

MEASURING NEST-TO-SURF MORTALITY OF FLORIDA'S EAST AND WEST
COAST LOGGERHEAD SEA TURTLE (*CARETTA CARETTA*) HATCHLINGS

by

Brianna Villegas Vindiola

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Jeanette Wyneken, Department of Biological Sciences, and has been approved by all members of the supervisory committee. It was submitted to the faculty of the Charles E. Schmidt College of Science and was accepted in partial fulfillment of the requirements for the degree of Master of Science.


SUPERVISORY COMMITTEE:



Jeanette Wyneken, Ph.D.
Thesis Advisor


John Baldwin, Ph.D.


Michael Salmon, Ph.D.


Dale Gawlik, Ph.D.
Chair, Environmental Sciences Program


Ata Sarajedini, Ph.D.
Dean, Charles E. Schmidt College of Science


Khaled Sobhan, Ph.D.
Interim Dean, Graduate College

April 26, 2019
Date

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ABSTRACT

Author: Brianna Villegas Vindiola
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Sea turtle hatchlings emerge from their nest and quickly crawl to the surf. During the crawl, hatchlings may encounter threats, biotic and abiotic, which can affect their ability to successfully reach the surf. The impact of these threats on hatchling survival during that crawl is largely undocumented. Current methods used to estimate cohort recruitment rely heavily on nest inventory data. This method, however, does not account for post-emergent hatchling mortality that occurs during the crawl.

During the 2017-2018 nesting seasons, I quantified the fates of 1,379 loggerhead (*Caretta caretta*) hatchlings from 26 nest emergences during their crawl from the nest to the surf on the east and west coasts of Florida. I documented hatchling fates at 5 Florida nesting beaches: Wabasso, Boca Raton, Keewaydin Island, Naples, and Anna Maria Island. Overall, 6.5% of all emergent hatchlings died during the crawl from the nests to the surf. Ghost crabs, night herons, foxes, and coyotes killed hatchlings and

photopollution and barriers on the beach (both abiotic threats) caused hatchling mortality. Anthropogenic (abiotic) threats accounted for more mortality than did predators.

In order to assess how beach urbanization impacts hatchling mortality, I categorized each study site as urban (Wabasso and Naples), intermediate (Anna Maria Island and Boca Raton), or natural (Keewaydin Island) based on the relative levels of shoreline development and human activity at each beach. Sites with intermediate levels of urbanization accounted for greater levels of hatchling mortality than at other beaches due to the absolutely larger numbers of hatchlings lost to a disorientation event and to a beach barrier. Given the small numbers of emergences, at all sites, only a small proportion of the hatchlings mortalities (e.g., between 3 and 12 percent), site type could not be rigorously used as a discriminator.

My results provide a better understanding of how specific environmental threats contribute to hatchling mortality. While nest-to-surf mortality is relatively low, its cumulative costs add up to several hundreds of thousands of hatchlings. Armed with this information, nesting beach managers can assess risks and focus their efforts to implement the most effective management practices to minimize losses of this imperiled species.

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INTRODUCTION

Globally increasing human activity degrades the natural environment and interrupts many natural processes (Heywood and Watson 1995; Crutzen 2006). Physical modification of ecosystems, both terrestrial and marine, disturbs organisms that use these habitats and the services/resources they provide (Grimm et al. 2008; Chapin et al. 2013). Ultimately, the loss of habitats and biodiversity can lead to the loss of species that are required for the sustainable function of ecosystems and populations (Cardinale et al. 2012). It is important to understand how human perturbations of the environment can be countered to mitigate habitat and biodiversity loss (Halpern et al. 2007).

Recent estimations suggest that 60% of the world's human population lives within 100 km of the coast (Cohen et al. 1997; Rick and Erlandson 2008). This relatively recent concentration at coastal regions has stressed ecosystems and organisms that use these habitats (Creel 2003). Sea turtles are prime examples of marine organisms that are threatened by development of and increased human activity in, coastal regions as their nesting beaches are as a result substantially transformed. These threats include harvesting of eggs (legal or illegal), beach erosion, artificial lighting, beach nourishment, as well as vehicular and foot traffic (Lutcavage et al. 2017). Increased urbanization of coastal areas exacerbates those threats.

Sea turtles, like many marine vertebrates, are long-lived and late maturing (Bjorndal and Zug 1995; Musick 1999). Females deposit eggs in underground nests.

Once eggs complete development and hatch, hatchlings remain in the egg chamber for approximately four days (Godfrey and Mrosovsky 1997) while their carapaces harden and their plastrons straighten (Miller 1985). When development is complete, hatchlings dig their way out of these nests ("emerge") and crawl to the ocean. Emergences primarily take place at night (Carr and Ogren 1959) in response to cooling sand temperatures (Mrosovsky 1968; Witherington et al. 1990; Gyuris 1993). Hatchlings emerge in large numbers (Carr and Hirth 1959). This "safety in numbers" strategy, sometimes termed "predator swamping", is thought to minimize each individual's predation risk (Santos et al. 2016).

During the crawl, hatchlings face many predators (Kurz et al. 2012). Mammalian predators include raccoons (*Procyon lotor*, Stancyk et al. 1980; Ehrhart and Witherington 1986; Barton and Roth 2007; Sandrian-Tomillo et al. 2010), grey foxes (*Urocyon cinereoargenteus*, Peterson et al. 2013), coyotes (*Canis latrans*, Lamarre-DeJesus and Griffin 2013), feral pigs (*Sus scrofa*) (Engeman et al. 2016), and occasionally bobcats (*Lynx rufus*, Engeman et al. 2006). Avian predators include yellow crowned night herons (*Nyctanassa violacea*, Witherington and Martin 2000). Invertebrate predators include red imported fire ants (*Solenopsis invicta*, Allen et al. 2001; Parris et al. 2002) and ghost crabs (*Ocypode quadrata*, Ehrhart and Witherington 1986; Lucrezi and Schlacher, 2014; Brost et al. 2015). Predators vary in abundance and species composition by location (Madden et al. 2008). Hatchlings have no defenses against predators except to accurately and quickly crawl to the ocean, minimizing their exposure time on land (Burger and Gochfeld 2014).

Once hatchlings emerge, they use differences in horizon brightness and landward silhouette elevation to locate the ocean (Salmon et al. 1992). When horizon brightness is altered by anthropogenic lighting, hatchlings may be unable to orient appropriately (Salmon and Witherington 1995; Witherington and Martin 2000; Lorne and Salmon 2007) and are either disoriented (unable to maintain a direction) or misoriented (crawl in a consistent, but incorrect, direction; Witherington and Martin 2000). Both responses delay seafinding and increase exposure time to predators on land while simultaneously increasing probabilities of exhaustion and dehydration (Witherington and Martin 2000).

Other anthropogenic threats include debris on the beach that can delay or prevent hatchlings from reaching the water (Triessnig et al. 2012; Özdilek et al. 2006). When motor vehicles operate on the beach, ruts are created across the beach hatchlings that impede the hatchling crawl toward the surf zone (Hosier et al. 1981; Lamont et al. 2002; Van de Merwe et al. 2012) and simultaneously increase their risk of both fatigue and predation (USFWS and NMFS 2008).

Florida coastal beaches are important sites for nesting green turtles (*Chelonia mydas*), leatherback turtles (*Dermochelys coriacea*) and loggerhead turtles (*Caretta caretta*). At the same time, Florida is a highly desirable vacation destination, and its beaches attract over 100 million tourists annually (Visit Florida, 2017). Florida's economy relies heavily on coastal tourism. Development of coastal areas is continuous and as a consequence coastlines are altered in ways that negatively impact sea turtle nesting and hatchling production (Marshall et al. 2014). The Northwest Atlantic Ocean loggerhead population (Casale and Tucker 2015) is the world's largest. Approximately 84% of their nests are deposited on Florida beaches (USFWS and NMFS 2008; Ceriani

and Meylan 2015; IUCN RED LIST 2017). Because Florida as an important nesting ground, it is increasingly important to understand what environmental degrade nesting beaches. Currently, hatchling production, a component of loggerhead demographics, is estimated by the analysis of the nest contents after an emergence (Brost et al. 2015). However, these estimates do not adequately address or identify the causes of hatchling mortality that occur during seafinding, potentially leading to misleading estimates.

The purpose of my study was to better estimate the sources, and effects, of the variables that reduce the survival of hatchlings as they crawl from their nest to the surf zone. To do so, I posed four questions.

- What percentage of loggerhead sea turtle hatchlings fail to complete their crawl and die?
- What are the sources of this hatchling mortality?
- What biotic and abiotic threats do hatchlings face, and are they responsible for similar or different proportions of hatchling mortality?
- Are differences in hatchling mortality correlated with differences in beach development?

METHODS

I. Measuring Hatchling Mortality

To estimate how many hatchlings die during their crawl to the surf zone, I documented what transpired while they were *en route* using infrared time lapse photography, in-person observations, and track mapping. Track mapping allowed me to confidently determine hatchling fate even when I could not directly observe an interaction between the turtle and its predator and thus characterize the fate of each hatchling as it crawled away from its nest.

Infrared Time Lapse Photography

I used infrared photography to obtain photographic evidence of hatchling fate with time-lapse cameras (Stealth Cam™ G42 No-Glo Trail Game Cameras, model #STC-G42NG) placed on tripods behind nests when an emergence was expected (Fig. 1; erb 2017). The cameras took pictures every 10 s throughout the night. When nests were placed close to the dune and far from the surf line, two cameras were used. One camera was placed directly landward of the nest and the other camera was placed between the nest and the high tide line, facing the surf zone (Erb 2017). I then smoothed the sand between the nest and the surf zone with a broom to make hatchling and predator tracks more apparent. Photos taken throughout the night were then analyzed to estimate the number of hatchlings that emerged from each nest and to identify the predators or predator activity that took place that night.

In-person Observations

I inspected each focal nest several times per night using a night vision scope. While doing so, I stayed minimally 10 m from the nest so as not to interfere with any natural predation events, or influence the cues used by the hatchlings for orientation. These observations allowed me to watch hatchlings that crawled outside the field of view maintained by the cameras.

Track Mapping

The morning after an emergence, I traced the tracks left behind by each turtle to determine how many reached the surf zone and how many did not. The tracks also allowed me to identify the fate of each hatchling, as its path directions away from the water provided evidence of probable death. Track mapping was an effective method for detecting hatchling mortality when it could not be directly documented using the cameras.

Assigning Hatchling Fate

Hatchlings that crawled directly from the nest to the surf zone were categorized as “surviving”. Hatchlings that disappeared into the dune, became trapped in a barrier, or were taken by predators were characterized as mortalities.

II. Site Categories

I explored post-emergent hatchling mortality at five nesting beaches, two on the east and three on the west coast of Florida. These sites were selected because they differed both in their exposure to human activity and their degree of shoreline development. I characterized those differences relative to one another into three site categories: urban, natural, or "intermediate" beach environments. Two sites (Wabasso Beach on the east coast; Naples Beach on the west coast) were categorized as urban

because of their extensive use by human visitors during the day and at night, and their exposure to artificial lighting from condominiums placed just behind the beach. Inland development behind these structures also contributed at night to high levels of skyglow.

Two study sites (Boca Raton on the east coast; Anna Maria Island on the west coast) were classified as "intermediate" beach environments. These sites were exposed to less human activity during the day and at night time as they were not as easily accessible to the public, particularly at night. Access points were located in residential areas or areas with restricted access hours. In addition, both beaches were fronted by vegetated parks that served as buffer between inland development and the beach. Intermediate locations were also characterized by a unique assemblage of predators as the parks serve as habitat for many mammalian predators that foraged for food from park visitors, and also raided garbage receptacles.

A single site, Keewaydin Island, qualified as a natural beach environment. While a few houses have been placed on the island, there no electricity so lighting problems are minimal. Access to the island is only by boat. There is little to no human activity on the beach day or night.

III. Biotic and Abiotic Threats and Hatchling Mortality

At each nest site, I walked 5 m to either side of a straight line to the water, then again to the dune. Within this area, I documented and described the presence of predators or any residual predator evidence (i.e., predator tracks, crab holes). Abiotic threats included barriers such as debris, driftwood, holes, and man-made structures that could potentially entrap hatchlings. At night, I also qualitatively described nearby sources of photopollution (e.g., sky glow, individual bright lights on nearby buildings, etc.).

IV. Quantitative analyses and statistics

My observations were used to quantify the total number of hatchlings that emerged from each nest, the number of turtles that crawled directly to the sea, and the number of hatchlings that were either taken by predators, trapped by obstacles on the beach, or whose orientation paths were disrupted by artificial light. In most cases, I could identify the predators (based upon track information, photographs, or both with certainty). It was difficult on some occasions to identify night herons as predators as when they take a hatchling, the track abruptly ends. Distinguishing between a track that ended because of a predation event from one that ended because it was washed out by an advancing tide was, in a few instances, problematic.

I made every attempt to record "first" emergences, or those that occurred when the majority of the hatchlings left the nest. However, in a minority of cases, I was unable to do so and so I witnessed the emergence of smaller numbers of hatchling that exited the nest the following evening (see below).

I used X^2 tests, corrected for continuity, to determine whether (i) different species of predators varied in their ability to capture hatchlings, or if (ii) predators as a group were responsible for more hatchling deaths than abiotic factors (barriers, photopollution). In both cases, the null hypothesis was that no differences existed (rejected when probabilities were ≤ 0.05 ; Townsend 2003).

RESULTS

I. Characteristics of the sites at night

Artificial lighting, coupled with sky glow, characterized the nocturnal environment at the urban sites (Fig. 3). At the "intermediate" sites, lighting was restricted to sky glow that varied in degree over portions of the beach (Fig. 3). The beach at Keewadin Island was dark at night.

II. Impact of biotic vs. abiotic factors

Five predator species (Fig. 4) were documented in different combinations and densities at my study sites (Table 1). Ghost crabs were present at all sites except Keewadin Island. Mammalian predators (foxes and/or coyotes) were present at 3 sites and night herons were observed at 4 sites (Table 1). Abiotic factors affected hatchling survival at all sites except Keewadin Island (Table 1).

III. Hatchling mortality as a consequence of biotic vs. abiotic factors

Across all sites, the number of hatchlings that died as a consequence of interactions with predators ($n = 35$) was fewer than the number that died as a consequence of abiotic factors ($n = 54$, Fig. 5). However, those differences were not statistically significant ($X^2 = 2.01$, $p = 0.15$, 2 d.f.). Among the predators, ghost crabs killed the largest number of hatchlings ($n = 16$, Fig. 6) but once again, differences in lethality among the predators failed to achieve significance ($X^2 = 5.60$, $p = 0.13$, 3 d.f.).

IV. Hatchling mortality and differences in site development

At all sites, only a small proportion of the hatchlings (e.g., between 3 and 12 percent; Table 1) failed to complete their crawl to the sea. Differences among the sites were as a consequence quite small. I observed only one emergence at the natural (Keewadin Island) site and so was unable to characterize hatchling survival probabilities from nests deposited at that "natural" site.

Three of the emergences observed at Boca Raton and two at Wabasso Beach were "second" night emergences in which 5 or fewer hatchlings emerged.

The two intermediate beaches showed no statistical differences between the frequencies of hatchlings that survived or died after an emergence (95:10 vs. 282:41; $X^2 = 0.76$, $p = 0.38$, 1 d.f.). Similarly, the two urban beaches showed no statistical differences though they closely approached that criterion (331:6 vs. 601:26; $X^2 = 3.82$, $p = 0.051$, 1 d.f.).

DISCUSSION

The relative importance of threats must be known in order for recovery plans for threatened and endangered species to work (Lawler et al. 2002). The NMFS and USFWS (2008) and subsequently, Bolton et al. (2011) assessed known threats and identified data gaps in life history data for the loggerhead. They developed a threats table to identify, categorize, and prioritize threats to the loggerheads. One of the persistent data gaps was information on perturbations to post-emergent hatchlings during their terrestrial period (the nest to surf crawl). Because sea turtles are late maturing, it may take longer to identify the effects of such perturbations to younger life stages (Crowder et al 1994). Thus it is important to have well-developed and comprehensive understanding of threats at each life stage. The present study contributes to the understanding of post-emergent hatchling mortality on Florida beaches by identifying relationships between hatchling mortality and biotic and abiotic threats.

Approximately 6.5% of the hatchlings did not survive the crawl from the nest to the surf zone. Previously, Erb (2017) worked on Florida's east coast nesting beaches, exclusively, and characterized the fate of 1,089 loggerhead hatchlings and estimated that 7.6% of the post-emergent hatchlings did not survive the crawl. The estimates provided by both of these studies establish that nest-to-surf mortality reduces the number of hatchlings entering the water and is not the same as nest inventories would suggest. Brost et al. (2015) estimated that minimally 3.5 million loggerhead hatchlings are produced at Florida beaches annually. Removing 6.5 - 7.6% from the average annual hatchling

production estimates, it is possible that we are overestimating production estimates by 227,500 – 266,000 hatchlings annually.

The potentially large overestimation of hatchling production is important because hatchling recruitment is one key input in many population demographic models. Such models help identify long-term population trends, which allow us to identify long-term effects of perturbations (Heppell et al. 2003). Although relative reproductive value varies among each sea turtle life stage (Bolten et al. 2011), and hatchlings have low reproductive value, life stages are necessarily linked to one another. Hence, identifying post-emergent hatchling losses both improves the hatchling production component of population estimates and may focus species managers' attention on an underappreciated source of mortality.

Biotic Threats

I observed ghost crabs, night herons, foxes, and coyotes capturing post-emergent hatchlings (Table 1). Ghost crabs were the most prevalent and common predator found on both coasts (Boca Raton, Wabasso, Naples Beach, Anna Maria Island). Other studies identify this semiterrestrial crab as a common and prevalent predator (Erb 2017; Sandrian-Tomillo et al. 2010; Trocini 2013). However, raccoons are also sea turtle nest and egg predators. A study of ghost crab - raccoon population dynamics and egg predation on a natural Florida beach (Cape Canaveral) found an inverse relationship between raccoon densities and ghost crab densities and egg predation (Barton and Roth 2008). They found that when raccoons were least abundant, ghost crab abundance was highest and hence so was egg predation by ghost crabs. While photos of ghost crabs with hatchlings are relatively common, literature on their attacks is limited to just a few

studies (Sandrian-Tomillo et al. 2010, Erb 2016). Post-emergent hatchling mortality caused by ghost crabs can be cryptic (Erb 2017). Ghost crabs may leave little to no evidence of predation events. During this study ghost crabs intercepted single hatchlings, drug them into their burrows, and often times close the entrance. Closed ghost crab burrows can be difficult to identify, and ghost crab risk may be underappreciated.

Night heron predation was documented on both coasts (Boca Raton Beach, Naples Beach, Anna Maria Island). Much like the ghost crab, night heron predation can also be cryptic. Night herons preyed on hatchlings close to the surf zone. When night herons hunt close to the surf, the hatchling tracks look as if they made successfully it to the surf (Glen et al. 2005). This is because predation at the surf and evidence of night heron activity, is washed away by waves.

Gray fox predation was observed only at Boca Raton Beach. Preventative measures from general fox predation on beaches include caging nests (Kurz et al. 2012; Yerli et al. 1997), using self-releasing screens, or using capsaicin (chili pepper) powder as a deterrent (Lamarre-DeJesus and Griffin 2013). Although these preventative measures aid in increasing hatchling production by protecting the nest, they do not prevent fox predation during hatchling's crawl to the surf zone. Self-releasing screens did nothing to protect hatchlings once they emerged.

I documented both coyote predation and nest depredation at Keewaydin Island. Predation took place at the surf zone. Nest depredation by coyote and wild hogs was severe at Keewaydin Island during the 2017 nesting season. Due to the low number of nests that remained and a shortened survey period, I only observed a single emergence at this natural beach.

Overall, predation events often resulted in a low number of mortalities per emergence. While nest-to-surf mortalities due to predators is low, the frequency of predation events was noteworthy. Across 15 nest emergences that resulted in hatchling mortality, 13 of these emergences involved predation events. The number of emergent hatchlings that died per emergence ranged from 1- 6.

In general, predators have an upper limit to how many prey can be killed per unit time, as they spend time locating prey (during the emergence) and consuming prey (Mill 2012). Predator handling time was not directly recorded, yet clearly varied among all hatchling predators. Smaller predators, such as ghost crabs, did not have the ability to consume many hatchlings in a short period of time (Peterson et al. 2013). In my study, ghost crabs typically captured 1-2 hatchlings during an emergence. In some cases when there were multiple ghost crabs at an emergence, more hatchlings were caught. In contrast, mammalian predators (foxes and coyotes) captured slightly more hatchlings than ghost crabs. The greatest number of hatchlings that I documented as killed by mammalian predator during a single emergence was 6 (coyote, Keewaydin Island). Coyotes and foxes are known for killing more prey than they can immediately eat, also termed “excessive killing” (Short et al. 2002; Mill 2012). Erb (2017) documented excessive killing behavior by foxes on Boca Raton beach.

Abiotic Threats

While there were fewer nests affected by abiotic threats than biotic threats, there were a higher number of mortalities per emergence caused by abiotic threats than biotic threats. More than half of all hatchling deaths were due to abiotic threats. Both photopollution and barriers on the beach were the mortality sources.

Photopollution is a well-known abiotic threat to hatchlings and occasionally leads hatchlings inland, where they may dehydrate, become crushed on roads and paths, entangled in vegetation, or caught by predators (Erb 2017; Peters and Verhoeven 1994; Salmon 2013, Witherington et al. 2000). During this study, emergence J resulted in relatively high mortality (39 hatchlings) due to misorientation to a bright streetlight (photopollution). Hours before this emergence occurred, the beach manager attempted to mitigate the problem light by installing a restraining cage over the area where hatchlings were expected to emerge. However, cage positioning was poor and the hatchlings emerged outside of the restraining cage and crawled to the road. Thus, although mitigation measurements can be both spatially and temporally correct, they may be ineffective. There are many beach management strategies that address lighting issues on developed coasts, such as turning lights off, redirecting light downward, using light with longer wavelengths, etc. (Witherington and Martin 2000; Salmon 2003). Yet, mitigation is not always effective.

Physical barriers, such as beach furniture, tire tracks (ruts), sand castle structures, and holes have been reported previously as major problems impeding hatchlings during emergences and contributing to mortality (Hosier et al. 1981; Lamont et al. 2002; Sandrian-Tomillo et al. 2010; Widmer and Hennemann 2010; Van de Merwe et al. 2012). One experimental study (Triessnig et al. 2012) found that hatchlings that become entrapped in common marine debris (inside mesh nets, cavities of cups, etc.) do not have problem-solving or motor skills to physically remove themselves. Historically, hatchlings have always had to cross variable landscapes, such as mounds of beach wrack. However, in recent years increases in the volume and diversity of debris have posed greater

challenges to reach the surf (Derraik 2002). Nest emergences J and Z resulted in hatchling deaths due to barriers. During emergence J, a hatchling crawled into an uncovered umbrella hole and was unable to escape. During emergence Z, 14 hatchlings became trapped between two large storm water pipes that were exposed on the beach. These observations add to the list of physical barriers as risks to hatchlings crawling to the surf.

Management Implications

Overall, threats vary among all beaches. The quantification of how many hatchlings die during the crawl to the surf allows for refinement of Florida's loggerhead hatchling production. Adjusting hatchling production estimates by the nest-to-surf mortality estimate of 6.5 – 7.6 % (this study and Erb [2017]) may be a reasonable starting point. Sandrian-Tomillo et al. (2010) studied post-emergent hatchling mortality of Leatherbacks (*Dermochelys coriacea*) in Costa Rica, and found that 17% of hatchlings did not survive the crawl to the surf zone. While that site and species differ from this study, it too points toward the value of adjusting production estimation.

Overall, if the nests are protected to emergence, and the abiotic threats are reduced, the hatchlings most hatchlings may reach the surf and mortality is lowered. By highlighting the issue of post-emergent hatchling mortality and threats specific to each site, beach managers can assess the importance of mortality sources at their sites. Because threats vary in type and abundance by site, management strategies that work at some locations may not be the most effective at other beaches.

Challenges of Data Collection

Attempting to predict the exact day and time a nest was going to emerge was a challenge. Since eggs incubate under the sand, there are few signs to identify when hatchlings will emerge by using external features. It was important to not dig into nests to verify if emergences might occur because of the risk of attracting predators or altering their behavior. Incubation duration for loggerheads ranges from 42-65 d, and varies depending on several environmental factors (USFWS and NMFS 2008) including sand characteristics (Mortimer 1990) and nest temperature (Matsuzawa et al. 2002).

I had difficulty locating emergences during the 2017 nesting season and consequentially sample sizes were low. I overcame this challenge in the 2018 season by keeping in regular contact with each study beach's manager. Beach managers and monitors survey nests daily and therefore were able to help me identify candidate study nests by supplying me with deposition (lay) dates of nests that are most likely to emerge during my study period. With up to date emergence information, I was able to target sampling nests just subsequent to the previous day's emergences. Further, beach managers were able to inform me of any factors that might have affected the viability of the nests so that I did not waste time on probably dead nests in 2018.

Overall, predicting emergences on the west coast was more difficult than on the east coast, as there were fewer nests laid at these locations than on the east coast. Due to the lower number of nests, there were fewer number of nests expected to hatch within the time frame that I sampled each location. I overcame this challenge in 2018 by spending 4-7 consecutive days at each nesting site maximizing my chances of documenting multiple emergence events per site.

In order to combat unpredictable and often devastating tropical weather, data collection was heavily concentrated in the early months of “emergence season,” July-September, when most nests emerge.

Finally, I was unable to survey Keewaydin Island more than once in 2017 because a hunter was hired to kill the feral hogs during hatching season. Hence, I could not be on the island. I was unable to survey the island during the 2018 season due to logistic constraints of getting to the island. In order to survey a similar beach with low urbanization, I attempted to survey nests at Delnor-Wiggins State Park. However, I was unable to get permission to conduct the nighttime surveys due to non-response from the persons responsible for managing and monitoring nesting activities.

Nest Emergence ID	Coast	Study Site	Urbanization Category	Total Emergent Hatchlings	# Died	# Survived	Source of Mortality (category)	Biotic Threat Presence				Abiotic Threat Presence		
								Ghost Crab	Night Heron	Fox	Coyote	Barrier	Photopollution	# Crab Holes
A	west	KEE	Natural	64	6	58	Predator	no	no	no	yes	no	no	N/A
B	east	BOC	Intermediate	26	1	25	Predator	no	no	yes	no	no	yes	0
C	east	BOC	Intermediate	18	6	12	Predator	no	yes	yes	no	no	no	0
D	east	BOC	Intermediate	20	0	20	N/A	no	no	no	no	no	no	0
E*	east	BOC	Intermediate	1	0	1	N/A	no	no	no	no	no	no	0
F	east	BOC	Intermediate	23	2	21	Predator	yes	no	no	no	no	no	0
G*	east	BOC	Intermediate	4	1	3	Predator	yes	no	no	no	no	no	0
H*	east	BOC	Intermediate	3	0	3	N/A	no	no	no	no	no	no	0
I	west	AMI	Intermediate	30	0	30	N/A	no	yes	no	no	no	no	1
J	west	AMI	Intermediate	112	40	72	Photopollution	no	no	no	no	yes	yes	4
K	west	AMI	Intermediate	50	1	49	Predator	yes	no	no	no	no	no	4
L	west	AMI	Intermediate	90	0	90	N/A	no	no	no	no	no	no	2
M	east	WAB	Urban	95	0	95	N/A	no	no	no	no	no	yes	2
N*	east	WAB	Urban	4	0	4	N/A	no	no	no	no	no	no	0
O	east	WAB	Urban	38	3	35	Predator	yes	no	no	no	no	no	1
P*	east	WAB	Urban	5	2	3	Predator	yes	no	no	no	no	no	2
Q	east	WAB	Urban	54	0	54	N/A	yes	no	no	no	no	no	3
R	east	WAB	Urban	64	1	63	Predator	yes	no	no	no	no	no	5
S	east	WAB	Urban	77	0	77	N/A	no	no	no	no	no	no	0
T	west	NAP	Urban	85	0	85	N/A	no	no	no	no	no	no	3
U	west	NAP	Urban	72	6	66	Predator	yes	yes	no	no	no	no	5
V	west	NAP	Urban	50	0	50	N/A	no	no	no	no	no	no	1
W	west	NAP	Urban	73	2	71	Predator	yes	no	no	no	no	no	3
X	west	NAP	Urban	115	1	114	Predator	yes	no	no	no	no	no	5
Y	west	NAP	Urban	108	3	105	Predator	yes	no	no	no	no	yes	0
Z	west	NAP	Urban	98	14	84	Barrier	no	no	no	no	yes	yes	1
Totals				1,379	89	1,290								

Table 1 Summary of 26 nest emergences observed during the 2017-2018 nesting seasons. Each study site (Keewaydin Island, Boca Raton, Anna Maria Island, Wabasso, and Naples) is listed by the first three letters in the site name. * Indicates nests that were second or third emergences (not first). Threats are summarized by categories and sources of mortality. Ghost crab hole counts are based on the number observed at the start of the night the emergence occurred



Figure 1. An infrared camera placed behind a nest. Each nest was marked using tape and stakes by local beach surveyors. Photo by B. Villegas Vindiola

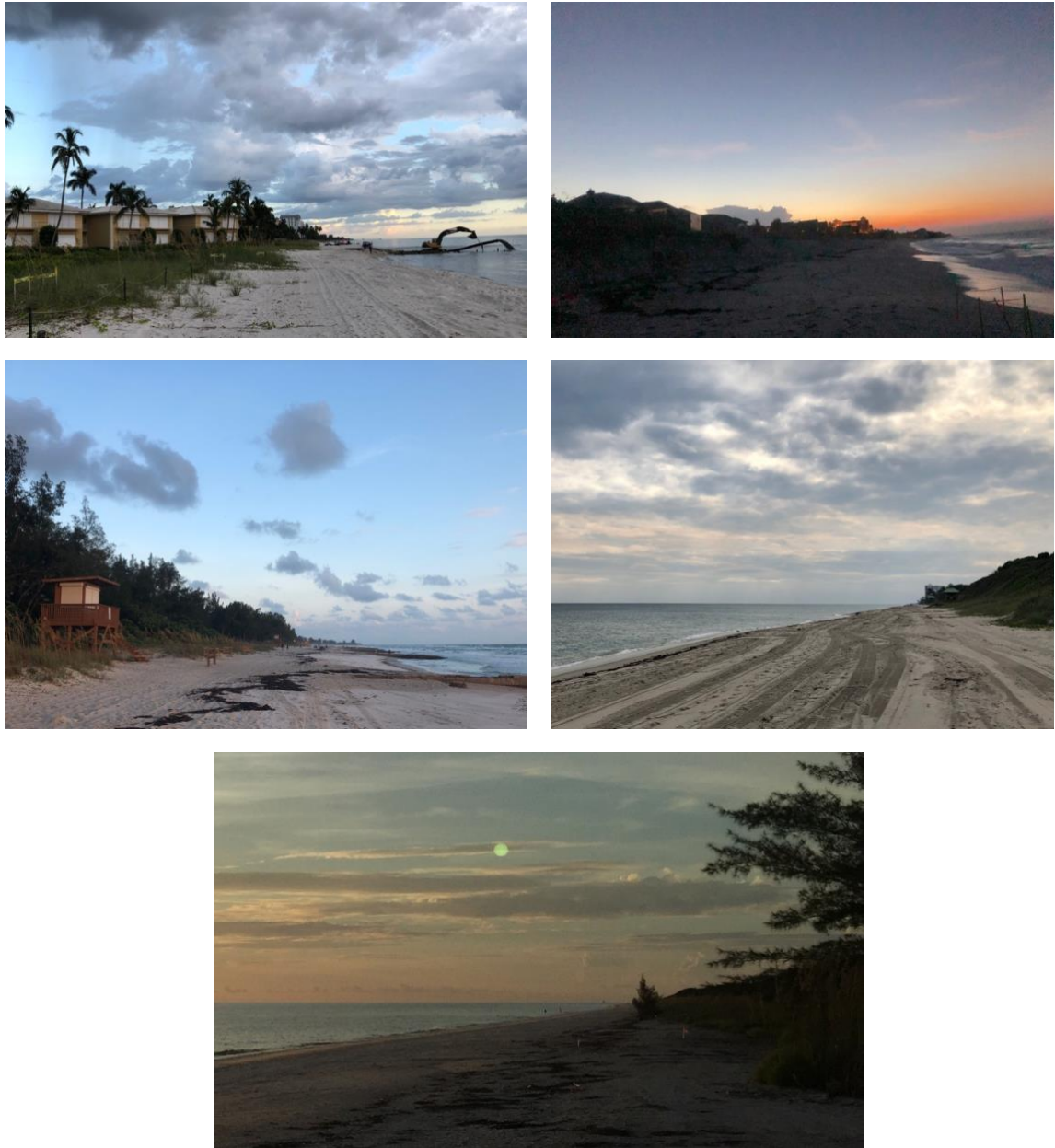


Figure 2. The five study sites, photographed during the day. Above, two urban sites. Left, Naples Beach on the West coast; right, Wabasso Beach on the East coast. Middle, two intermediate sites. Left, Anna Maria Island on the West coast; right, Boca Raton on the East coast. Bottom: Keewaydin Island, a natural site, on the West coast. See the text for more information. All photos by B. Villegas Vindiola



Figure 3. Photographs of the study sites at night. Above, Naples Beach, an urban site where many lights are directly visible at the beach. Below, Boca Raton, an intermediate site, where the dominant threat is sky glow from inland development. All photos by B. Villegas Vindiola



Figure 4. The biotic threats. Above left, coyote (*Canus latrans*); middle, raccoon (*Procyon lotor*); right, grey fox (*Urocyon cinereoargenteus*); Below left, night heron (*Nyctanassa violacea*); right, ghost crab (*Ocypode quadrata*). All photos by B. Villegas Vindiola

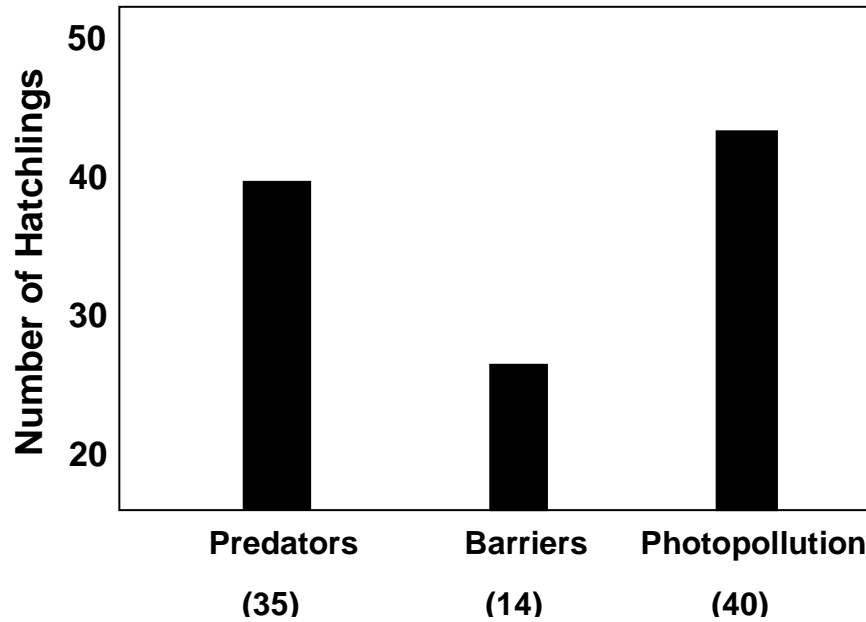


Figure 5. Causes of mortality among the hatchlings that emerged from their nest but failed to successfully crawl to the sea. Values in parentheses are the numbers of hatchlings that died.

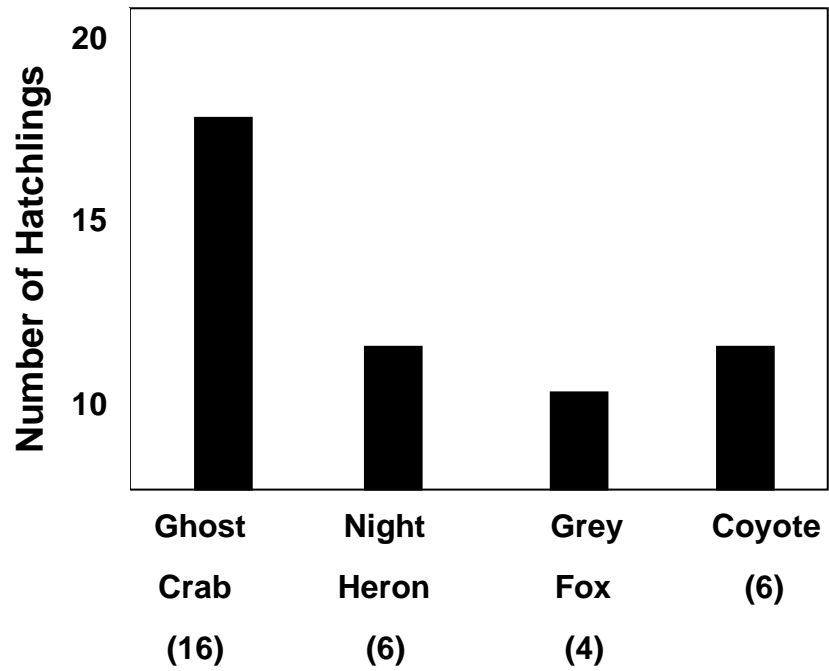


Figure 6. Predators responsible for mortality among the hatchlings that emerged from their nest, but failed to enter the sea. Values in parentheses are the number of hatchlings that died.

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