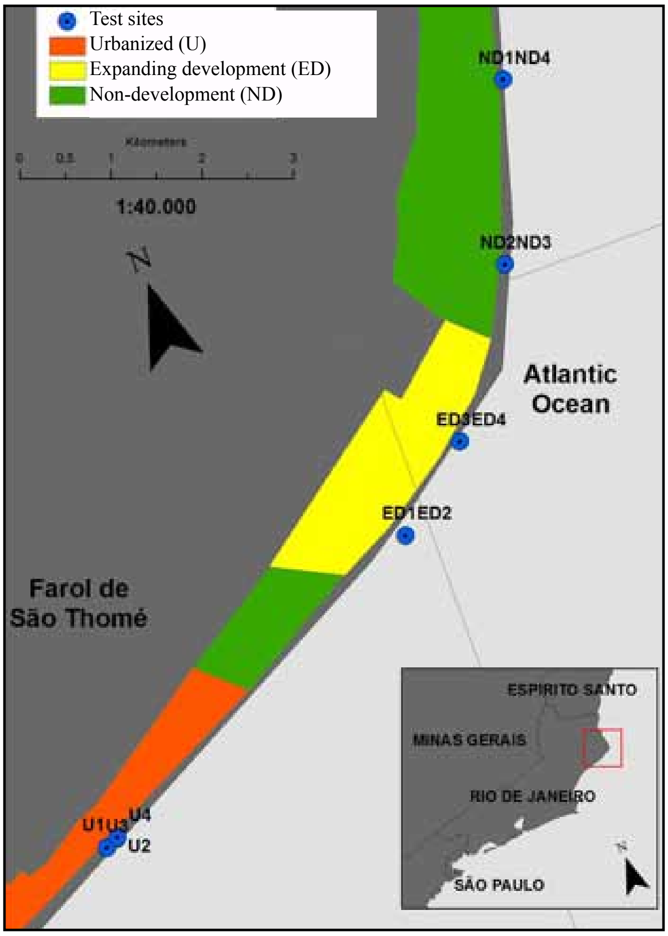

Figure 1. Location of the 12 test sites along the beach of Farol de São Thomé. The region is subdivided into three main areas: red: urbanized (U), yellow: expanding development (ED) and green: non-developed (ND). In each area, we had four independent test sites.

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, $z = 8.6$, $p \ll 0.01$). 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, $z = 11.23$, $p \ll 0.01$; ED vs. ND, $z = 3.82$, $p \ll 0.01$).

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.

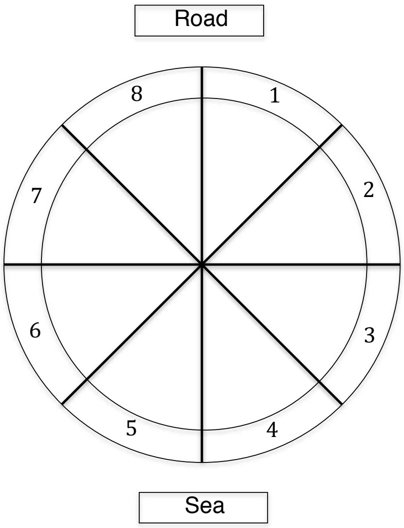

Figure 3. Diagram of the circular pitfall area. Hatchlings were placed in the center of the circle and allowed to disperse for 5 minutes. Hatchlings that reached the pitfalls fell into one of eight compartments. Compartments 1, 2, 7 and 8 were combined to make up the road half of the arena. Compartments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

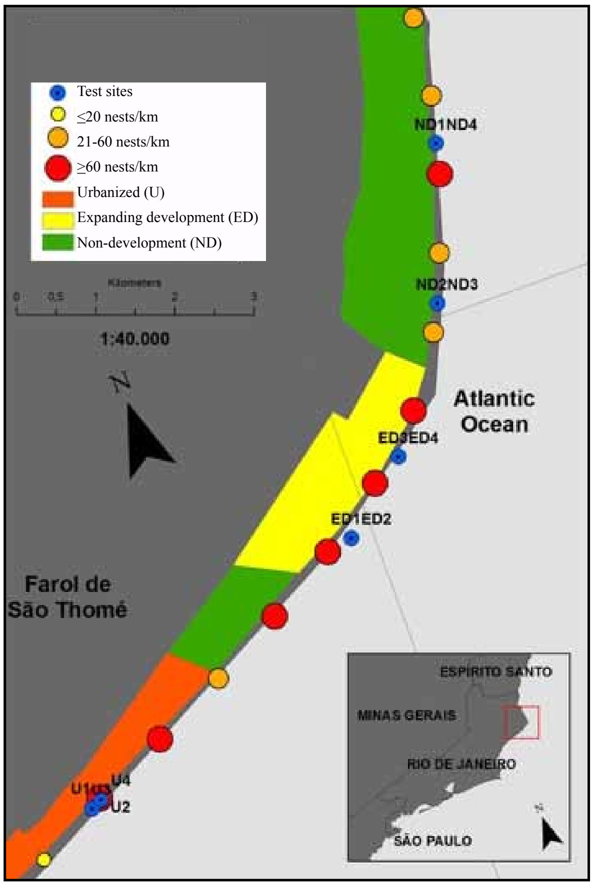

Figure 4. Loggerhead nest density of urbanized (U), expanding development (ED), and non-development (ND) areas. The 12 test sites (U1-U4, ED1-ED4, ND1-ND4) are also marked on the map. The urbanized and expanding development areas have the highest nest densities.

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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