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RESEARCH ARTICLE

Influence of artificial lights on the orientation of hatchlings of *Eretmochelys imbricata* in Pernambuco, Brazil

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ABSTRACT. Sea turtle hatchlings, in natural abiotic conditions, emerge from their nests at night and go directly to the sea, following the moonlight's reflection in the ocean. Increased human activities such as tourism and artificial lights on the coasts, however, have interfered with the ability of sea turtle neonates to find their correct destination, negatively affecting their survival rates. Here we endeavored to assess the influence of artificial lights on the hatchlings of the sea turtle *Eretmochelys imbricata* (Linnaeus, 1766) in the south coast of the state of Pernambuco, Brazil. To that end, 10 experiments were conducted with 15 hatchlings/test subjects. Five experiments took place in artificially illuminated areas and five in non-illuminated areas. Circles with a 2 m radius were drawn on the sand a small 2–3 cm depression was made at the center of each circles. The neonates were then placed in the depressions to simulate their coming from a nest. After the neonates crossed the edge of the circles, their tracks were photographed and drawn on a diagram. To ascertain if the trajectories of the neonates differed between the two groups (hatchlings from illuminated versus non-illuminated nests), the Rayleigh test was used. The significance of those differences was tested using ANOVA. To evaluate similarities and significance of clusters, a Multi-Dimensional Scaling was used. The tracks of 86.67% (N = 65) of the hatchlings from nests at illuminated areas departed from their correct trajectory. The distribution of trajectories was considered random ($V = 19.4895$, $p > 0.05$) only for tracks originating from artificially illuminated areas. The movement patterns of hatchlings from illuminated and non-illuminated areas differed significantly ($F < 0.0001$, $p < 0.01$). Consistent with this, two distinct groups were identified, one from illuminated and one from non-illuminated areas. Therefore, we conclude that artificial illumination impacts the orientation of hawksbill hatchlings. This suggests that in order to protect this species it is necessary to safeguard its nesting areas from artificial lights.

KEY WORDS. Anthropogenic impacts, cheloniidae, conservation, hawksbill turtle, light pollution.

INTRODUCTION

Sea turtle hatchlings, after emerging from their nest at night, are immediately oriented to the ocean in environments without light pollution. The main signs for their orientation are visual, and are primarily associated with light intensity and relief elevation (Salmon et al. 1992, Witherington and Martin 2003). The hatchlings move towards the brightest regions, usually following the reflection of the moonlight over the ocean, a mechanism known as phototaxy (Mrosovsky and Shettleworth 1968, Mrosovsky 1970, 1972, Van Rhijn and Van Gorkom 1983, Lohmann and Lohmann 1996).

An increase in tourist activities and the development of small towns along the Brazilian coast have contributed to an increase in the amount of artificial light pollution on beaches (Witherington and Bjorndal 1991b). This has altered the ability of hatchlings to follow the natural light from the moon, which is what orients them toward the sea (Witherington 2000, Silman et al. 2002, Salmon 2003, Tuxbury and Salmon 2005, Deem et al. 2007).

According to Verheijen (1960), artificial lights are stronger stimuli than natural light, although they are less intense than celestial sources, they have more glare. In order to mitigate the impact of artificial lights on beaches, the Ordinance #11 of Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA), implemented in Brazil on January 30, 1995, prohibits the use of artificial lights on beaches where sea turtles nest. Despite this ordinance, the use of artificial lighting is still common and is responsible for the death of thousands of hatchlings of hawksbill turtles, *Eretmochelys imbricata* (Linnaeus, 1766), green turtles, *Chelonia mydas* (Linnaeus, 1758), and loggerhead turtles, *Caretta caretta*, every year (Witherington 1997).

The presence of artificial lights causes several problems to turtle hatchlings, for instance dehydration, and increased predation and mortality (Limpus 1971, Philibosian 1976, Mann 1978, Mortimer 1979, Peters and Verhoeven 1994, Witherington and Martin 2003). Even when the hatchlings are able to reach the ocean despite the stimuli from artificial lights, they might be already significantly weakened by then, since the energy be required for their first few hours of swimming is reduced (Kraemer and Bennett 1981).

These impacts, associated with other anthropogenic interferences such as fishing activities (Gallo et al. 2006, Marcovaldi et al. 2009), pollution and degradation of nesting environment, have contributed to a reduction in the numbers of sea turtles (Hamann et al. 2010). As a consequence, all sea turtle species are, to some degree, under threat of extinction. The hawksbill, which will be addressed in this study, is classified by the International Union for Conservation of Nature (IUCN 2016) as "critically endangered".

In order to contribute useful information for the proper management and conservation of the hawksbill turtle at the coast of the state of Pernambuco, this study aimed to verify the influence of artificial light sources and moon phases on the ability of hatchlings to orient themselves.

MATERIAL AND METHODS

The study area is located in Ipojuca, 57 km from Recife, with geographic coordinates 08°24'06"S, 35°03'45"W. It comprises 32 km of coastal area. Sea turtles nestings are recorded by the Ecoassociados Non-governmental organization (institution working in the monitoring and conservation of sea turtles) in Muro Alto, Cupe, Merepe, Porto de Galinhas, Maracaípe and Pontal de Maracaípe, totaling 12 km.

The Merepe beach, where the experiments were conducted (coordinates 08°27'15"S, 34°59'52"W), has a coastal length of 3.47 km. There is a great concentration of nesting in this area. The conditions are favorable for nesting because the area is free from reef barriers and the strip of sand is wide. In addition, the coastal vegetation and the terrain are flattered where compared to the other beaches. Along the Merepe beach there is a great number of hotels and resorts, generating a great amount of artificial lighting, but there are still some areas without interference of artificial illumination.

The data was collected under the authorization number 22741-1 issued by the ICMBio (Instituto Chico Mendes de Conservação da Biodiversidade). The experiments were conducted from March to May, 2012. To record the paths of hatchlings, ten experiments were performed with 15 hatchlings/tests at a time. Five experiments were conducted in areas without artificial illumination and five experiments were carried out in areas with the interference of artificial lighting, such as LED reflectors (methodology modified from Salmon and Witherington (1995).

For each experiment, hatchlings were randomly selected during the nesting period from 10 nests. The hatchlings were kept in thermal containers until we conducted the experiments and were shortly released near the sea. Circles with a 2 m radius were drawn on the sand. At the center, a small depression of 2–3 cm was made to simulate the natural conditions of emergence of the hatchlings. First, 15 hatchlings were placed in the center of the circles in order for us to observe how artificial light, or the absence thereof, influences their capacity to orient themselves towards the ocean.

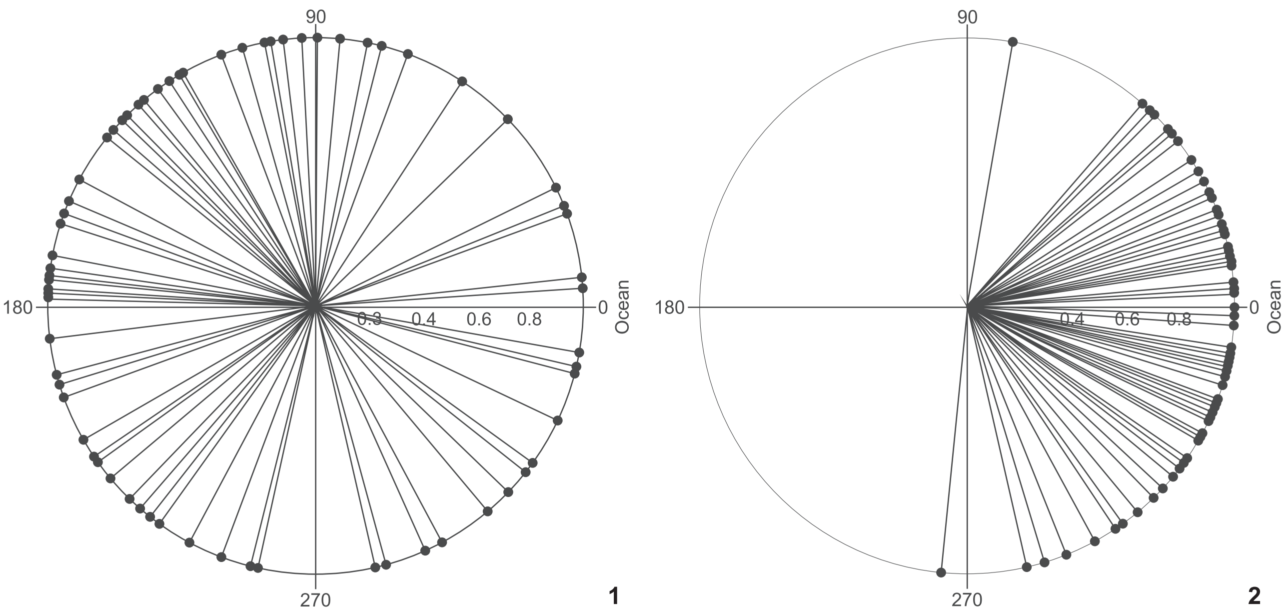
After neonates crossed the edge of the circles, the tracks were photographed and drawn on a diagram to record the circular motion or the change of direction. For the diagram, a compass and a 360° protractor were used to estimate the orientation angles of each hatchling from the center of the circle to its edge in relation to the sea.

The direction of the hatchlings in relation to the ocean was considered deviated when it departed from it by more than 30° (Salmon and Witherington 1995).

Later, the data were subjected to circular statistical analyses using the Rayleigh V test (Zar 1999) and the software Bioestat version 5.0 to verify whether the orientation of the trajectories of neonates significantly differed from random. A uniform distribution of neonates around the circumference was considered the null hypothesis. The percentage of deviation of hatchlings was determined in illuminated and non-illuminated areas in relation to the lunar phase. The significant differences between the movement of the hatchlings from illuminated and non-illuminated nests were processed using the BioEstat 5.0 software, the ANOVA variance test and Tukey test conducted a posteriori. The Primer 6.0 software (Clarke and Gorley 2001) was used to evaluate the significance and similarities of groups formed using Multi-Dimensional Scaling (MDS).

RESULTS

The tracks of hatchlings from simulated nests placed in illuminated areas showed trajectory changes in 86.67% of the total (N = 65), with an angular range from 4 to 350° (Fig. 1). Neonates originating from simulated nests placed in non-illuminated areas showed deviations in only 33.33% (N = 25) of all tracks, with an angular change from 0 to 95° (Fig. 2).



Figures 1–2. Trajectory deviations of hatchlings of the species *Eretmochelys imbricata* in (1) illuminated nests and (2) non-illuminated made in Merepe Beach, coast of Ipojuca, Pernambuco, Brazil.

The distribution of trajectories was considered random (V = 19.4895, p>0.05) for simulated nests located in artificially illuminated areas (Fig. 1). However, the experiments conducted in non-illuminated areas had an irregular distribution around the circumference, although the hatchlings' tracks were directed towards the sea (Z = 63.4377, p < 0.01) (Fig. 2). Movement patterns of hatchlings in illuminated areas were significantly different from non-illuminated areas (F < 0.0001, p < 0.01).

Through the Multi-Dimensional Scaling, it was possible to observe a separation of the two groups of hatchlings regarding the presence or absence of artificial light (Stress = 0.02) with a 75% similarity (Fig. 3).

We observed that during the crescent and first quarter moon for both illuminated and non-illuminated experiments the percentage of deviation was lower in comparison with the experiments conducted during the waning moon, which showed 77% of deviation (Fig. 4).

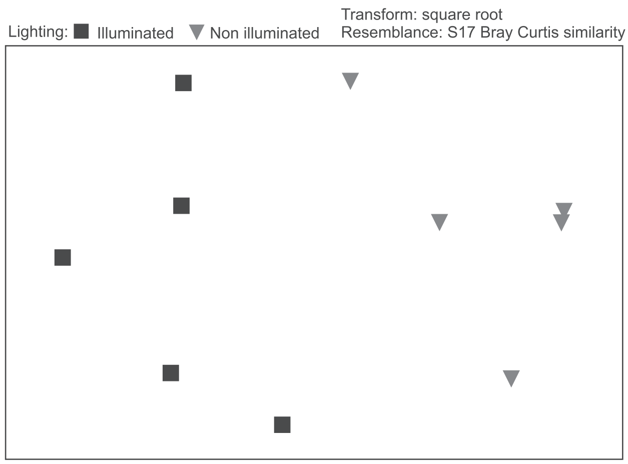


Figure 3. Multidimensional scaling (MDS) showing the existence of differences between the degree of orientation of hatchlings in relation to the ocean in illuminated and non-illuminated areas; formation of distinct groups (stress = 0.02) in samples collected in Merepe Beach, coast of Ipojuca, Pernambuco Brazil.

DISCUSSION

When the levels of artificial light are high, hatchlings may either ignore the natural light or be unable to perceive it (Lohmann and Lohmann 1996). This problem occurs in Florida's beaches, USA, where hatchlings originating from nests in illuminated areas had their trajectories changed in approximately 83% of the cases (McFarlane 1963, Salmon and Witherington 1995). This is similar to the results of the present study, in which changes in the trajectories of hatchlings were observed in 86% of the cases (Fig. 1).

The largest angular variation reinforces the strong attraction that artificial lights exert on neonates. Similar results were recorded in experiments with *C. caretta* (Salmon and Witherington 1995), *C. mydas* (Mrosovsky and Carr 1967),

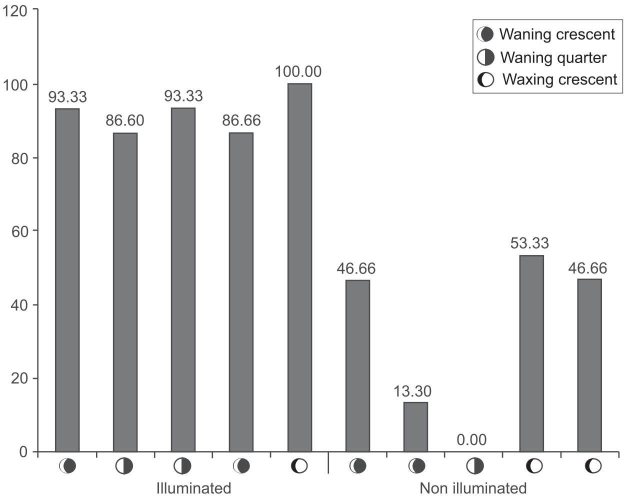


Figure 4. Percentage of emergence events diverted in function of the lunar phase and in illuminated and non-illuminated areas. Data based on ten experimental events in different lunar conducted in Merepe Beach, coast of Ipojuca, Pernambuco, Brazil.

Lepidochelys olivacea (Eschscholtz, 1829) (Mrosovsky and Carr 1967) and *Dermochelys coriacea* (Vandelli, 1761) (Bourgeois et al. 2009). In all of those studies, severe hatchling disorientation and increased disruption in their ability to find the sea were recorded. The disruption caused by artificial lights on neonate behavior includes crawling in the opposite direction of the ocean (Witherington and Martin 2003), or walking in circular paths, or abrupt changes in direction (Witherington and Bjorndal1991a, Salmon and Witherington 1995, Witherington and Martin 2003).

In addition, according to Wyneken (2000), disoriented hatchlings spend more energy to find the ocean and by doing that they become more vulnerable to predators. Nevertheless, the characteristics of the light influences the level of hatchling disorientation (Witherington and Bjorndal 1991b). In the absence of strong light stimulus, the hatchling will walk toward a dispersed light stimulus. The turtle *C. mydas*, for example, is attracted by light that has smaller wavelengths, while *C. caretta* not follows light with color yellow, like the ones with low sodium pressure (Mrosovsky and Shettleworth 1968, Witherington and Bjorndal 1991b).

Therefore, besides the fact that hatchlings are attracted to artificial illumination, we also know that the light's wavelength plays a role in the disorientation of sea turtles. Since is not known which wavelengths affect *E. imbricata*, more strongly, studies addressing this specific topic are needed to complement our findings.

According to Salmon and Witherington (1995), the lunar cycles are correlated with the trajectory of marine turtle hatchlings heading towards the sea. The highest number of path disruption occurs at night during periods close to the new moon (darker nights), while during the full moon, which is characterized by brighter nights, the hatchlings are oriented directly to the sea. However, when the levels of artificial light are high, hatchlings ignore these natural stimuli (Lohmann and Lohmann 1996).

Light pollution occurs mainly in highly developed locations with a higher population density. The coast of Ipojuca is one of the most developed beaches of Pernambuco and has a great number of hotels and resorts along its waterfront, which direct their lights toward the sea at night. Our findings reinforce the idea that the lights commonly used in this area is inadequate and harmful to *E. imbricata* hatchlings', contributing to their death by precipitating exhaustion, dehydration and increasing the risk of predation.

As a mitigation measure, the Ordinance #11 of 30 January 1995 was implemented in Brazil. It reads as follows:

"Article 1-Prohibit light sources that cause a light intensity higher than zero LUX in a strip of beach between the highest low-water mark up to 50 m (fifty meters) above the highest tide of the year (syzygy tide)."

Even though the ordinance covers the Fernando de Noronha District, and beach Boldro, Conceição, Caieira, Americano, Bode, Cacimba do Padre and Baía de Santo Antonio beaches in the state of Pernambuco, it does not cover Ipojuca's beaches.

In conclusion, the artificial lights in the studied region are negatively impacting the orientation of *E. imbricata* hatchlings' towards the sea and are affecting their survival in this region. We highlight the necessity for including Ipojuca's beaches within the protected area under Ordinance No. 11 and reinforce the need to control the level of light pollution in this turtle's nesting area.

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