ILLUMINATING THE IMPACTS OF TOURISTS WITH HAND-HELD LIGHTS ON SEA TURTLES

An Undergraduate Research Scholars Thesis

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MARGARET GUY

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TABLE OF CONTENTS

ABSTRACT

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Margaret Guy
Department of Wildlife and Fisheries Sciences
Texas A&M University

Research Advisor: Dr. Lee Fitzgerald
Department of Wildlife and Fisheries Sciences
Texas A&M University

The marine life of the ocean is in decline. Over a period spanning 300 years, the human ecological footprint decimated sea turtle populations. Though sea turtle over-exploitation is mostly controlled, recent documented anthropogenic threats such as light pollution remain a pervasive threat to sea turtles. Light pollution is obtrusive artificial light originating form infrastructure and other forms of human development that can alter animal behaviors critical for survival. The implications of artificial light for both nesting females and hatchling sea turtles are well documented. Light pollution can disrupt female egg-laying and may result in lower density in favorable habitat. Artificial light at night can also disorient hatchlings upon emergence from the nest as they attempt to orient to the sea. Policies enacted to protect turtles from light pollution often restrict hand-held light use on beaches due to claims that tourists with flashlights can disturb nesting females and disrupt hatchling sea-finding. However, a review of all the science and literature found limited research that examines the significance of tourists with hand-held lights for marine turtles. Lack of published literature identifies a gap in knowledge concerning this topic and highlights that future research is needed on the effects of hand-held lights on nesting and hatchling sea turtles.

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NOMENCLATURE

HPS	High-Pressure Sodium Vapor Light
LPS	Low-Pressure Sodium Vapor Light
MV	Mercury Vapor Light
MH	Metal Halide Light
FW	Fluorescent White Light

CHAPTER I

INTRODUCTION

Tourism's mark on conservation can be classified as a relationship of conflict, coexistence, or symbiosis. As coexistence rarely remains static, this relationship can stabilize as parasitic or as a state of beneficial symbiosis with Nature (Budowski et al., 1976). Symbiosis is reached through a combination of social, political, and economic mechanisms (Buckley, 2011). Symbiosis in the form of ecotourism may "shield" endangered species by generating revenues to local communities, which fosters direct incentives to protect biodiversity and broader ecosystems (Fitzgerald et al., 2016). Conversely, tourism, which stabilizes as parasitic, may lead to a relationship of conflict and even the exploitation of Nature (Budowski et al., 1976).

This relationship of exploitation extends beyond tourism and is widely witnessed in the fundamental shifts of nature evident as the Earth accelerates into the Anthropocene (Steffen et al., 2015). Accelerated human-induced shifts in the state of the Earth is resulting in a rapid loss of biodiversity as species perish (Ceballos et al., 2015; Dirzo et al., 2014). Sea turtles are a group of species heavily impacted by this shift, as most are classified as vulnerable or endangered due to the human ecological footprint (Lutcavage et al., 1997; IUCN, 2020). This group faces a menagerie of threats, but one of the most pervasive is artificial light pollution (Choi et al., 2009).

Light pollution is obtrusive artificial light originating from infrastructure and other forms of human development that can alter critical animal behaviors (Bliss-Ketchum et al., 2016). Ecological light pollution is rapidly increasing at a global rate of 6% per year (Hölker et al., 2010). This global pollutant fluctuates across space and time and stems from a variety of sources. Offshore oil platforms and fisheries saturate marine ecosystems, and light spills into nearby waters from spreading coastal development (Davies et al., 2014; Longcore et al., 2004). Loss of darkness has profound impacts on biodiversity and results in a wide range of behavioral responses across taxa (Hölker et al., 2010). Behavioral responses to artificial illumination range from extension of foraging in diurnal or crepuscular organisms to suppression of activity and disorientation in migratory fishes and birds (Hölker et al., 2010; Spoelstra et al., 2015; Longcore et al., 2004).

The invasion of artificial light into coastal ecosystems can also alter marine turtle behavior. Artificial light disrupts hatchling sea-finding and may repel nesting turtles (Dimitriadis et al., 2018; Price et al., 2018; Oliver et al., 2017; Brei et al., 2016). My goal was to complete a comprehensive review of research and published policy papers treating the subject of if, and how, lights on nesting beaches may affect sea turtles. Throughout the world, tourists are generally discouraged, or prohibited, from using lights when observing sea turtles. Thus, I was particularly interested in synthesizing research findings on the effects of tourists' use of hand-held lights around marine turtles. My review of the literature revealed a relatively large body of research on the effects of artificial light pollution from infrastructure, such as beach lighting, and lights from buildings, on sea turtle behavior. However, only limited research exists that addresses the impacts of hand-held lights. In addition to synthesizing the research on effects of lights on sea turtles, I identify knowledge gaps and point out specific topics in need of further study.

CHAPTER II

METHODS

I conducted a literature review to examine the significance of tourists with hand-held lights on nesting and hatchling sea turtles. Using the database Web of Science accessed through the Texas A&M University library, I performed a search of all relevant publications on sea turtles. After an initial search using the keywords "sea turtle" AND "flashlight" OR "hand-held light" OR "torch" returned no relevant results, I broadened the search terms. A broadened investigation using “sea turtle” AND “light” as keywords resulted in a comprehensive list of 242 articles. After reviewing titles and abstracts to eliminate irrelevant records, I was left with 50 relevant publications on the effects of light pollution on sea turtles. I also searched Web of Science using “sea turtles” AND “tourism” as keywords, which returned 88 publications. These 88 items were further sorted using the title and abstract, leaving 15 articles that discuss the impact of tourism on sea turtles. Subsequently, we searched for relevant literature cited in the publications I compiled. This search protocol identified a total of 84 papers on effects of light and 59 papers on effects of tourism, with publication dates ranging from 1958 to 2020 (Figure 1).

The Archie Carr Center for Sea Turtle Research of the University of Florida hosts the CTURTLE listserv, which serves as a network for sea turtle biologists. To further gather information on the significance of hand-held lights on sea turtles, in September 2019, we emailed a message to members of the listserv (Appendix 1), requesting information in publications, grey literature, white papers, and official policy documents which regulate tourist behavior around sea turtles.

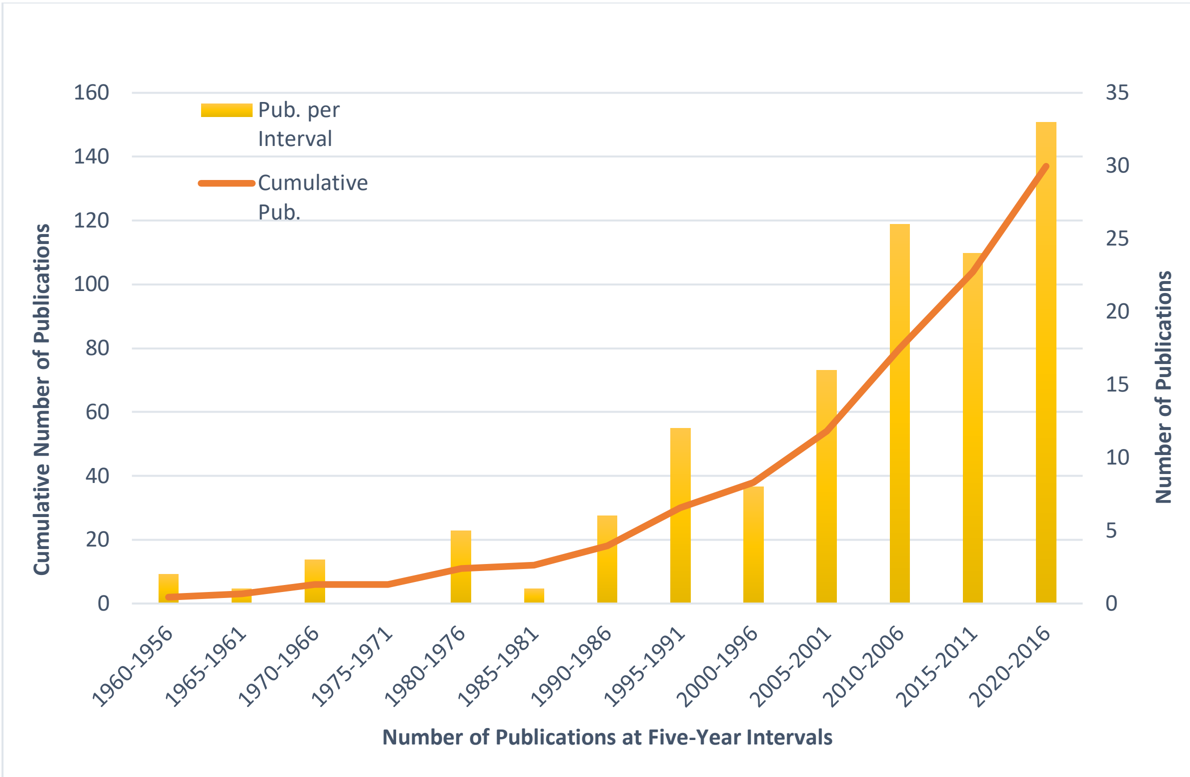

Figure 1. Cumulative number of publications and publications at 5-year intervals on the impact of tourists or artificial lighting on sea turtles.

CHAPTER III

NARRATIVE – CTURTLE LISTSERV

The query to the CTURTLE listserv provided some interesting results worthy of explanation and interpretation. In total, of the 1,781 members on the CTURTLE listserv, we received only four replies to our query for information. As the membership of the listserv includes many experts and others knowledgeable on the policies and research findings, I received relatively few replies. I had predicted a much larger response, based on the widely held belief that tourists with lights have negative impacts on sea turtles.

One respondent sent a graphic demonstrating 'disturbance factors' at various stages of sea turtle nesting and another advised we consider light from cell phones. Another respondent directed us to the US Fish and Wildlife Services guidance for sea turtle protection, which states the use of flashlights can deter nesting and cause aborted nesting attempts. One respondent who self-identified as a beach lighting officer for a local government's environmental division expressed that flashlight usage is a problem, especially around dense tourism areas. However, the respondent stated they are "unaware of any literature out there about the direct use of flashlights around nests just beside the basic assumption that it can disrupt orientation."

In November 2019, we sent a second email to the CTURTLE listserv (Appendix 2) as a last call for any additional information on the topic of hand-held lights. We received a response concerning a recent research note published in Marine Turtle Newsletter. The publication entitled, “Beach Crabbing as a Possible Hindrance to Loggerhead Marine Turtle Nesting Success”, explores the behavioral response of nesting turtles to varying densities of human activity at different times and locations (Drobes et al., 2019).

CHAPTER IV

IMPACT OF ARTIFICAL LIGHT POLLUTION ON SEA TURTLES

Light pollution is a threat that may impact the reproductive cycle of marine turtles by disrupting nesting turtles and hatchling sea-finding. The primarily nocturnal event of sea turtle reproduction begins with a nesting turtle ascending the beach. Before returning to the sea, she selects and excavates her nest site, lays her eggs, and conceals the eggs. After an incubation span of 50-80 days, hatchlings emerge and descend the slope of the beach by orienting to the water (Salmon et al., 2003). It is during this critical reproductive period that light pollution impacts sea turtles by 1) disrupting hatchling sea-finding as they attempt to orient to the sea and 2) repelling gravid turtles from illuminated nesting beaches (Hu et al., 2018; Price et al., 2018).

Marine turtles inhabit deep-water environments, which shapes their visual ecology and behavioral response to artificial light (Cruz et al., 2018; Horch et al., 2008). With increasing depth of oceanic waters, light is restricted to blue-green wavelengths. The eyes of marine turtles, which are receptive to a wide range of visible light from 440-700nm, are therefore adapted to exhibit peak sensitivity to blue-green light around 500-580 nm. (Horch et al., 2008; Hunt et al., 2018; Levenson et al., 2004). Artificial light of short wavelength and high intensity may broadly provoke a disrupted behavioral response, although there are variations across species (Witherington et al., 1991). Adult leatherback sea turtles (*Dermochelys coriacea*) are the deepest diving marine turtle species with eyes adapted for foraging in the open ocean (Horch et al., 2008). While leatherbacks exhibit minimal reaction to light at wavelengths shorter than 440 nm, green sea turtles (*Chelonia mydas*), which forage at shallow depths, perceive wavelengths as low as 400nm (Cruz et al., 2018). Loggerhead sea turtles (*Caretta caretta*) differ from other species of marine turtles in their distinct xanthophobic aversion to yellow light (Magyar et al., 2008; Witherington et al., 2014). Witherington & Bjorndal (1990) exposed hatchling loggerheads to contrasting artificial lights of varying intensities. Hatchlings presented with intermediate-wavelength yellow light (LPS, 590nm) exhibited negative-phototactic behavior, even when the light originated from the direction of the ocean (Witherington et al., 1990). Despite slight differences in visual ecology, the behavioral response of sea turtles to artificial light pollution is broadly similar across marine turtle species. Sea-finding by hatchling sea turtles of all species appears to be disrupted when exposed to artificial light of specific wavelengths and intensities (Karnad et al., 2009; Pendoley et al., 2016; Rivas et al., 2015; Salmon et al., 1995; Simões et al., 2017; Truscott et al., 2017; Witherington et al., 2014). Light pollution may also alter nesting sea turtle behavior (Witherington, 1992).

Light Pollution and Sea Turtle Nesting

Light pollution is a reproductive threat that impacts nesting sea turtles for a minuscule yet critical period of their lives (Weishampel et al., 2016). Nesting is preceded by an egg-laden turtle selecting where she will emerge from the water to lay her eggs. However, artificial light pollution may deter the female from emerging (Witherington et al., 2014). Once a turtle has emerged, she begins the next stage of the nesting process with an arduous crawl up the beach to her chosen nest site. The turtle then digs a body pit and uses her rear flippers to construct an egg cavity. Eggs are then deposited before she casts sand with broad front-flipper strokes to hide her clutch. Turning toward the sea, the turtle then makes her way down the beach and into the water (Witherington et al., 2014). Each stage of the nesting process may present varying levels of sensitivity to artificial light, resulting in differing behavioral responses (Table 1). External stimuli predominantly have a diminished impact on the pattern of each of these nesting behaviors. Meaning stimuli such as light pollution or the presence of tourists on the beach do not affect how these behaviors are performed as significantly as the decisions that determine the accuracy, timing, and duration of the behaviors (Witherington et al., 2014). External stimuli appears to have no impact on the timing, duration, or accuracy of certain nesting behaviors, such as egg-laying, while artificial light may substantially alter the behavioral response of turtles during a different phase of the nesting process.

Table 1. The impact of artificial light pollution on nesting phases and knowledge gaps in understanding.

NESTING STAGES AND FINDINGS FROM LITERATURE OF THE EFFECTS OF LIGHT						
1.Survey Nesting Beach	2.Emerge from Sea	3.Constructing Body Pit	4.Digging Egg Chamber	5.Laying Eggs	6.Covering and Concealing Nest	7.Return to sea
Artificial light may deter turtles from emerging from the water (Witherington et al., 2014). Light pollution is linked to a significant decline in nesting attempts (Silva et al., 2017). Some turtles will deposit their eggs in the sea without nesting (Hu et al., 2018).	Artificial light produced no significant difference in the time spent crawling up the beach (Silva et al., 2017). False crawls may result due to artificial light (Oliver et al., 2017).	Artificial light significantly increases nest construction time but has no effect on the distance of nests from the tidal zone (Silva et al., 2017).	Highest vulnerability to disturbance, such as artificial light, during the initial phases of nesting to digging the egg chamber (Witherington et al., 2014).	Turtles enter a trance-like state in which they are relatively unreactive to disturbance, including from lights (Whaling et al., 2017)	Abbreviated nest covering and concealment seen in some nesting turtles. Turtles may spend less time concealing her eggs due to disturbances such as artificial light or tourists (Hu et al., 2018; Johnson et al., 1996)	Artificial light may significantly increase the duration and length of a sea turtles return to the sea (Silva et al., 2017). Research also documents cases of disorientation due to artificial light (Witherington et al., 1992)

KNOWLEDGE GAPS

- No research confirms egg deposition in the ocean as being the result of artificial light pollution.
- A turtle successfully emerging from the water might experience a false crawl from a number of factors other than artificial light, and some research documents no significant relationship between false crawls and light pollution (Price et al., 2018).
- The impact of artificial light on the individual nesting phases of body pit and egg chamber construction is not thoroughly researched.
- After a turtle covers her eggs and orients to the sea, disruptions in sea finding can occur, sometimes in large numbers. However, disorientation is surprisingly rare as most individuals quickly orient to the sea even when exposed to artificial light (Witherington et al., 2014).
- Researchers are unsure why nesting turtles experience such low levels of disorientation compared to hatchlings.

Artificial light may repel marine turtles from illuminated nesting beaches, resulting in decreased nest density (Price et al., 2018; Hu et al., 2018; Weishampel et al., 2016; Windle et al., 2018). With decreasing nest density, hatchlings may be exposed to inferior nesting conditions

(Silva et al., 2017). In Florida, diminishing darkness, as a result of coastal development, leads to a higher concentration of nests in the remaining dark portions of the beach. The spatial concentration of nests may attract marine and terrestrial predators and increase the probability that weather events simultaneously destroy a large portion of nests (Salmon et al., 2003). Findings from research on the impact of artificial light pollution reveals a range of effects from no-effect to a variety of disturbances. The major findings from this body of research is synthesized in Appendix 3. However, most research concentrates on the effects of light on hatchling sea-finding behavior, and evidence is limited on nesting turtles. This subject requires further study as the effects of artificial light pollution on nesting marine turtles is largely unknown (Silva et al., 2017).

Hatchling Sea Turtle Orientation

A number of studies support that artificial light pollution can disrupt hatchling sea-finding. Upon emergence from the nest, hatchlings orient to the sea using visual cues. On a beach not polluted by artificial light, hatchlings move away from elevated dark silhouettes, such as beach dunes, and travel down the slope of the beach by orienting toward the lower and brighter horizon (Bourgeois et al., 2009; Limpus et al., 2013; Salmon et al., 1995; Wilson et al., 2018). The effects of artificial light pollution vary depending on the stage of sea-finding as hatchlings emerge, orient to the sea, and finally swim from the shore (Table 3).

Light pollution on nesting beaches disrupts photic cues, which may alter sea-finding behavior (Davies et al., 2014; Karnad et al., 2009). Consequently, hatchlings sea turtles may become disoriented and wander in a circuitous path due to altered photic cues stunting a hatchlings' ability to orient towards the water. Misorientation may also occur when hatchlings orient in a straight path away from the sea, often directly toward an inland light source (Rivas et al., 2015; Salmon et al., 1995). These behavioral responses were observed in loggerhead sea turtle hatchlings on a light-polluted island off the coast of Greece where many hatchlings oriented directly towards the brightest light source while others crawled in an irregular path lacking any orientation pattern (Dimitriadis et al., 2018). A relatively substantial body of research documents the varied impacts of artificial light on hatchling orientation (Appendix 4).

Table 3. The consequences of artificial light on hatchling stages and gaps in knowledge where research is needed.

HATCHLING STAGES		
1.Concealed in Nest	2.Orienting to Sea	3.Swimming in Water
Carr & Ogren (1960) observed the activity of hatchling 3 inches below the surface of the beach to stop abruptly when the beam of a flashlight passed across the nest. This is anecdotal, no systematic research has been reported in the literature.	Artificial light can disrupt hatchling sea-finding behavior resulting in disorientation or misorientation. Extended crawling leads to significantly longer time spent resting which may increase predator exposure (Pankaew et al., 2018)	Artificial light may reduce swimming speed, increase the amount of time spent in nearshore water, increase variation in bearing, and cause misorientation (Wilson et al., 2018, Truscott et al., 2017)
KNOWLEDGE GAPS		
Limited research documents the potential impacts of artificial light on hatchlings still in the nest. Carr's observation of stagnated activity of concealed hatchlings is the only mention I found of such an observation.	Disrupted sea finding behavior may lead to mortality, but more research is needed to quantify mortality as a result of altered orientation.	Most behavioral studies focus on the impacts of artificial light on hatchling that have yet to reach the water. More research is needed to document the swimming response of hatchlings to artificial light.

CHAPTER V

ILLUMINATING THE IMPACTS OF HAND-HELD LIGHT

Early reports on the impacts of lights on sea turtles are anecdotal. The renowned sea turtle biologist, Archie Carr, made one of the first observations of the behavioral response of hatchling marine turtles to a beam of a flashlight. In 1960 Carr observed 10 hatchling marine turtles orient themselves, then crawl seaward after they emerged from the nest. However, once the beam of a flashlight was pointed across their path, Carr observed all but one hatchling to abruptly orient towards the light (Carr et al., 1960). A similar observation was made even earlier in 1947, when 5 hatchlings became misoriented by a flashlight (Daniel et al., 1947). Carr also briefly discussed the response of nesting sea turtles to the beam of a hand-held light claiming to have experimentally witnessed turtles 'scurrying' back to the water after shinning a flashlight on her eyes (Carr et al., 1957).

Another early observation reported disrupted sea-finding in hatchling softshell turtles (*Trionyx muticus*) to the beam of a flashlight laid on the sand at a right angle to their path. Of the three turtles orienting in the direction of the water, two showed signs of disrupted behavior. One turtle showed positive phototaxis, wandering up the beam of light, while the other individual briefly stopped before continuing to the water (Anderson, 1958).

Surprisingly limited research has since documented the impacts of hand-held light on nesting or hatchling sea turtles. A recent publication looked at the impacts of beach crabbing on loggerhead nesting success. Beach crabbing often involves people walking on the beach shinning flashlights as they chase ghost crabs. Results showed the area with the greatest density of crabbing activity had the lowest concentration of nesting (Drobes et al., 2019). However, avoidance behaviors may not be the result of hand-held light but a consequence of nesting turtles avoiding areas of increased human activity or other unaccounted factors.

The Department of Conservation and Land Management in Australia has a voluntary code of conduct designed as a self- regulatory guide for tourists to follow when observing nesting marine turtles. The code presents a seven-part list of instructions, one of which states to not shine lights on any turtle as she emerges from the water or before she begins constructing a nest. The code also instructs to wait until a turtle is laying her eggs before using a hand-held light. Researchers in Australia observed the behavioral response of nesting turtles to non-compliance behavior of the code by tourists. Results showed 51% of interactions where a breach in the code occurred resulted in disturbance of the nesting turtle's behavior. High levels of disturbance were observed if any of these four components of the code were breached: (1) shining light on a turtle, (2) staying at least 3 meters from the turtle, (3) avoiding sudden movement, (4) staying behind the turtle. The greatest disturbance was seen when tourists broke the code with hand-held light use. However, this pilot study has a small sample size (n=49) and may be influenced by confounding variables, making it difficult conclude if one or a mix of factors was causing disruptions in nesting behavior (Waayers et al., 2006).

Sixty years after Carr made one of the first know observations with a flashlight, there is still limited research on the impacts of tourists with hand-held lights. Understanding the consequences of human action on the environment is necessary to effective conservation (Hu et al., 2018). With such limited research on the impacts of tourists with hand-held light, more is needed to understand how hand-held light effect sea turtle populations.

CHAPTER VI

CONCLUSION

Tourism's mark on marine turtle conservation has the potential of being a symbiotic relationship, helping populations recover and thrive. Understanding the consequences of tourist behavior is vital for shaping such a relationship. The literature as a whole stands as evidence that light pollution, especially beach lighting and lights from buildings, effects hatchling and nesting sea turtle behavior. Artificial light originating from infrastructure can repel nesting sea turtles, decreasing nest density. Hatchlings may show disrupted sea finding behavior, becoming disoriented or misorient directly towards an artificial light source.

However, limited research reveals the impacts of hand-held light on hatchling or nesting sea turtles. Most observations are anecdotal and the few published studies have not been designed to isolate effects of hand-held lights on sea turtle behaviors. Despite the lack of published findings, policies often restrict hand-held light use by tourists on nesting beaches with claims that hand-held lights will disrupt nesting or hatchling sea-finding. It is clear that more research on the effects of lights carried by tourists and other beach goers is needed to broaden our scope of knowledge. My review of the literature has shown important knowledge gaps that, if filled, would inform policies and help design new conservation strategies aimed at protecting sea turtle nesting beaches. Systematic studies designed to isolate effects of tourists' lights on each phase of nesting and on the movements of hatchlings upon emergence are needed. Comparing results from such studies carried out on a variety of beaches and on different species would allow general patterns of disturbance to be identified. Though challenging, carrying out such a research program would provide results that would advance conservation actions designed to protect sea turtle nesting beaches.

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APPENDIX

Appendix 1. Message on September 9th, 2019 to the Cturtle listserv:

Effects of Hand-Held Light Use by Tourists on Sea Turtles

Hello,

I'm a student at Texas A&M working on a literature review on the effects of flashlight use by tourists on sea turtles.

Though there is relatively extensive literature on the effects of light pollution, I am not finding much published research on the impact of tourists with hand-held lights on sea turtle behaviors. I am looking for articles I may have missed that are in gray literature or white papers.

It has also proven challenging to locate official policy documents. If you know where I can access written policies that regulate tourist behavior around sea turtles, I would very much appreciate you pointing me to them. In particular, I am seeking written policy documents referring to the use of flashlights around nesting turtles or hatchling sea turtles.

Thank you in advance for your help. I will acknowledge you by name in any written products that come out of my review.

Sincerely,

Margaret Guy
Department of Wildlife and Fisheries Sciences
Texas A&M University
margaret.guy@tamu.edu

Appendix 2. Follow up message on November 19th, 2019 to the Cturtle listserv:

Effects of Hand-Held Light Use by Tourists on Sea Turtles

Hello,

I'm a student at Texas A&M working on a literature review on the effects of hand-held light use by tourists on sea turtle nesting behaviors.

I sent an email to this listserv requesting information on this topic last September. First, I would like to thank those who responded to my message for all your helpful information and insights. I am sending out this message as a final call for any more information regarding this topic.

I compiled what I believe is a comprehensive collection of literature on the effects of light pollution on nesting turtles and hatchlings. However, I am finding there is not much published research on the impacts of tourists with hand-held lights. I am also still looking for articles I have missed that are in grey literature or white papers, including published regulations and policies about hand-held lights.

Thank you in advance for your help. I will acknowledge all those who help in any written products or presentations that come out of my research.

Sincerely,

Margaret Guy
Department of Wildlife and Fisheries Sciences
Texas A&M University
margaret.guy@tamu.edu

Appendix 3. Research documenting the impacts of artificial light for nesting marine turtles

PUBLICATION	ARTIFICIAL LIGHT	BEHAVIORAL RESPONSE
Silva et al., 2017	HPSV	-increase in time of nest construction -no change in time taken to come ashore -decrease in nest success
Salmon et al., 2006 Urban Beach I	Urban beach in FL exposed to city light	-placement of nests on the beach statistically identical over the study period -nesting density variation strongly correlated with the presence of tall objects (tall building, trees) which shield the beach from light
Salmon et al., 2006 Urban Beach II	Urban beach in FL exposed to city light	-the highest proportion of nests placed in front of tall objects that act as a light shield
Price et al., 2018	Variable level of light on St. George Island, FL	-total nesting activity significantly decreased as mean landward luminance increased -nest density significantly lower above a particular beachfront luminance value -proportion of false crawls had no significant relationship with luminance
Hu et al., 2018	Satellite sensor obtained nighttime annual average radiance data in FL	-significant negative relationship between nest density and light pollution for three species of turtles
Windle et al., 2018	Autonomous terrestrial rover used to measure light conditions on three nesting beaches in NC	-elevated light levels positively correlated with low nest density with a significant relationship between nest density and light pollution
Oliver et al., 2017	Artificial light originating from tourist infrastructure	-pressure from tourism classified as high impact and resulted in abandon nests (34.15%) with beach furniture having the highest

		impact
Weishampel et al., 2016	Satellite-based remote sensing assessed artificial light in FL	-artificial light negatively associated with nest density
Brei et al., 2016	Satellite-derived nighttime light imaging in the Caribbean	-significant negative impact of light on nesting activity in Guadeloupe -an increase in one unit of nighttime illumination reduced the number of nests by four -fertility drop due to light pollution predicted to accelerate the extinction of sea turtles
Mazor et al., 2013	Satellite night light imagery used to predict disturbance in the Mediterranean across a broad scale	-light negatively correlated with total number of nests and nest persistence -light found to be a significant explanatory variable of sea turtle nesting activity.
Witherington, 1992	White MV 80 W light Yellow LPSV 35 W light	-significantly fewer nesting crawls during MV treatment compared to control -not significantly fewer nesting crawls during LPS treatment compared to control -no relationship to experimental treatment and the stage at which non-nesting emerges was abandoned -misorientation of a few turtles during MV treatment and one during LPS treatment

Appendix 4. Research documenting the impacts of artificial light for hatchling sea turtles

PUBLICATION	ARTIFICIAL LIGHT	BEHAVIORAL RESPONSE
Cruz et al., 2018	LED flashlight (930 lumens) with red, yellow, or green filter placed at three different angles with intensities increasing every minute	-oriented towards red light only at high intensities (84.2 lx) -oriented towards green and yellow light at even at low intensities
Robertson et al., 2016	Tested turtle 'friendly' fixed lighting with LED amber peak intensity of 620 nm, LED red peak intensity 640 nm	-89% oriented seaward with amber LED treatment during the full moon -71.9% oriented seaward with amber LED treatment during the new moon -97% oriented seaward with control (no light) during all moon phases -65% oriented seaward with red LED light -84% in the absence of red LED light
Truscott et al., 2017	Swimming hatchlings adjacent to a light-polluted beach from a resort	-misorientation rates highest during moonless nights with 66.75 of trials seeing hatchlings return to shore; -misorientation rates lowest during moonlit nights with no hatchlings returning to shore.
Pendoley et al., 2016	HPSV, MH, FW light at 250 W and 500 W intensity positioned at a distance of 100, 200, 500, or 800 m	-sea finding disrupted by all light types when positioned less than or equal to 200 m -sea finding not disrupted when lights positioned greater than or equal to 500 m
Rivas et al., 2015	LED headlamps (28-35 lumens) with orange, red, blue, green, yellow, and white light wavelength treatments	-misorientation low with red and orange light trials -disorientation lowest with red light -crawl duration low for misoriented (shortest mean under yellow light) hatchlings and high for disoriented individuals (longest mean

		under red light) -no significant influence of light treatment on track pattern with moonlight -without moonlight hatchlings attracted to the experimental focus of blue, yellow, and white light
Witherington et al., 2006	Light of a standard source of constant intensity and color (peak 520 nm) and an adjustable light with five colors and seven photon intensities	-high rates of orientation toward near-ultraviolet (360nm), violet (400 nm), and blue-green (500 nm) light -orient towards standard light source over yellow-orange (600 nm) and red (700 nm) light -a positive relationship between intensity and preference with 300, 400, and 500 nm light
Salmon et al., 2006 Urban Beach II	Field trials looked at a light-polluted urban beach in FL. While lab trials looked at natural and urban silhouettes using a translucent screen with light wavelengths confined to 420-620 nm and max transmission 520.	-disorientation occurred with low or incomplete light barriers -misorientation occurred when exposed to direct bright light -in the lab, urban silhouettes failed to provide adequate cues while natural silhouettes often provided adequate cues for orientation -adding a low light barrier in from of light gaps improved orientation accuracy
Wilson et al., 2018	HPSV (500-630 nm) and MH (500-600 nm)	-MH trials 80% of hatchlings attracted to light -HPSV trials 63% of hatchlings attracted to light -light increased the amount of time spent in nearshore water by 50-150% -light increased variance in bearing by 100-180% -with light treatment, hatchlings traveled 12-30% slower

Price et al., 2018	Variable levels of artificial light on an island off the coast of FL	-disorientation significantly positively associated with relative land luminance
Simoes et al., 2017	Artificial light originating from LED reflectors on infrastructure	-track pattern of 86% of illuminated trials deviated from the correct trajectory -movement patterns of illuminated and non-illuminated trials significantly different
Oliver et al., 2017	Artificial light from tourist 'eco-hotel.'	-artificial light classified as high impact with artificial light accounting for 94.03% of tourist pressure
Thums et al., 2016	MH (400 W) with hatchlings tracked under artificial light and ambient treatments	-under ambient conditions, hatchling trajectories fanned out -with artificial light 80-100% of hatchlings misoriented -bearing closely aligned with light regardless of current speed or direction -no evidence that swimming speed was effected by artificial light -a longer time (23%) was spent near the shore during light treatment trials.
Pendoley et al., 2015	HPSV (500-630 nm), MH (400-500 nm), FW (400-650 nm) with trials at intensities: 500 W, 1000 W, or 1300 W. Light positioned behind a bund (trial 1) or in a creek bead (trial 2)	-for trial 1 hatchlings significantly oriented towards the sea regardless of light type or intensity -significant difference between trial 1 and trial 2 in hatchling orientation at medium and high intensities of all light type -significant difference between trial 1 and trial 2 in orientation at low intestines of MH -no significant difference in orientation between trial 1 and trial 2 at low intensities of FW and HPS
Berry et al., 2013	Artificial light from sky glow	-6% disrupted sea finding

	and direct sources of illumination	behavior - no disrupted sea finding behavior occurred around the full moon -highest rates of misorientation around the new moon
Kawamura et al., 2009	Arena test - near UV radiation at 340 and 370 nm and 90 or 180 degrees from the sea T maze – alternated use of LED lights, UV LED (peak 380 nm), green-LED (530 nm)	-during the arena test when presented with light many hatchlings were misoriented while no hatchlings showed disrupted orientation during control tests -T maze with green-LED and no light, 67% oriented to the green-LED light -T maze with UV-LED and no light 84% oriented to the UV light -T maze with both lights hatchlings were attracted to both, but preference depended on relative intensities
Karnad et al., 2009	Arena test with LED light of two intensities and four wavelengths (red, yellow, blue, violet) and field trials with artificial light from nearby industry with a tree light barrier	-in arena test, highest proportion oriented to short-wavelength (violet and blue) compared to long-wavelength light with a significant orientation to all light wavelengths except red - in arena test, highest proportion oriented to high intensity compared to low-intensity light (expect violet) -during field trials, highest rates of misorientation on portions of beach exposed to light -significant seaward orientation seen only on beaches with a tree line barrier
Harewood et al., 2008	Light pollution from developed beaches	-less swimming success of 34.8% from illuminated beaches compared to a

		swimming success of 65.7% on dark beaches -moonlight significantly improved swimming success -predation rate not significantly impacted by light
Peters et al., 1994	Artificial light from nearby infrastructure with the beach divided into area A (directly in front of light) and B (off-centered from light)	-in arena A 21% of hatchlings oriented seaward with 79% disorientation rates -in arena B 52% disorientation rates -in total 63% of hatchlings showed disrupted sea finding and oriented towards the light source
Salmon et al., 1995	Surveyed track patterns on multiple urban beaches in FL and used an arena method with artificial light originating from infrastructure.	-a significant inverse relationship between the frequency of disruption and the number of days from the closest new moon -the full moon helped restore correct orientation
Tuxbury et al., 2005	Arena method with book lights used as street light surrogates for illumination and natural cues (high or low dark silhouettes)	-significantly oriented when exposed to only lights -significant seaward oriented when presented with lights and high silhouettes -not significantly oriented when presented with light and low silhouettes