Ocean and Coastal Management 153 (2018) 108–115

Contents lists available at ScienceDirect

Ocean and Coastal Management

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

Reduction of sea turtle population recruitment caused by nightlight: Evidence from the Mediterranean region

Charalampos Dimitriadis[a,*], Ivoni Fournari – Konstantinidou[b,c], Laurent Sourbès[a], Drosos Koutsoubas[a,b], Antonios D. Mazaris[c]

[a] National Marine Park of Zakynthos, El. Venizelou 1, 29100 Zakynthos, Greece
[b] Department of Marine Science, Faculty of Environment, University of the Aegean, 81000 Mytilene, Lesvos Island, Greece
[c] Department of Ecology, School of Biology, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

ARTICLE INFO

Keywords:
Sea-finding
Coastal lighting
Marine turtles
Disorientation
Light pollution

ABSTRACT

The spread of artificial night lighting is increasingly acknowledged as a major threat to global biodiversity. Identifying and exploring the impacts of nightlight pollution upon species behavior, ecology and population dynamics could enhance conservation capacity. Sea turtle hatchlings emerge from nest at night and use visual cues to direct towards the brightest and lowest horizon, eventually leading them to the sea. Nightlight pollution could alter the cues perceived, disorienting the fragile hatchlings. We examined the level of artificial lighting and orientation patterns of sea turtles hatchling, in Zakynthos Island, Greece, one of the main nesting rookeries of the loggerheads (*Caretta caretta*) in the Mediterranean Sea. We analyzed movement patterns of 5967 hatchlings from 230 nests, and demonstrate that nightlight pollution could reduce population recruitment by more than 7%, suggesting that mitigation measures should become a high conservation priority. Our results further suggest that the responses of sea turtle hatchlings to artificial nighttime lighting could vary significantly depending on various factors, either anthropogenic or natural. Local conditions operating at the nesting site level determine the fine scale responses of hatchlings, thus conservation measures should be drawn in respect to site-specific properties.

1. Introduction

The coastline represents an attractive zone for the establishment of various economic activities (IPCC, 2007; Halpern et al., 2008). Still, the development and increased utilization have come together with new threats for coastal biodiversity (Lotze et al., 2006; Coll et al., 2012) and for the organisms which temporary use the coastal habitat (e.g. marine mammals, seabirds, estuarine fish, sea turtles) for resting, foraging or reproduction. Yet, the ability to quantify the impacts of coastal threats is critical for prioritizing conservation actions (Beger et al., 2010; Micheli et al., 2013).

Coastal development has accelerated the spread of artificial nightlights. As a result, over the last years, an increased number of studies had explored the impacts of artificial night lighting upon the behavioral and physiological ecology of amphibian, reptile, bird, mammal, invertebrate and fish species inhabiting the coastal realm (e.g. Rich and Longcore, 2006; Gaston et al., 2015; Davies et al., 2014, 2015; Troy et al., 2011; Becker et al., 2013; Luarte et al., 2016). The impacts of artificial nightlights are often translated as a disruption of foraging, reproductive, navigation, orientation, dispersal and migration behavior, as an increased risk of predation and fitness reduction (Perry and Fisher, 2006). Artificial night sky brightness is therefore accounted as driver affecting population viability and dynamics (Gaston and Bennie, 2014). This is actually the reason why nightlight pollution is increasingly acknowledged as an additional threat for biodiversity and thus should be treated as a modern challenge for global conservation and management (Gaston et al., 2014; Davies et al., 2014).

Sea turtles are charismatic megafauna for which the impact of artificial nighttime lighting has been tested both experimentally and empirically (e.g. Witherington and Martin, 1996; Tuxbury and Salmon, 2005; Thums et al., 2016). Adult female sea turtles lay their nests in the coastal beaches at the close vicinity where they were born several decades ago. The hatchlings emerge from nest at night and use visual cues which will drive them towards the brightest and lowest horizon, eventually directing them to the sea (Kawamura et al., 2009; Limpus and Kamrowski, 2013). As artificial nighttime lighting overrules the effect of natural visual cues (Witherington and Martin, 1996) it can directly (light sources visible from the beach) and indirectly (sky-glow

* Corresponding author.
E-mail address: xdimitriadis@marine.aegean.gr (C. Dimitriadis).

https://doi.org/10.1016/j.ocecoaman.2017.12.013
Received 17 July 2017; Received in revised form 11 December 2017; Accepted 13 December 2017

caused by inland light sources not directly visible from the beach) disrupt the sea-finding orientation of the hatchlings (e.g. Tuxbury and Salmon, 2005; Limpus and Kamrowski, 2013; Berry et al., 2013). For the fragile hatchlings, the loss of orientation could lead to mortality due to exhaustion, dehydration, and exposure to predators. Nightlight pollution could therefore lead to reduction of population recruitment (Lorne and Salmon, 2007).

Each nesting beach has distinct topographical features (e.g. slope, width, silhouettes that back the shore) which could alter the cues for orientation perceived by sea turtle hatchlings. The visual behavior of sea turtle hatchlings could also differ between populations of the same species (Fritsches, 2012). Alternatively, sea turtles have shown different intrinsic abilities with respect to nesting site microenvironment features [e.g. thermal adaptive differentiation to finer scale nesting conditions (Weber et al., 2011); varying thermal tolerance of embryos (Howard et al., 2014); varying pivotal sex determination temperatures (Hays et al., 2014)]. Yet, the diversity of local conditions along with the fine scale adaptive potential could lead to differences in the level of exposure, the sensitivity of responses and the vulnerability of different population to nightlight pollution.

Despite these concerns, there is a lack of estimates regarding how the impact of hatchlings' disorientation due to artificial nighttime lighting could be translated to reduced recruitment. Similarly, there is a gap in the spatial extent of relevant studies along the distribution of sea turtle nesting sites. For example, in the Mediterranean region that currently hosts 45 major nesting sites of loggerheads and 13 of green turtles (Almpanidou et al., 2016; Casale and Margaritoulis, 2010) such evidence is very scarce (but see Peters and Verhoeven, 1994).

Here, we attempt to contribute to this research, by providing quantitative evidence on the responses of loggerhead sea turtle hatchling to artificial night sky brightness in the Mediterranean region. We investigate hatchling orientation patterns and light pollution level at both light impacted and naturally dark nesting beaches of the National Marine Park of Zakynthos (NMPZ), Greece. The NMPZ hosts one of the most important nesting rookeries of loggerhead turtles in the Mediterranean, while it is subjected to intense tourism activities annually, with the peak tourist period synchronized with the middle of sea turtle reproduction period. The objectives of this study are twofold. First, we aim to provide insights on sea turtle hatchling responses to lighting from an underrepresented region. Second, we attempt to identify the degree to which specific measures are needed to be taken for mitigating potential impacts of nightlight pollution upon this critical nesting aggregation.

2. Methodology

2.1. Study area

The study was conducted at the nesting beaches of loggerhead sea turtles, *Caretta caretta*, located within the boundaries of the NMPZ, eastern Mediterranean (Fig. 1). The rookery contains 6 nesting beaches with a total length of approximately 6 km. All beaches are enclosed within the boundaries of the NMPZ which was established in 1999 as the first protected area in the Mediterranean focusing mainly on the protection of sea turtles. Measurements of nighttime lighting and observations of sea-finding ordination patterns were conducted to the 5 nesting beaches (i.e. Kalamaki, Crystal, Sekania, Gerakas and Marathonisi) which support more than 85% of the nesting activity. These nesting beaches have different environmental conditions (e.g. beach slope, width, length) and are subjected to different human use and thus pressures (Katselidis et al., 2012).

In NMPZ the nesting activity of loggerheads is taking place from late May to early August with the incubation duration ranging from 51.3 to 69.8 days (Margaritoulis, 2005). The island of Zakynthos is an international tourist destination; annually more than 800,000 people are visiting the beaches located within the boundaries of the NMPZ, and use the facilities (e.g. settlements, hotels, resorts, shops, bars, airport) hosted along the coastline (Appendix A). Therefore, a high overlap in the hatchling emergence period and the peak of the tourist period (during August) is taking place subsequently raising conservation challenges.

2.2. Field work

2.2.1. Light pollution assessment

Measurements of nighttime lighting were conducted during the 2014 nesting period. In order to ensure comparability of patterns and processes across the nesting rookery, a strict protocol was followed for the nighttime light measurements. The nesting beaches were divided into 12 stations which were identified to share similar topographical characteristics and level of exposure to artificial light sources (Management Agency of the NMPZ, 2008). For each one of these stations, one-off nighttime lighting measurements were taken under the absence of cloud cover between 11:00 and 12:00 p.m. during the new moon phase of August (i.e. no moon light) (Kamrowski et al., 2015). The nests which were laid within the boundaries of a given station were characterized by its nightlight properties.

At each sampling station the following parameters were recorded: a) 360° bearing of the coastal lighting and the brightest sources of light visible from the beach, b) 360° bearing of sky-glow (degrees) and its strongest sources and c) light intensity (average of 4 successive point measurements) at each station. Given that hatchlings are oriented by using a visual ‘cone of acceptance’ from 0 to 30° in the vertical level, light intensity at each sampling station was measured at an elevation of 15° from the beach surface (Limpus and Kamrowski, 2013). The mean light intensity at a nesting beach level was then produced as the average of the measurements taken at each station. Measurements were conducted by means of a portable light meter (WETEKOM ST-8820), compass and GPS.

2.2.2. Orientation patterns and nest environment

To delineate the potential impact of nighttime lighting upon hatchling sea-finding orientation, we reported movement patterns of hatchlings emerged from 230 nests by visiting the nesting beaches during the dawn from August to October 2014. Hatchling tracks were counted and their routes were recorded by using a GPS (at 5 m intervals).

When more than 15 hatchling tracks were found to originate from the same nest we used the fan mapping method (Salmon and Witherington, 1995; Pendoley, 2005) (Fig. 2). In this respect, we measured the angle (North direction was used as reference point) of the right and left outer tracks of the fan, the modal direction and the direct line from the nest to the sea (shortest route to the sea). Bearings were recorded by means of a compass at distance of 5 m from the nest (Kamrowski et al., 2015). These measurements were used to provide a set of hatchling sea-finding orientation metrics for each nest: a) fan spread defined as the difference of compass bearings between the outside arms of the track fan, b) offset angle defined as the difference between the modal direction and the bearing of the most direct line to the sea (i.e. shortest distance from the nest to the sea bearing), and (c) mean offset from the sea direction defined as the difference between the bearings of the two outer arms of the track fan and the direct line to the sea (indicating skew pattern of the tracks). To list a sea-finding orientation behavior as disturbed we used two alternative thresholds (see Salmon and Witherington, 1995): the offset angle been higher than 30° and/or the fan spread angle been higher than 90°.

Irrespectively of the number of tracks found at each nest (i.e. both for the cases of more or less than 15 tracks), bearings and routes of the stray tracks (i.e. hatchling tracks found in a different direction to the bulk of the nest) were reported, but they were not included in the fan mapping method (Pendoley, 2005). The routes of the stray tracks were recorded individually when they were less than 5 while their main