The use of autonomous terrestrial rovers
for high resolution light pollution sampling in beach environments

by

Anna Windle
Dr. David Johnston, Advisor
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Abstract

Nesting sea turtles have been known to actively avoid brightly lit beaches and often turn back to sea prematurely when exposed to artificial light. Observations and experiments have noted that nesting turtles prefer darker areas where structures such as buildings and high dunes act as light barriers. As a result, sea turtles often nest on darker beaches, creating spatial concentrations of nests. Artificial nighttime light, or light pollution, has been quantified using a variety of methods. However, it has proven challenging to make accurate assessments of light impact on smaller nesting beaches. Additionally, light has traditionally been measured from stationary tripods perpendicular to beach vegetation, disregarding the view a nesting female experiences. In the present study, nighttime ambient light conditions were assessed on three different nesting beaches in central North Carolina. Using an autonomous terrestrial rover, high resolution light measurements were collected every minute (Sky Quality Meter-LU-DL, Unihedron). Spatial comparisons between ambient light conditions and nesting density at and between these locations revealed the highest densities of nests occurring in regions with lowest light levels, supporting the hypothesis that light pollution from coastal development may impact turtle nesting distribution. These results can be used to support ongoing management strategies to mitigate this pressing conservation issue.
Introduction

All six species of sea turtles found in waters in the United States are listed as threatened or endangered by the U.S. Endangered Species Act of 1973 (Witherington et al., 2014). Therefore, protection of nesting habitat is crucial to ensure these species can rebound in population. Nest site selection is influenced by many environmental factors including sand characteristics, wave energy, terrestrial predation, and nearby oceanic currents (Mortimer, 1990; Witherington & Martin, 2003). Nesting sea turtles also face a number of anthropogenic threats such as bycatch in fisheries, interaction with marine debris, and habitat degradation from coastal development, which have all contributed to a global sea turtle population decline (Salmon, 2003; Witherington & Martin, 2003). Light pollution, often in the form of excessive artificial light from coastal development, is considered amongst the most serious anthropogenic threats (Salmon, 2003; Witherington, 1997). All U.S. sea turtle species nest primarily at night and many are exposed to sources of artificial light on nesting beaches (Witherington, 1997). Managing light pollution is crucial for sea turtle population recovery and will help guide and target conservation efforts (Kamrowski et al., 2012).

In areas of light pollution, nesting sea turtles can experience disorientation from direct glare or may be repelled from or attracted to bright lights (Longcore & Rich, 2004). Light pollution can disrupt nest-site selection and can lead to detrimental nesting behavior such as nest abandonment, abbreviation, and the disruption of sea-finding (Witherington et al., 2014). Female sea turtles are known to avoid brightly lit beaches in favor of dark beaches for nesting (Witherington, 1992; Salmon et al., 1995). In some cases, light pollution can affect egg-laying behavior of female sea turtles, triggering them to turn back to the ocean prematurely, failing to nest (Witherington et al., 2014).

Field observations have indicated that sea turtles that become deterred from an illuminated beach can re-emerge onto beaches with background vegetation, no artificial light, and minimal human activity (Worth & Smith, 1976). Many studies have noted a relationship between coastal development and reduced sea turtle nesting (Verutes et al., 2014; Longcore & Rich, 2005; Witherington & Martin, 2003). Field experiments have also demonstrated that sea turtles prefer to nest where light pollution is blocked by structures that act as ‘light barriers’ such
as buildings or tall dunes, indicating that beach geomorphology and structures may alter the amount of light a nesting sea turtle is exposed to (Salmon et al., 1995).

Light pollution limits the extent of nesting habitat for sea turtles, contributing to a form of habitat loss (Witherington et al., 2014). As artificial light deters sea turtles from nesting sites, sea turtles may select suboptimal nesting sites or cluster their nests on darker beaches (Witherington, 1992). This can lead to concerns such as destruction of previously deposited nests, increasing probability of nest washouts, and attraction of terrestrial predators (Salmon, 2003).

The amount of light pollution has been quantified using available technology throughout the years, although discrepancies amongst the methods have led to a lack of accurate and comparable light measurements for sea turtle nesting conservation plans and management. Instruments such as wide-field charge-coupled device (CCD) camera systems can be used to accurately measure brightness of a night sky by stitching together images taken from a robotic mount to form a mosaic of an entire sky (Pendoley et al., 2012; Duriscoe et al., 2007). This method involves collecting highly accurate measurements of light from the night sky; however, it may be challenging to compare extensive data to a smaller nesting beach.

Researchers have also used handheld or tripod mounted stellar photometers and light meters to study how nighttime light affects sea turtle behavior (Salmon et al. 1992, 1995; Salmon and Witherington 1995; Bertolotti and Salmon 2005; Sella et al. 2006; Kamrowski et al, 2015). Researchers have mounted light meters on small tripods aimed at the horizon to collect relative light radiance in various directions (Salmon and Witherington, 1995). Sky Quality Meters (SQM, Unihedron) have been used to assess impacts of light pollution on sea turtle nesting behavior, proving to be an accessible, affordable, and accurate tool to measure nighttime sky brightness (Kelly et al., 2017; Constant, 2015; Bonner, 2015). SQMs have conventionally collected nighttime light on stationary tripods across dune transects or perpendicular to the dune in specific increments along the beach (Constant 2015; Bonner, 2015). Measurements have also been taken at a sea turtle’s ‘height’, roughly 5 to 10 cm above the sand at known nest locations (Kelly et al., 2017). However, these techniques do not produce an encompassing representation of surrounding nighttime light a nesting sea turtle would encounter when crawling onshore to nest.

Studies have also utilized satellite-based remote sensing to assess broad scale effects of light pollution on nesting patterns of sea turtles (Weishampel et al., 2016; Kamrowski et al., 2012; Brei et al., 2016). Satellite artificial light maps have been used to compare amounts of
light to nesting density on individual nesting beaches; however, satellite pixel size is much coarser than the width of most nesting beaches. This leads to the integration of light sources not directly on the beach and includes light that could potentially be shaded by vegetation, buildings, or high dunes that nesting sea turtles would not experience (Weishampel et al., 2016). Beachfront lighting in an undeveloped area can also be disregarded in satellite data but could have a significant potential to disrupt local sea turtle nesting (Kamrowski et al. 2012).

Viewshed analysis, a geographic information system (GIS) approach, models how light illuminates a nesting beach (Verutes et al., 2014). Line of sight calculations are computed from a viewer’s location to a pixel on a landscape, representing an area that can receive direct light. This method incorporates topographical information to highlight areas where light from nearby coastal development can emit light onto known sea turtle nesting area and reveals where the path of light is obstructed (Verutes et al., 2014). When a viewshed approach is coupled with a high resolution digital elevation models, locations of buildings, vegetation, and dunes can more accurately model how features can block the path of anthropogenic light (Verutes et al., 2014).

For the present study, nighttime ambient light levels were measured on three adjacent beaches on the central North Carolina coast to assess impacts on sea turtle nesting density. The methods used overcome the shortcomings of previous work by sampling high resolution light levels continuously at a sea turtle’s eye-level with regards to beach topography. This novel method can repeatedly sample light at the level of detail needed to make sound coastal management decisions about light pollution limitations.

Methods

Study Area

Light pollution data were collected on moonless nights between astronomical dusk and dawn in summer 2017 on three adjacent beaches in central North Carolina (Figure 1). Atlantic Beach is a developed coastline situated on a barrier island bordered by the Atlantic Ocean and Bogue Sound interspersed with private homes and businesses. Fort Macon State Park located on the eastern end of the same barrier island is comprised of protected and undeveloped land. Shackleford Banks, an adjacent barrier island in the Cape Lookout National Seashore contains completely uninhabited wilderness. All three beaches experience sea turtle nesting during the
months of May through October, primarily of loggerheads, with the potential of greens, leatherbacks, and Kemp’s Ridleys (NCWRC, 2005).

![Figure 1. Map of study area: Atlantic Beach, Fort Macon State Park & Shackleford Banks, North Carolina, USA](image)

**Data Collection**

Two ambient light sensors (Sky Quality Meter-LU-DL, Unihedron) were mounted on an autonomous terrestrial rover (Figure 2). The chassis of the rover platform was derived from a commercially available radio-control (RC) car kit and enhanced with four-wheel drive and steering capabilities, and a ruggedized suspension. The rover was autonomously piloted by an open source PixHawk autopilot ([https://pixhawk.org](https://pixhawk.org)) loaded with the latest APM: Rover software ([http://ardupilot.org/rover/](http://ardupilot.org/rover/)). Mission Planner, an open source software program ([http://ardupilot.org/planner/](http://ardupilot.org/planner/)) was used to set the route and velocity of the rover during sampling. The rover was guided using onboard GPS and progress was constantly tracked through standard UHF telemetry. The rover deployed from coordinates 34.69, -76.67 on Fort Macon to 34.69, -76.78 on Atlantic Beach and from 34.63, -76.53 to 34.69, -76.65 on Shackleford Banks (Figure 3).
Figure 2. Autonomous terrestrial rover platform equipped with continuously datalogging Unihedron Sky Quality Meters

Figure 3. Autonomous terrestrial rover deployments on Atlantic Beach, Fort Macon, and Shackleford Banks, N.C. during Summer 2017

The sky quality meters (SQM) were programmed to collect ambient light in magnitudes per square arc second (mag/arcsec²) over a ~20-degree arc every minute (Unihedron). ‘Magnitudes per square arc second’ is an astronomical term meaning brightness in magnitudes spread out over a square arc second of the sky (Unihedron). Lower values indicate high light
pollution. A decrease in magnitude (numerically), corresponds with approximately 2.5 times more ambient light from a given light reading (Unihedron). An onboard GPS recorded XY coordinates of the rover path corresponding to coordinate locations where light was collected.

Sea turtle nesting records for all three beaches during 2011-2017 were provided by respective sea turtle beach coordinators. Nest date and XY coordinates were collected for each nest verified on each beach.

Data Analyses

Light pollution and nesting density data were aggregated into 500-meter along-shore bins to assess the spatial relationships of these data. Mean light pollution (mag/arcsec²) and nesting density (nests/year) were calculated for each bin. The number of verified nests and light pollution measurements recorded in 500-meter increments were considered sufficient data for comparison of light measurements and nesting density. A linear regression analysis was conducted to study the relationship between mean light and nesting density within each 500-meter bin (JMP statistical software).

Due to an uneven spatial distribution of nesting density, the Spatial Statistics toolbox in ArcMap (ESRI) was used to analyze spatial distributions and patterns of light pollution and nesting. A Global Moran’s I Spatial Autocorrelation test using a Euclidian inverse distance weight was employed to evaluate whether nesting density exhibited significant clustering on each beach. Anselin Local Moran’s I Cluster and Outlier Analysis tests were then run on these data to display where nesting density and light pollution were significantly high and low with regards to neighboring data.

Results

Trends in light

Light pollution levels on the three beaches varied from 10.13 mag/arcsec² (bright) to 21.35 mag/arcsec² (dark) (Table 1). The brightest lights occurred in several locations on Atlantic Beach while dimmer light occurred on Shackleford Banks (Figure 4). Nesting density (number of nests laid per year/ beach length) on all three beaches varied from 0 to 5.33 (Table 1). Shackleford Banks had the highest average nesting density and lowest average light pollution, and Atlantic Beach had the lowest nesting density and highest average light pollution (Table 1).
Solely through observation, it is apparent that nests were sparser in areas of high light pollution on Atlantic Beach, were relatively more abundant on Fort Macon State Park, and considerably more clustered on Shackleford Banks (Figure 4).

Table 1. Average, minimum, maximum and standard deviation of light pollution (mag/arcsec$^2$) and nesting density (nests/year/beach length) on Atlantic Beach, Fort Macon State Park, and Shackleford Banks, N.C. Low mag/arcsec$^2$ values indicate high light pollution.

<table>
<thead>
<tr>
<th></th>
<th>Light pollution (mag/arcsec$^2$)</th>
<th>Nesting Density (nests/year/beach length)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Min</td>
</tr>
<tr>
<td>Atlantic Beach</td>
<td>16.29</td>
<td>10.13</td>
</tr>
<tr>
<td>Fort Macon State Park</td>
<td>18.57</td>
<td>15.06</td>
</tr>
<tr>
<td>Shackleford Banks</td>
<td>20.23</td>
<td>16.03</td>
</tr>
</tbody>
</table>

Figure 4. (A) Light pollution values (mag/arcsec$^2$) taken every minute on autonomous terrestrial rover on study sites in summer 2017. Low mag/arcsec$^2$ values indicate high light pollution. (B) Verified nest locations on study sites from 2011-2017.
Figure 5. Enlarged map insets illustrating the increase of total nesting density (nests/year) from 2011-2017 as light pollution levels increase on (A) Atlantic Beach, (B) Fort Macon State Park, and (C) Shackleford Banks. Black dots represent 2011-2017 sea turtle nests overlaid on color dots representing light.

When aggregating light pollution measurements and nesting density by 500-meter increments, direct comparisons of the amount of light and the number of nests were made. Mean light pollution values in all bins ranged from 13.56 to 20.95 mag/arcsec² (Figure 6). Nesting density from 2011-2017 ranged from 0 to 1.86 nests/year in all bins (Figure 6). Visual observations demonstrate lower nesting density in regions along Atlantic Beach corresponding to regions of high light pollution, and high nesting density in regions along Shackleford Banks corresponding to regions of low light pollution (Figure 6).
Figure 6. (A) Mean light pollution value (mag/arcsec²) in 500-meter bins along study sites. (B) Nesting density (nests/year) from 2011-2017 in 500-meter bin along study sites.

**Light Pollution and Nesting Activity**

Mean light pollution and nesting density per 500-meter bin were significantly correlated, with lower nesting density corresponding to locations of high light pollution (n = 44, R² = 0.28, p = 0.0002) (Figure 7). On Shackleford Banks, nesting density ranged in areas from low to high light pollution, with low nesting density potentially occurring due to environmental factors. On
Atlantic Beach, nesting density occurs primarily in areas of high light pollution indicating a strong threat of light on nests laid on this beach.

![Graph showing the correlation between nesting density and light pollution.](https://via.placeholder.com/150)

**Figure 7.** Significant correlation ($n = 44$, $R^2 = 0.28$, $p = 0.0002$) between nesting density (nests/year) and light pollution (mag/arcsec$^2$) per 500-meter bin on Atlantic Beach, Fort Macon State Park, and Shackleford Banks, NC. Line of best fit: nesting density = $-1.70 + 0.13 \times$ light pollution. Dashed lines represent 95% confidence interval for mean nesting density for a given value of light pollution.

The Moran’s I spatial autocorrelation conducted on nesting density revealed a significant 0.629 global statistic from 999 random permutations, demonstrating high clustering of nests in the study area ($p = 0.00001$). The Anselin Local Moran’s I test conducted on light pollution levels exhibits regions of statistically significant high light pollution clusters ($p < 0.05$, Figure 8) on Atlantic Beach and significantly low light pollution clusters ($p < 0.05$, Figure 8) on Shackleford Banks. The Anselin Local Moran’s I test identifies regions of statistically significant high nesting density on Shackleford Banks and significant low nesting density on Atlantic Beach ($p$-value $< 0.05$, Figure 8). The regions of low nesting density were located in areas of high coastal development, such as in front of a brightly lit pier on Atlantic Beach and near a waterfront hotel. All significantly high light pollution levels on Atlantic Beach correspond to low
nesting density, supporting the hypothesis that light pollution may influence sea turtle nesting density (Figure 8).

Figure 8. Cluster and Outlier Analysis (Anselin Moran’s I) portraying regions of significantly high light pollution and high nesting density in red and significantly low light pollution and low nesting density in green.

**Beach Type Variability**

To assess differences of light pollution amongst nesting locations, each sea turtle nest location was linked to the closest light pollution value by using a spatial join tool on GIS, producing a table listing every nest with a corresponding light value. The results of an ANOVA
and nonparametric multiple comparisons demonstrate that light pollution levels at nests on the three study sites were significantly different, indicating that sea turtles are choosing to nest in significantly different areas in terms of light pollution across the three different beaches (Table 2). Average light pollution on Atlantic Beach was 8 times brighter than the average light pollution on Fort Macon State Park, and 36 times brighter than Shackleford Banks.

Table 2. Nonparametric multiple comparisons of closest light pollution level (mag/arcsec²) at nests located on each study site using Wilcoxon test on each pair. P-values < 0.0001 on every pair indicating significantly different light pollution levels all three study sites.

<table>
<thead>
<tr>
<th></th>
<th>Score Mean Difference</th>
<th>Standard Error Difference</th>
<th>Z-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic Beach – Fort Macon State Park</td>
<td>30.34</td>
<td>4.73</td>
<td>6.41</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Fort Macon State Park – Shackleford Banks</td>
<td>90.79</td>
<td>11.14</td>
<td>8.15</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Shackleford Banks – Atlantic Beach</td>
<td>96.85</td>
<td>10.39</td>
<td>9.31</td>
<td>&lt;0.0001*</td>
</tr>
</tbody>
</table>

Figure 9. Significantly different light pollution values (mag/arcsec²) at each nest location on study sites (One-Way ANOVA, p < 0.0001). Solid horizontal line represents total mean light pollution of all study sites, diamonds represent 95% confidence intervals for each mean.
Discussion

In this study, sea turtle nesting was less dense in areas of high light pollution compared to areas of low light pollution. There was a significant relationship between nesting density and light pollution levels, with more nests occurring in regions of darker beach. The novel light collection method employed in this study using a terrestrial rover accurately illustrates where problematic light pollution exists. Results from this study suggest that management action should target bright areas near a pier and in front of a waterfront hotel on Atlantic Beach where light is bright and nesting density is low or absent. This precise data can assist beach management in identifying locations for conservation action.

Using a terrestrial rover to collect light data is a more consistent method of data collection because it reduces human error. It is also safer to use than traditional sampling techniques and can be used in places hard to access by foot. Since the rover is approximately the size and height of a nesting female sea turtle, it collects the data necessary to make accurate estimates of where light pollution is most harmful to nesting sea turtles. Light was collected on the moving rover travelling over topographical features across a beach landscape, mimicking the crawling movements of a nesting sea turtle. High resolution light measurements take beach topographical features into account, providing additional information on the amount of light a nesting sea turtle encounters while nesting.

Advancements in autonomous robotics

The advent of small durable microelectronics, 3D printers, open source hardware designs, and software packages has resulted in a vibrant small robotics community with a growing set of environmental applications. Autonomous sampling approaches such as the rover employed in this study can increase the resolution, reduce costs of sampling, and in some cases, reduce the effects of human disturbance on environmental sampling. Future iterations of the rover platform should include real-time sensing and avoid functionality to reduce interactions with obstacles and wildlife. Technological advancements in battery life and GPS functionality can improve autonomy and accessibility.

While the affordable robotic terrestrial rover described in this study is suitable for sampling ambient light conditions in beach and coastal environments, it can be tailored with
other sensors to measure environmental and anthropogenic factors such as temperature, motion, noise, dune vegetation, and more. These variables can provide more data on what nesting sea turtles might encounter that could potentially impact the success of nesting and hatching, providing valuable information on how to properly manage nesting areas.

**Beach Type Variability**

The beach study sites consist of a developed public beach, a state park, and a national seashore. With varying management and objectives, nesting density differs on each beach. The Natural Sounds and Night Skies Division of the National Park Service works to protect, maintain and restore dark night sky environments throughout National Parks and Seashores (NPS, 2017). National Parks could be considered as refuges for species that rely on darkness for breeding and feeding patterns (Manning, 2015). The lack of development on Shackleford Banks and the National Seashore’s dark skies initiative may both contribute to the abundance of sea turtle nesting activity.

North Carolina state parks strive to conserve and protect the state’s natural beauty, ecological features and cultural resources (N.C. State Parks, 2018). Since housing and business development is not permitted on state parks, they too can become dark night refuges for nocturnal species. Fort Macon State Park has a considerably higher density of sea turtle nests due to lower light pollution levels than on Atlantic Beach, supporting to the hypothesis that sea turtles prefer to nest on dark beaches (Witherington & Martin, 2003). Atlantic Beach has no consistent light management and contains substantially brighter areas along the beach. While some sea turtles still choose to nest on this beach, there are significant gaps in nesting, and the beach has a considerably lower nesting density overall than the adjacent barrier island of Shackleford Banks.

**Caveats and Considerations**

Associated anthropogenic variables such as noise and human activity can also significantly influence nesting trends. For example, the collected data indicate that bright lights associated with hotels impact nesting; however, hotels also increase the probability of nesting activity being disturbed by tourists. Studies have shown that the presence of people moving within the field of view of a nesting turtle can cause nest abandonment just as often as lighting
(Witherington et al., 2014). Future research on anthropogenic variables in addition to light that may affect a sea turtle's decision to nest at a particular beach is warranted. Ongoing development may also result in changes in relationships of nesting data and light. This study’s methods can be replicated over time to analyze changes in light data.

Environmental factors can also influence nesting such as sand characteristics, spatial orientation of land, temperatures, currents, etc. (Mortimer, 1990; Best, 2017). In order to properly manage light pollution on sea turtle nesting beaches, areas where anthropogenic and environmental impacts are most significant need to be accurately identified and managed. Further investigation is warranted to provide explanations as to why nesting turtles are avoiding certain areas of a nesting beach year after year.

Future management and research

Of all of the anthropogenic variables threatening sea turtle populations, light is arguably one of the most manageable (Witherington & Martin, 2003). Light serves an undeniably important feature for homes and businesses. Homeowners may choose to keep exterior and interior lights on to prevent burglaries, and businesses such as restaurants and hotels can perceive light as an efficient technique to attract customers and guests. Coastal town management utilizes lights in parking lots and public beach access sites for the safety and satisfaction of vacationing tourists.

With proper light management, artificial light does not need to be completely prohibited. Light sources can meet the needs of humans while minimizing the disruption of nesting sea turtle behavior. Techniques can reduce the intensity of artificial light such as lowering the wattage of lights, focusing a light source toward the ground, and implementing light barriers to shield direct light sources (Witherington, 1997). Technological advances such as motion detector switches and timers can also be utilized to lessen the effects of light pollution on nesting beaches. Those responsible for harmful light sources are usually unaware of the detrimental effects to nesting sea turtles (Witherington et al., 2014). Simple educational measures such as informational material or public signs could prove useful tactics to reduce the amount of light occurring on a beach at night.

Technological advancements in the use of unmanned aircraft systems (UAS), or drones, can produce highly accurate digital elevation models derived from Structure-from-Motion (SfM)
photogrammetry and aerial LiDAR. These models can accurately extract environmental and topographical features of a shoreline such as beach slope, locations of buildings, vegetation, and escarpments that can influence nest site selection (Kelly et al., 2017). If coupled with high resolution light pollution measurements, this method could accurately estimate where topographical features obstruct the path of anthropogenic light, and which lights are most problematic. Integrating these additional metrics into a viewshed approach would yield precise estimates of where light pollution is most harmful to nesting sea turtles, providing the information needed for effective and successful management policies (Weishampel et al., 2016).

Sea turtle nest density data does not include lighting impacts on hatchlings; the effects may not be evident until decades later when the females come back to the beach to nest. Light pollution has been known to cause thousands of hatchling deaths per year in Florida (Salmon, 2003). Experimental lab and field studies have concluded that hatchlings orient to the brightest light on a beach (Salmon et al., 1995; Tuxbury & Salmon, 2005). Disoriented hatchlings can exhaust energy stores while spending additional time trying to find the ocean (Pankaew & Milton, 2018). Some hatchlings never do find the water at all, getting lost in dunes or getting run over by cars (Salmon, 2003). Hatchlings still on the beach during daylight risk death from dehydration and predation (Pankaew & Milton, 2018). Most sea turtle organizations on developed beaches in east coast nesting states have some type of management in place to protect hatchlings from surrounding light. Monitoring of disorientation and documenting mortality rates can help identify specific lights that continue to be problematic to sea turtle hatchlings.

Conclusion

This study points to the potential of using a terrestrial drone as a new and efficient way to quantify light pollution. High-resolution light data collected from a sea turtle’s eye-level were used to make comparisons with sea turtle nesting density. High light pollution levels were positively correlated with low nesting density, supporting the hypothesis that coastal development leads to a concentration of nests in a decreasing area of dark beaches (Salmon, 2003). The collected data can also be used to determine target areas of light management on a particular beach. The potential resolution of the data (light pollution measurement every second) can help pinpoint the location of specific problematic lights. This pilot study can be replicated elsewhere to assist town and beach managers in making more knowledgeable decisions on how
to properly manage artificial light to protect nesting sea turtles. If properly developed and implemented, light sources can meet the needs of humans while decreasing the harmful impact on nesting sea turtle behavior.
References


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