FINAL REPORT

IMPACTS OF COASTAL ROADWAY LIGHTING ON ENDANGERED AND THREATENED SEA TURTLES

(CONTRACT No. BB850)

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16. Abstract

Florida's oceanic beaches are the primary nesting sites for the world's second largest population of loggerhead sea turtle (a threatened species), and for smaller, but increasing, populations of green turtles and leatherbacks (both endangered species). But coastal development in the state has led to habitat degradation in the form of "photopollution": exposure of formerly dark beaches to artificial lighting. Lighting repels many females from those beaches. It also interferes with the ability of hatchlings that emerge from nests at night to locate the sea. In many locations state-wide, lighting reaches nesting beaches from coastal roadway streetlights. This project was sponsored by the FDOT to help resolve coastal roadway lighting impacts at adjacent nesting beaches, and to assist in revisions to the FDOT Roadway Lighting Standards to include sea turtle conservation measures. With this end in mind, the following tasks were completed. (i) Roadways adjacent to nesting beaches were inspected, and criteria were developed, to categorize the severity of roadway lighting problems. (ii) Sites were selected, and procedures were formulated, for correcting lighting problems and for measuring the efficacy of lighting modifications. (iii) Experiments were carried out to determine whether two recent technologies of lighting management (use of filters to exclude portions of the luminaire spectra; use of embedded roadway lighting) provided effective protection to both females and their hatchlings.

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Introduction

Five species of sea turtles (loggerhead, *Caretta caretta;* leatherback, *Dermochelys coriacea;* green turtle, *Chelonia mydas;* hawksbill, *Eretmochelys imbricata;* and Kemp's ridley, *Lepidochelys kempi)* are found in U. S. coastal waters. Of these, three species (all but the Kemp's ridley and hawksbill) nest in significant numbers on U.S. shores. Loggerheads (the second largest population of this species in the world) place about 90 % (~70,000 annually) of their nests on the east coast of Florida. In addition, about 2000 green turtle, and more than 120 leatherbacks, nest on Florida's beaches each year.

Over the last 500 years, populations of sea turtles have suffered a precipitous decline. All species frequenting U. S. waters have been designated as endangered, with the exception of the loggerhead whose status is officially listed as "threatened". The causes are multiple and complex; many are problems that arise outside of U.S. waters. These include overfishing of adults and juveniles; egg harvesting; accidental capture in trawls, long lines, and other fishing gear; ingestion of pollutants and debris; collisions with boats; failure to enforce the laws designated to protect turtles; and destruction or degradation of critical developmental, feeding, and breeding (nesting beach) habitats. The recovery of sea turtles is a worldwide problem, one that ultimately depends upon cooperation between many groups (national and outside the U.S.) in efforts to eliminate and/or minimize each of the many concurrent threats.

A. Photopollution as a threat at the Nesting Beach

"Photopollution" (the negative influence of stray, artificial lighting on the survival and/or reproductive activities of nocturnally active organisms; Verheijen, 1985) is a major factor degrading sea turtle nesting beaches in Florida. It arises as a consequence of 40 years of intense immigration to the state, and settlement along its coastline. Stray light from homes, businesses and municipalities reaches the beach where it repels gravid turtles that nest at night (Witherington, 1992). Today, most Florida sea turtles nest within the few remaining areas where light levels are low. However, some turtles continue to place nests at sites where the beach is exposed to lighting. At such sites, extraneous lighting affects their hatchlings, which emerge from nests at night and must immediately crawl to the ocean.

Hatchlings depend primarily upon visual cues to locate the ocean. This behavior is known as "seafinding" orientation, or simply "seafinding". Turtles accomplish this feat by crawling away from the dark elevated silhouettes of the dune vegetation on land and toward the open, lighter horizon over the ocean (Salmon *et al*., 1992; Witherington and Martin, 2000). In areas that have been developed by humans, artificial lighting near nesting beaches appears brighter to the hatchlings than any natural cues, and causes them to respond abnormally in one of two ways. They either crawl inland instead of toward the ocean (misorientation), or they appear incapable of crawling on a straight path (disorientation). To conserve these species it is imperative to control artificial lighting, even at coastal areas where lighting is required for human safety (e.g., paths for walking and/or biking; at roadways and intersections). Disoriented and misoriented turtles usually die from predation (capture by raccoons and foxes), dehydration, crushing by cars on roadways, or heat exposure after sunrise. An estimated one million hatchlings are affected by artificial lighting every year on Florida beaches (Witherington, 1997).

Habitat alterations associated with FDOT coastal highways contribute to many beach lighting problems. Some problems may arise because streetlights placed by coastal roads are visible from the beach. Others can occur when vegetation between the beach and road is removed, exposing the beach to lighting on or near roads. Currently, FDOT Design Standards do not take into account the biological conditions of adjacent properties when designing lighting systems.

B. Objectives

The Florida Department of Transportation (FDOT) sponsored this research in an attempt to include sea turtle conservation measures into the Roadway Lighting Design Standards, and to comply with the National environmental Policy Act (NEPA). The research was conducted by three scientists (Profs. M. Salmon and J. Wyneken, Department of Biological Sciences, Florida Atlantic University; Ms. Jerris Foote, Mote Marine laboratory), and had three objectives – inspect and classify coastal roadways adjacent to sea turtle nesting beaches throughout the state, explore alternative lighting systems, and determine how the turtles (nesting females and hatchlings) responded to these alternatives. This information will be used to develop new and improved lighting standards for coastal communities.

C. Overview of the Tasks

To accomplish these objectives, FAU/Mote Lab. personnel performed five tasks. As each was completed, a report was submitted to FDOT that outlined and discussed the results (see appendices A-E). The tasks, described in their order of completion, were as follows.

Task 1 - Identification and classification of problem areas (roadways) adjacent to nesting beaches, and classify them according to the severity of the problem. This was accomplished by lighting inspections using established protocols (Witherington and Martin, 1996). All coastal roadways adjacent to nesting beaches on Florida's East, West, and Gulf ("panhandle" region) were inspected.

Task 2 - Select experimental sites where there were suspected lighting problems representative of those found state wide, so that these locations could be used to test the effect of lighting modifications on the turtles (adults and hatchlings).

Task 3 - Conduct arena experiments with hatchlings at problem sites to confirm that lighting affected the turtles, and to determine the effect of lighting modifications. These experiments were conducted on Florida’s West Coast.

Task 4 - Determine if filtered lighting provided effective protection for female (nesting) turtles from poled streetlights on coastal roadways. These experiments were conducted on Florida’s East Coast.

Task 5 - Evaluate the effectiveness of embedded roadway lighting on adjacent sea turtle nesting beaches. These experiments were also conducted on Florida’s East Coast.

METHODS, CONCLUSIONS AND RECOMMENDATIONS

Task 1: Coastal Roadway Classification

A. Methods

Because knowledge of where lighting problems existed on coastal roadways was either incomplete or non-existent, lighting inspections were conducted for coastal roadways on the East, West and Gulf coasts of Florida. Inspections were done during the day to pinpoint the location of landmarks, light sources and lighting structures. They were then repeated at night by walking the length of the beach or by inspection from an ATV to determine where lighting reached the beach. Photographic records were made to document and confirm the extent and nature of the lighting problems. These photographs were submitted to the FDOT (Ms. Ann Broadwell) as part of the task report, along with detailed descriptions of each roadway section.

State Maps were color-coded to reflect the following lighting classifications:

Type I: Roadway is without lights and the surrounding area (as well as the adjacent beach) is dark.

Type II: Roadway is furnished with lighting fixtures, some or all of which are visible at the beach. Other lighting is rarely present.

Type III: The beach is illuminated, either directly (light sources visible) or indirectly (by sky glow), by poled streetlights and other sources (homes, businesses, condominiums, etc.) Modification of roadway lighting is likely to significantly reduce this illumination but in some areas, is unlikely to render the beach totally dark.

Type IV: Lights from streets and roadways make relatively insignificant contributions to already serious lighting problems caused by extensive coastal development.

The task was completed for nine counties on Florida's East coast (Nassau, Duvall, St. Johns, Volusia, Brevard, Indian River, Martin, St. Lucie, and Palm Beach), four counties on Florida's West coast (Manatee, Sarasota, Charlotte and Lee), and six counties in the Panhandle (Escambia, Okalossa, Walton, Bay, Gulf, and Franklin).

B. Conclusions

The initial steps required to solve lighting problems require that (i) problem areas be identified, and that (ii) the severity of the impact be assessed and expressed objectively. This survey of coastal roadways provides FDOT with that critical information. We hope that our maps will enhance and expedite FDOT's coordination with Federal and State agencies, enabling agencies to make corrections consistent with the National Environmental Policy Act (NEPA). The classification system can also be used to preserve and protect Type I roadways from photopollution**.** Although procedures for light management of coastal roadways are outlined extensively in the Florida Power and Light's (FPL) Coastal Roadway Lighting Manual (Ernest and Martin, 1998), some of these procedures may adversely impact the integrity of the lighting system under the current FDOT Roadway Lighting Standards. The identification and classification of coastal roadways needs to be used by the FDOT to further develop alternative lighting standards, implemented to retrofit offensive existing street lights and improve street lighting proposed for other coastal roadways. The classification of coastal roadways is the first step in establishing “Sea Turtle Lighting Zones” where alternative FDOT Lighting Standards would be used for designing roadway lighting systems.

In the event FDOT were to address the coastal roadway lighting issue with a state-wide project, the following could be used to correct roadway lighting problems:

At Type II locations, where all lighting reaching the beach comes from poled streetlights, an immediate improvement would come from the addition of proper shielding. Shielding would limit the spread of radiance from lamps to areas other than roadway. It would be necessary to first establish why the lighting was installed in the area and provide sufficient evidence that attaching a shield would not effect the light distribution on the pavement. Other improvements that would not hinder the lighting system could be made by the following modifications: installing cut-off fixtures where they are absent, reducing wattage if it is currently higher than what the roadway classification guidelines call for, lowering the lights or, if there is no safety reason for the lighting system, simply turning them off during the nesting season.

Type III locations are defined as those where not all lighting that reaches the beach comes from streetlights, and thus modification of poled luminaries is unlikely to solve the problem. However even at these locations, such modifications will improve conditions and should reduce the incidence of hatchling misorientation and disorientation. But clearly, solving the photopollution problem at such sites will require that municipalities work with the FDOT and the Florida FFWCC to create land use plans and ordinances that include modifications not only to streetlights, but to other luminaries as well.

C. Recommendations

The sections of State roadways that are adjacent to sea turtle nesting beaches have been identified and classified. This information, along with the Florida Index Nesting Beach Survey compiled by Florida Marine Research Institute (FMRI) and Florida Wildlife Conservation Commission (FWC), needs to be used to establish Sea Turtle Lighting Zones. The engineering aspect for developing FDOT Design Standards in those zones was beyond the scope of work for this research team but alternative lighting standards should be developed through another contract with an engineering team that has experience in developing Design Standards for FDOT. Much value could be achieved by developing a Practice Manual for Designing Roadway Lighting Systems in Environmentally Sensitive Areas. The manual would not necessarily offer new lighting criteria, but would show the designer how to use alternative lighting products in the design. This would be a valuable resource for Florida and for the nation (Ellis and Washburn, 2003).

Within the Sea Turtle Lighting Zones, Lighting Engineers should implement specialized Coastal Roadway Lighting Standards that would meet the needs of the roadway and satisfy the requirements of the Endangered Species Act. The FDOT should do more work to develop specialized Coastal Roadway Lighting Standards and establish the Sea Turtle Lighting Zones in a Geographical Information Database format. Such a database would allow users to link geographic information (the Sea Turtle Lighting Zones) with descriptive information (specialized Coastal Roadway Lighting Standards). The database would also allow FDOT engineers who improve future roadways and bridges to identify Sea Turtle Lighting Zones within their project corridor, implement alternative lighting standards, and retrofit existing lighting systems within Zones, if necessary.

If the lighting system is maintained by a government entity other than FDOT, the database could be used to identify retrofit projects that could be funded by FWC Sea Turtle license tag revenues.

Task 2: Selection of Experimental Sites

A. Methods

The objective was to select several nesting beach sites on the East and West Coast of Florida where "typical" lighting problems exist, and where their correction may provide insights into appropriate solutions at other comparable locations, state wide. Sites were chosen where the lighting problems could be easily corrected, as they were largely a function of streetlights (Type II locations), and sites where both streetlights and other luminaries resulted in hatchling misorientation and disorientation.

B. Conclusion

The task report included detailed instructions for completing arena assays. These are staged hatchling emergences that enable managers to quickly and efficiently determine whether (i) lighting at a nesting beach affects hatchling orientation, and whether (ii) a lighting modification has reduced or eliminated the problem. The assay has two advantages: it is simple to carry out (minimum training is required) and it provides managers with quantitative data that evaluate progress toward achieving restoration goals. In two of the Task Reports, the arena assays illustrate how they can be used to more accurately to define the problem, and to test the efficacy of lighting modifications.

C. Recommendation

Arena assays need to be utilized in determining if street lights on coastal roadways are the cause of disorientation at locations where existing street lights are creating disorientation and when designing new lighting systems within the proposed "Sea Turtle Lighting Zones".

Task 3: Arena Experiments at Experimental Sites: Florida's West Coast

A. Methods

Arena assays at three sites were used to determine whether lighting modifications resolved a misorientation problem. At one site (Coquina Beach, Manatee County; a Type II site), open-bottom, unshielded 100 W high-pressure sodium (HPS) street lights were visible under a canopy of Australian pine trees (*Casuarina*) between the beach and roadway. An arena assay carried out before lighting modification revealed that the hatchlings crawled landward (east), toward the lights. The streetlights were modified by replacing the 100 W HPS luminaries with 70 W cut-off fixtures and #2422 acrylic flat lenses. The hatchlings tested after modification continued to show abnormally high scatter, but about two-thirds of the turtles crawled between W (toward the ocean) through NW to N. An arena assay done after the streetlights were turned off resulted in strong orientation within $\pm$ 20^0 of W (toward the ocean).

At the remaining two sites (Longboat Key, Lido Beach; Type III sites) streetlights, vehicular lights, and residential lighting were visible at the beach which lacked any substantial vegetation barrier between the roadway and the beach itself. Poled lamp luminaires ranged between 100 – 200 W. Some of these lights were partially shielded (7.6 – 15.4 cm overhang of flashing placed on the W [ocean-facing] side of the fixture), while others were painted black on the W side. The lights were modified by increasing shielding depth to > 20 cm. "Before" vs. "after" arena assays revealed no improvement in hatchling orientation performance. At the Lido Key site, but not at the Longboat key site, it was possible to turn off the streetlights. Doing so had no effect on hatchling performance, indicating that levels of lighting from sources other than (or in addition to) the streetlights were sufficiently bright to disrupt behavior.

B. Conclusions

The results confirmed the hypothesis that it should be easier to carry out successful lighting modifications at Type II than at Type III sites. However, even at the Type II site (Coquina Beach), lighting modification improved, but did not entirely resolve, the lighting problem since only turning off the lights resulted in normal seafinding orientation. On the other hand, shielding and/or lowering the lights might be a successful next step, especially if turning the streetlights off during nesting season can't be done for other reasons (such as pedestrian and vehicular safety).

This study also illustrates the value of arena assays as a tool for assessing lighting modifications. In the past, changes have been made in the lighting environment before determining which lights were causing the problem, and whether their elimination would be beneficial. To illustrate, consider what happened when Delray Beach, at great expense, replaced its HPS streetlight lamps on highway A1A with low-pressure sodium luminaires. Hatchlings departing from the few nests placed on that beach continued to crawl inland, toward the lights, rather than toward the sea because the fundamental causes (sky glow from car dealerships and shopping centers, located inland; a low and incomplete vegetation barrier between the road and the beach) had not been identified. Arena experiments done on an evening when the streetlights had been switched off, or before and after a temporary (artificial) light barrier had been placed against the vegetation, would have revealed those elements and could have prompted alternative, and better, strategies of lighting modification.

C. Recommendations

Arena assays, by their nature, encourage managers to use a step-by-step procedure for solving lighting problems; one that we believe ultimately leads to an analytical, objective, and more efficient approach to the problem of habitat restoration. It is the recommendation of this study that arena assay methodology be the established protocol used by FDOT when identifying and resolving coastal roadway lighting issues.

Task 4: On-Site Test of Lighting Modifications (Florida's East Coast)

A. Methods

The goal of this project was to test the efficacy of a new method of lighting modification - the use of amber-colored plastic filters to exclude the shorter wavelengths of light (violet, blue, green) that are most attractive to hatchlings (Withington and Bjorndal, 1991a, 1991b) and most repelling to nesting females (Ehrenfeld, 1968; 1979; Witherington, 1992).

Florida Power and Light Corp. installed filters (# 2422; manufactured by General Electric Lighting) on many of its streetlights located on coastal roadways. These streetlights contained 75 W, HPS luminaries that emitted wavelengths known to attract hatchlings. The purpose of this project was to determine whether the filter resulted in emissions that females ignored. A Type II site (Carlin Park, located just North of Juno Beach on Florida's East coast) was chosen as the study area.

The Carlin Park site had several advantages. First, the distribution of nests on a relatively long length of beach (approx. 1.4 km) had been recorded for 12 years previously, and thus provided the requisite "baseline" information needed to assess how any change in lighting conditions affected the distribution of the nests. The historical data indicated that on average, over 500 nests were placed on the beach with little variation in nest "density" from one place to another at the site. Second, over the 12-year period, the streetlights had been switched off during the nesting season. Third, the beach was otherwise dark so that if a change in nesting density occurred in response to a lighting manipulation, a cause-effect relationship was likely.

The beach was divided into three sections of equal length: two peripheral (North and South) control zones and one central experimental zone. Three streetlights located on the road adjacent to the experimental zone were visible from the beach. Each was fitted with a #2422 filter. The lights were turned on and off at one week intervals throughout the nesting season. The number and location of each nest placed on the beach every night was tallied from the beginning to the end of the nesting season. The data were subjected to statistical analysis to determine if nesting in the experimental zone was inhibited during periods when the streetlights were turned on, compared to when they were switched off.

B. Conclusions

There was no evidence that females avoided the experimental zone during periods when the lights were turned on. Nesting densities in the three zones showed no statistical differences, either from one another or from those observed historically during the previous 12 years. Thus, filtered lighting provided effective protection to nesting turtles.

However, the following points must also be kept in mind. First, while loggerheads nested frequently at Carlin Park, green turtle and leatherback females rarely nest there. Because those numbers were so low, we could not determine if filtered lighting also protected females of these two species.

Second, females and hatchlings respond differently to artificial lighting. Thus a failure to demonstrate any effect upon females does not guarantee that hatchlings (which are more sensitive to light) will be similarly unaffected. Recent experiments have shown that hatchling loggerheads and green turtles are attracted to HPS filtered lighting, though less strongly than they are to unfiltered HPS lighting (Masters theses by K. Nelson and S. Tuxbury).

Therefore, the use of filtered lighting should be viewed as an additional technology that may be useful in light management, but one that will work best as part of a plan that includes several types of modification used simultaneously. Thus the use of light filters should be combined with shielding, a reduction in luminaire wattage, and with lowering of the problem lights.

C. Recommendations

Filters may be especially effective at Type II sites where managers report relatively few instances of disorientation and misorientation. However, filtering also decreases illuminance and may therefore reduce illumination of the roadway below levels considered acceptable for public safety. Should that be the case, alternative methods of light management (shielding, lowering the lights, etc.) should be considered.

Task 5: On-Site Testing of Embedded Roadway Lighting

A. Methods

The FDOT sponsored a project that involved the use of embedded roadway lighting as an alternative to pole lighting. This modification transfers bright and elevated light sources (that typically also illuminate the beach) to the street itself. In theory, such a modification places the light where it is needed (to the pavement surface) while reducing its scatter to other areas of the environment (such as the beach). The goal of this study was to determine whether these lighting modifications provided effective protection for sea turtle hatchlings.

The project was initiated at a Type II site: a 0.7 km length of highway A1A located at Spanish River Park in Boca Raton, Florida. Because the park consisted of a dense stand of tall (Australian Pine) trees, it acted as a barrier that shielded the beach from development and its associated lighting to the North, South, and West. The only lights directly visible from the beach were the streetlights placed on the highway. These were 150 W HPS luminaries in cobra head fixtures, mounted on concrete poles 7.5 – 9.0 m high and 61 m apart.

The embedded lights were "Smartstud Wayfarer" light-emitting diodes (LED's), placed in the road centerline at 9 m intervals. Smartstuds emitted ~ 30 lumens of amber light while those placed at turning lanes emitted similar amounts of white light. LED lighting was complemented by 28 cm high HPS (100 W) louvered beach luminaries (Bronzelight RFB), spaced at 9.14 m intervals, that bordered the bike lanes on the West side of the roadway. Existing pathway lights were elevated by 5.5 m poles, and fitted with amber filters that excluded wavelengths < 550 nm. These lights were not visible from the beach and were left on during all experiments.

Arena experiments at the beach were used to determine how hatchling orientation was affected under three conditions ("treatments"). The treatments were: (i) during exposure to streetlights, (ii) during exposure to the embedded and louvered lights (hereafter, embedded lights), and (iii) during an absence of artificial lighting (Both streetlights and embedded lights were extinguished.). The null hypothesis was that hatchling orientation should be disrupted in the presence of any lighting, but not in its absence. However if embedded lighting provided effective protection, then hatchling orientation should be normal and identical under conditions (ii) and (iii), but disrupted under condition (i).

B. Conclusion

Results were consistent with the hypothesis that seafinding was disrupted only when the beach was exposed to poled street lighting, but not when it was exposed to embedded roadway lighting or when all lighting was switched off. We conclude that embedded roadway lighting is an effective method for reducing the impact of roadway lighting on hatchling marine turtles. As with any lighting modification measure, embedded lighting does have some limitations. It is imperative with any lighting modification to first identify the street lights as the only source of disorientation. Where the lighting environment is more complex (e.g., other light sources are present), other lighting modifications may be more appropriate.

For FDOT, an initial challenge may well be to determine whether a site is really an optimal one for the installation of embedded lighting. Originally, the Spanish River Park site was classified as Type II, on the basis of a roadway survey. But in reality, the turtles were affected by light sources other than the streetlights. On two evenings when there was complete overcast, hatchlings were disoriented even when only the embedded lights were on (presumably, by skyglow from the city). But on nine other evenings when the sky was clear or there was partial cloud cover, embedded lighting was correlated with normal seafinding behavior. Thus, arena assays were important for revealing unanticipated complexities in lighting at this site. Before any lighting modification is installed on any “Type II” roadway, arena assays should be completed under a variety of weather conditions to verify that categories have been assigned accurately.

Other considerations may also have bearing on any decision regarding the installation of embedded lighting at Type II sites. A companion study to this research project, also funded by FDOT, assessed the poled street lighting and the embedded roadway lighting systems in terms of lighting sufficiency and public acceptance of alternative street lighting. It was important to FDOT to determine whether this method of street lighting would be acceptable to the traveling public. It is important to note that neither the poled lighting system nor the alternative lighting systems made significant contributions to roadway lighting. The existing lighting system was configured to provide area lighting of the pedestrian area on the western side of the roadway. The location of the overhead cobra head luminaires permitted limited illumination of the bike lane but contributed little illumination to the travel lanes. Through the use of a motorist/pedestrian survey, the study was able to conclude that a majority of respondents were supportive of the efforts to minimize the impact of lighting on nesting turtles and their hatchlings. The review of traffic accident data showed that there was no difference in the number of lighting related accidents before or during the use of the alternative lighting system. The results of this task demonstrate that alternative lighting systems are safe and acceptable to the motorist and pedestrian (Ellis and Washburn, 2003).

This report does not address the long-term costs of installing, maintaining, and powering an embedded roadway system compared to those required to modify and maintain existing poled luminaries.

C. Recommendations

A cost/benefit analysis should be completed to address all alternative lighting standards that are proposed for use in the "Sea Turtle Lighting Zones" before concluding that the use of embedded roadway lighting is the preferred alternative on type II coastal roadways.

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Impacts of Coastal Roadway Lighting on Endangered and Threatened Sea Turtles.
Task I. Coastal Roadway Classification

I. Introduction

This report summarizes the procedures and results of a coastal roadway lighting inspection. The task was completed for ten counties (Nassau, Duvall, St. Johns, Volusia, Brevard, Indian River, Martin, St. Lucie, and Palm Beach) on Florida's East Coast, and for four counties (Manatee, Sarasota, Charlotte and Lee) on Florida's West coast. The beaches included in this survey on average are where 94% of all loggerhead nests are deposited in the state (Meylan, Schroeder and Mosier, 1995).

The objectives of this survey were as follows:

(1) To inspect FDOT roadways adjacent to important sea turtle nesting beaches.

(2) To identify where lighting problems exist, and

(3) To develop a classification of roadway lighting problems. This classification ranges (at one extreme) from undeveloped habitats without any roadway lighting, to those (at the other extreme) where beaches are strongly illuminated as a consequence of extensive coastal development (e.g., Daytona and West Palm Beaches).

II. Methods

A. *General procedures:* Roadway lighting surveys were conducted during August, 1998. Inspections were carried out both during the day and at night (Witherington and Martin, 1996). Local conditions were recorded as field notes, and by photographs. On the East Coast, most highway inspections were done by car. These were supplemented by frequent stops at beach access areas to determine whether roadway (and other sources of) lighting was visible at the beach. On the West Coast, inspections were done from an ATV driven down the beach. Night photos (taken with a Pentax or Canon 35 mm cameras equipped with telephoto lenses) were made with 100 ASA film using exposure times of 5-15 sec.

B. *Roadway lighting classification:* Our survey suggested that most roadways could be classified as one of the following "types".

Type I: Roadway is without lights and the surrounding area (as well as the adjacent beach) is dark.

Type II: Roadway is furnished with lighting fixtures, some or all of which are visible at the beach. Other lighting is rarely present.

Type III: The beach is illuminated, either directly (light sources visible) or indirectly (by sky glow), by FDOT luminaires and other sources (homes, businesses, condominiums, etc.) Modification of roadway lighting is likely to significantly reduce this illumination but in some areas, is unlikely to render the beach totally dark.

Type IV: Lights from streets and roadways make a relatively insignificant contribution to an already serious lighting problem (caused by extensive coastal development).

III. Results

(1) Field note descriptions: These are attached as Appendix I (East Coast) and Appendix II (West Coast).

(2) Photographic records/maps: These are appended to this document by county.

(2) Classification of roadways: This material is in two tables (Table 1, East Coast; Table 2, West Coast).

IV. Overview and Synthesis

We found areas of dark roadway and beach (Type I locales) in nine (8 of 10 East Coast; 3 of 4 West Coast) of the fourteen counties we surveyed. In the majority of cases, these were located within, or adjacent to, state parks, preserves, and recreation areas. Exceptions include: (i) A1A to the North and South of the St. Lucie Nuclear Power plant; adjacent (undeveloped) property is owned by the Florida Power and Light Corporation; (ii) SR 707, which courses through large estates (largely unoccupied during the summer) on Jupiter Island; and (iii) some areas of private property that at present, remain undeveloped (e.g., A1A between Indian River Shores and Sebastian Inlet State Park.

Areas classified as "Type II" are especially significant to the FDOT as they represent roadways (and adjacent nesting beaches) where lighting problems should be easily corrected. At these locations our observations suggest that roadway lighting is the significant (and typically, only) source of beach illumination. Any of a variety of known corrective procedures (lowering the lights; shielding them to restrict scatter; reducing the wattage of the luminaire; replacing these lights with "street imbedded" sources; or turning off the fixtures entirely) is likely to improve the quality of sea turtle nesting beach. Such an improvement should increase nesting density and reduce (if not eliminate) hatchling disoriention problems.

We designate as "Type II" one locale that is *not* illuminated by FDOT lighting: a portion of beach adjacent to Patrick Air Force Base. For the most part, this military facility is a model community, one that demonstrates how effectively residential lighting can be controlled to meet human needs, yet not impinge upon an adjacent nesting beach. But two bright hangar lights elevated on tall poles illuminate both a section of airfield runway and (as a consequence of sky glow) the nesting beach in the immediate area.

Areas classified as "Type III" have in common that light reaching the beach comes from both FDOT roadway fixtures and other (residential, business, etc.) sources of moderate development.

We anticipate that at such locales correction of the roadway lighting problem will render the adjacent nesting beach darker. But only in some cases will such modifications eliminate hatchling orientation problems or increase nest density.   Examples include: (i*) Outskirt areas of some towns* (So. Patrick Shores, So. Cocoa Beach, Wilbur-by-the-Sea, Melbourne Beach) where roadways are illuminated by rows of street lights. These contribute to sky-glow in the general area. (ii) *Roadways in front of condominiums* overlooking the ocean. In many instances the buildings themselves block most of the light, but illumination from roadway (as well as building entrance) fixtues reaches the beach from gaps between adjacent buildings. Examples include A1A in South Juno Beach, a cluster of condominiums North of the jetty at Ft. Pierce, and the complex of condominiums at Boca Raton, south of Palmetto Park road (extending to the Broward County line). (iii) *Intersections between A1A and bridge causeways* over intracoastal waterways and bays. These areas are typically illuminated by many street lights, are populated by small businesses, and usually provide beach access via a park (e.g., South and North Beach Causeway, Ft. Pierce; Melbourne beach where A1A makes a sharp turn West; Lake Worth Pier). (iv) *Residential areas of smaller communities*, where luminaires from parking lots/businesses, some private homes, and roadway street lights are in close proximity to the beach (Canova Beach, No. Ormond Beach, Vero Beach); and (v) *residential areas adjacent to large cities* (e.g., southern portions of West Palm Beach).

Areas classified as “Type IV” are extensively developed regions directly on the beach. In such areas, street lights (while always present) are a minor contributor to the beach lighting problem. Thus, modifying those lights is unlikely to improve conditions for nesting sea turtles. Indeed, few turtles even frequent those areas; occasional nests must be relocated to prevent hatchling disorientation.

Finally, we emphasize that correcting present lighting problems, particularly at Type II sites, can only lead to a “permanent” solution if conditions do not change (i.e., there is no further development). For example by modifying roadway lights on A1A in North Volusia County, the beach can be rendered dark. But the absence of any significant vegetation barrier between the highway and the beach means that this areas is vulnerable to new construction (with its associated lighting) that might occur in the future.

References

Meylan, A., B. Schroeder, and A. Mosier. 1995. Sea turtle nesting activity in the State of Florida 1979-1992. Florida Marine Research Publications No. 52, 51 p.

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Table 1. Classification of roadways (A1A unless stated otherwise) by "types" for counties on the East Coast of Florida. Areas under each category are listed from North to South within the county

County	Type I	Type II	Type III	Type IV
Nassau		A1A S of Fernandina Beach to Amelia Is.	Fernandina Beach (downtown)	
Duvall			So. outskirts of Jacksonville Beach	Neptune Beach through Jacksonville Beach
St. Johns	Guano River State Park Usinas Beach A1A So. of Crescent Beach to Marineland	Most of SR 203 between Ponte Vedra and So. Pointe Vedra	Villano Beach Ponte Vedra Beach S. Ponte Vedra Beach	
Flagler	A1A for ~ 2 miles N of Painters Hill	Painters Hill Beverly Beach No. outskirts of Flagler Beach So. outskirts of Flagler Beach to County line	Marineland Flagler Beach	
Volusia	Pembroke State Recreation Area Ponce Inlet State Park	Pembroke Recreation Area to Flagler Line A1A for ~ 4 mi. north of Ponce Inlet S.P. A1A for ~ 2 miles north	S outskirts of Wilbur-by-the-Beach No. Ormond Beach	Ormond Beach Daytona Beach New Smyrna Beach

(Table 1 continued next page)

County	Type I	Type II	Type III	Type IV
Brevard	A1A N of the Park for about 1.3 miles	Sebastian Inlet Park and Patrick Air Force Base DeSoto Park Indiatlantic Park Most of A1A So. of Melbourne Beach	So. Patrick Shores So. Cocoa Beach Satellite Beach Area Canova Beach Melbourne Beach, A1A turns W	Cocoa Beach
Indian River	A1A from Sebastian Inlet Park through Indian River Shores		South of Indian River Shores through Vero Beach	
St. Lucie	So. of Ft. Pierce to FPL Power Plant So. of FPL Power Plant to County line	No. County Line to 2 mi No. of Pepper Beach Recreation area.	Junction of A1A with No. Beach Causeway, Ft. Pierce Junction of So. Beach Causeway with A1A, at South Inlet Park (Ft. Pierce)	
Martin	SR 707, from Hobe Sound to County Line at Blowing Rocks Preserve		North County Line to Indian River Plantation	
Palm Beach	Blowing Rocks Preserve (SR 707) North Juno Beach	Manalapan Red Reef Park MacArthur State Park	So. Juno Beach So. West Palm Beach So. Palm Beach Lake Worth Ocean Ridge Spanish River Park Boca Raton So. of Palmetto Park Rd.	Downtown West Palm Beach Downtown Delray Beach Riviera Beach

Table 2. Classification of roadways by "types" for counties on the West coast of Florida. Areas within each county are listed from North to South. CM = commercial; MFR,= multi-family residence; SFR = single family residence; PB = public beach.; PIER = municipal fishing pier, PARK = local, county or state park.

MANATEE	**TYPE 1**	**TYPE 2**	**TYPE 3**	**TYPE 4**
Anna Maria (SFR/MFR/C/ PB)	Coquina Beach Park (13th St. S to Longboat Pass)		*SR-789 S to Coquina Beach*	City of Bradenton Beach
Longboat Key			*SR-789, Gulf of Mexico Drive. (4.2 miles)*	

SARASOTA	**TYPE 1**	**TYPE 2**	**TYPE 3**	**TYPE 4**
Longboat Key (SFR/MFR/C)			*SR-789, Gulf of Mexico Drive (5.0 miles)*	
Lido Key (SFR/MFR/C PB)			*Lido Public Beach*	*Ben Franklin Drive*
Siesta Key (SFR/MFR/PB)			789A at Beach Rd. S to 758	789A/758 Junction S 1.2 miles.
Casey Key (SFR/MFR/C/ PB)	.		*Casey Key Rd. (south 5 miles)*	
Venice (SFR/MFR/C/ PB/PIER)	*Brohard Beach S to Casperson Bch.*			*City of Venice*
Manasota Key (SFR/PB)	*C-774 (9.5 miles)*			

(Table 2 continued next page)

CHARLOTTE	TYPE 1	TYPE 2	TYPE 3	TYPE 4
Manasota Key (SFR/MFR/C/PB)			*C-774 & Gulf Blvd.*	
Gasparilla Island	SR771			

LEE	TYPE 1	TYPE 2	TYPE 3	TYPE 4
Gasparilla Island (SFR/MFR/PB/Park)			*SR-771*	
Fort Myers /Estero Island (SFR/MFR/C/PB/Park)			*Estero Blvd N of SR-865 and SR-865 south of "Times Square"*	*Fort Myers Beach "Times Square"*
Bonita Beach (SFR/MFR/PB/C)			*SR-865, Hickory Blvd.*	

East Coast

Nassau County Lighting Survey

Area Surveyed: from Fernandino Beach [junction of SR 200 and A1A] south about five miles, to where A1A curves SW away from the ocean and toward Amelia Island. See survey chart ("Nassau and Duvall Counties; St. Johns County [part]").

Location	Subject	Notes and Photo #
000	A1A & SR 200	State road is E-W, and meets A1A at a park (Fernandino Beach Park). Street lights on A1A are relatively dim, and either shielded by a shallow circular rim or by a flange that projects down on the seaward side (photos 1, 2). At junction between SR 200, there are unshielded lights from the street and from the Park parking lot that brighten the beach. There is no vegetation barrier (Photos 3 & 4).
0.0 – 2.9	A1A	Junction of Sadler Road and A1A. (photo 5). Street lights reach the beach at this junction. Otherwise, view to S (photo 6) and N (photo 7) at the beach is dark. There is a faint glow to the S, perhaps from Amelia Island Beach (photo 7).
2.9 – 5.0	A1A	Mostly single family homes are on the ocean side of A1A, except for a small hotel district (3.2 – 3.6 miles). Street lights on A1A are widely spaced while homes are closely packed, and probably shield the beach from lighting.

Duvall County Lighting Survey

Area Surveyed: from Neptune Beach [junction of SR 10 with A1A] south to junction of A1A with SR 203; SR 203/A1A south to county line.

Location	Subject	Notes and Photo #
000	A1A – SR 203	This is a highly developed commercial section of the roadway, several blocks from the beach. There is no convenient access to the beach, and it is not surveyed.
3.0	SR 203–County line	Roadway curves SE, but is still not close to the beach. There are very few street lights up to County Line.

St. Johns County Lighting Survey

Area Surveyed: From N county line (SR 203/A1A) south to Vilano Beach; A1A from Crescent Beach (SR 206/A1A) south to Marineland (county line).

Location	Subject	Notes and Photo #
1.1	Ponte Verda Beach	This development is lined with pole street lights, probably not of FDOT origin (photos 8, 9). Large estates and clubhouses line the East side of the road; a large golf course, and more homes, are on the West side. There is no convenient access to the beach and it is not surveyed inside the development.
4.4 – 7.5	Ponte Verda Beach	End of development at 4.4. From here to where A1A joins SR 203, there are very few street lights and the beach is dark.
7.5 – 14.2	A1A	There are no street lights on A1A in this area. Entrance to Guano River State Park is at 10.0. There are no lights inside the Park (photo 10, 11). At 14.2, unshielded street lights are on the East side of the highway (Photo 12; South Ponte Verda Beach), facing East.
14.2 – 19.8	A1A	Street lights continue on East side of A1A to 19.8. A small park access at 19.8 is used to inspect the beach. It is dark to the N. To the S is a weak glow, presumably from Villano Beach.
19.8 – 24.0	A1A	Only occasional clusters of highway lights; these are not shielded. Area is largely undeveloped and the beach is dark. (see photos 1-3, “St. Johns County [part], Flagler County”)
24.0	A1A	Outskirts of Vilano Beach. East and/or West side of the highway is lined with widely-spaced, drop-globe fixtures. Single family homes are between the highway and the beach, closely packed, and probably shield most of the beach from these lights. Spaces between homes might, however, might pose local problems. Lights continue into town.

0.0	SR 206 & A1A	Crescent Beach. Street is lined with hotels and condominiums, shops, and gas stations. There are occasional street lights but these become less frequent a short distance to the south (within 0.3 miles).

St. Johns County Lighting Survey (concluded)

Location	Subject	Notes and Photo #
0.3 – 7.2	A1A	Single family homes line E side of street, up to 2.7 miles from town. There is no development on the W side of the street. From 2.7 – 7.2 miles (Marineland), there are no lights on the highway (see photos 4 – 9). Beach view S at Crescent Beach is dark, except for the glow of Marineland.
7.2	A1A	Marineland has bright lights on the west side of the highway. These are not present S of the complex, where A1A curves SW away from the beach.

Flagler County Lighting Survey

Area surveyed: A1A north of Painters Hill [after it curves SE and parallels the beach] south to the Flagler County line.

Location	Subject	Notes and Photo #
00	A1A	No development on A1A, and no lights on the highway.
0.9	A1A	Varn park (photo 10). View at night to the N and S is dark.
1.3	A1A	Occasional street lights located on tall poles from here on. They become more frequent in Painters Hill (photo 11), and continue into Beverly Beach (on the West side of the street), and Flagler Beach (photos 12, 13). These lights are visible at the beach because there is no vegetation barrier.
3.9-7.0	A1A	Flagler Beach to County line. Tall pole lights line the W side of A1A to the County line.

Volusia County Lighting Survey

(Area surveyed: A1A from Apollo Beach State Park to New Smyrna Beach; A1A from Ponce de Leon Inlet Park to Flagler Beach). "Location" is auto odometer reading and doesn't necessarily correspond to straight-line (map) distance.

Location	Subject	Notes and Photo #
000	A1A & S Atlantic Ave.	View N from Apollo park is dark except for one street light. S Atlantic Avenue turns off immediately and runs parallel to A1A, adjacent to beach. Beach view is dark to the S (towards Canaveral National Seashore). There is a glow to the distant N, and New Smyrna Beach. Only a few rows of street lights are present on S Atlantic Avenue, which is residential. These may be LPSV luminaires. Most folks keep lights off. (1-3).
2.3	A1A	First condos. Roadway is still dark, with few light fixtures (4).
7.0	A1A	Roadway is dark until just before this point, where A1A turns W at New Smyrna Beach. Drop globe fixtures at the turn line both sides of street and are very bright.
000	Ponce de Leon	Road is dark by park, and to north.
2.3	A1A	First street lights in consistent series, both sides of street. Up to here, only an occasional fixture present.
3.7-8	A1A, beach	Beach view is dark to the S; to the North, glow from Wilber-by-the-Beach and its pier is visible (5).
5.0 - 17.5	A1A	Heavy development from Wilbur-by-the-Beach through Daytona Beach and N of Ormond Beach, ~ 5.0 miles. Street light contribution to photopollution problem is prob. negligible (6-10).
18-21.0	A1A	Largely undeveloped, with occasional street lights. However lack of high vegetation on "dune" allows lights to be visible from the beach.
24.0	A1A	S entrance to Pembroke State Recreation Area. No street lights or development. Beach is very dark.
26.5 - 28.4	A1A	From Volucia/Flagler line to town of Flagler Beach. Near county line, no lights. However street lights are present on W side of A1A just S of Flagler Beach, facing E. These are partially shielded (by a flap on the E side of the fixture). Lights are visible from the beach and apparently cause some severe disorientation problems. Work crew says these are HPSV lamps (11-14).

Brevard County Lighting Survey

(Area surveyed: From A1A, Sebastian Inlet State Park to intersection of SR 520 and A1A, north of Cocoa Beach.)

Location	Subject	Notes and Photo #
Inlet	Overpass	Two bright lights under, but not visible at beach (1, 2)
		Beach, looking north (3, 4). Totally dark except for glow of Melbourne Beach in distance.
1.3-4	A1A	First cobra lights. Park just to the south is completely dark.
2.8	Beach, A1A	Bonsteel Park, view north. No lights except for "glow" of Melbourne Beach (5, 6). Row of 6 street lights visible ahead (7, 8).
4.8	A1A	Aquarina. Beach is dark except for lights from condo to N about 500 yd. (Tidewater).
5.2	Park, A1A	S side of park entrance, there are 6 cobras approaching the intersection flasher (9).
7.3	Beach	Access opposite Mark's Landing. Beach is dark except for N glow. One street light visible at beach (10).
7.8	A1A	There are 7 street lights in a row, Melbourne Shores.
11.8	Mall	Publix shopping center. Lot now with dual system of lights; LPSV are used during nesting season (Erhardt).
12.7	A1A	Row of cobra street lights on west side of street.
13.4	Access	Just S of Versailles. Street light is visible at beach.
14.2	Park, A1A	Street lights visible from Spessard park pavilion, but not from beach which drops off behind.
15.0	A1A	Melbourne Beach city limits. Unbroken row of street lights (drop globes?) on W side of A1A. A1A eventually turns west, away from beach (11-13). Disorientation problems reported here. Probable cause: lack of any vegetation barrier, and street lights to the W.
17.6	Indiatlantic	Park on S side of town large parking lot, and row of street lights on tall poles facing W. However these are visible from the beach, esp. to from the side of the luminaire. There is no vegetation barrier (14-16).
18 - 19.6	A1A	Wall-to-wall condos. Probably block street lights placed on W side of A1A.

20.1	Park	Paradise Beach park. View S on beach dark; view N shows lights from condos.
20.3-21.5	Canova	Canova Beach with large hotels (Holiday Inn, Radisson, Hilton) that probably block most lighting on A1A.
22.8	Satellite Beach	In most locations, houses, condos block lighting from the street. Cleared dune in a construction area allows street lights to be seen from dune. (17)
23.4	DeSoto Park	Street lights are visible on beach. Could be lowered and/or shielded.
25.1	Atlantic Plaza	Huge complex includes Ramada Inn. Street lights are generating little light compared to those in complex.
25.2 - 30.4	So. Patrick Shores Patrick AFB	There are no lights on the roadway. This whole area is amazingly dark. Difficult to even find beach accesses by E side of highway! Only blemish: hanger lights (18), W side of highway.
30.4 - 32.0	So. Cocoa	A1A with rows of lights, facing W on E side of hwy. Most prob. blocked by ~ two blocks of private residences between road and beach. View at beach (2nd street So) shows glow of Cocoa to N, but is dark to S.
32.0 -SR 520	Cocoa Beach	Wall-to-wall condos and hotels. Street lights present on A1A. Their contribution to lighting problems at beach is prob. minimal. Photo (19) just S of Sidney Fischer Park. End survey at SR 520.

Indian River, St. Lucie and Martin County Lighting Survey

(Areas surveyed: From Martin Co. line, SR 707, N to Hobe Sound National Wildlife Preserve (Jupiter Island); A1A from Seminole Shores N to South Jetty Park (Ft. Pierce); A1A from Ft. Pierce Inlet Recreation Area to Sebastian Inlet State Park.

Location	Subject	Notes and Photo #
(Hobe Sound to Martin County line)		
0.0-1.7	707	No lights on road between here and the public beach (junction of SR 707 & 708). View at beach to N and S (at public beach access) is very dark.
1.7-7.8	707	Between here and Blowing Rocks, only a few widely scattered street lights. These are shielded by estates between road and beach.
7.8-9.0		No lights to county line (9.0).
(Seminole Shores N to St. Lucie County Line)		
0.0	end roadway	View at beach access is very dark to both the N and S.
0.3	Park	Bathtub reef. Beach view totally dark (1, 2)
1.1	roadway	Several bright street lights are placed around street in front of House of Refuge (3).
1.8-9	roadway	Street curves to the west, away from beach, and into Indian River Plantation.
2.5	A1A	Intersection of roadway and A1A, stoplight.
3.2	A1A	Street lights clustered just S of Islander.
5.5	A1A	Street lights clustered in front of Holiday Inn.
5.5-12.5	A1A	Largely devoid of street lights until opposite FPL nuclear power plant (at 12.7). This complex is brightly illuminated and produces sky glow (indirect lighting) that probably affects local nesting density at the beach (4).
12.5-20.1	A1A	Road is totally dark until outskirts of Ft. Pierce. Roadway curves E and borders beach as entering Ft. Pierce. Within city proper, roadway is dark, though street lights are present. They have either been painted or covered with a black filter. Most lighting comes from shops and businesses on W side of A1A. However, there is little in the way of a vegetation barrier.

20.6-7	A1A	Road curves W at Surfside Park, toward town (and Rt. 1). There is no vegetation barrier. Street lights are present on this W section, and are probably visible at the beach (5, 6).
000	A1A	A1A reaches beach on the N side of Ft. Pierce (and jetty). At intersection, many street lights (esp. in front of Radisson). Road is still several blocks from the beach. Beach view at Pepper Park to S is fairly dark, except for jetty lights. View N with some lighting from cluster of condos, located immediately N (7, 8).
1.9	A1A	Small cluster of tall condos, with their attendant lights. There are no street lights on A1A.
1.9-2.7	A1A	To N line of St. Lucie Co. A1A is dark (no street lights).
2.7-10.8	A1A	Gated communities for the affluent. Area is dark except for lights within these complexes.
10.8	A1A	Intersection with SR 656. Street lights are on E side, directed W. Because street (A1A) is several blocks from the beach, these are unlikely to contribute directly to lighting problem. However, they may cause general sky glow.
12.2	A1A	Intersection with SR 60, with street lights.
13.8	A1A	Vero Beach city limits. Start of condos by beach and street lights that could cause problems.
15.4-20.6	A1A	Little development and only a few odd clusters of occasional street lights. At 20.6, SR 510 (Wabasso Beach). View to N and S at the beach is dark (9, 10).
20.6 - 27.5	A1A	To Sebastian Inlet State Park. Only a few scattered developments and no lights of any significance on A1A.

Palm Beach County Lighting Survey

(Areas surveyed: From N county line [S of Blowing Rocks Preserve] to Jupiter Inlet; Carlin Park to Juno Beach; J. D. MacArthur State Park to Palm Beach Shores; Palm Beach [at SR 704] to Broward county line (Boca Raton city limits). Survey direction is S.

Location	Subject	Notes and Photo #
0.0	A1A	Condos are just S of line, with street lights.
3.2-3.6	A1A	High cobra lights on E side of hwy, but several blocks from the ocean.
4.0	A1A	Carlin Park. All (of the many!) lights in the parking lot, and near the beach access area, are turned off.
4.0-5.0	A1A	Includes N Juno Beach. No lights
6.3-4	A1A	Several lights are present at intersection of A1A and Marcinski road (1, 2). This area has had disorientation problems (Paul Davis, pers. comm.)
7.3	A1A	S Juno (3, 4). A1A curves toward SW, where condos begin. Street lined with bright pole lights, 7.3-8.0. These produce light reaching the beach between condos, and cause disorientation (P. Davis, pers. comm.)
11.8	A1A	Enter MacArthur park. No lights.
12.9-15.5	A1A	Street lights from S end of MacArthur park until A1A curves SW to cross intracoastal (SR 708).
23.3-25.0	A1A	Downtown West Palm Beach, on S Ocean Avenue (by beach). Street is relatively dark but lined with pole lamps and close (~200') intervals (5, 6). There is no vegetation barrier to shield the (renourished) beach.
27.8	A1A	Same light types but beach is natural, here. These lights are set back so that they do not illuminate beach. They would, however, produce a substantial glow visible to females approaching the beach. For this reason, nesting may be discouraged.
30.0	A1A	Intersection between SR 802 and A1A, at Lake Worth pier. Several lights are on inside park. Street lights from 802 probbly contribute sky glow to general area. To the S (31.7), there are street lights on both sides of A1A (7, 8).
31.7-34.0	A1A	Lights decrease in number to the S. After Manalapan, they are widely spaced and infrequent.
34.0-36.0	A1A	No lights of any consequence.

West Coast

Manatee County

(Area surveyed: Anna Maria Key, SR-789 [Gulf Drive] at Bradenton Beach to Longboat Pass; Longboat Key, SR-789 [Gulf of Mexico Drive] to Sarasota/Manatee County line. "Location" corresponds to approximate straight-line (map) distance.

Anna Maria Key:

Location	Subject	Notes & Photo #
00.5	789-Gulf Drive	View E from Holmes Beach at 30th St. Beach is illuminated by two pole mounted open bottom fixtures. Area is residential single & multi-family (1 to 2 story). SR 789 (Gulf Drive) is intersected by numbered streets that dead-end at the beach. Beach view is dark to the north and south. (1).
00.6	789	Single family residences. Open bottom street light visible between houses. (2).
00.7	789	Open bottom street light at corner of 29th St. and Avenue F. This fixture illuminates the beach at this dead end street. Street lights are also visible from 789 which is lined with either open bottom fixtures cobra fixtures. (3-4). This is similar to all E-W streets that dead end at the beach along the entire length of Anna Maria Key.
01.2	789	View E from beach, the area becomes more heavily developed and includes residential single & multi-family and condominium. Street lights are visible between structures. (5-6)
1.7	789	Bradenton Beach, showing a small roadside pedestrian park, "Kitty Peirolia Park", extends for approximately 1/4 of a mile along the shoreline. There are no lights in the park. Street lights along 789 illuminate the beach. (7).
1.7-2.8	789	Bradenton Beach is heavily developed residential and commercial property. Street lights that line 789 and lights from the residential and commercial establishments combine to illuminate the beach. (8-9).
2.0	789	Cortez Road and bridge intersect with SR-789 (Gulf Drive) at this location. The ll+ street & bridge lights and car lights illuminate the beach. (10).
2.1-2.3	789	City of Bradenton Beach and Bridge Street is heavily developed commercial property. The beach here is illuminated by open bottom street lights, globe City lights, approximately 6 street lights along Bridge Street, and numerous lights from the commercial establishments. (11).
02.8	789	Coquina Beach, view to the east and south. The upland here is residential single & multifamily. The beach is partially illuminated by the row of open bottom street lights but is partially shielded by trees and dune vegetation. (12).

2.9-3.4	789	Coquina Beach, County park. This area is dark with the exception of shielded lighting at the 3 County operated public restrooms and the lights from automobiles accessing the parking lots.

Longboat Key:

000-4.2	789-Gulf of Mexico Dr.	Gulf of Mexico Drive. The north end of Longboat Key beach is relatively dark. The area consists of residential single & multi-family units and high rise condominiums. The street lights (consisting of halogen & HPS directional, open bottom, and cobra fixtures are visible from the beach in only a few locations. Photo 13 shows a HPS directional fixture that has been directed downward. (13-15).
03.5	789	View E from the Holiday Inn parking lot. The directional fixture (pointed downward) on Gulf of Mexico drive and the extremely bright halogen parking lot fixture are visible from the beach. (16).

Sarasota County

(Area surveyed: Longboat Key, SR-789 [Gulf of Mexico Drive] from the Sarasota County line south to New Pass; Lido Key, New Pass south to Big Sarasota Pass; Siesta Key, 789A [Beach Rd.] to 758 [Midnight Pass Road] south to Midnight Pass (closed); Casey Key, Casey Key Road from the northern terminus south to Venice Inlet; Manasota Key , C-774 south to the Charlotte County line. "Location" corresponds to approximate straight-line (map) distance.

Longboat Key:

Location	Subject	Notes and Photo #
000-5	789-Gulf of Mexico Dr.	Longboat Key in Sarasota County consists predominately of single family and multi-family residences, high rise condominium, and commercial establishments. With the exception of one stretch of Gulf of Mexico Drive (SR 789) that runs parallel to the beach for approximately 4000 feet, the roadway is separated from the beach by developed property. Street lights remain visible between some of the buildings (predominately single family residences) along the entire 5 miles of Longboat Key (Sarasota County portion). (3).
0.5	789	View from the beach showing 2 open bottom street lights (the shade on the fixture to the far right has been painted black, but appears blue/green from the beach), a security light behind Lynch's Landing Restaurant, and the neon lights of the 7/11 convenience store. These lights all contribute to illuminate the beach. (4).
0.5-1	789	View from the beach showing the section of 789 that runs parallel to the shoreline. There are a series of street lights (combination of directional, open bottom and cobra) which have been redirected, shielded and/or painted during the 1998 sea turtle season. The photographs show the lights as they appear currently. Numerous sea turtle hatchling disorientation events have occurred and continue to occur at this location. (5-6).

Lido Key

0.7-2.5	Ben Franklin Dr.	Lido Key along Ben Franklin Drive is characterized by high-rise condominium, and motel establishments. In the past, Lido Public Beach was impacted by street lights, parking lot lights and lights at the Public Beach Pavilion. The street lights and parking lot lights were shielded, and the Pavilion lights were replaced with LPS fixtures during the 1998 season. Lido Beach currently is impacted primarily by lights from the heavily developed upland - condominium and motel lights. The North .7 mile and the southern approximate .4 mile of Lido are County parks.

Siesta Key 000-1.2	789A-Beach Road	Siesta Key along the section of 789A which runs parallel to the shoreline consists of single and multifamily residences, high rise condominiums and Siesta Key Public Beach. Street lights are visible between buildings and along the road at the Public beach. The street lights near the Public beach have been shielded or painted. The beach here is impacted primarily by multiple lighting sources from the upland development and street lights which are occasionally visible between buildings.
1.2-2.7	758-Midnight Pass Rd.	The shoreline here is not directly impacted by roadway lighting with the exception of a few open bottom fixtures which are located on side streets that intersect 758. The upland is highly developed and is characterized by high-rise condominiums. Lighting from the upland development illuminates the beach here.
2.7-5	758	Street lights are not visible on the beach here. The area is characterized by single family residences, high rise condominium complexes and a county owned public beach - Turtle Beach. Roadway lighting at Turtle Beach are shut off during the sea turtle season.
Casey Key: 000-5.5	Casey Key Road	This area of Casey Key contains residential single family homes and two small resort motels. The beach is not currently illuminated by street lights as the street lights in this area are turned off during sea turtle season
5.5	Casey Key Road	View from the beach to a painted open bottom street light at 213 Casey Key Road. The beach here is impacted slightly by small resort rental establishments but is also affect by the few street lights in the area. (7).
5.6	Casey Key Road	View from the beach toward the Nokomis Pavilions. The directional street light located near the Coast Guard Station is visible at the far right in photo #8. The lights from Albee Road and the Albee Bridge are visible below the Nokomis Pavilion in photo #9.
Venice: 000	Venice	View from the beach at south Casey Key looking south to the City of Venice. beach is illuminated bythe dense upland development and only incidentally by roadway lighting. Roadway lights that impact the beach are typically turned off during the sea turtle season. The street lights at the north end of Venice, near the jetties do impact the beaches of Venice, but rather impact the beach at the south end of Casey Key. (10-12).
Manasota Key: 000-9.5	C-774	The Sarasota County portion of Manasota Key consists of one County Park , Two Public beaches, two small resort motels, and single family residences. There are only three street lights along this stretch of roadway. The beach appears dark. C-774 runs adjacent to the shoreline at Stump Pass Beach where lights from automobiles traveling the roadway impact the beach.

Charlotte County

(Area surveyed: Manasota Key, C-774, from the Charlotte County line south to the north end of the Port Charlotte State Recreation Area; Gasparilla Island, SR-771 south to the Lee County line. "Location" corresponds to approximate straight-line (map) distances.

Manasota Key

Location	Subject	Notes and Photo #
000-2	C774-Manasota Key Rd.	From the Charlotte County Line south, the upland becomes more developed, including single and multi-family residences, a trailer park, and commercial establishments. A series of street lights also begins at the county line and continues south. The beach is relatively dark, but street lights are visible between some of the buildings. (4).
2-2.5	C774	Englewood Public Beach. Multiple street lights and lights from the commercial district across C774 from the beach impact the beach here. Street lights have been shielded but several disorientation events occurred here during the 1998 season when the shield on one of the lights off.
2.3	C774	View from Englewood Public Beach. Cars pull into the beach thus multiple car light impact the beach.(5).
2.5-3	Gulf Blvd.	The upland is characterized by heavily developed single and multi-family residences, high-rise condominiums, and resort rentals. E-W streets also dead end at the shoreline, these streets often have street lights which impact the shoreline. The impacts from these street lights are incidental to the lights caused by the upland development. (6).

Gasparilla Island:

000-0.7	SR771	Gasparilla Island. Street lighting does not impact the beach here.

Lee County

(Area surveyed: Gasparilla Island, SR-771 to Boca Grande Pass; Ft. Myers Beach/Estero Island, SR-865 south to Big Carlos Pass; Bonita Beach, SR-865 south to the Collier County line. "Location" corresponds to approximate straight-line (map) distance.

Gasparilla Island:

Location	Subject	Notes and Photo#
0.7-4.8	771	The upland here is characterized by single and multi-family residences and state and county parkland. A few street lights are visible at roadways that intersect 771 are also visible, occasionally, between buildings. Automobile lights along the roadway at Boca Grand Beach illuminate the beach. Gasparilla Island State Park and Lighthouse Beach Park are located at the southern end of Gasparilla Island. The beach here is relatively dark.

Fort Myers Beach/Estero Island:

1.0	865	View E towards the Matanzas Pass Bridge and SR 865 (San Carlos Blvd.) roadway lighting. The daytime shot is taken from the road while the nighttime shot is taken from the beach. The shoreline at this location if part of Lynn Hall Park which is illuminated by covered park lights and numerous lights from the commercial district. Lighting from the elevated roadway at the bridge does impact the shoreline. (7-8).
000-1	Estero Blvd. (N)	North of the park the area is characterized by single and multi-family residences and high rise condominiums. The shoreline is relatively dark with illumination created by lighting of the structures rather than street lights. The street light fixtures here, consisting of cobra and open bottom fixtures, have been painted or shielded and only occasionally illuminate the beach.
1.0-1.7	865-Estero Blvd.	Street light fixtures in the commercial district of Fort Myers Beach ("Times Square") have been modified or replaced using more "turtle friendly" fixtures. The decorative lighting fixtures have a recessed bulb (9), the new street lights are recessed LPS fixtures (10), and one of the cobra type fixtures that has been documented as illuminating the beach in the past has been shielded (11). The shield was created by utilizing the covering from a stoplight and riveting it in place over the exposed cobra fixture. This shield as been in place for three years.
0.75	Fort Myers Bch.	View from the beach at Lynn Hall Park south to the fishing pier and commercial district of Fort Myers Beach - the "Time Square" area. The beach is illuminated by lighting from the commercial establishments. (12).
1.7-6.1	865	The upland is heavily developed along the entire length. The area is characterized by single and multi-family residences, high rise condominium complexes, motels and commercial establishments. Street lights along 865 and at intersecting streets are visible between buildings at many locations. Street lights consist of cobra and open bottom fixtures. The beach is illuminated by the street lights and by lighting from the upland structures.
1.1	865	View from the beach of cobra type street lights on Primo Dr. and 865. (13).

	865	View friom beach of two open bottom fixtures. (14).
2.5	865	View from beach of street light between two single family residences. (15).
5.0	865	View from 865 south along the roadway showing a series of street lights. The fixture immediately south of the Holiday Inn sign has been painted black on the beach side. This fixtures was previously implicated in sea turtle hatchling disorientation events. (16).

Bonita Beach: 000-2.0	865-Hickory Dr.	Bonita Beach is characterized by residential single and multi-family residences and high rise condominium complexes. The beach is relatively dark, especially considering the heavy development noted along the shoreline. The beach is illuminated predominately by lighting from the upland development and occasionally by street lights that are visible between buildings. Bonita Beach Park is located at the south end of Bonita Beach.
1.2	865	View from the beach of a street light on the corner of Bay and Seagrape (Bay Street runs parallel to the east of Hickory Dr-SR865). (18).
1.5	865	View of open bottom cobra fixture at 26804 Hickory Dr. (19).
2.0	Bonita Beach	View from the beach looking north. Numerous unshielded LPS fixtures at the restaurant on the north end of Bonita Beach Park illuminate the beach. Lights in the background are from Fort Myers Beach to the north. The bright white "glowing" area at Fort Myers Beach is lighting at the ballpark which is located approximately 10 miles away. (20).
2.0	865	View from the beach looking east to 865 and associated street and bridge lights visible from Bonita Beach Park. (21).

Table 3. Classification of roadways by "types" for counties along the **Florida Panhandle**. Areas within each county are listed from West to East within the county.

County	Type I	Type II	Type III	Type IV
Escambia			292 from Florida State - line W to State Rec.Park.	
	Perdido Key State Rec.Pk. Rosamond Johnson Bch		Perdido Shores W	
	Fort Pickens St. Park			300 / Pensacola Bch.
	Santa Rosa Island		E. Navarre Bch.	Navarre Bch.
Okaloosa			Santa Rosa Blvd.	98/30 Ft. Walton Bch.
	Eglin Air Force Base			Destin
			2378/Scenic Old 98	
Walton			2378/Scenic Old 98 30A S through Seagrove Bch.	
	30A between Seagrove Bch.- and Seacrest.		Seacrest E to County line.	
Bay			98/30 Hollywood & - Laguna Bch.	
				Panama City Bch
			392/Gulf Lagoon Bch.- Biltmore Bch.	
	St. Andrews St. Rec. Area. 98/30 Tyndall Air Force Base.		Mexico Bch.	
Gulf			98/30 Beacon Hill &- St. Joe Bch.	
	St. Joe Bch. to Highland View. 30E / St. Joe Peninsula - Cape San Blas. 30A to County line. 30B / Indian Peninsula.			
Franklin	300 / N St. George Island.		G1A/300 intersection - Community of St. George Island.	
	Dr. Julian G. Bruce Bch. S ST. George Island. St. George Island St. Pk.			

Coastal Roadway Lighting - Panhandle Survey

4/19-4/24/99
Survey descriptions are from west to east.

Escambia County Lighting Survey:

Perdido Key (Alabama/Florida state line) - State Road 292.

Location	Subject	Notes
000-002	292	The Panhandle survey begins at the Alabama/Florida state line on State Road 292. Development along the roadway consists of commercial (C), residential single family (RSF), and residential multi-family (RMF) units. There are few street lights but those present are high pressure sodium Cobrahead (CH) and open-bottom (OB) fixtures.
002-004	292	Perdido Key State Recreation Park. No street lights, RSF on the north side of SR 292, the beach is on the south.
004-006	292	Perdido Shores West, RSF, RMF high-rise and C development. Street lights are OB fixtures (some shielded), and pole mounted floodlighting (PMF).
006	292	Junction 292 and Johnson Beach Road. There are no street lights, development is RSF and RMF high-rise.
006.5-008	292	Rosamond Johnson Beach. End of paved road and no street lights. Car lights blocked from beach by dunes and dune vegetation. Park closes at sunset and the remainder of island (approximately 8 miles) has no public roadway and no lights.

Pensacola Beach and Santa Rosa Island - State Rd. 399.

000-006	399	The survey begins at the western end of the island in Fort Pickens State Park. There is no roadway lighting, car lights may be visible at some locations, but are blocked by dunes and dune vegetation.
006-013	399	Development ranges between RSF, RMF high-rise, and C. Numerous street lights on State Road 399 and intersecting streets. Street lights are high pressure sodium (HPS), CH, OB, and PMF fixtures, few are shielded. Low pressure sodium (LPS) fixtures are present at Pensacola Beach and at Pensacola Beach Pavillion.

Escambia County Lighting Survey (concluded):

Location	Subject	Notes
013-024	399	Santa Rosa Island. No street lights. Car lights are visible on beach where dunes and dune vegetation are low or non-existent. One shielded OB at Santa Rosa Recreational Facility. The beach is dark.
024-027	399	Navarre Beach, predominately RSF with small C and RMF high-rise at the eastern end of 399. Street lighting is OB (some shielded) and CH. CH fixtures numerous where 399 turns north to the mainland. The remainder of the island is the property of Eglin Air Force Base. There is no public access.

Okalossa County Lighting Survey:

South Santa Rosa Island and Fort Walton Beach - State Rd. 98/30.

Location	Subject	Notes
000-002	98/30	Survey starts at gate to Eglin Air Force Base - heading east on Santa Rosa Blvd. away from the Base. Development is primarily RSF, RMF high-rise and C. Street lights are CH, intersecting streets also have CH. Some of the street lights are blocked from the beach by high-rise condominium units.
002	98/30	Junction of State Road 98/30 and Santa Rosa Blvd.
002-003.5	98/30	Intense development consisting of RSF, RMF high-rise and C. Street lights line the north and south sides of St. Rd. 98/30 and are predominately CH and PMF fixtures. Most street lighting is blocked by commercial and high-rise development.
003.5-008	98/30	Eglin Air Force Base - no street lights. Bridge over East Pass to Destin has no lights.
008-011	98/30	Destin. This area is heavily developed, the highway is located away from the beach (1 mile at the west end and ~1/4 mile at the east end). The beach was not surveyed.
011-015	2378	SR 2378 or Scenic Old Highway 98. C, RSF and RMF high-rise development, CH fixtures on north and south sides of road. Most street lights blocked by buildings.
015-017	2378	SR 2378 or Scenic Old Highway 98, Silver Beach. RSF, RMF high-rise and C, street is one lot from beach, street lights consist of CH, OB (both sparse), and decorative "old fashioned street lights". The "decorative old fashioned street lights" may be owned by the Development rather than FDOT. The beach is illuminated primarily from the CH and OB fixtures on SR 2378 and at Crystal Beach Public Beach Access.

Walton County Lighting Survey:

Seascape, Miramar Beach, Beach Highlands, Blue Mountain Beach, Grayton Beach, Seaside, Seagrove Beach - SR 2378 (or Scenic Old Highway 98).

Location	Subject	Notes
000-002	2378	Development is low density RSF, RMF and C. Street lights are OB, CH and PMF.
002-003	2378	Development remains RSF, RMF and C but no street lights are present in this one mile long stretch of SR 2378. The beach is illuminated by automobile lights.
003.5-004	2378	Development remains RSF, RMF and C. Street lights are OB on both the north and south sides of SR 2378. The beach is illuminated by the street lights and automobile lights.
004-009	2378	SR 2378 or Old Highway 98 vears north and intersects with SR98/30. This section of the road is away from the beach with lighting being blocked from the beach by trees.
009-019	30A	Scenic Highway 30A (Fort Panic Road). This area is characterized by RSF, RMF and small C districts. Street lighting is sparse and consists of OB fixtures. SR 30A is winding here with street lights being blocked from the beach by a heavy tree canopy.
011	393	SR 393 intersects SR 30A here. SR 393 ends at Ed Wallen Park in Santa Rosa. There are no street lights.
013	83	SR 83 intersects SR 30A here. SR 83 ends at Blue Mountain Beach Access. There is one shielded OB fixture at the beach access. This does not appear to be an FDOT light.
017	283	SR 283 intersects SR 30A just north of Grayton Beach and ends in Grayton at the Grayton Beach State Recreation Area. Three OB fixtures line the west side of SR 283 in Grayton. The southern-most light is located just on the north side of the landward most dune on Grayton Beach. It is not known if these lights are FDOT lights or city owned lights but they do cause illumination of the beach.

Walton County Lighting Survey (concluded):

Location	Subject	Notes
019-021.5	30A	SR 30A through Seaside and Seagrove Beach. Development is C, RSF and RMF. Street lighting is sparse, OB fixtures. All street lights are located on the north side of the road and are fairly well blocked from the beach by development on the south side of the road.
022-028	30A	At the east end of Seagrove, SR 30A vears north and east away from the beach. There are no lights present on this stretch of road. The road heads back to the coastline at Seacrest.
028-030	30A	SR 30A through Seacrest. Development is RSF and RMF. The highest RMF is six stories. Sparsely placed OB fixtures are present on both the north and south sides of the road.
030-032	30A	SR 30A through Seacrest Beach and Rosemary Beach to the junction with SR 98/30 and the County line.. Development is RSF. Street lighting is absent to very sparse. A few OB fixtures, some shielded are located on the north side of the street.

Bay County Lighting Survey:

Location	Subject	Notes
000-003	Alt. 98/30	Beginning at the Bay County line. The coastline here is characterized by RSF and RMF moderate density. The development is primarily on the north side of SR 98/30. The beach is illuminated by sparsely placed CH, OB and PMF fixtures along the roadway.
004	Alt. 98/30	Through Sunnyside, where the CH are cutoff fixtures, and Santa Monica, where there are no street lights. Development is on the north side of the road. Car lights illuminate the beach which is otherwise fairly dark.
005-007	Alt. 98/30	West end of Laguna Beach, development is primarily RSF and some small C establishments. Street lights, present on both the north and south sides of the street, are comprised of CH, OB and PMF fixtures. These street lights plus automobile lights illuminate the beach.
008	Alt. 98/30	Junction of Alt. 98/30 and SR 79.
008-014	Alt. 98/30	Panama City Beach, intense development predominately RMF high-rise, Motel, and C interspersed with Public parks and RSF. Street lights are partially blocked by high-rise units. City glow, along with privately owned lights illuminate the beach.
014-019	SR 392	SR 392 intersects with Alt. 98/30 south of the Miricle Strip Parkway. Development continues to be heavy but becomes lower and more widely spaced. Street lights visible between buildings. Street lights consist of CH, PB and PMF.
019	SR 392	SR 392 turns north to the mainland just west of the entrance to St. Andrews State Recreation Area. There are no street lights in the park which closes at 7 PM effectively keeping automobile lights off of the beach for the eastern end of the island.

000-015	98/30	The survey begins at the Dupont Bridge and proceeds through Tyndall Air Force Base. There are no street lights along this section of roadway. Shell Island and Crooked Island, to the south, have no roadways and no lights.

Bay County Lighting Survey (concluded):

Location	Subject	Notes
015-016	98/30	Mexico Beach. RSF, RMF and low-rise commercial development located between the roadway and the beach. City streets that intersect with SR98/30 and end at the beach have streetlights that illuminate the beach.
016-017.5	98/30	Mexico Beach. RSF and low-rise commercial development is located primarily on the north side of the roadway. CH fixtures are sparsely placed, primarily on the north side of the road, but street lights and automobile lights illuminate the beach. The upland is relative dark.
017.5-018	98/30	West end of Beacon Hill to the Bay/Gulf County line and the intersection of SR 98/30 and SR 386. RSF located on both sides of the roadway. No street lights are present and the beach is dark.

Gulf County Lighting Survey:

Location	Subject	Notes
000-001.5	98/30	Beacon Hill, RSF and few small C establishments located on both the north and south side of the roadway. No street lights are present but there are a few CH fixtures in parking lots. The beach remains relatively dark. Automobile lights do illuminate the beach.
001.5-003	98/30	St. Joe Beach, RSF and few small C establishments located primarily on the north side of the road. There are very few street lights, the ones present are CH. Automobile lights illuminate the beaches which are, otherwise, relatively dark.
003-007	98/30	St. Joe Beach to Highland View. No street lights are located along the roadway and the shoreline is dark except when illuminated by automobile lights.
000-007	30E	St. Joe Peninsula State Park. No street lights present. The Park closes at sunset thus automobile lights doe not illuminate the beach.
007-012	30E	Sparse SFR with some private CH fixtures. There are no street lights. Risk Park, a state owned park for developmentally disabled, has numerous OB fixtures on the beach side of the road.
012-015.5	30E	30E to intersection with 30A. Sparsely developed RSF with no street lights.
015.5-17.5	30A	30A to intersection with 30B. Sparsely developed RSF with no street lights.
17.5-20.5	30B	Indian Peninsula. Sparsely developed RSF and no street lights. 30B ends at Indian Pass Campground and General Store. There is only one light, an OB fixture, which is located at the boat ramp.

Franklin County Lighting Survey:

Location	Subject	Notes
000-002	E of 300	St. George Island. RSF with few small C establishments. There are no street lights. A few privately owned CH fixtures are located at intersections and parking lots, these fixtures are shielded on the beach side.
002		Intersection of G1A and SR 300. St. George Island.
002-003	SR 300	Small C area. No street lights. A few cut-off CH fixtures are located in parking lots and intersecting streets.
003-007	SR 300	Sparse RSF. No street lights. The beach is dark.
007-014	SR 300	St. George Island State Park. No street lights or any other lights. The Park closes at sunset thus automobile lights do not illuminate the beach here.

End of Survey.

Impacts of Coastal Roadway Lighting on Endangered and Threatened Sea Turtles.
Task II. Selection of Experimental Sites

I. Introduction

In this report, our objective is to select several sites on the East and West Coast of Florida where "typical" lighting problems exist, and where their correction may provide insights into appropriate solutions at locations where there are similar problems. We therefore propose to select sites on the basis of four criteria. These are (in order of importance): (i) Sites where the lighting problem is largely determined by *roadway* lighting conditions and where we can be reasonably certain that the problem can be eliminated by correcting those conditions. Thus, we emphasize Type II and Type III locations. (ii) Areas that show roadway configurations that occur commonly in Florida; (iii) Regions that are of major importance as sea turtle nesting beaches; and (iv) Areas where turtle specialists have observed (and reported) hatchling disorientation.

II. Methods

We have outlined elsewhere the procedures used for completing arena assay experiments, and the methods used to determine whether hatchlings locate the beach normally. We include in Appendices I-III a summary of these procedures.

III. Proposed Sites

(1) Location: A1A, North Volusia County
Problem: Row of street lights on one side of the highway are visible from the beach.
Alternative sites: Indiatlantic Park; Spanish River Park

At this site, there is little development along the highway. The dune is low and covered with sea grape. Tall pole lights on the west side of the highway are clearly visible from the beach and have caused severe disorientation problems. The lights are high pressure sodium vapor luminaires, partially shielded by a metal flap on the east side. The lenses are covered by a cut-off filter of unknown type.

(2) Location: A1A, City of Melbourne Beach
Problem: Street turns west, away from the beach. Street lights are visible at the turn-off.
Alternative site: Ft. Pierce, by South Inlet Park.

Street lights are present along the highway after it turns west. Light escaping from these fixtures reaches the beach because there is no significant dune or vegetation at the turn-off. Disorientation is severe at both the Melbourne and Ft. Pierce sites.

(3) Location: South Boca Raton
Problem: Street lighting reaches the beach in the gap between adjacent condominiums.
Alternative site: North Juno Beach; North Hutchinson Island, just north of Pepper Park (Fort Pierce)

APPENDIX I

Protocols for completing an arena assay

I. Materials required

Hand-bearing compass
Clipboard with (waterproof paper) data sheets
Mechanical pencil, tied to clipboard, plus extra leads
Standard flashlight
Keychain “squeeze” lights (2-3)
Binoculars
Stopwatch
Two 3’ lengths of PVC pipe, tied together by a 2 m length of string
Photometer (optional)
200’ outdoor tape measure
GPS and laminated county map for the location
Min of 20 hatchlings in a closed, light-tight container.
Inclinometer
3’ x 3’ muslin sheet

II. Preliminary measurements and procedures

These assays are most easily completed by two persons. After selecting the location, draw the arena in the sand by standing one the PVC pipes in the arena center, walking to the periphery with the other PVC pipe until the string is drawn tight, then using the end of the second pipe to scribe a 360^0 circular depression (boundary) for the arena. It’s circumference will be 4 m. Use the two pipes together to smooth the sand inside the arena, eliminating footprints; also remove any rocks, shells, or other debris. Finally, dig a shallow depression (4-6 cm deep) in the arena center, where you will place the turtles.

Record on your data sheet (see suggested format, below) the location (GPS reading), general weather conditions (wind speed and direction, cloud cover, temperature) and date. Take a compass reading perpendicular to the surf zone to define the seaward direction. From the arena center, take a compass bearing to any light source(s) and estimate distance and elevation (using the inclinometer). Include, also, a qualitative description of conditions (e.g. relative amount of sky glow).

Finally, measure the arena’s position on the beach using the tape measure. From a location parallel to the arena center, measure the distance to the surf zone and to the upper boundary of the beach. Field notes should be as complete as possible! Be sure to also record any significant change in conditions (light switched on or off; cloud cover increasing or decreasing, etc.) as a “running commentary”. With practice, all the above should be completed in less than 15 min.

All equipment taken to the beach (generally, in one or two large buckets) should be placed at least 5 m from the arena boundary. Spread the sheet on the beach and place all items on its surface. Turn the empty buckets on their sides to lower their profile. If it's windy, add sand to the four corners of the sheet and to the inside of the buckets.

III. Use of a photometer

The lighting environment can be more precisely described if you use an appropriate photometer. To our knowledge, the least expensive, simplest, and most convenient instrument is one used in astronomy to measure star "brightness". It's called a stellar photometer and is made by Optec, Inc. (199 Smith St., Lowell, MI 49331; 616/897-9351). Convenient features are its size (small), spectral sensitivity (matches a dark-adapted sea turtle eye), ruggedness, power requirement (9 volt rechargable nicad battery), and angle of acceptance (field of view ~ 17^0): small enough to characterize lighting in particular directions. The instrument is also easily calibrated to give absolute intensity measurements.

We mount the photometer on a small tripod, placed in the center of the arena, then measure horizon lighting in eight cardinal directions (N, NE, E, SE, etc.). The resulting "light intensity octagon" serves to generally characterize the lighting environment. Light from specific luminaires in other directions is also measured. These data can be presented simultaneously with the crawling paths shown by the turtles in arena experiments (Fig. 4; see, also, reference 13).

This instrument does not provide any information on the spectral energy distribution of wavelengths emitted by light sources. Instruments which do tend to be expensive, bulky, and inconvenient to power in the field. As an alternative approach, one can seek to identify the light by luminaire type and manufacturer, then obtain the spectral information from the company. For a good description of how wavelength and intensity can influence hatchling orientation, see B.E. Witherington & K.A. Bjorndal (1991), "Influences of wavelength and intensity on hatchling sea turtle phototaxis: implications for sea-finding behavior". Copeia 4: 1060.

IV. Care and use of the hatchlings

Hatchlings should be stored in light-proof (but not air-tight!) container, placed in a dark room exposed to ambient (outside) temperatures. Styrofoam coolers, of sufficient thickness to be impermeable to light, are ideal. The cooler top should be ajar and covered with black plastic sheeting. Hatchlings should not be disturbed until you are ready to depart for the beach. Once the cooler is placed in a car and carried to location, the turtles will become active (begin crawling inside the cooler). It is essential to avoid exhausting them! The entire trip from the storage site to the assay location should take no more than 30 min.

We recommend a standard sample size of 20 hatchlings. If you plan to run more than one assay, house the turtles to be used in each in separate coolers.

Remove the lid from the cooler about 5 min before beginning the assay. Exposure to ambient lighting and to cooler temperatures will stimulate the turtles, and keep them active. Hatchlings to be used in later tests should be left in closed coolers, undisturbed until you are ready to use them.

Place no more than 4 turtles in the center of the arena, then quickly depart. You and your partner should lie prone on the beach, at least 2 m outside the arena boundary, facing toward its center. One observer should be located on each side (generally, to the North and to the South on an East-facing beach. Hatchlings should crawl to the periphery within 2 min (use the stopwatch to time them). Recapture all the turtles and (if dark beach is adjacent) immediately released them according to standard guidelines. If the local area is exposed to too much light, used turtles should be placed in an empty cooler, covered, and transported to an acceptable location for later release that evening.

APPENDIX II

A program for the Rayleigh Test

This program prompts you to enter the sample size for your arena assay, followed by the arena exit angle for each turtle. After the last exit angle is entered, it calculates the group mean angle, r-vector (dispersion), and Rayleigh z which can be used to determine if the sample is significantly oriented.

For those interested in reading more about “circular statistics”, both in theory and practice, consult Chapters 24 and 25 in J. H. Zar (1984), “Biostatistical Analysis”, published by Prentice-Hall, Inc., Englewood Cliffs, NJ.

```
10   Print “ ”
20   T(1) = 0
30   U(1) = 0
40   Print “This program calculates the Rayleigh r statistic and”
50   Print “the mean angle of orientation.”
60   Print “ ”
70   Print “ ”
80   Print “How many turtles are in this set?”
90   Input N
100  Print “ ”
110  IF N = 0 THEN GOTO 490
120  FOR W = 1 TO N
130  Print “What was the orientation of turtle” W “?”
140  INPUT Q
150  S = SIN (Q/57.29577951000001#)
160  C = COS (Q/57.29577951000001#)
170  T(1) = T(1) + S
180  U(1) = U(1) + C
190  NEXT
200  Y = T(1)/N
210  X = U(1)/N
220  REM X + mean X; Y = mean Y
230  P = Y^2
240  Z = Y^2
250  R = SQR (P+Z)
260  Print “Rayleigh R value =“ R
270  Print “Z statistic =“ N*R^2 ”, N =“ N
280  G = X/R
290  REM cosine of theta is G
300  A = -ATN (G/SQR (-G * G + 1)) + 1.5708
310  B = A * 57.29577951000001#
320  H = Y/R
330  IF H > 0 THEN 430
```

```
340    IF H < 0 THEN 460
350    IF H = 0 THEN PRINT "Warning: calculate by hand!"
360    PRINT "Want to analyze another set?"
370    INPUT A$
380    IF A$ = "yes" THEN 20
390    IF A$ = "Y" THEN 20
400    IF A$ = "y" THEN 20
410    PRINT "You're done!"
420    END
430    PRINT "Mean angle of orientation is " B
440    PRINT " "
450    GOTO 360
460    PRINT "Mean angle of orientation is " 360 - B
470    PRINT " "
480    GOTO 360
490    PRINT "You've messed up!  Check again!"
500    GOTO 80
```

APPENDIX III

Calculating an Arena Index Score

The **Arena Index Score** is determined by adding the *angle score* (ranging from 1 - 40) to the *scatter score* (ranging from 1 - 20; see illustrations, below). All raw data necessary for these calculations are contained in your arena test field notes.

I. Procedures

The steps involved to complete the calculations are simple.

1. Enter the arena exit angle for each turtle into the **Raleigh Test program** (Appendix II). After the last angle is entered, the program will present you with the group mean angle and r-vector. You can use this information for your preliminary assessment.

2. The **angle score** is calculate as the *difference* (in degrees) between the observed group mean angle and the direction toward the ocean. A difference $\leq 10^0$ receives a score of 1, $11\text{-}45^0$ a score of 3, $46 - 90^0$ a score of 5, etc. (see **A**, below).

3. You determine the scatter score (**B**, below) by calculating *the difference* (in degrees) between the vectors of *the two turtles in your test whose exit angles are farthest apart.* This difference is measured (in degrees) around the arena, spanning the region *which also contains the group mean angle.*

4. Divide the difference by 2 to determine the median.

5. Use the median to determine the **scatter score**. Add the scatter score to the angle score to determine the **Index**.

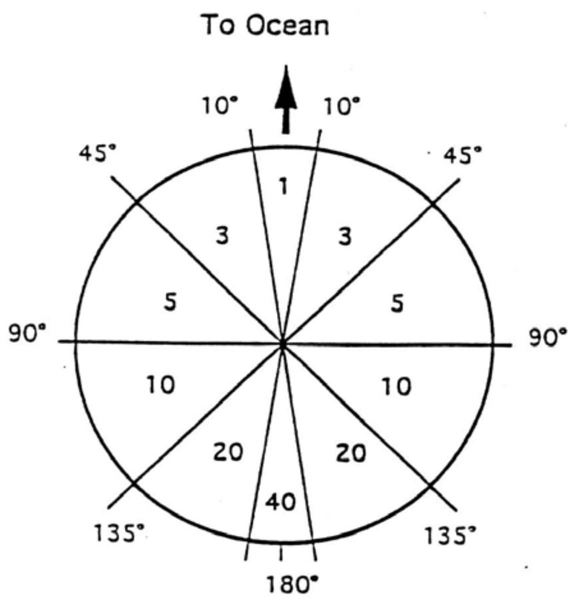
II. An example and its interpretation

The crawling paths for a group of turtles are shown for a factitious arena experiment (**C**), as they would appear in your field notes. The Rayleigh test shows that the group mean angle is 90^0 (black triangle), which is close to a heading directly toward the ocean (black arrow, 78^0). However, a few turtles crawl South and West, suggesting there is a lighting problem in that general area. The r-vector (0.7) is lower than normal, indicating that the sample as a whole shows too much dispersion.

The difference between the group mean angle and the angle toward the ocean (12^0) yields an angle score of "3". The two most divergent turtles ($A = 249^0$, $B = 45^0$) differ in vector, as measured through the hatched region (with the mean angle) by 204^0 ; the median is therefore $204^0/2$, or [$\pm$]102^0 for a scatter score of "8". Finally, the **Arena Index Score** (8 + 3) = **11.**

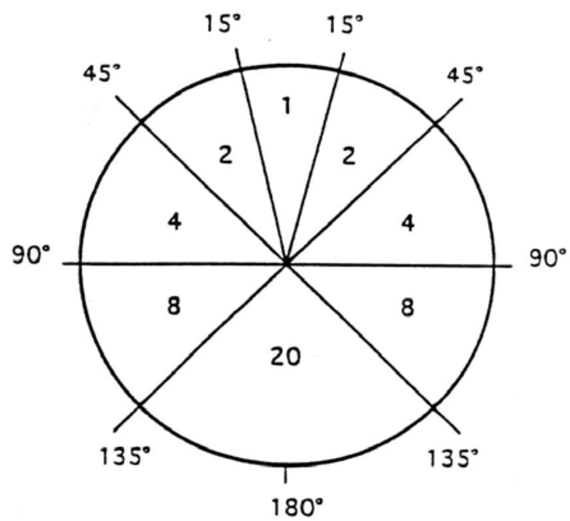
This score, while not acceptable, is close to the minimum acceptable score of **4**. The problem might be a weak light source (or sources) to the South or Southwest that attracts some of the turtles. The occasional “loops” shown by two of the crawling hatchlings are indications that artificial lighting makes it difficult, at least for some individuals, to detect appropriate orientation cues.

A. Angle Score

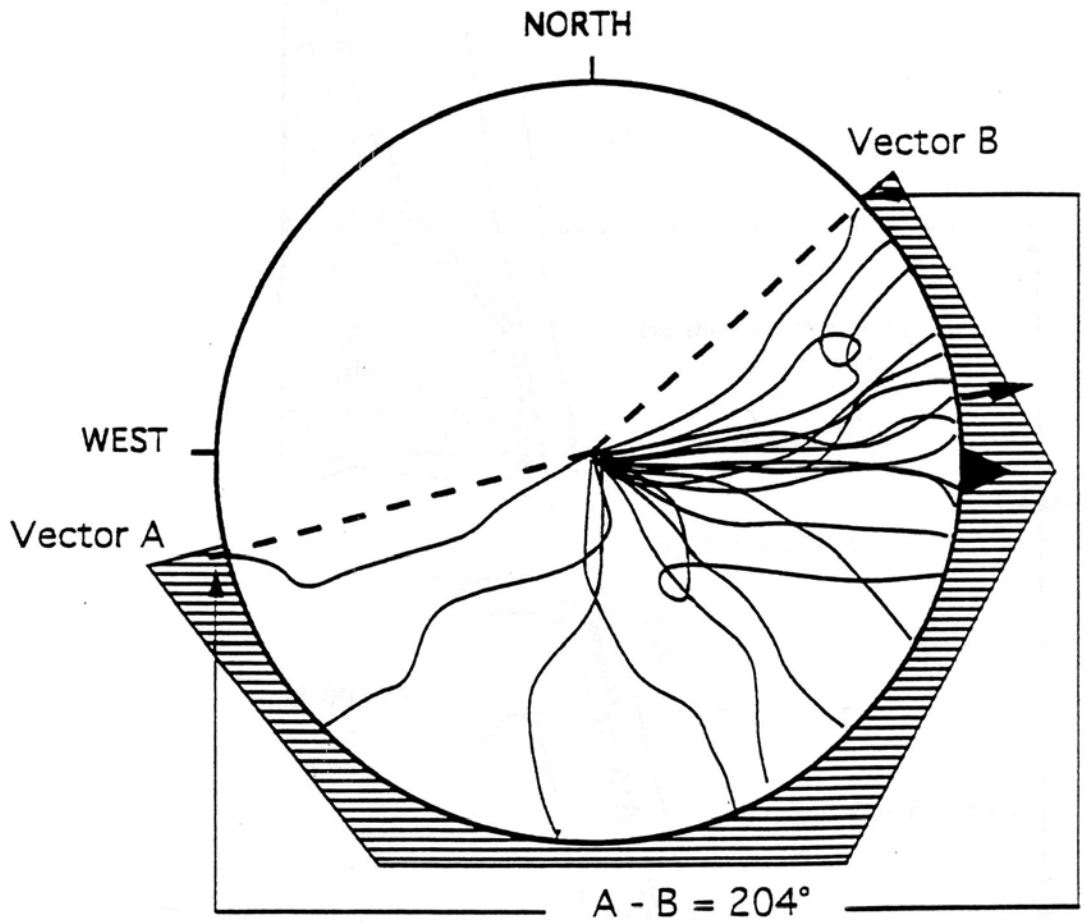


1 = ± 10°
3 = ± 11-45°
5 = ± 46-90°
10 = ± 91-135°
20 = ±136-160°
40 = +161-180°

B. Scatter Score



1 = ± 15°
2 = ± 16-45°
4 = ± 46-90°
8 = ± 91-135°
20 = ±136-180°



An example of crawling paths for a group of hatchling turtles for a hypothetical arena experiment. Source: M. Salmon, Department of Biological Sciences, Florida Atlantic University, Boca Raton, Florida.

Effect of Coastal Roadway Lighting on Endangered and Threatened Sea Turtles. Task III. Arena Experiments at Experimental Sites: Florida's West Coast

ABSTRACT

Mote Marine Laboratory personnel completed a coastal roadway lighting survey along the west coast of Florida during the spring of 1999 as part of a contract with the Florida Department of Transportation (FDOT) and Florida Atlantic University (FAU). During this survey, areas were identified in which street light modification could have a positive impact on the nesting habitat of marine turtles. Three experimental sites were chosen that typified these areas. Night-time hatchling 'arena' experiments were conducted at all three sites with street lighting as it currently existed, with the street lights modified, and with the street lights turned off. At Coquina Beach, an area where roadway lighting is the significant source of beach illumination, modification of streetlights with the use of filtered lenses resulted in a significant improvement in hatchling orientation. At Longboat Key and Lido Key, areas affected by roadway lighting and urban development, modification or removal of street lighting did not have a significant impact on hatchling orientation.

INTRODUCTION

When attempting to locate the ocean, a "hatchling turns to maximize the strength of visual input to multiple comparators in the retina of each eye. As a consequence, the hatchling orients toward the brightest direction" (Lohmann et al, 1997). In a natural setting, this method of orientation results in orientation toward the ocean. However, in areas where artificial lighting exists, hatchlings may become misoriented (and travel in a relatively straight direction toward the light source) or disoriented (and demonstrate uncertainty in direction by frequently changing direction and circling; Witherington and Martin, 1996).

In an effort to reduce the number and severity of hatchling disorientation and misorientation events, Mote Marine Laboratory contracted with FAU and FDOT to establish guidelines for coastal roadway lighting on the west coast of Florida. This study involved selecting three sites which: 1) demonstrated a lighting problem that was largely determined by roadway lighting conditions, 2) consisted of roadway configurations which occur commonly in Florida, 3) were of major importance to sea turtle nesting, and 4) had previous reports of hatchling disorientation events.

Night-time hatchling arena experiments were performed at each of the study sites to measure changes in hatchling orientation when exposed to streetlight modification.

METHODS

Site Descriptions

All three study sites were located in Sarasota and Manatee counties, on the central gulf coast of Florida. Experiments were performed at each site under three different conditions: the streetlights left "as is", the streetlights modified with lenses or shields, and the streetlights turned off.

Site #1: Coquina Beach, Manatee County, Florida. The lighting in this area is mostly from streetlights, with a few lights from single family homes. Gulf Drive, a two-lane roadway, is separated from the beach by a row of Australian pine trees (*Casuarina equisetifolia*), sea purselain *(Sesubium portulacastrum*), and sea oats *(Uniola paniculata*). This vegetation shields the beach from low-level lighting, but streetlights can be observed underneath the canopy of the trees.

Site #2: Longboat Key, Sarasota County, Florida. Gulf of Mexico Drive, a two-lane roadway, is separated from the beach by an intermittent row of 3' sea oats (Uniola paniculata). In addition to streetlights, headlights from cars traveling along the roadway can be seen directly on the beach. The lighting consists of entryway, security, and interior lights from multi-family residences along with commercial lighting.

Site #3: Lido Public Beach, Sarasota County, Florida. This site is the most highly developed of the three sites chosen for the studies. Ben Franklin Drive, a two-lane roadway, runs adjacent to the beach separated by a short cement wall and sparse vegetation. Lighting visible from the beach includes shielded streetlights, car lights, interior/exterior hotel and condominium lights.

Table 1. Lighting Conditions at Arena Sites

Site	"As is"	"Modified"	"Off"
Coquina Beach	•100 W, HPS Open bottom, Unshielded	•70 W, HPS, #2422 Acrylic Flat Lenses	Off
Longboat Key	•2-200 W HPS Shielded Directional (North) •2-100 W HPS Painted Open-Bottom (South) •2-150 W HPS Painted Cobra (East)	•60 degree 6" to 8"X12" shields around cobra fixtures	N/A
Lido Key	•250 W HPS Cobra w/6" 90 ^{o} and 3" 180 ^{o} shields	•250 W HPS Cobra with 8" to10" 270 ^{o} shields	Off

Arena Experiments

Loggerhead hatchlings (<u>Caretta caretta</u>), about to emerge from their nests, were captured during the daytime and kept in a light-proof Styrofoam cooler lined with moist sand until being transported to the study site later that same evening.

At each study site, an "arena" was created by drawing a 4 m circumference circle in the sand. A slight (2 to 3") depression was created in the center of the arena to represent natural emergence conditions. The area within the circle was smoothed by raking so the hatchlings and their tracks would be clearly visible. Approximately five minutes before placing hatchlings in the arena, the lid was removed from the Styrofoam cooler to allow exposure of the hatchlings to ambient lighting and temperature. While observers lay prone in the sand outside the arena, four to six hatchlings at a time were placed in the center and allowed to crawl undisturbed until they crossed the arena boundary. Each hatchling was only used once during the study. After exiting the arena, the hatchlings were recaptured and placed in a bucket to await release on a dark section of beach (Salmon and Witherington, 1995).

All arena experiments were performed on moonless nights. Because lighting modifications were done between each trial, all tests could not be performed on the same night. Although care was taken to provide similar conditions for each trial, slight changes in environment and in hatchling performance could not be avoided.

Data Analysis

The track of each hatchling was drawn on a circular diagram to document any circling or changes in travel direction. Each hatchling's "mean angle of orientation" (arena center to the position where it left the arena) was recorded (Salmon and Witherington, 1995). Rayleigh tests were used to determine whether groups within each trial were significantly oriented. A Watson circular statistic test was used to determine whether differences among the trials were statistically significant (Zar, 1999).

RESULTS

Site #1: Coquina Beach

All modifications to streetlights at Coquina Beach resulted in significant improvements to hatchling orientation (lights on vs modified, $p < 0.01$, lights modified versus off, $p < 0.01$; Watson tests). Hatchlings that were exposed to existing streetlights headed east toward the roadway. After streetlights were modified (using cobra cut-off fixtures with #2422 acrylic lenses), hatchling orientation showed a significant shift toward the northwest, with over half of the hatchlings heading toward the water. When streetlights were turned off, all hatchlings headed directly toward the water.

Table 2. Hatchling orientation in response to lighting situations.

Site	Sample Size	Mean Angle	r-vector	Direction to Gulf
Coquina Beach: Lights on	24	73^0	0.83	260^0
Coquina Beach: Lights modified	24	334^0	0.54	260^0
Coquina Beach: Lights off	24	259^0	0.98	260^0
Longboat Key: Lights on	24	41^0	0.77	245^0
Longboat Key: Lights modified	24	22^0	0.78	245^0
Lido Beach: Lights on	24	82^0	0.86	240^0
Lido Beach: Lights modified	24	82^0	0.94	240^0
Lido Beach: Lights off	24	79^0	0.97	240^0

Site #2: Longboat Key

On Longboat Key, the mean angle of orientation for hatchlings exposed to existing streetlights and those exposed to streetlights modified by installing shields did not differ significantly ($p=0.16$, Watson test). Both sets of hatchlings showed an overall orientation toward the northeast. A significant number of hatchlings exhibited signs of disorientation before exiting the arena (“as is” - 4 of 24, “modified” - 5 of 24).

Site #3: Lido Public Beach

At Lido Beach, modifying or turning off the streetlights did not have a significant impact on hatchling orientation (lights on vs modified, $p < 0.92$; lights modified vs off, $p < 0.58$, Watson tests). Hatchlings headed east toward the roadway under all three lighting situations.

It is important to note that modifications to the original streetlights on Longboat Key and Lido Public Beach, which resulted in a decrease in the number of hatchling disorientation events, had been implemented before the start of this study.

DISCUSSION

The effects of lighting modification varied at each site. At Coquina Beach, modification of streetlights resulted in a significant improvement in hatchling orientation. At Longboat Key and Lido Public Beach, modification or removal of street lighting did not have a significant impact on hatchling orientation.

At Coquina Beach, lighting due to development is minimal. While modifying the streetlights with #2422 acrylic lenses significantly improved hatchling orientation, the most advantageous situation for hatchling survival was provided by turning off the streetlights. However, complete elimination of roadway lighting may not be the most realistic solution. Additional modifications, such as tilting the streetlights or installing shields in addition to the lenses, may further improve hatchling orientation while allowing the roadway to remain lighted for pedestrians and motorists.

At Lido Public Beach and Longboat Key, modification of streetlights did not render the beach dark enough to significantly improve hatchling orientation. Because lighting from upland development and automobile headlights continue to illuminate the beach, a solution was not found by correcting the streetlights alone.

Optimal conditions are obtainable if streetlight modification is done in conjunction with corrections to lighting from upland development. Formation of an overall lighting plan for each area, including guidelines for roadway lighting and lighting from upland development (single and multi-family residences, restaurants, etc.), is necessary to provide suitable habitat for nesting marine turtles and emerging hatchlings.

ACKNOWLEDGMENTS

Permission for this study was obtained through FWCC permit #073, issued to Jeanette Wyneken, PhD, Florida Atlantic University. We would like to thank Bob Lewis and Kurt Richter (City of Sarasota) and Don Sayre (Florida Power & Light) for their assistance with lighting modifications. Thank you also to Kristy Carey and Patricia Clune (MML interns), who spent

many sleepless nights assisting in data collection.

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Zar, J.H. 1999. Biostatistical Analysis. Prentice Hall, Inc., Englewood Cliffs, NJ.

Figure 1A.
Diagram of hatchling tracks in response to lights "ON" at Coquina Beach.

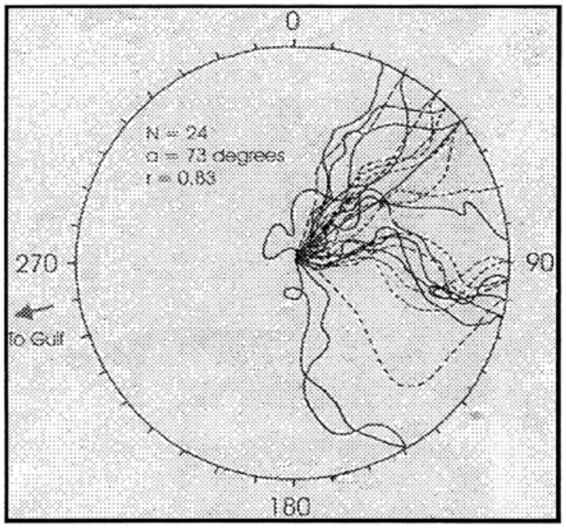


Figure 1B.
Diagram of hatchling tracks in response to lights "MODIFIED" at Coquina Beach.

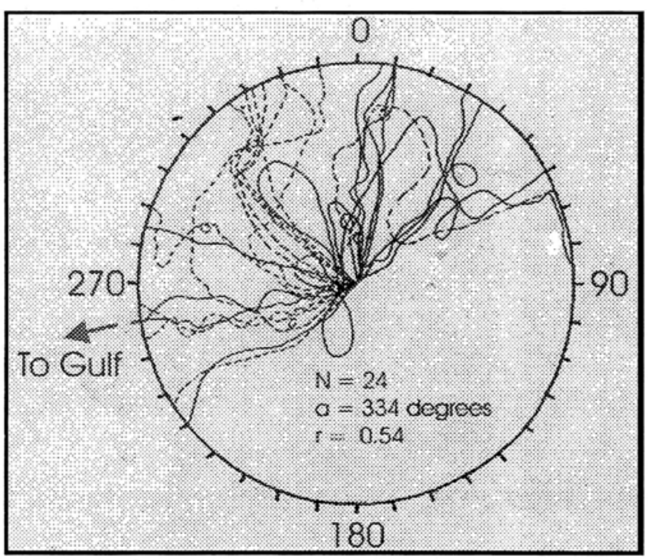


Figure 1C.
Diagram of hatchling tracks in response to lights "OFF" at Coquina Beach.

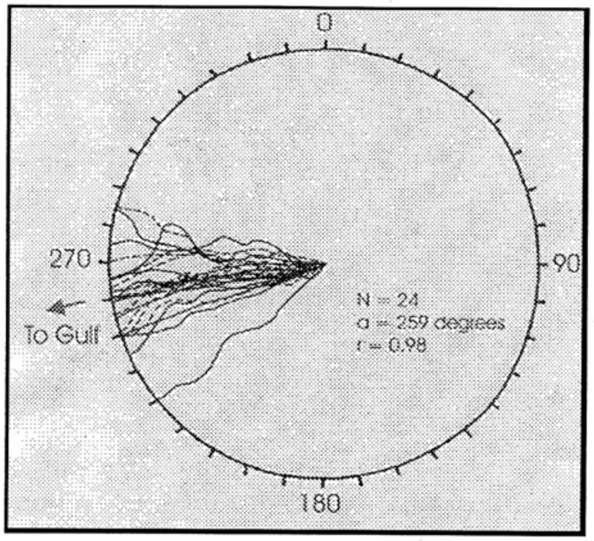


Figure 2A.
Diagram of hatchling tracks in response to lights "ON" at Longboat Key.

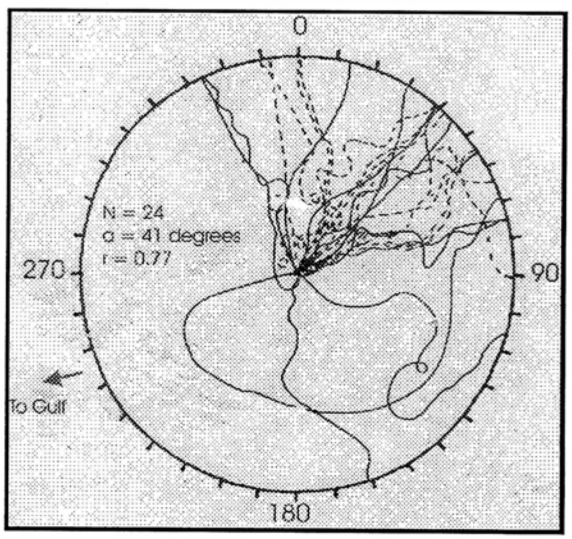


Figure 2B.
Diagram of hatchling tracks in response to lights "MODIFIED" on Longboat Key.

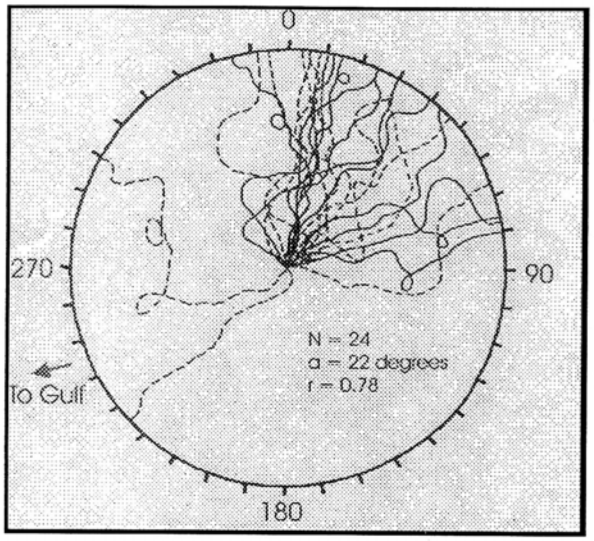


Figure 3A.
Diagrams of hatchling tracks in response to lights "ON" at Lido Public Beach.

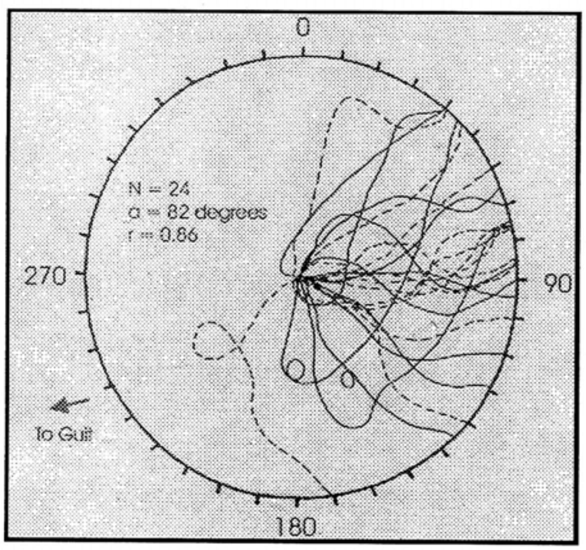
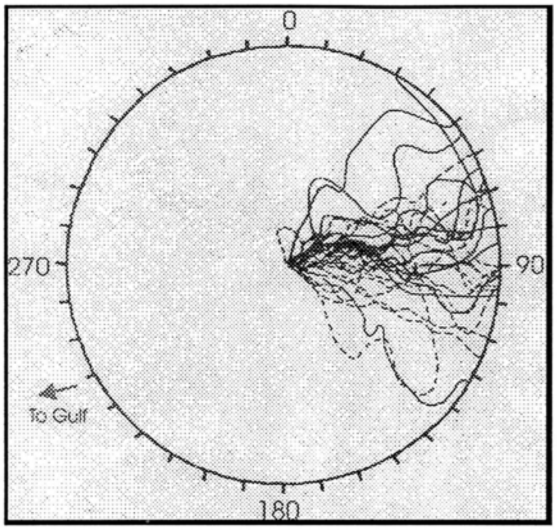
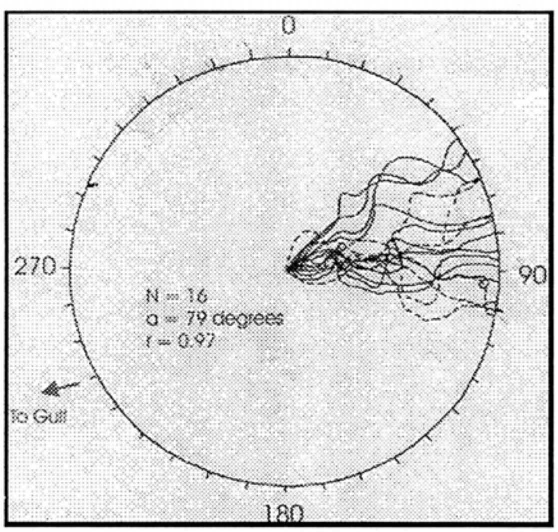


Figure 3B.
Diagram of hatchling tracks in response to lights "MODIFIED" on Lido Public Beach.



N = 24
A = 82 degrees
R = 0.94

Figure 3C.
Diagram of hatchling tracks in response to lights "OFF" on Lido Public Beach.



Impacts of Coastal Roadway Lighting on Endangered and Threatened Sea Turtles. Task IV. On-Site Test of Lighting Modifications (Florida's East Coast)

Introduction

Artificial lighting disrupts the normal behavior of both hatchling and adult sea turtles. Hatchlings, after emerging from their nests, normally crawl towards the ocean ("seafinding") and begin their migration to oceanic nursery areas. But when exposed to artificial lighting, they instead crawl toward land where they often perish. Females searching for nesting sites are repelled by beaches exposed to light and as a result, either fail to nest or nest in lower than average numbers at these sites. Thus from the perspective of a sea turtle, artificial lighting can be considered a form a habitat destruction ("photopollution"; Verheijen, 1985) that degrades a nesting beach, and compromises survival and reproductive success.

The most obvious solution to this problem is to control artificial lighting by shielding luminaires, reducing the intensity of light sources, and/or turning off lights. But at some sites, among them coastal highways, street lights must be left on for traffic and public safety considerations. In these areas, a new technological advance might represent a satisfactory compromise. It consists of interposing a light filter between the bulb and lens of the street light. These filters exclude the transmission of the shorter light wavelengths, allowing the longer light wavelengths that turtles perceive with less sensitivity to pass to the environment. If this technology functions as needed, it may be possible to illuminate coastal roadways using lights that are "turtle safe".

However, we know little about how sea turtles respond filtered lighting. A proper analysis must consider how both hatchling and adult turtles respond to these lights. Studies reported elsewhere (see Objective IV) center on the response of the hatchlings (loggerheads, *Caretta caretta;* green turtles, *Chelonia mydas;* and leatherbacks, *Dermochelys coriacea).* Our objective in this report is to characterize the response of the nesting turtles (loggerheads).

To achieve this goal, we counted the number of nesting attempts made by females over an entire nesting season. A beach site was divided into an experimental section, exposed to filtered lighting, and two adjacent control beach sections, left dark. We hypothesized that if filtered lighting was effective, loggerheads should show no difference in nesting performance at the three sites.

Methods

1. Study site

The experimental site (Carlin Park, located in Jupiter [Palm Beach County], Florida, USA; Figs. 1 & 2) was chosen because it satisfied four prerequisites. (1) Nesting densities of loggerheads at this beach were high (~541 nests/km/year; L. Wood, pers. comm.; P. Davis, pers. comm). High nesting densities are required to provide a sample size that will reveal trends. (2) The entire strip of beach (length, approx. 1.4 km) was relatively dark, reducing the probability of confounding effects of other light sources. (3) Street lights located on the ocean highway (State road A1A) were visible from the beach. (4) Historical data (1991-1998) existed to provide a "baseline" of normal nesting performance when the street lights were turned off. This information allowed us to determine whether any differences we observed represented departures from an expected pattern.

Permissions were obtained from the Town of Jupiter, the Florida Fish and Wildlife Conservation Commission (which permitted this study), and the Palm Beach County Department of Environmental Resource Management to complete this study. The Florida Power and Light Company agreed to install the filters, and to follow a specific schedule for turning the lights on and off (see below).

2. Lights and light measurements

The street lights (Fig. 3) used for this experiment were standard "cobra heads", equipped with drop lenses and elevated by 9.1 m tall poles.. Street lights were modified for this experiment as follows. First, each was fitted with a 75 W high-pressure sodium (HPS) lamp, a light source that is normally disruptive to sea turtles (Witherington and Martin, 1996). Second, the drop lenses were replaced with flat lenses. Finally, each light was equipped with a # 2422 acrylic filter. This filter prevents the transmission of wavelengths below 540 nm (Fig. 4).

Light intensities were measured (in lumens/m^2) using either a Tektronic (Model #J17) illuminance meter, equipped with a J1811 illuminance head, or a Minolta Illuminance Meter (Model T-1), that measures light levels in lux. Light measurements were made at night while the lights were off, as well as after they had been turned on. When the lights were on, measurements were made at the following locations: directly underneath the light (under the light pole); on the beach side of the highway (15 m from the source), and at the foot of the dune (30 m from the source). All such measurements were made on the darkest evenings (minimal cloud cover; no lunar illumination).

3. Beach zones and nesting data

The beach was divided into three sections: a central Experimental section and two Control sections immediately to the North and South (Figs. 1 and 2). Each zone was the same (~ 425 m) length. The three zones were also similar in their dune structure and beach topography.

All street lights located adjacent to the two control zones were turned off. The experimental beach was exposed to lighting from four street lights on the West side of A1A (Fig. 3). Distances between each light varied from 62 to 172 m. The poles were located between 60-70 m from the high tide strand line, as measured directly East of the roadway.

Preparations for the experiment were completed by mid-April, 1999. We began gathering data on 6 May, 1999 (when loggerhead nesting usually begins). Each morning, we surveyed the entire beach and determine, based upon tracks left in the sand, the number of successful and unsuccessful nesting attempts made the previous night. All nesting attempts were plotted by location on scale maps. Beach surveys ended 12 August.

4. Lighting schedule and its rationale

The street lighting regime (Fig. 5) enabled us to make several comparisons between the absolute number and proportion of nesting attempts. These comparisons were: (i) nesting attempts in 1999 and during previous years; (ii) nesting attempts within the control and experimental beach sections; and (iii) nesting attempts within the experimental section when the street lights were on and off, and when the beach was and was not exposed to lunar illumination.

5. Data Analysis and Statistics

Our null hypothesis was that filtered street lighting had no effect on either the absolute number, or the proportion, of successful and unsuccessful nesting attempts. We rejected that hypothesis when comparisons resulted in chi-square probabilities (corrected for continuity) $\geq$ 0.05 (Siegel, 1956).

Results

The number of successful and unsuccessful nesting attempts observed historically (1990 – 1998) is shown in Table 1. The number of successful and unsuccessful nesting attempts we observed during the 1999 nesting season is shown in Table 2.

1. Comparisons between the historical and the 1999 data

There were a total of 995 nesting attempts in 1999. These numbers fell within the range of those witnessed historically (high of 1444 nesting attempts in 1998; low of 964 nesting attempts in 1997; Table 3). When comparisons were subdivided by beach section, the successful nesting attempts observed in 1999 were within the range of those witnessed historically (Table 4). However, in the North control section, unsuccessful nesting attempts were below the range observed historically (Table 4).

The mean proportion of successful (623 nests, or 49 %) to unsuccessful (640 false crawls, or 51 %) nesting attempts witnessed historically did not differ statistically from the proportion witnessed in 1999 (521 nests, or 52 %; 474 false crawls, or 48 %). When the mean historical proportions were compared to the 1999 data for the entire beach, there were no statistical differences (Table 5). A comparison by beach section also failed to reveal statistical differences (North control $X^2 = 3.53$; Experimental $X^2 = 2.95$; South control $X^2 = 3.02$, 1 d.f.; all n.s.).

2. Comparisons among the beach sections: 1999 data

There were no statistical differences among the beach sections in either the proportion of successful nesting attempts, or in the proportion of unsuccessful nesting attempts, as a function of exposure to filtered street lighting (Table 6). There were also no statistical differences between the proportion of successful to unsuccessful nesting attempts within the experimental zone, as a function of exposure to street lighting (Table 6; 101:86 vs. 69:59; n.s. by a 2 x 2 chi-square test, 1 d.f.).

Table 1. Number of loggerhead nesting attempts in the three beach sections, 1990 – 1998. Data for 1995 followed a beach nourishment project and were not used in subsequent comparisons. N = successful nesting attempts; F = unsuccessful nesting attempts (false crawls).

Year	North Control		Experimental		South Control	
	N	F	N	F	N	F
1990*	-	-	-	-	156	143
1991	170	204	201	214	268	162
1992	298	286	200	262	199	183
1993	247	260	149	204	105	76
1994	257	314	238	223	181	166
1995**	162	471	374	299	268	179
1996	212	237	245	243	297	186
1997	163	181	172	140	172	136
1998	219	326	216	298	187	198
Mean $\pm$ sd	224$\pm$48	258$\pm$55	203$\pm$34	226$\pm$50	196$\pm$61	156$\pm$39

*Palm Beach County (monitoring the North control and Experimental sectors) began keeping records in 1991.
**Data for this year not used to calculate mean $\pm$ sd.

Table 2. Observed number of successful (N) and unsuccessful (F) nesting attempts at the Carlin Park experimental site, summer of 1999. The total number of nesting attempts was 995.

Month (Lights)	Moon	North Control N	North Control F	Experimental N	Experimental F	South Control N	South Control F
May							
(off)	Full	16	6	8	10	19	20
	New	3	5	2	4	4	3
	Quarter	19	12	19	10	16	17
June							
(on)	Full	27	13	18	7	17	8
	New	24	10	24	18	14	9
	Quarter	13	6	22	11	13	12
(off)	Quarter	17	18	22	8	20	12
July							
(on)	Full	11	8	6	9	9	9
	Quarter	26	32	26	26	37	43
(off)	New	20	40	18	27	14	30
August							
(on)	New	2	2	4	3	1	3
	Quarter	4	7	1	12	5	4
	Totals:	182	159	170	145	169	170

Table 3. Nesting attempts witnessed historically, and during the 1999 nesting season.

Category	Historical High (1998)	Historical Low (1997)	1999
Nesting	622	507	521
False Crawls	822	456	474
All	1444	964	995

Table 4. Nesting attempts witnessed historically, subdivided by beach zone, and those observed during the 1999 nesting season. Historical high and low data points represent the extremes observed, regardless of the year when they occurred.

Category	North Control		Experimental		South Control	
	N	F	N	F	N	F
Historical High	298	326	245	298	297	198
Historical Low	163	181	149	140	105	76
1999	182	159*	170	145	169	170

*Below historical range

Table 5. Mean number of successful (N) and unsuccessful (F) nesting attempts (from Table 1) witnessed historically in each beach section, and those observed in 1999 (Table 2). A comparison between the two data sets reveal no significant differences (Chi square test, 3 x 2 format, 2 d.f.).

Category	North Control		Experimental		South Control	
	N	F	N	F	N	F
Historical Mean	224	258	203	226	196	156
1999	182	159	170	145	169	170

Table 6. Comparisons among the beach sections, 1999. Number of successful (N) and unsuccessful (F) nesting attempts in the sections when the beach was exposed to filtered street lights, compared to when the lights were off. There were no significant differences (Chi-square tests for nests and for false crawls done separately in a 3 x 2 test format, with 2 d.f.).

Condition	North Control		Experimental		South Control	
	N	F	N	F	N	F
Lights on	107	78	101	86	96	88
Lights off	75	81	69	59	73	82

Table 7. Comparisons within the Experimental section, 1999. Data were gathered while the beach was exposed to filtered street lighting. The proportions of successful vs. unsuccessful nesting attempts show no significant differences as a function of lunar phase (Chi-square test, 3 x 2 test format, 2 d.f.).

Lunar Phase	Nesting	False Crawls
Full Moon	24	16
New Moon	28	21
Quarter Moon	49	49

In the Experimental sector, there were no statistical differences in nesting attempt proportions as a function of lunar phase (Table 7).

Discussion and Conclusions

1. Response to filtered lighting

The data suggest that at Carlin Park, the nesting behavior of loggerhead females is unaffected by exposure of the beach to filtered (# 2422 acrylic) street lighting. The evidence in support of this conclusion is as follows.

First, overall levels of nesting were not reduced, compared to those observed historically (Tables 3 – 5). Nesting attempts during the 1999 season were lower (995) than the historical average (1263), but above those that occurred during the 1997 season (Table 1) when all street lights were off. The proportion of nesting attempts on the three beach sections during the 1999 season also failed to differ statistically from the proportion observed historically (Table 5). Specifically, most nesting attempts occurred in the North control section, while similar (but lower) numbers of nesting attempts occurred in the Experimental and South control sections. This pattern occurred historically (Tables 3-5).

If filtered street lighting had affected the females, then two changes should have been evident. First, there should have been a reduction in the number of nesting attempts within the experimental section, compared to the number that occurred in the two control sections. Such a reduction did not occur (Tables 4 and 5). Second, the relative proportion of unsuccessful to successful nesting attempts should have increased in the Experimental section. However, these proportions failed to differ statistical from the historical mean proportions (Table 5). Both of these effects have been documented as correlations in previous studies (literature reviewed by Witherington and Martin, 1996). In the only experimental study (Witherington, 1992), these effects could be positively attributed to artificial lighting (rather than to some unknown factor correlated with artificial lighting).

In addition, if filtered lighting had affected the females then those effects should have been more apparent during new moon (when background light levels were reduced) than during periods when the beach was exposed to lunar illumination (quarter moons, full moon). Again, no such effect was evident (Table 7). Verheijen (1980, 1985) was the first to document that the response of animals to artificial lighting depended upon the perceived contrasts between background illumination and the intensity of artificial light sources. He showed that during full moon periods, the deleterious effects of artificial lighting were reduced compared to new moon periods. While no such effects have been documented for nesting turtles, they have been described for hatchlings. Hatchling seafinding orientation is more often disrupted by artificial lighting when the beach is dark (new moon) than when it is exposed to full moon illumination (Salmon and Witherington, 1995).

2. Filtered lighting as a management solution

Filtered lighting may be an attractive management option for several reasons. First, in some locations, coastal roadway lighting must remain on to promote public safety (for vehicles and for pedestrians). When these roadways are located behind nesting beaches, the use of filters reduces the overall intensity of transmitted light, and confines the wavelengths that are transmitted to spectral energies that have a reduced effect upon sea turtle behavior.

Secondly, filters are easily installed on existing fixtures, thus reducing the costs required for lighting modification. In most cases, the acrylic sheets can be cut to an appropriate shape, attached to an opaque plastic holder, then installed upon the existing light. The units also provide flexibility; they can be installed at the beginning of the sea turtle nesting season, then removed at the end of the nesting season. In contrast, the use of an alternative lamp (such as a low-pressure sodium vapor [LPS] luminaire) is initially expensive because the entire fixture must be changed.

Thirdly, the 2422 filter allows the transmission of a range of (yellow to red) wavelengths. This broader spectrum is more attractive to humans than LPS lighting that transmits a narrow band of yellow wavelengths (monochromatic light).

While these features make filtered lighting an attractive management option, there are also limitations that must be considered. Among these are the following. First, while filtered lighting may be ignored by nesting loggerheads, nesting turtles of other species may respond differently. Comparative studies have shown that both spectral sensitivity and perception vary among hatchling species (Witherington, 1992; Lohmann et al., 1996). These differences may persist as the turtles grow to adulthood. Thus it would be inappropriate to assume that the results obtained with loggerheads can be applied to the other species. Leatherback and green turtles also nest on Florida’s East Coast. Based upon current knowledge, it would be wise to use filtered lighting only at sites in Florida where leatherbacks and green turtles rarely nest.

Secondly, filtered lighting might by ignored by nesting (adult) turtles, but not by their hatchlings. We already know that loggerheads will nest at sites where artificial lighting seriously interferes with hatchling orientation. Adult green turtles and leatherbacks often behave similarly. We do not know whether this situation occurs because hatchlings are more sensitive to light than are the adults, because hatchlings depend upon different visual stimuli for orientation than do the adults, or because of both of these factors. The point is that filtered lighting must protect *both* life history stages to be an effective management tool.

Thirdly, how adult turtles respond to filtered lighting may be a function of the levels of artificial lighting already present. This hypothesis is certainly consistent with what we know from other animal studies (Verheijen, 1980; 1985). The Carlin Park site was exposed to low, but nonetheless obvious, incidental lighting from the city of West Palm Beach, as well as from local residences and businesses. Thus our experiments should be repeated at any beach location that is darker than Carlin Park before exposing the turtles to filtered lighting. At the present time our results must be interpreted strictly as follows: that filtered lighting will probably be ignored by nesting female loggerheads where background light levels are comparable to, or above those measured at, the Carlin Park site.

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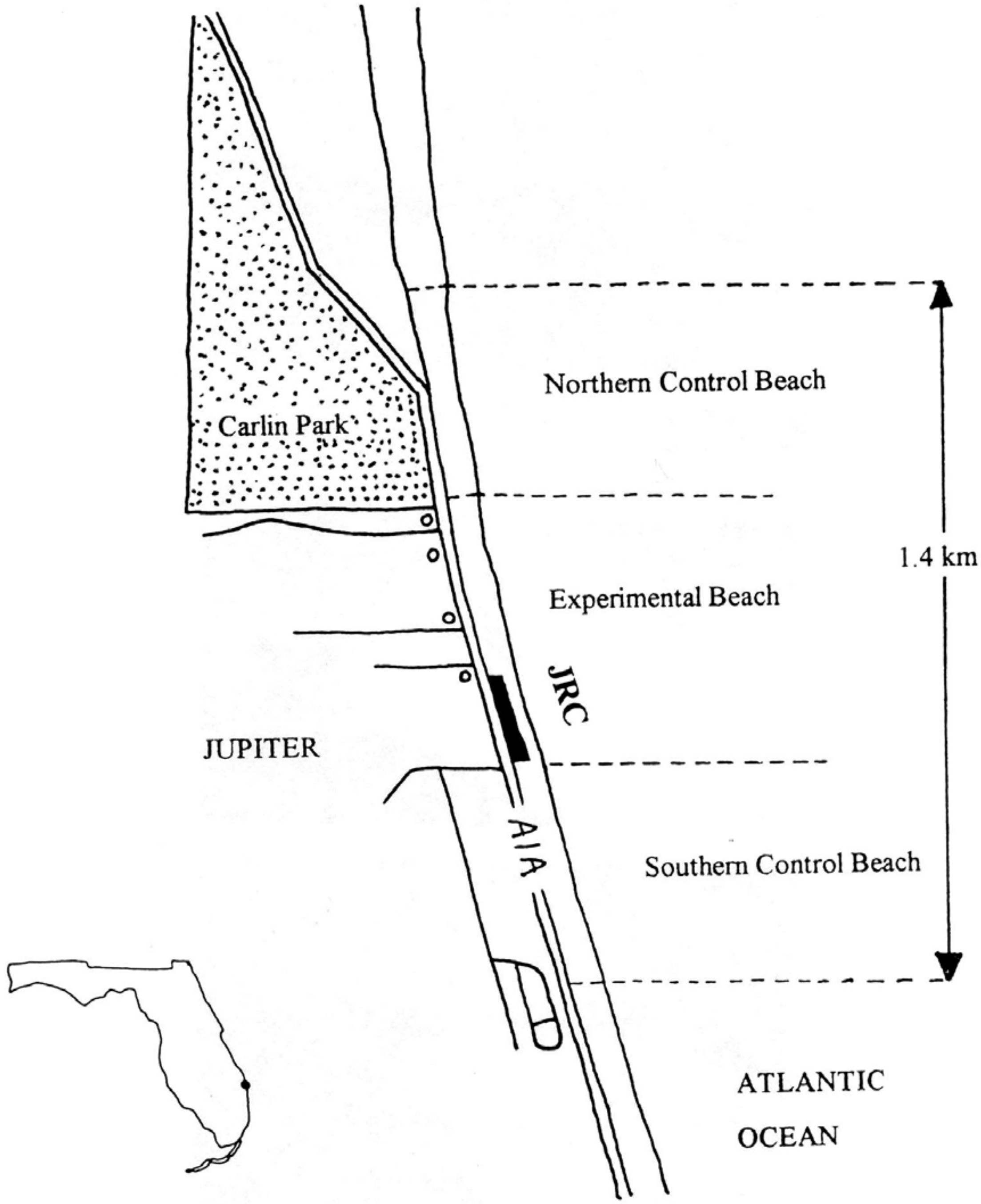

Figure 1. The study site at Carlin Park, Jupiter, Florida. JRC, Jupiter Reef Club. The four small circles between the JRC and Carlin Park are the street lights that illuminated the experimental beach.

A.

B.

C.

Figure 2. The study site at Jupiter, Florida. Photos are taken at the southern end of each study zone, looking north. (A) The northern control zone, (B) the central experimental zone, and (C) the southern control zone. Each zone is 425 m. in length.

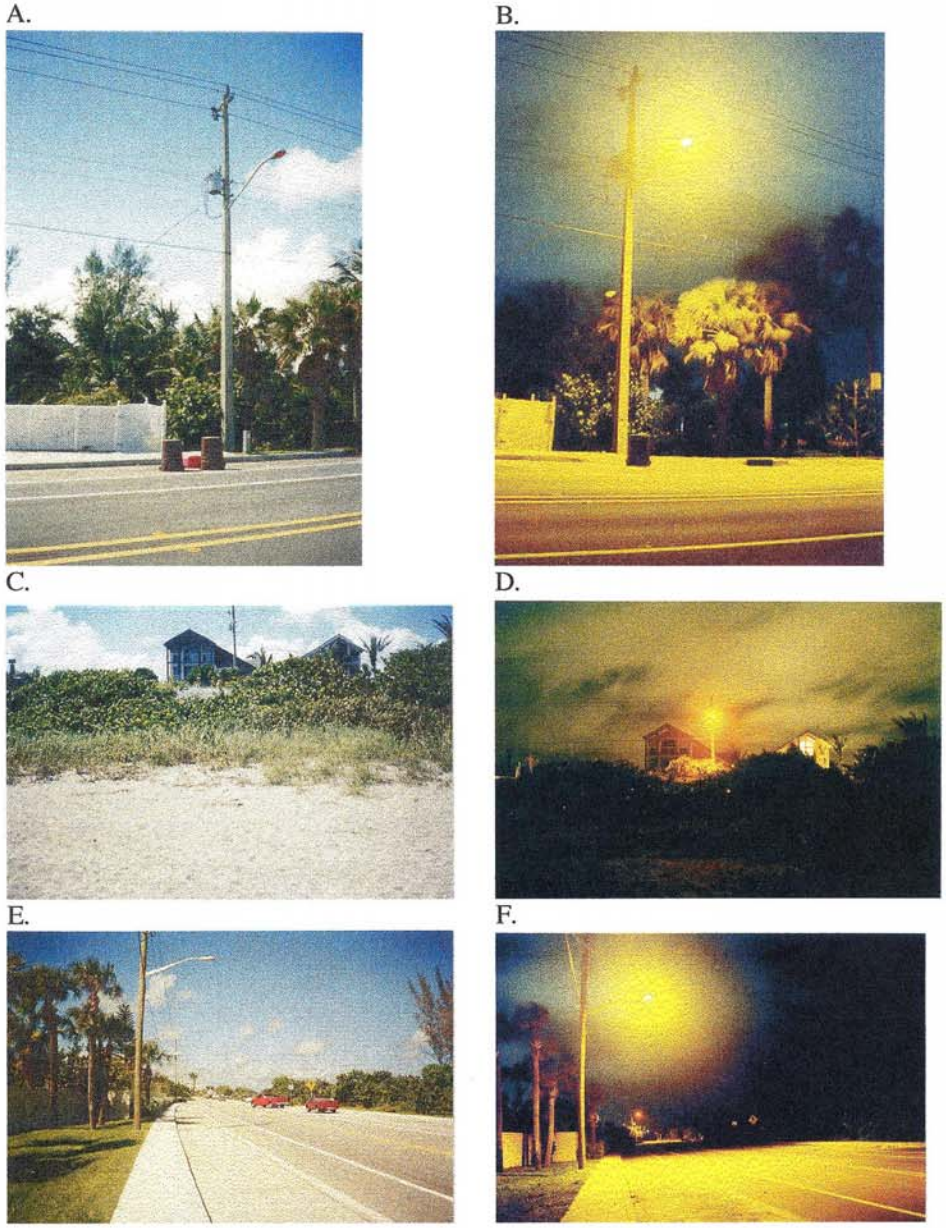

Figure 3. Day and nighttime views of streetlights used in the central experimental zone. (A-B) One streetlight on the west side of A1A. (C-D) One streetlight viewed from the beach. (E-F) The streetlights viewed looking north along A1A.

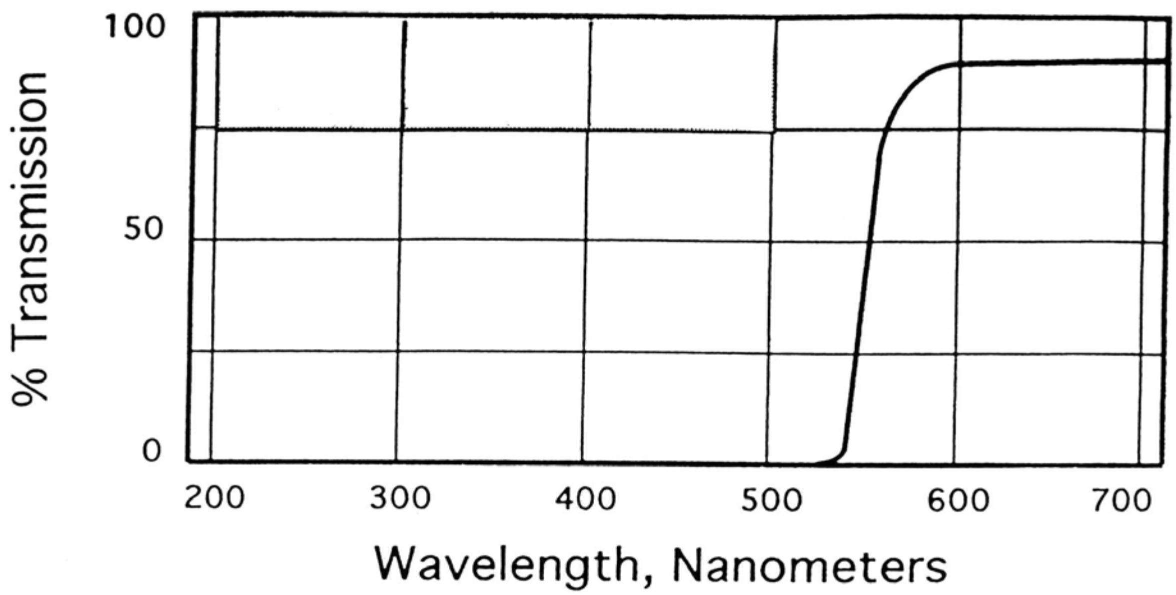

Figure 4. Transmission characteristics of the acrylic (2422) filter used in these experiments. The filter blocks transmission of wavelengths below 530 nm. It transmits ~ 85 % of the energy in wavelengths above 600 nm.

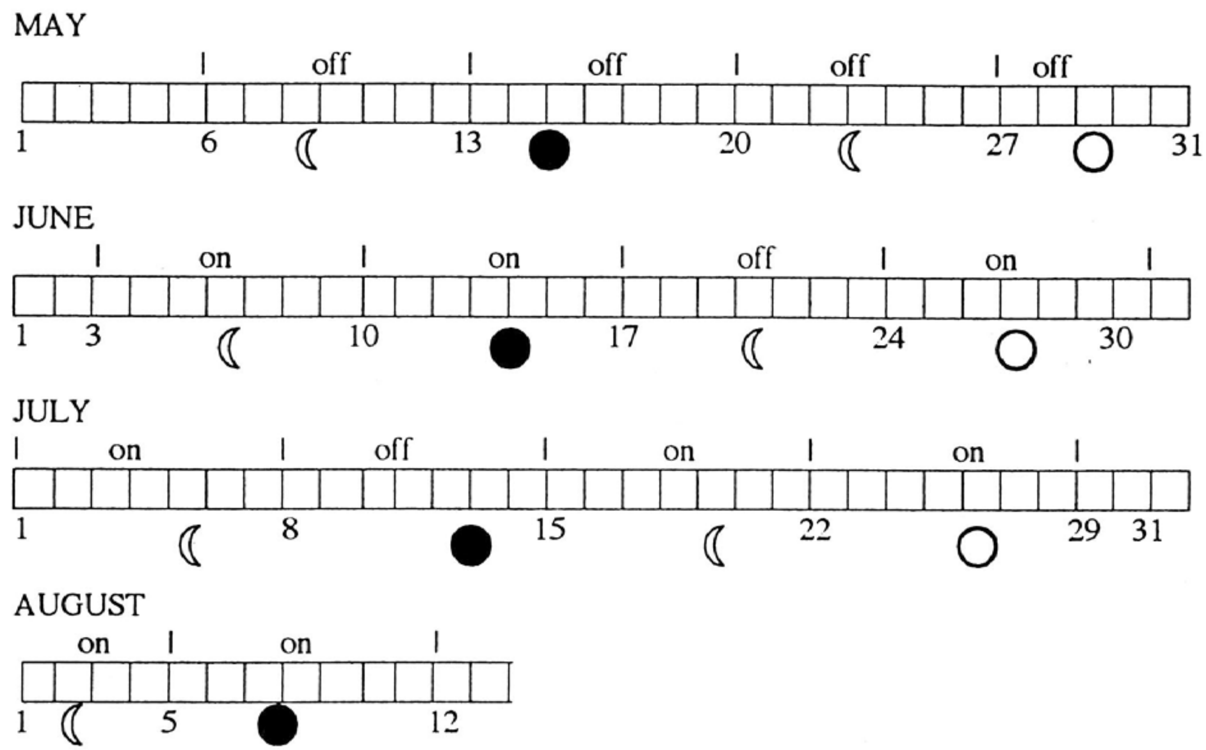

Figure 5. Lighting schedule in the Experimental sector, May 6 through August 12, 1999. Four street lights were turned on or off for one week. Each week encompassed a different phase of the lunar cycle. For further details, see text.

Effect of Coastal Roadway Lighting on Endangered and Threatened Sea Turtles.
Task V. On-Site Testing of Embedded Roadway Lighting

INTRODUCTION

The orientation of hatchling sea turtles from the nest to the ocean (seafinding) is the first step in a migration required for later growth and development. To complete this process, hatchlings must emerge at night and, under the cover of darkness, quickly locate the ocean from the nest.

On dark, natural beaches hatchlings find the ocean within two minutes (Adamany et al. 1997), relying on visual cues. One cue is horizon "brightness", a function of both the wavelength and intensity of nocturnal light. Vegetation on or behind the dune absorbs light while light is reflected from the ocean surface; thus the horizon toward the ocean is typically brighter than the landward horizon and attracts the turtles (Mrosovsky, 1972; review: Lohmann et al. 1997). Hatchlings also use form vision to crawl away from elevated landward silhouettes (dune and vegetation) and toward the lower silhouette characteristic of the view toward the surf zone. Experiments by several workers (Limpus 1971; Salmon et al. 1992; Witherington 1992) showed that form vision cues are more potent than brightness cues for directing orientation.

Orientation from the nest to the sea can be disrupted by artificial light (review: Witherington and Martin, 1996). Artificial lighting differs from natural (celestial) light in its spectral composition and contrast with background. Because artificial light sources are near by, they show virtually no atmospheric scatter. As a result, contrast between sources of artificial light and background illumination greatly exceeds contrast between sources of celestial (stellar, lunar) light and background. This greater "directivity" makes artificial light sources “super-stimuli”, that is, such sources are so attractive that natural visual stimuli are ignored. Sea turtle hatchlings exposed to artificial light either crawl toward the source (“misorientation”), or crawl in circuitous paths as if incapable of detecting (or responding to) natural cues (“disorientation”; Verheijen, 1958, 1985).

Misoriented and disoriented sea turtle often hatchlings fail to find the ocean and usually die from dehydration, exhaustion or exposure to terrestrial predators.

I. Roadside Lighting

Both residents and tourists are attracted to Florida’s beaches. This attraction has led to extensive coastal development. Coastal communities and parks necessitate the construction of roadways, many of which paralleling the shore. Roadways, in turn, must be properly illuminated to satisfy concerns for vehicular, as well as pedestrian, safety. Not surprisingly, lights on coastal roadways adjacent to sea turtle nesting beaches are often responsible for hatchling misorientation. Thousands of hatchlings in Florida die annually because they crawl toward streetlights instead of toward the ocean.

II. Correcting Roadway Lighting Problems

This FAU research study is an attempt by FDOT to resolve coastal roadway lighting impacts to adjacent nesting beaches. This document will support revisions to the FDOT Roadway Lighting Standards to include sea turtle conservation measures. The goal is to provide lighting for motorist and pedestrian safety without compromising the lives and reproductive success of marine turtles. With this end in mind, the FDOT sponsored a project that involved the use of embedded roadway lighting as an alternative to pole lighting. This modification transfers bright and elevated light sources (that typically also illuminate the beach) to the street itself. In theory, such a modification places the light where it is needed (to the pavement surface) while reducing its scatter to other areas of the environment (such as the beach). The goal of this study was to determine whether these lighting modifications provided effective protection for sea turtle hatchlings.

METHODS

I. Description of the Study Site

All experiments were performed at an East Coast beach site in Boca Raton, Florida (Palm Beach County), between July and September of 2001 (Fig. 1). The site (Spanish River Park) was chosen for three reasons. First, the park is a forested area interposed between the city and the beach; it acts as a barrier that reduces (but does not eliminate) city lighting that reaches the beach. Second, the park is a zoning barrier that eliminates residential lighting (that might also upset hatchling orientation) from the area. As a consequence, the lighting environment is "simplified" making it likely that if detrimental behavioral effects occur, they are caused by street lighting. Third, a coastal highway (A1A) parallels the beach in front of the park. It contains poled streetlights with high-pressure sodium vapor (HPS) luminaires. At several locations where there are gaps in the dune vegetation (between the beach and roadway) for public beach access, these lights are visible at the beach and could disturb hatchling orientation.

There is good evidence that they do. Sea turtle nesting activity and hatchling orientation have been monitored by the City of Boca Raton for many years (using personnel from the Gumbo Limbo Nature Complex). Records extending for more than a decade indicate that hatchling orientation at Spanish River Park is frequently disrupted, and most likely by the HPS streetlights. Experiments have established that HPS lighting attracts hatchlings (Withington and Bjorndal, 1991). In recent years, the streetlights have been turned off, eliminating the problem. However the park experiences heavy vehicular traffic and is a popular site for nocturnal joggers, pedestrians and bicyclists. Extinguishing the streetlights appears to solve the sea turtle "issue", but may compromise human safety.

II. The lighting project

The embedded roadway lights were "Smartstud Wayfarer" light-emitting diodes (LED's), placed in the road centerline at 9 m intervals (Fig. 2). Smartstuds emitted ~ 30 lumens of amber light while those placed at turning lanes emitted similar amounts of white light. LED lighting was complemented by 28 cm high HPS (100 W) louvered beach luminaries (Bronzelight RFB), spaced at 9.14 m intervals, that bordered the bike lanes on the West side of the roadway. Existing pathway lights were elevated by 5.5 m poles, and fitted with amber filters that excluded wavelengths < 550 nm. These lights were not visible from the beach and were left on during all experiments.

Streetlights were 150 W HPS luminaries in cobrahead fixtures, mounted 7.5 – 9.0 m high on 2.44 m arms. These were placed on concrete poles spaced 61 m apart.

III. Experimental design and hypotheses

Experiments were designed to determine how hatchling orientation was affected under three conditions ("treatments") of artificial lighting. The treatments were (i) exposure to streetlights, (ii) exposure to the embedded and louvered lights (hereafter, embedded lights), and (iii) an absence of both sources of artificial lighting (streetlights and embedded lights switched off). The null hypothesis was that hatchling orientation should be disrupted in the presence of any lighting, but not in its absence. However if embedded lighting provided effective protection, then hatchling orientation should be normal and identical under conditions (ii) and (iii), but disrupted under condition (i).

Arrangements were made with the FPL Corp. to turn on and off the appropriate lighting systems for several days at a time during the 2001 nesting season. Experiments under each treatment condition were carried out over several evenings during the time period when hatchlings emerge from their nests (July – Sept).

Three locations along the length of the beach were selected as sites for arena experiments (Fig. 1). Two of these were Experimental Sites (those where four or more street lights were visible from the center of the arena); the third location was a Control Site (where dune vegetation blocked the transmission of street lighting to the beach). The two Experimental sites were located South of the Control Site. Experimental Site 2 was located immediately to the East of the Spanish River Park south tunnel. Experimental Site 1 was located 155 m, while the Control Site was located 212 m, to the north of Experimental Site 2.

The control site, then, differed from the experimental sites in two ways: by exposure to street lighting and by the presence of a barrier of vegetation between the beach and the coastal roadway. However, much taller Park vegetation (from a dense stand of Australian Pine trees) on the landward side of A1A provided a uniformly high horizon behind the beach at all of the sites. Experiments have shown that horizon elevation is the most important natural cue used by hatchling sea turtles for orientation (Salmon et al, 1992). Thus the experimental and control sites did not differ in “overall” horizon elevation.

Finally, the disruptive effects of artificial lighting depend critically on their directivity, or contrast, with background. Full moon illumination decreases both the directivity of artificial lighting and its disruptive effects upon hatchling orientation (Salmon and

Witherington, 1995). For this reason, tests at all sites were carried out during full and moon new moon. These experiments were required to determine whether embedded roadway lighting protected turtles under the full range of background lighting conditions they naturally experience.

IV. Hatchling collection

Hatchlings were obtained in the afternoon before each evening experiment was performed. All turtles used in these experiments were loggerheads and all came from nests relocated to the Hillsboro Beach Hatchery (in Broward County). Excavated nests were those containing turtles likely to emerge that evening. These nests are characterized by a depression in the sand on top of the egg chamber; the hatchlings taken from these nests appeared ready for migration (flattened plastron and umbilical region).

Captured turtles were immediately placed in individual Styrofoam containers, lined with moist sand. They were placed in a dark room until transported to the study site (in about 20 min) after dark. At the beach each hatchling was used once in a brief, single trial (see below). Approximately equal numbers of hatchlings from at least two (or more) nests participated in each experiment. This procedure reduced the possibility that differences in orientation were a function of sampling (nest) error.

V. Bioassays: arena experiments

Arena assays are “staged emergences” that simulate a natural emergence from an undisturbed nest (Task Report II for a complete description of the procedure.). Arena experiments done in this study were completed each evening when 24 hatchlings from two or more nests had been tested.

Arenas were 4 m in diameter, and drawn as a circle in the sand. The center each arena was located 7 - 10 meters from the base of the dune. All debris on the sand surface was removed; the arena interior was then smoothed with a broom. A 4 - 6 cm shallow depression was made in the arena center.

Six hatchlings at a time were released from inside the depression, facing in random directions. The turtles almost immediately crawled out of the depression, and toward the arena boundary. The tracks they left in the sand were used as a record of their orientation behavior. Turtles were recaptured as they crossed the arena boundary, and immediately released at an adjacent dark site.

About 10 minutes prior to each experiment, the cooler lid was removed to expose the hatchlings to ambient (cooler) evening temperatures and background lighting (both of which stimulate locomotor activity). Tests began once the turtles were actively crawling inside their cooler. An experiment was completed when 24 hatchlings had been released from the arena center. On each evening, hatchlings were released from the center of two arenas (at both experimental sites, or at one experimental and the single control site). Experiments each evening were generally completed 1.0 - 1.5 h.

VI. Observations and measurements

The tracks left by each hatchling were traced on a data sheet to recording their path and exit angle. Each exit angle was measured from the arena center to the place where the hatchling’s track crosserd the arena boundary, using an electronic (“data scope”) compass. Weather conditions were recorded before and (if they changed) after each experiment was completed.

An Optic stellar photometer (16^0 angle of acceptance; maximum sensitivity at 520 nm), mounted on a small tripod, was used to measure ambient lighting at each site before the tests commenced. One set of measurements was made on the horizon, in each of eight cardinal directions (N, NE, E, SE, etc.). Light reflected from the beach surface was also measured by pointing the photometer directly downward. This datum recorded variation in reflected light, generally from cloud cover. A second set of measurements was made to record street light radiance (in photons/cm^2/s) and direction (using the electronic compass). The Optec photometer was also used to measure lunar radiance during full moon.

Preliminary measurements indicated that when the embedded lights were on, background light levels were no different from those recorded when the street lights were turned off.

VII. Data analysis

The escape angles for the turtles tested each evening were tallied to obtain a distribution of vectors for groups of turtles tested under a single treatment condition. Standard circular descriptive statistics (Zar, 1999) were used to determine a group mean angle and dispersion (r-vector). Raleigh tests were used to determine if such groups were significantly oriented. Finally, group distributions were plotted in circle diagrams subdivided into four 90^0 – wide sectors (East, West, North and South). The East quarter faced the sea. Data were plotted as the percentage of the turtles in each group whose exit angles fell within that sector.

Watson-Williams two-sample tests were used to make two between-group comparisons. First, groups tested under the same treatment conditions, but on different evenings, were tested to determine if they showed statistically identical orientation. If they did, the data were pooled. Second, tests were used to compare, at each site, group orientation when all lights were off with orientation shown by other groups exposed to streetlights or embedded lights.

RESULTS

I. Group orientation (Rayleigh tests)

Turtles tested at the Control Site showed strong seaward orientation under all treatment conditions (Fig. 3; Raleigh probabilities ≤ 0.001). Turtles at the Experimental Sites also showed significant orientation under all treatment conditions under full moon illumination ($p \leq 0.001$). The majority (≥ 80 %) of these hatchlings exited the arena from the seaward (eastward facing) sector.

Significant seaward orientation was also shown at all sites during new moon in the absence of lighting ("all off" column, Fig. 3; Raleigh probabilities ≤ 0.001).

When exposed to street lighting, orientation performance varied depending upon lunar phase. During full moon, scatter (r-vectors between 0.82 – 0.94) was lower and Raleigh probabilities ($p \leq 0.001$) were more significant than when tests were done during new moon (r-vectors between 0.22 – 0.76; probabilities range between n. s. – 0.001).

When exposed to embedded lighting, four groups showed little variation in either scatter (r vectors between 0.89 – 0.98) or orientation (Rayleigh $p < 0.001$) under either full or new moon conditions. All of these groups were tested when the sky contained either scattered clouds or no cloud cover. However one group of turtles, tested under overcast skies at Experimental Site 1, showed more scatter (r-vector = 0.70), though as a group were significantly oriented (Rayleigh $p < 0.001$).

II. Comparisons among treatments (Watson-Williams tests)

The three "all-off" groups were statistically identical (Watson-Williams tests).

Orientation when the hatchlings were exposed to either embedded or street lighting was compared to orientation by the "all off" group at their site (an "internal" site-specific control). At the control site, there were no significant differences in orientation between the "all-off" group and the groups exposed to street or embedded lighting (Table 1).

Three of four groups of turtles exposed to street lighting at the experimental sites (full or new moon) showed significant differences in orientation from the "all off" group at their site (Table 1). The exception was a group of turtles tested under full moon at Experimental Site 2.

Four of five groups of turtles exposed to embedded lighting at the experimental sites (full or new moon) showed no statistical differences from the "all off" group at their site (Table 1). The exception was one group of turtles tested under overcast skies at Experimental Site 1. The orientation of this group also differed significantly from the orientation of a group of turtles, tested under partly cloudy conditions at the same site (Watson-Williams $p \leq 0.001$).

DISCUSSION AND CONCLUSIONS

I. Do embedded lights protect the turtles?

Our results support the hypothesis that embedded roadway lighting protects hatchling sea turtles. Almost all groups of turtles, whether tested under full moon or new moon, showed significant seaward orientation when exposed to embedded lighting. The only exception was one group of turtles tested under atypical weather conditions: total overcast.

Tests conducted during that evening exposed the hatchlings to high levels of artificial lighting (sky “glow”), reflected from inland sources and not roadway sources.

Indeed, such variation in hatchling performance is typical when experiments are performed in the field, and at locations near major cities (e. g., Cowan and Salmon, 1998). At these sites, extraneous sources of artificial lighting cannot be controlled and often complicate the results. In this study lights from Boca Raton, from Highland Beach to the North, and from Hillsborough Beach to the South of the Park, are many times brighter than the specific light sources (street lights or embedded lights) we were testing. Differences in local weather conditions (atmospheric humidity, cloud cover) caused large fluctuations in how much of this extraneous lighting was reflected to the beach. These differences, apparently, overwhelmed any effect we could measure from the embedded lights. But in the absence of complete cloud cover, and under conditions typical of most evenings when arena experiments were done (scattered clouds or clear skies), turtles tested in the same location, and under the same treatment conditions, were unaffected by embedded lighting (Fig. 3; Table 1).

We could not detect any difference in landward illumination between the “embedded” treatment, and the “all off” treatment. Our results suggest that the turtles responded to both treatments identically.

II. Benefits of embedded lights

Generally, any light visible from the beach will affect sea turtle behavior. The Coastal Roadway Lighting Manual (1998) lists methods for identifying lighting problems, and proposes a step-wise strategy, using the “Best Available Technology”, for correcting roadway lighting problems. These include: (i) turning off extraneous lights, (ii) shielding required sources to prevent light from reaching the beach; (iii) reducing illuminance (by minimizing the number of lights and/or replacing higher with lower wattage luminares); and (iv) eliminating attractive (to the turtles) light wavelengths by using colored light filters and lenses that block their transmission.

The use of embedded lighting incorporates two features that help correct lighting problems. Embedded lighting reduces illuminance. It also confines light to where it is intended – the roadway surface.

III. Costs and limitations of embedded lighting as a management solution

Although we conclude that embedded lights can effectively eliminate roadway lighting problems, their use may not under all circumstances be the most effective "solution" under all circumstances. Below, we elaborate on this point.

Embedded lighting is effective at a site (such as ours) where the main source of artificial lighting is both identified and easily controlled. At Spanish River Park, there was good preliminary evidence that hatchling orientation was disrupted primarily by the streetlights. When these lights were turned off, seafinding behavior returned to normal. Under these circumstances, embedded lighting was beneficial because it providing a safe lighting alternative, and because at Spanish River Park, few other sources of light were present.

But embedded lighting would be ineffective at any location where the beach was exposed to a more complex lighting environment (many sources of lighting), at least until these were also controlled or eliminated. For example, other sources of lighting are not controlled near the Patrick Air Force Base, in Brevard County. Lighting on the entire base was modified, at great expense, to darken a sea turtle nesting beach adjacent to the facility. The project was initially successful but currently, hatchling disorientation is on the increase, especially at the North and South ends of the beach, because these areas are now exposed to increasing illumination from adjacent coastal communities (D. George, personal communication).

Finally, studies are pending to determine whether embedded lighting at coastal roadways is as safe and effective as other kinds of lighting systems. A companion study to ours, also funded by the FDOT, and will measure the psychological impact and efficacy of embedded roadway lighting, from the perspective of those operating motor vehicles.

ACKNOWLEDGEMENTS

We thank Ann Broadwell of the FDOT for initiating the embedded lighting project, and for providing the support from that agency for this study.

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Table 1. Outcome of Watson-Williams test comparisons between the "all off" group, and the groups of turtles exposed to street or embedded lighting at the same site. Sample size in the "all off" group is 48 turtles. Sample sizes for the light exposed group (N) varies between 24 - 72 turtles.

Location	Lunar Phase	Lights	N	p
Control Site	Full	Street	48	n. s.
		Embedded	72	n. s.
	New	Street	48	n. s.
		Embedded	48	n. s.
Experimental Site 1	Full	Street	48	n. s.
		Embedded	72	n. s.
	New	Street	48	< 0.001
		Embedded	48*	< 0.001
			24**	n. s.
Experimental Site 2	Full	Street	48	< 0.01
		Embedded	48	n. s.
	New	Street	48	< 0.001
		Embedded	48	n. s.

* tested under overcast skies.
**tested under partly cloudy sky at the identical location.

Figure Legends

Figure 1. Arial photograph of the study site at Spanish River Park, showing the control and two experimental sites.

Figure 2. Photographs looking North from the South end of the coastal roadway (A1A). Above, with the streetlights (filtered HPS luminaries on, and (below) with the roadway illuminated only embedded roadway lighting.

Figure 3. Results of the arena experiments, presented as circle diagrams. Each circle is subdivided into four sectors; the upper sector faces seaward (see diagram, top of figure). Length of the black bars within each sector is proportional to the percentage of the hatchlings that left the arena within that sector (circle radius = 100 %). Top row is orientation shown at the Control Site; middle and bottom rows show orientation at Experimental Sites 1 and 2, respectively. Turtles were exposed to the three lighting "treatments" at each site: embedded lights on ("Embedded"), streetlights on ("Street"), and both street and embedded lights off ("all off"). The two columns to the left show tests done under full moon illumination; the three columns to the right were done during new moon. Parentheses indicate the number of evening experiments, with n = 24 hatchlings from two or more nests used in each experiment. At Experimental Site 1, results for the "embedded" treatment during new moon are separated into two groups: two tests done under overcast skies, and one test completed under scattered cloud cover.


Spanish River Blvd
N
A1A
Spanish River Park
Control Site
Exp. Site II
Exp. Site I

Figure 1

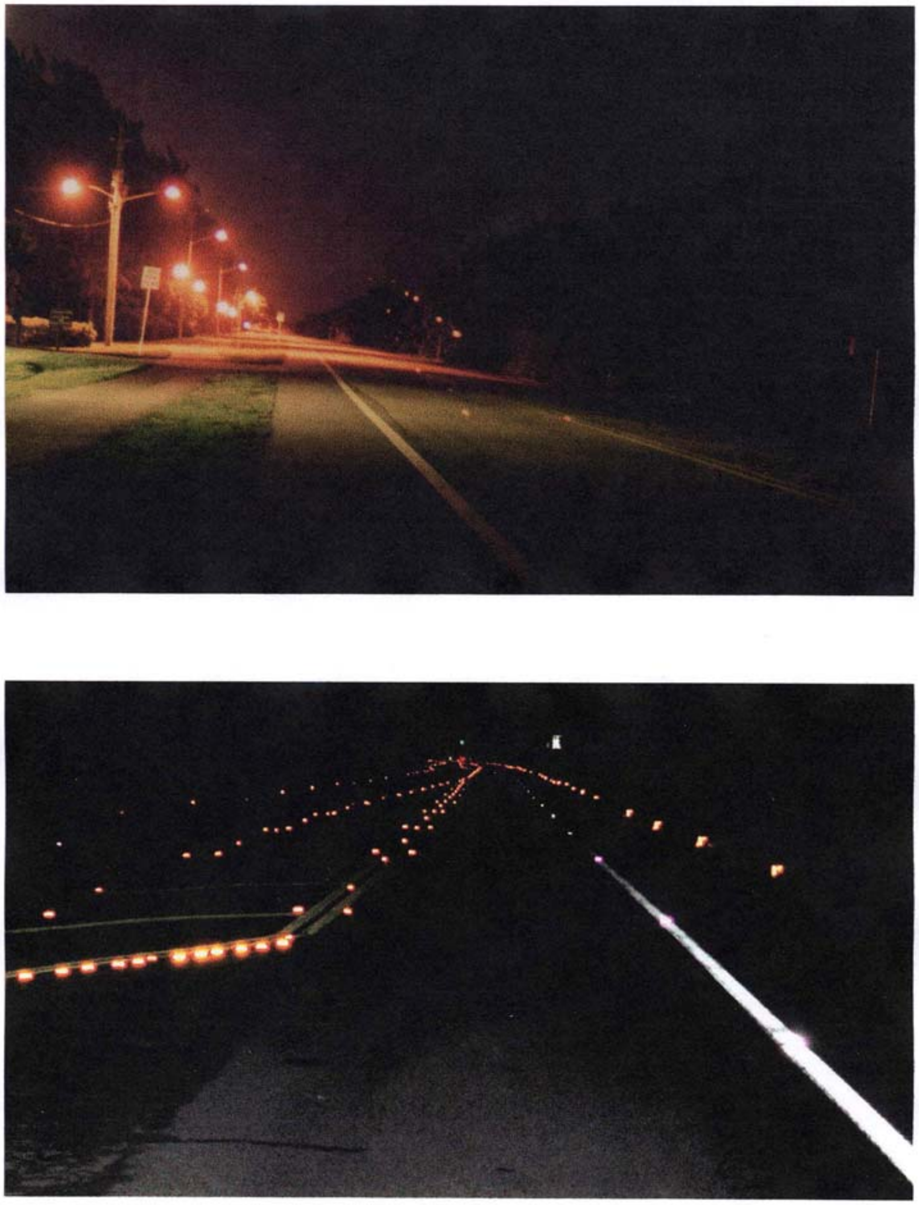

Figure 2

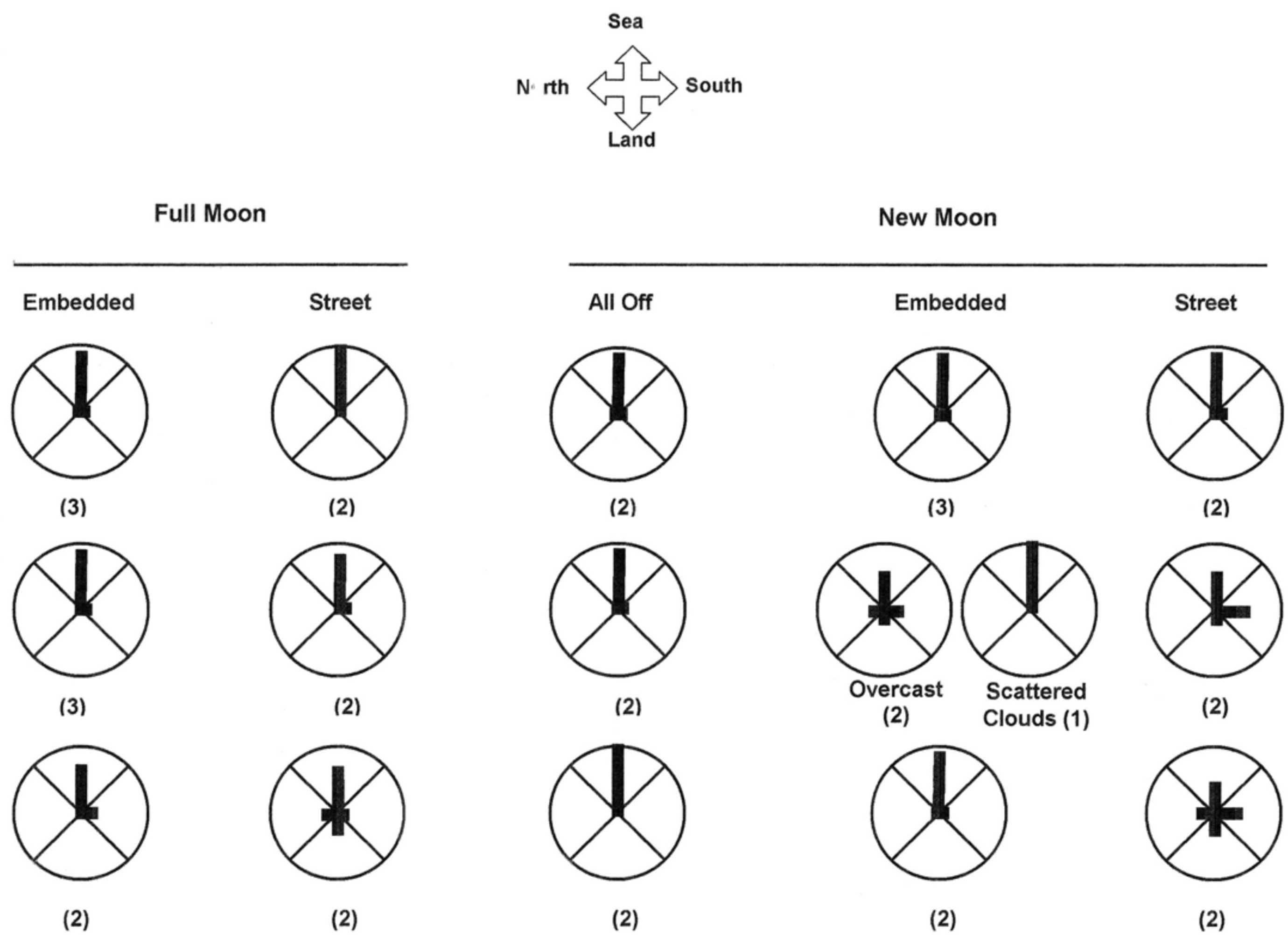
Sea
N rth
South
Land
Full Moon
New Moon
Embedded
Street
All Off
Embedded
Street
(3)
(2)
(2)
(3)
(2)
(3)
(2)
(2)
Overcast
(2)
Scattered
Clouds (1)
(2)
(2)
(2)
(2)
(2)
(2)

Figure 3