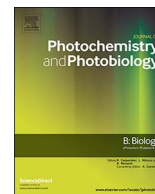




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Light pollution affects nesting behavior of loggerhead turtles and predation risk of nests and hatchlings



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ABSTRACT

The introduction of artificial light into wildlife habitats is a rapidly expanding aspect of global change, which has many negative impacts on a wide range of taxa. In this experimental study, which took place on a beach located on the island of Boa Vista (Cabo Verde), three types of artificial light were tested on nesting loggerhead sea turtles as well as on ghost crabs, which intensively predate on nests and hatchlings, to determine the effects they would produce on the behavior of both species. Over the course of 36 days, female loggerheads and ghost crabs were studied under yellow, orange and red lights, with observations also being made on dark nights that served as a control treatment. During this period, the frequencies of nesting attempts, the time taken by turtles to complete each phase of the nesting process, and ghost crab abundance and behaviors were carefully recorded. 1146 loggerhead nesting attempts were observed and recorded during the experiments, and results showed a decrease in nesting attempts of at least 20% when artificial lighting was present. A significant decline in successful attempts was also observed within the central sections of the beach, which corresponded to those that received more light. This artificial lighting significantly increased the time that turtles spent on the nesting process and forced them to do more extensive beach crawls. Despite this, the presence of light had no apparent effect on the final selection of the nesting site. Yellow and orange lights significantly disrupted the sea finding behavior and turtles were often unable to orient themselves seaward under these color lights. Disoriented turtles were observed crawling in circuitous paths in front of the light source for several minutes. In addition, artificial lights had the potential to increase the number of ghost crabs present within the illuminated stretches of the beach. However, only yellow lighting produced a significant change on aggressive and prey searching behaviors. These changes in abundance and behavior could cause a greater predation on loggerhead turtle nests. Red light had no significant impact on the behavior of either species. It should be a priority to enforce preventive measures and light mitigation strategies to ensure the conservation of important loggerhead rookeries.

1. Introduction

The natural light-dark cycle is vital to the survival of a vast number of species, yet, essential for the correct synchronization of periodic behaviors: used to regulate metabolic processes, growth and behavior [1]. Sea turtles are reptiles that are known for coming ashore to lay their eggs, which they have been doing for an estimated 200 million years. Of this ancient group of animals, only seven species remain in the oceans today [2,3], occupying a diversity of ecological niches in marine ecosystems [4] and mostly presenting nocturnal nesting behavior [5,6]. Over the course of their evolutionary history sea turtles have faced a great variety of threats, both natural and (in recent times)

anthropogenic [7]. Many human-related activities including both legal and illegal fishing, direct exploitation, the alteration or even loss of habitats, pollution, light pollution, coastal development and climate change are threats that are faced by sea turtles [8–11].

Sea turtles, as well as most other living organisms, require regular intervals of natural diurnal and nocturnal light. Cinzano et al. [12] singled out light pollution as the most widespread man-made threat in recent years and subsequently the impact that artificial lights generate on humans and on ecosystems during nights is a rising concern among scientists and conservationists [13]. Although artificial lights have been used for over a century for many purposes, only in recent years it has been widely recognized as an environmental issue of importance [14],

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Fig. 1. Maps of the Cabo Verde Archipelago, the island of Boa Vista and the study beach of Joao Barrosa.

causing profound changes to the nightly environment [15].

Worldwide light pollution, which is an open term that includes excessive or obstructive artificial light that is caused by bad lighting design [16], has grown at a rate of 6% per year [17]. Light pollution primarily affects nocturnal species, and it does so by triggering unnatural processes that can result in important physiological and behavioral changes [18]. In some cases, it can influence competitive interactions, something that has the potential to reduce the survival of those affected species [19]. Some species may see their predator-prey interactions altered, as well as that of species directly linked to them [18], generating changes that can in some cases reshape the composition of entire communities [20].

The ever-growing effects that light pollution has on nesting beaches and surrounding areas are a consequence of the rapid increase of anthropogenic activities along the planet's coastlines [5], and it is now evident that it has significant and critical impacts on many behavioral responses exhibited by sea turtles [21]. Light pollution tends to reduce the availability and suitability of sea turtle habitats and can become a primary threat to entire sea turtle populations [22].

Despite the importance of this topic, there are few published studies on the effects that light pollution has on sea turtles, and almost all of them focus solely on hatchlings and specifically the alterations to their sea-finding abilities immediately after emerging from the nest [11,23]. This behavior can change due to artificial light on nesting beaches [6,24]. Other than predation risk, disorientation of hatchlings by artificial light can also cause exhaustion, dehydration, or being run over by vehicles on coastal roads [16]. Furthermore, most studies on the effects of light pollution concentrate on sea finding behavior of hatchlings and evidence is very limited on females [25]. The effects that this hazard has on nesting females are still largely unknown and is a subject that requires further studies.

Five species of sea turtle have been observed in the Cabo Verde Archipelago, where our study took place [26]. The loggerhead sea turtle (*Caretta caretta* L.) is the most common, the most representative, and it is the one that is known to breed on its shores [26,27]. This species of sea turtle is highly migratory, occurs in coastal and pelagic habitats [28] and it is found in all tropical, subtropical and temperate waters in all the world's oceans [29–31]. Different population structures are present in each region because of natal philopatry [32], adult loggerheads that nest in Cabo Verde are reproductively isolated from the

rest of loggerhead rookeries [33] and considered as the Eastern Atlantic Regional Management Unit [34]. This population is listed as Endangered in the International Union for the Conservation of Nature's Red List of Threatened Species [35]. It is the second largest loggerhead sea turtle rookery in the whole Atlantic [27,36], and is considered to be the third largest in the world. The majority of the nests are dug on the island of Boa Vista. On other islands, such as Sal, Santa Luzia, Maio, São Nicolau and São Vicente the number of females that are found to come ashore is much lower [27,37,38].

Loggerheads turtles are also vulnerable to natural hazards like ghost crabs that predate on eggs and hatchlings. This group of crabs is the most representative within the Ocypodidae family, and typically inhabits sandy beaches in subtropical and tropical regions [39,40]. This genus has a cosmopolitan distribution [41], and can be found in estuarine regions [42]. In the archipelago, and especially on Boa Vista, *Ocypode cursor* Linnaeus, 1758 (locally known as “plart”) is the only relevant species that predate on turtle nests [27,43]. Ghost crabs are nocturnal, spending the daytime hiding in holes that they dig in the sand [44], therefore the presence of light pollution would surely affect their behavior, consequently altering the predator-prey dynamics between them and the loggerhead turtles.

This study arises due to the growing concern regarding the potential threat that coastal urban development has on many turtle rookeries including the Boa Vista Island. The aim of the present study was to determine whether light pollution on nesting beaches has any influence on the nesting processes of female loggerhead turtles and/or on the behavior of the ghost crab (*Ocypode cursor*), the main egg predator. This study was conducted on a beach where human influences were absent. These following questions were addressed: (1) does light pollution decrease the frequency of turtle nesting events? (2) Does light pollution increase/reduce the time that the nesting process takes? (3) Does light pollution alter turtle behavior during the nesting process? (4) Does light pollution alter the nest predation risk by ghost crabs?

2. Materials and Methods

2.1. Study Site

This study was conducted from mid-July to early September 2012 at Joao Barrosa Beach on the Southeastern side of the island of Boa Vista,

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