Journal of Experimental Marine Biology and Ecology 463 (2015) 143–149

Contents lists available at ScienceDirect

Journal of Experimental Marine Biology and Ecology

journal homepage: www.elsevier.com/locate/jembe

Leatherback hatchling sea-finding in response to artificial lighting: Interaction between wavelength and moonlight

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ARTICLE INFO

Article history:
Received 17 October 2014
Received in revised form 2 December 2014
Accepted 3 December 2014
Available online 16 December 2014

Keywords:
Costa Rica
conservation
misorientation
light pollution
sea turtles
tourist development

ABSTRACT

Over the last decades, growing human populations have led to the rising occupation of coastal areas over the globe causing light pollution. For this reason, it is important to assess how this impact threatens endangered wildlife. Leatherback turtles (*Dermochelys coriacea*) face many threats of anthropogenic origin including light pollution on nesting beaches. However, little is known about the specific effects. In this study we studied the effect of different light wavelengths (orange, red, blue, green, yellow and white lights) on hatchling orientation under the presence and absence of moonlight by analyzing: (i) the mean angle of orientation, (ii) crawling duration, and (iii) track patterns.

Hatchling orientation towards the sea was always better under controlled conditions. In the absence of moonlight, leatherback hatchlings were phototaxically attracted to the experimental focus of light (misoriented) for the colours blue, green, yellow and white lights. Orange and red lights caused a lower misorientation than other colors, and orange lights produced the lowest disrupted orientation (disorientation). On nights when moonlight was present, hatchlings were misorientated under blue and white artificial lights. Crawling duration was low for misoriented hatchlings and high for the disoriented individuals. Our conclusion to this is that hatchlings can detect and be impacted by a wide range of the light spectrum and we recommend avoiding the presence of artificial lights on nesting beaches. Additionally, actions to control and mitigate artificial lighting are especially important during dark nights when moonlight is absent.

1. Introduction

Sea turtles nest on sandy beach ecosystems. These habitats are severely threatened by global climate change and anthropogenic effects (Schlacher et al., 2007). Light pollution associated with coastal development is one of the important anthropogenic alterations that can reduce the reproductive success of sea turtles (Verheijen, 1985; Witherington et al., 1990). Artificial illumination on nesting beaches alters both the nest site selection by females, hatchling behaviour and also has a direct impact on hatchling survival (Kamrowski et al., 2012; Witherington et al., 1990). After emergence, sea turtle hatchlings crawl rapidly from the nest towards the sea to avoid predation (Salmon and Wyneken, 1987; Santidrián Tomillo et al., 2010). Sea-finding seems to be mainly visual as sea turtle hatchlings are proven to be attracted to the brightest area within their field of vision and is also related to the brightness and lower elevation of the sea. Moreover, sea-finding abilities can also be affected by the presence of dark silhouettes that are cast by dunes and other objects (Bartol et al., 2003; Limpus and Kamrowski, 2013; Mrosovsky, 1970; Salmon et al., 1992; Tuxbury and Salmon, 2005) that continue to be important even after they enter the aquatic environment (Bartol et al., 2003). However, a hatchling's ability to detect these natural cues is reduced in the presence of artificial lights (Lorne and Salmon, 2007). As a result, beach lighting disrupts the orientation of hatchlings, which will eventually lead to exhaustion, dehydration, entanglement in dune vegetation, and/or an increase of the risk of predation (Salmon, 2003; Zheleva, 2012).

The effects of artificial light on hatchling disorientation (when they crawl in circuitous paths and are not able to find a cue) and misorientation (when they direct themselves to the artificial source) have been previously documented (Mcfarlane and Mar, 1963; Philibosian, 1976; Salmon and Witherington, 1995; Verheijen, 1985). However, the effect on the behaviour of the turtles varies among species and depends on the light's characteristics such as its intensity, wavelength, polarization and periodicity (Witherington, 1985).

Previous field experiments conducted on loggerhead (*Caretta caretta*) and green turtles (*Chelonia mydas*) show that both short and long light wavelengths at any intensity influence hatchling orientation. The effect of artificial lighting on hatchling orientation was reduced in the presence of moonlight and its effects on hatchlings varied

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http://dx.doi.org/10.1016/j.jembe.2014.12.001
0022-0981/

depending on the characteristics of the luminaries (Witherington and Bjorndal, 1991a; Witherington, 1991; Witherington and Martin, 1996). There are differences in the behavioral response between species (Witherington and Bjorndal, 1991b). Green turtles show phototactic spectral sensibility (phototaxis or light attraction) for the wavelength of the visible light region 440-700 nm, and show signs of slight ultraviolet discrimination (Levenson et al., 2004). Loggerhead turtles show positive phototaxis (misorientation) for blue (450 nm), green (500 nm) and yellow (580 nm) colors (Young et al., 2012). Likewise, olive ridley (*Lepidochelys olivacea*) (Karnad et al., 2009), hawksbill (*Eretmochelys imbricata*) (Eckert and Horrocks, 2002) and flatback turtles (*Natator depressus*) (Fritsches, 2012; Pendoley, 2005) show preferential orientation towards low wavelengths.

The disorientation of hatchling leatherback turtles (*Dermochelys coriacea*) as a consequence of light pollution has been documented in Gabon. This important nesting site was highly contaminated by light pollution and hatchlings showed a higher attraction to artificial lights than to silhouettes (Bourgeois et al., 2009). Although leatherback turtles respond to a wide range of light wavelengths and are capable of color vision (Horch et al., 2008), no experimental studies have analyzed the effect of the presence of artificial lights of different wavelengths (colors) on the sea-finding behaviour of hatchlings under natural conditions. This type of studies is important not only because of the increasing number of artificial lights on beaches, but also because of the use of lights by tourists and observers on the nesting beaches. Given the increasing pressure of coastal development on nesting beaches and the critical situation of some leatherback populations, it is important to assess the impacts of artificial lighting on hatchling behaviour and therefore on the overall reproductive success of the species. Consequently, the aim of this study was to characterize the effects of both artificial lights (different wavelengths) and natural lights (the presence or absence of moonlight) on hatchling behaviour. Studying the impact of light sources on leatherback turtles provides the basis for understanding the effects of this growing environmental threat. This information is essential to characterize the threat and prioritise responses and mitigation strategies in sea turtle conservation efforts (Hamann et al., 2010; Wallace et al., 2011).

2. Methods

2.1. Study site

The study was conducted at Pacuare beach, located in the Pacuare Nature Reserve (PNR) (10°10 ′00″ N, 83°14 ′00″ W), an important leatherback nesting beach on the Caribbean coast of Costa Rica (Rivas et al., in press). The experiment was done during the leatherback hatchling season (May through August) in 2013. Between March and May, 39 clutches laid by nesting turtles were relocated to a protected fenced hatchery. These clutches were laid on the first kilometer of the beach and were relocated due to the high risk of inundation in this area. After hatchlings emerged from the nest, seven hatchlings were randomly taken to run the experiments. Experiments with lights were conducted during the night (between 18:00 h and 02:00 h), immediately after hatchlings emerged from the nest. Each hatchling was immediately released from the experimental area located close to the hatchery after the experiment was completed.

*2.2. N**atural beach light***

Experiments with light in the turtle's natural beach conditions (in the presence and absence of moonlight) were conducted in June and July 2013. Before conducting each experiment, the level of natural sky light was measured on the beach with a portable photometer, the Sky Quality Meter (SQM) by Unihedron. This photometer measures average luminance from a relatively wide solid angle (1.5 steradian; the Half Width Half Maximum (HWHM) of the angular sensitivity is ~42°) and measurements are displayed in astronomical units of magnitude per square arcsec (mag/arcsec^2). The SQM is temperature calibrated and gives the luminance with the precision of 0.1 mag/ arcsec^2, which is equivalent to 10 percent in linear (cd/m^2) units. Sky brightness was converted to the standard luminance scale (SL) (cd/m^2) using the formula $(SL) = 10.8 \times 10^4 \times 110^{(-0.4*[mag/arcsec2])}$ (www.darkskiesawareness.org/sqm-zlpa.php) (increasing luminance values correspond to lower brightness levels). Measurements were taken by pointing the device at the horizon on the seaside at 1.0 meter above the sand, always from the same place and before each experiment was conducted. Light readings were recorded during the absence of moonlight (during the new moon, before moonrise or after moonset, and/or with total cloud cover) and presence of moonlight (any lunar phase). Considering the fact that cloud coverage amplifies sky luminance (Kyba et al., 2011), cloudy nights were defined as with or without moonlight depending on luminance recordings: absence of moonlight (more than 500 μcd/m^2) and presence of moonlight (until 500 μcd/m^2).

The anthropogenic lights from the town of Limón are visible from Pacuare (~45 km) and therefore the mean angle of Limon from the emplacement of release was recorded (angle between Limon and hatchling releasing emplacement, Fig. 1) to assess the effect of these lights on the sea-finding orientation of hatchlings.

2.3. Experiments with artificial light

The experiments were conducted ten meters away from the hatchery and ten meters away from the highest tide line. A 2-meter radius circle was drawn in the sand around the point of release. The light source was located 5 meters away from the center of the circle in the direction opposite to the sea and the light was focused towards the center of the circle (Fig. 1). The light source was fixed to a stick at 1.0 meter above the surface of the sand. Seven treatments were used, one being a control in dark conditions and six using colours of the visible spectrum: orange, red, blue, green, yellow, and white. Conventional LED headlamps were used as artificial light sources (28 - 35 lumens), as they are frequently used by conservationists on sea turtle nesting beaches (Nichia, PETZL and Nebo brands). Polycarbonate filters were used for the yellow light. Seven hatchlings from each nest were randomly assigned to one light treatment. Hatchlings were placed in the center of the circle and were allowed to crawl by themselves. Information was collected on the following parameters under two natural light conditions (presence or absence of moonlight):

(1) Orientation. Previous methodology described by Salmon and Witherington (1995) and Salmon (2003) was followed. The point where hatchlings crossed the circle perimeter was considered to define the angle of orientation. The source of light was at 270°tand the ocean at 90°n (Fig. 1).
(2) Crawling duration. The time that it took the hatchling to move from the light emplacement to leave the circle was recorded. The maximum time allowed was four minutes. After four minutes we considered the test as a "no exit"oresult.
(3) Track pattern. Two types of track patterns were defined based on the hatchling's movements: "S" when the hatchling left the circle following a straight path regardless of the direction and "W"hwhen the hatchling left a wavy track or moved in circles.

Due to the fact that hatchlings can react to artificial lights by a) becoming disoriented (they crawl in circuitous paths and are not able to find a cue to orient themselves) or b) misoriented (they direct themselves to the artificial source; Salmon and Witherington, 1995), hatchling orientation was further classified into four groups depending on the exit point from the circle: group 1 (45° to 135°), group 2 (315° – 45°), group 3 (135° – 225°) and group 4 (225° – 315°) (Fig. 1). This