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Effect of light intensity and wavelength on the in-water orientation of olive ridley turtle hatchlings

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ABSTRACT

Light pollution, associated with coastal development, poses a growing threat to sea turtles. Hatchlings are particularly affected during their crawl to the ocean since they exhibit phototaxis and may move towards or be disoriented by artificial lights. Although much is known about how hatchlings respond to artificial light while crawling to the ocean, far less is known about their response after reaching the water. Here, we investigate how hatchling olive ridley turtles (*Lepidochelys olivacea*) held in artificial pools responded to light of different wavelengths (red, 720 nm; yellow, 660 nm and green, 520 nm) and intensities (0.1–3.3 lx, mean 0.87 lx, SD = 0.85, 10.3–45.9 lx, mean 15.75 lx,SD = 7.12; 47.5–84.2 lx; mean 52.02 lx, SD = 9.11; 91.3–140.8 lx, mean 105 lx, SD = 13.24; 150.1–623 lx, mean 172.18 lx, SD = 73.42). When no light or red light below 39 lx was present, hatchlings oriented at a mean angle of 180° from true north and did not orient towards any discernable feature. However, hatchlings swam towards the light at intensities of red light above 39 lx, yellow light above 10 lx and green light above 5 lx. Our findings indicate that sea turtles will swim towards artificial lights even after reaching the water. Thus, we recommend light mitigation efforts should extend beyond nesting beaches and into the associated oceanic habitats.

1. Introduction

With > 40% of the world's population living on coasts (Small and Nicholls, 2003), the degradation of beach habitats, due to human development, poses a significant threat to coastal ecosystems (Lotze et al., 2006). Human development can alter both the physical and chemical components of beach habitats in several ways (Frihy, 2001; Lotze et al., 2006; Evans, 2018; Jefferson et al., 2009) and even subtle changes, such as an increase in light pollution, can have dramatic effects. For example, sea turtles nest on sandy tropical beaches and when the hatchlings emerge, they head towards the brightest and lowest horizon (Tuxbury and Salmon, 2005). On undeveloped beaches this is usually the waterline; however, on developed beaches, artificial lights can cause hatchlings to crawl towards the source of light or in random directions. Various studies have documented the disorienting effect of artificial lights on leatherback, (*Dermochelys coriacea*)(Rivas et al., 2015), hawksbill (*Eretmochelys imbricata*) (Philibosian, 1976), olive ridley (*Lepidochelys olivacea*) (Karnad et al., 2009), green (*Chelonia mydas*) (Tuxbury and Salmon, 2005), loggerhead *(Caretta caretta)* (Lorne and Salmon, 2007) and flatback (*Natator depressus)*(Pendoley and Kamrowski, 2015) turtle hatchlings as they crawl to the ocean. While adult sea turtles exhibit similar disorientation in the presence of light (Witherington and Salmon, 1992), they have also been documented to avoid illuminated areas when selecting nesting habitat (Silva et al., 2017).

Hatchlings that reach the water use the circular wave motion to orient themselves through the surf (Lohmann and Lohmann, 1992) and into the open ocean. Away from the coastal waves, hatchlings use geomagnetic cues to migrate to open-ocean gyres (Lohmann and Lohmann, 1996), where they remain for many years (Reich et al., 2007). However, there are also data that indicate that hatchlings may still orient to artificial lights while in the water, potentially overriding the effects of waves or geomagnetisms on normal orientation behavior (Daniel and Smith, 1947b; Mann, 1978). Dispersing hatchlings swim

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towards shore lights on docks and boats (Daniel and Smith, 1947b; Mann, 1978) with some light intensities strong enough to redirect hatchlings back to the shore after entering the water (Daniel and Smith, 1947a). Experimental studies have also shown that loggerhead hatchlings may swim towards artificial lights (Lohmann, 1991; Light et al., 1993; Lohmann and Lohmann, 1996) and even continue to swim towards the location of the light stimulus after the stimulus has been removed (Lohmann and Lohmann, 1994). However, this response could vary between sea turtle species.

Sea turtles are not equally sensitive to light of all wavelengths. Their eyes are adapted to best perceive blue-green light (Lundgren and Højerslev, 1971). This is because they inhabit deep-water environments which absorb other light colors, restricting the light available to blue-green wavelengths (Lundgren and Højerslev, 1971). Although there is clear variation between species, leatherback, loggerhead and green turtles all exhibit peak sensitivity to blue-green wavelengths around 500-580 nm (Levenson et al., 2004; Horch et al., 2008). For instance, while leatherback and loggerhead turtles exhibited minimal to no reaction to light at wavelengths shorter than 440 nm (Levenson et al., 2004; Horch et al., 2008), green turtles were able to perceive light at wavelengths as low as 400 nm (Levenson et al., 2004).

Our objective was to investigate the in-water orientation of olive ridley turtle hatchlings towards artificial lighting of various intensities and wavelengths. Understanding the behavior of hatchlings to light intensities can further emphasize the need to eliminate lights thus reducing the harmful effects of light pollution on sea turtle nesting beaches to minimize any negative impacts.

2. Materials and methods

2.1. Study site

Playa Grande was located in Parque Nacional Marino Las Baulas (PNMB) on the Pacific coast of Costa Rica (10°19′58.1″N, −85°50'50.1″W). It was one of the most important nesting beaches for the Eastern Pacific leatherback turtle (Spotila et al., 2000) and also provided nesting habitats for green (Paladino, 2018) and olive ridley turtles (Dornfeld et al., 2015). The southern extent of Playa Grande was separated from the town of Tamarindo by the opening of the Tamarindo Estuary. Being less than a kilometer across the bay, Tamarindo was a year-round source of local light pollution from Playa Grande.

2.2. Clutch collection and preparation

During October 2015, we patrolled Playa Grande nightly to encounter nesting olive ridley turtles. When a turtle was encountered nesting below the high-tide line, the clutch was considered in peril and we relocated it to a beach hatchery where it would be safeguarded during incubation. The hatchery was approximately 50 m from the high tide line. We collected a total of 6 clutches from separate nesting females.

As the mean incubation duration for olive ridley clutches at Playa Grande is 49.1 ± 3.6 days (Dornfeld et al., 2015), we covered each nest with an opaque covering after 40 days of incubation to block any ambient light (e.g. starlight, moonlight and ocean reflectance) from reaching the hatchlings upon emergence. Premature exposure to light could allow early orientation and alter hatchlings orientation in the subsequent experiment. From each clutch, we randomly selected 5 hatchlings for use in orientation experiments. These hatchlings along with the others in the clutch were released onto the beach at different locations along PNMB.

2.3. Experimental setup

Adapting the methods used by Salmon and Wyneken (1990), we constructed a circular inflatable pool (60 l) with a diameter of 1.25 m within the beach hatchery. The pool was enclosed within a 6 × 6 × 3 m tent to block any ambient light.

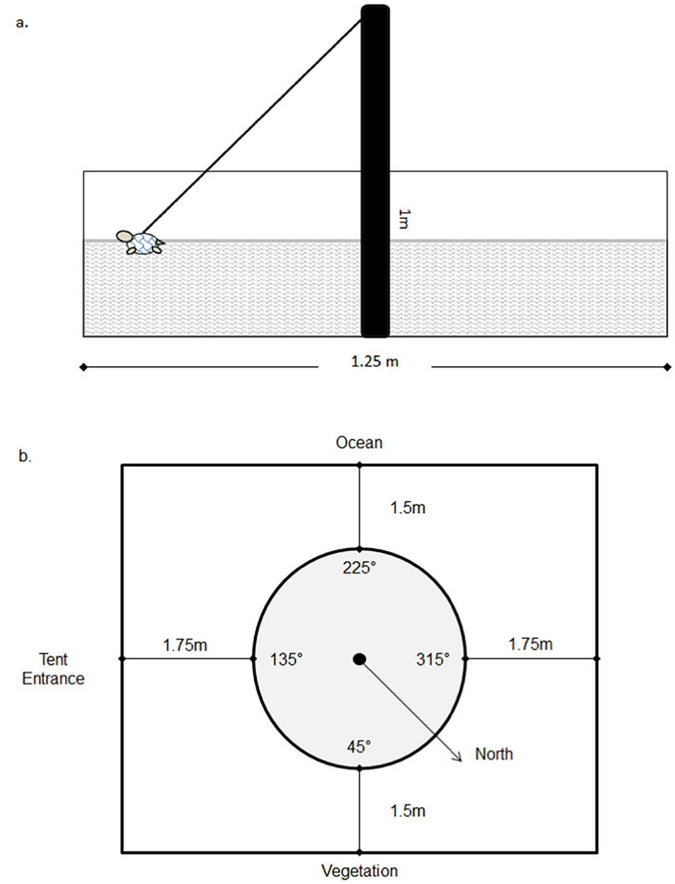

Fig. 1. Laboratory apparatus.
A longitudinal view of the pool (a) and the laboratory apparatus (b) including the tent outline (black rectangle), pool (gray circle), pole location (Black circle) and the locations from which light stimuli were shown at 135°, 45° and 315°.

We filled the pool with sea water and replaced at least 60% of the pool's water with fresh sea water 3–6 h before each trial. Water temperature ranged from 25.7–29.5 °C with mean (± SD): 27.4 °C ± 1.5 °C.

In the center of the pool, we placed a PVC pole with a swivel platform at its top that was connected to a nylon string that could rotate freely around the pool in any direction. A 2 × 1 cm section of Velcro was fastened to the loose end of the nylon string. Before each experiment, we attached the Velcro pad to a complimentary 1.0 × 0.5 cm Velcro pad that was glued (Vetbond glue) to the anterior portion of the carapace of each experimental hatchling. The nylon string was not long enough to let the hatchlings reach the edges of the pool (Fig. 1a).

We placed a 0.75 m tall PVC stand with one NITECORE SRT6 930 lm 3-Mode White Dimming Tactical LED Flashlight around the pool at angles of 45°, 135° and 315° (with 0° being true north; Fig. 1b). The light source was not placed at an orientation of 225° as this heading faced the ocean and we were primarily interested in whether artificial light could direct hatchlings away from the ocean. The flashlights were fitted with translucent filters of red (720 nm), yellow (660 nm) and green (520 nm) wavelengths.

To record hatchling behavior, we installed a Bell and Howell DNV16HDZ-MFull 1080p HD 16MP Infrared Night Vision Camcorder above the pool. After the completion of the trials, hatchlings had their Velcro attachments removed and were promptly released to the ocean.