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Understanding, Assessing, and Resolving Light-Pollution Problems on Sea Turtle Nesting Beaches

FWRI Technical Report TR-2, Version 2

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Understanding, Assessing, and Resolving Light-Pollution Problems on Sea Turtle Nesting Beaches

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FWRI Technical Report TR-2, Version 2

2014

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Cover Photographs

Green turtle hatchling (R. Erik Martin) and tracks of disoriented hatchlings (Blair Witherington)

Hatchling art, page vii:

NOTE
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Document Citation

Witherington, B. E., R. E. Martin and R. N. Trindell. 2014. Understanding, assessing, and resolving light-pollution problems on sea turtle nesting beaches, revised. Florida Fish and Wildlife Research Institute Technical Report TR-2. vii + 83 p.

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Acknowledgments

Earlier editions were funded by Florida's Marine Turtle Protection Trust Fund and grants from the U.S. Fish and Wildlife Service and the Florida Game and Fresh Water Fish Commission. This revision was funded by *Deepwater Horizon* NRDA Early Restoration. Partial funding of publication was contributed by an anonymous benefactor. We offer special thanks to Anne Meylan, Barbara Schroeder, Mike Sole, Karen Williams, Meghan Koperski, Tonya Long, Luke Davis, and Ann Marie Tavares for their review and contributions to the manuscript and to Alan Huff and David Arnold for their assistance with the publication process. The current revision was overseen by Dr. Nisar Khan, Erdman Anthony & Associates, Inc. We gratefully acknowledge the information provided by the companies listed in Appendix G. In the text and appendices, we list lighting products that are acceptable for use near sea turtle nesting beaches. This listing of products and the companies that offer them is not meant to be complete; additional products and companies are presented at http://www.myfwc.com/wildlifehabitats/managed/sea-turtles/lighting/.

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Understanding, Assessing, and Resolving Light-Pollution Problems On Sea Turtle Nesting Beaches

Executive Summary

Sea turtle populations have suffered declines worldwide, and their recovery largely depends upon managing the effects of expanding human populations. One of these effects is light pollution—the presence of detrimental artificial light in the environment. Of the many ecological disturbances caused by humans, light pollution is among the most manageable. Light pollution on nesting beaches is detrimental to sea turtles because it alters critical nocturnal behaviors, namely, their choice of nesting sites, their return path to the sea after nesting, and how hatchlings find the sea after emerging.

Circumstantial observations and experimental evidence show that artificial lighting on beaches tends to deter sea turtles from leaving the sea to nest. As a result, effects of artificial lighting on nesting are not likely to be revealed just by a ratio of nests to false crawls (tracks showing abandoned nesting attempts on the beach) because it does not account for those turtles who, discouraged by the artificial lights, never left the sea.

Although turtles do tend to prefer dark beaches, many nest on lighted shores, but when they do so, hatchlings' lives are jeopardized. This threat comes from the way in which artificial lighting disrupts a critical nocturnal behavior of hatchlings—crawling from their nest to the sea. On naturally lighted beaches, hatchlings escaping from nests show an immediate and well-directed orientation toward the water. This robust sea-finding behavior is innate and is guided by visual cues that include brightness, shape, and, in some species, color in the horizon. On artificially lit beaches, hatchlings are misdirected by light sources, and they are left unable to find the water and vulnerable to high mortality from dehydration and predators. Hatchlings become misdirected because they tend to move in the direction with the brightest light and away from darker silhouettes, especially when the brightness in one direction is overwhelmingly greater than that of other directions. Artificial lighting on beaches is strongly attractive to hatchlings and can cause them to move in the wrong direction (misorientation) and interfere with their ability to orient in a constant direction (disorientation).

Understanding how sea turtles interpret light cues in choosing nesting sites and how hatchlings locate the sea has helped conservationists develop ways of identifying and minimizing problems caused by light pollution. Light conditions on nesting beaches are complex, and measuring light pollution in a way that effectively captures the impacts to sea turtles is difficult. But quantifying light pollution is not necessary to the diagnosis of a problem. We offer this simple rule: *If light from an artificial source is visible to a person standing on a beach, that light is likely to cause problems for sea turtles that nest there.*

Because there is no single minimum measurable level of artificial brightness on nesting beaches that is acceptable in sea turtle conservation plans, the most effective conservation strategy is simply to use "best available technology" (BAT: a common strategy for reducing pollution using the best available pollution-reduction technologies) to reduce effects of lighting as much as practicable. Best available technology includes many light-management options that have been used by lighting engineers for decades and others that are unique to protecting sea turtles.

The simple strategy of "keep it long, keep it low, and keep it shielded" can be implemented on nesting beaches to help protect sea turtles. Light sources emitting low levels of long-wavelength light—sources that appear deep red or yellow—affect both hatchlings and nesting adults less than do sources emitting higher levels of short-wavelength light—sources that appear whitish or any color other than deep red or yellow. Light sources can be repositioned behind structures, shielded, redirected, lowered, or recessed so that their light does not reach the beach. While timers and motion detectors can be installed to ensure that lights come on only when needed, installing the correct lights only where needed for human safety is the best strategy for protection of sea turtles and people. Interior light levels can be reduced by moving lamps away from windows, drawing blinds after sundown, and tinting windows.

To protect sea turtles, artificial lighting need not be prohibited if it can be properly managed. Light is being properly managed when it cannot be seen from the beach.

The most recent version of this FWC technical report, its third and revised edition, was published in 2003. This 2014 revision provides a brief account of recent research in sea turtle behavior and lighting and summarizes data regarding the status of endangered sea turtles in Florida.

The four sections in the current report include Problems, Assessments, Solutions, and Overview. The Problems section describes the effects of artificial lights on humans and

sea turtles. The impact of artificial lighting on sea turtles and the development of good lighting management practices to reduce these impacts is the primary focus of this Technical Report. However, light pollution is harmful to humans also. In fact, a growing body of research in photobiology indicates that humans, wildlife, and plants are affected by artificial lighting.

The Assessment section includes updated information on lighting inspections and monitoring sea turtle behavior, as well as a brief discussion about laws regulating lights in Florida.

The Solutions section underscores the use of BAT to manage lights from indoor and outdoor sources. Amber light emitting diodes (LEDs), red neon, and low-pressure sodium-vapor luminaires are good substitutes for more disruptive lighting near sea turtle nesting beaches. Effective Methods for Managing Light includes an overview of the current status and lessons learned. Solutions are provided for several categories of common light-pollution problems: swimming pools, parks, piers, sidewalks, walkways, bikeways, streetlights, parking facilities, decorative lights, and illuminated signs.

Making the public aware of light pollution problems on sea turtle nesting beaches is a fundamental step toward darkening beaches. Many of those responsible for errant lighting are unaware of its detrimental effects and are generally willing to correct such problems once they are made aware of them. Nonetheless, legislation requiring light management is often needed, and on many nesting beaches it may be the only means of fully resolving light pollution problems.

The Overview section includes a brief assessment of past efforts of managing artificial lighting on the nesting beaches and information on the nesting trends. Success stories involving retrofitting problematic lighting for public and private buildings and streetlights are included. Future strategies, involving outreach to students and employing new technologies, are discussed. The last portion of this section attempts to address questions commonly raised by lighting design professionals involved in projects in coastal areas.

Appendices provide additional information on appropriate lamp types, lamp colors, fixture designs, and fixture mounting for various applications near sea turtle nesting beaches. They also provide information for contacting lighting companies that offer appropriate lighting fixtures and governmental and nongovernmental organizations that can help with sea turtle conservation. Last, they suggest responses to commonly encountered questions and comments regarding sea turtles and artificial lighting.

TRUST

The sea produced an ancient form
with aquatic wings for soaring
that gouged the sand away from tide
above the ocean's pouring.

She abandoned hope to trust the past,
heaved forth the future and at last,
buried it and left.

Now, two moons hence, little turtles pip,
with soft struggling bodies hatching.
The sands ensconce as eggs are
ripped by contorted masses scratching.

The siblings toil at a common chore
to whittle ceiling into floor,
until at sand's surface just short of sky,
the unsettled lie, becalmed.

The tangled turtles wait
as heat of day abates
and cool of night prods
their reluctance away.

At dusk the fits and starts begin and
then through claw and strain, above
their heads sand rains again, and
yields to sky of night.

This army boiling in the night gains might,
and in waves, pours forth to see the sight.
Soft flippers patter and wipe sand from view
that eyes might seize upon the cue that betrays the sea.

And then, eyes do, they catch the glow
and every hatchling keen
rushes on to the goal they know
but they have never seen.

As if clockwork toys tightly wound
they keep pace and bearing tight,
for unless the sea is quickly found,
they will not survive the night.

They choose their erring paths
with neither doubt nor anticipation,
and their consistency deals them life or death
with quiet resignation.

Thus, night wanes and sights of light remaining
scatter throngs persistent
and about the dune abundant obstacles restraining,
divide the dying from the spent.

Weakened few reach the sight they sought,
a deceptive brightness reassuring
where trusting forms are caught
by the sight of lights alluring.

Dawn now dries their searching eyes
and death now rests the weary.
Might fate have been more kind
to travelers more leery?

Were these turtles to awaken,
could they sense their mother's plight
having left her young forsaken
owing confidence in light?

Past's light offered not such bitter seas
nor played such deadly roles
to guide hatchlings on to sights like these
electric lights on poles.

Might we masters of the light adapt,
forgo complete control,
and lessen obsolescence
lest our presence take its toll?

To tread on earth with darkness soft
leaves not the night asunder
and preserves the stars and moon aloft,
and obsoleted wonders.

—BEW

Understanding, Assessing, and Resolving Light-Pollution Problems on Sea Turtle Nesting Beaches

Introduction

Sea turtles are marine reptiles that have declined from their historical abundance due to a variety of anthropogenic effects. Of the seven species of sea turtles, six are found in U.S. waters: green (*Chelonia mydas)*, hawksbill (*Eretmochelys imbricata)*, Kemp's ridley *(Lepidochelys kempii)*, leatherback *(Dermochelys coriacea)*, loggerhead *(Caretta caretta),* and olive ridley *(Lepidochelys olivacea)*. The seventh species, the flatback (*Natator depressus)*, is found only in Australia.

All six species found in U.S. waters are listed in the U.S. Endangered Species Act of 1973 as being threatened (i.e., likely to become an endangered species within the foreseeable future) or endangered (in danger of extinction). State and local laws affording protection to sea turtles also exist and are enforced. The flatback sea turtle species is also listed as vulnerable by the Australian government.

Sea turtle conservation requires solutions to threats in both the marine and terrestrial environments. Major threats to sea turtles in the United States include destruction and alteration of nesting and foraging habitats; incidental capture in commercial and recreational fisheries; entanglement in marine debris; and vessel strikes. International conventions and U.S. regulations have been enacted as well to reduce incidental capture.

Humans and sea turtles share ocean beaches. On these narrow strips of sand, humans live, recreate, and conduct commerce—and sea turtles nest. The consequences of the profound environmental changes triggered by human actions can be severe for sea turtles. While all aspects of habitat alteration deserve serious attention, our focus in this manual is the distinctive and particularly damaging type of habitat alteration that affects sea turtles at the nesting beach, namely, light pollution—the introduction of artificially produced, detrimental light into the environment. Light pollution is an important problem with achievable solutions that benefit humans by reducing exposure to the harmful effects of artificial lighting such as sleep deprivation, glare, and the possible connection to certain type of cancers. Reducing light pollution also saves energy and reduces sky glow which is defined as added sky brightness caused by the scattering of artificial light into the atmosphere. At high enough levels of scattered lights, the sky will appear as a self-luminous body, and will glow.

Light from artificial sources differs markedly from other pollutants both in its form and in its effect on sea turtles. Light pollution is not a toxic material, but it has great potential to disrupt behaviors such as the selection of nesting sites by adult turtles and the movement off the beach by hatchlings and adults, with profound effects on sea turtle survival.

This manual is intended to help conservation field workers, lighting design professionals, governmental and agency decision makers, and the general public, especially residents and business owners in coastal areas. Light management, if carefully developed and implemented, does not involve choosing between human safety and security and sea turtle survival. Techniques, products, and practices that help ensure sea turtle survival are also beneficial for humans in the coastal environment.

While the primary area of coverage for this manual is Florida, the concepts and details presented here are universal to any beach on which humans and sea turtles interact.

Problems: The Effects of Artificial Lighting on Humans and Sea Turtles

PHOTOBIOLOGY

The impact of artificial lighting and the development of good light-management practices for sea turtles are the primary foci of this technical report. But inappropriate nighttime lighting also impacts humans—the wrong type or amount of night lighting can affect human health as well (Hölker et al., 2010). Prudent light-management strategies for coastal communities therefore require understanding impacts to and needs of humans as well as of sea turtles.

Photobiology combines the studies of light and biology. Humans, wildlife, and plants evolved under a distinct pattern of light and dark that influenced many basic biological functions. Almost all species of plants and animals operate under an inherent circadian cycle, or rhythm, over a 24-hour day/night cycle. Shifts between daylight and darkness in turn influence important internal physical processes as well as the functioning of natural communities and animal behavior. Artificial lighting disrupts this natural cycle for animals and people. The impacts of light pollution on humans can be divided into those that affect human health, such as sleep disruption, and those that impact safety, such as interference with normal night vision. Light pollution affects both nesting female and hatchling sea turtles during their short but critical time on the nesting beach.

Sea Turtle Nesting

THE NESTING PROCESS

Sea turtles are marine reptiles that deposit their eggs above the high-tide line on sand beaches. Sea turtle nesting in Florida is seasonal and for most populations begins in late spring and concludes in late summer. Although more than one sea turtle species may nest on a given beach, their nesting seasons are often slightly offset. In Florida, for instance, leatherbacks begin nesting in mid-March and conclude in mid-July, loggerheads begin nesting in early May and conclude in late August, and green turtles begin nesting in early June and conclude by mid-September (Meylan et al., 1995).

Depending upon the species, females reach sexual maturity in 10–50 years. Nesting occurs from two to eight times in a season, at intervals ranging between 9 and 14 days. The nesting cycle is repeated in another 2–5 years. While nesting is widespread in Florida, the beaches of greatest nesting density for three species—loggerhead, green, and leatherback—are located along the southeast coast, suggesting that common selection pressures determine their choice. These sites are all close to the Florida Current (the western portion of the Gulf Stream). Since hatchlings are strong but slow swimmers, this proximity to favorable oceanic currents is believed to be one of many factors influencing the choice of a nesting beach by females (Salmon, 2003).

Except for the flatback turtle (B. Prince, personal communication), Kemp's ridley (Pritchard and Marquez, 1973), and some populations of hawksbills (Brooke and Garnett, 1983), sea turtle nesting occurs almost exclusively at night. All sea turtle species have in common a series of stereotyped nesting behaviors (descriptions given by Carr and Ogren, 1959; Carr et al., 1966; Bustard, 1972; Ehrenfeld, 1979; Hirth and Samson, 1987; Hailman and Elowson, 1992; Hays and Speakman, 1993; Salmon, 2003), although there are subtle differences between species and some elements of this behavior may vary between individuals and between nesting attempts. For example, nesting behavior may vary with regard to where turtles emerge onto land; where on the beach they begin to construct their nests; whether they abandon their nesting attempts and, if so, at what nesting stage they abandon it; and the directness of their paths as they return to the sea. These variations in nesting behavior can affect the success of egg deposition and hatchling production and the well-being of nesting turtles.

During nesting, an adult female sea turtle: 1) emerges from the surf zone; 2) crawls up the beach to a point typically between the high-tide line and the primary dune; 3) prepares the nest site by pushing or digging surface sand away to form a body pit; 4) digs an egg cavity within the body pit using the rear flippers; 5) deposits eggs within the egg cavity; 6) covers the eggs with sand; 7) camouflages the nest site by casting sand, principally with front-flipper strokes; 8) turns toward the sea; and 9) crawls into the surf (Hailman and Elowson, 1992, include an additional wandering phase). For the most part, the pattern of each of these behaviors (how they are performed) is not affected as greatly by external stimuli (such as the presence of humans or lights) as are the decisions that determine the timing, duration, and accuracy of the behaviors. Functionally, these decisions affect the selection of a nest site, the abandonment or abbreviation of nesting behaviors, and the accuracy of sea-finding.

DISRUPTION OF NEST-SITE SELECTION

Sea turtles select a nest site by deciding where to emerge from the surf and where on the beach to put their eggs. The most clearly demonstrated effect of artificial lighting on nesting is to deter turtles from emerging from the water.

Evidence for this has been given by Raymond (1984b), who reported a dramatic reduction in nesting attempts by loggerheads at a brightly lighted beach site in Florida. Elsewhere in Florida, Mattison et al. (1993) showed that there were fewer loggerhead nesting emergences at locations at which lighted piers and roadways were close to beaches. Mortimer (1982) described nesting green turtles at Ascension Island as shunning artificially lighted beaches. Other authors have noted a relationship between lighted beach development and reduced sea turtle nesting: Worth and Smith (1976), Williams-Walls et al. (1983), Proffitt et al. (1986), and Martin et al. (1989) for loggerheads in Florida; Witherington (1986), Worth and Smith (1976), and Ehrhart (1979) for green turtles in Florida; and Dodd (1988), Witham (1982), and Coston-Clements and Hoss (1983) in reviews of human impacts on sea turtle nesting. Salmon et al. (1995a) found that loggerheads that do nest on beaches where the glow of urban lighting is visible behind the dune tend to prefer the darker areas where buildings are silhouetted against the artificial glow. Other authors have mentioned reduced nesting activity at lighted and developed beaches (Kamrowski et al., 2012; Ziskin et al., 2008) or nesting in spite of lighted development (Mann, 1977), but in some areas other contributing factors such as increased human activity near developed areas may also have an impact on nesting (Mazor et al., 2013; Talbert et al., 1980).

In addition to evidence pointing to a correlation between lighted beaches and reduced nesting, evidence from experimental field work directly implicates artificial lighting in deterring sea turtles from nesting (Witherington, 1992a). In these experiments, undeveloped nesting beaches were left dark or were lighted with one of two types of commercial light sources. Both green turtles and loggerheads showed a significant tendency to avoid stretches of beach lighted with white mercury-vapor luminaires (Figures 1 and 2). But any effect of yellow low-pressure sodium-vapor luminaires on loggerhead or green turtle nesting could not be detected. Because the mercury-vapor luminaires reduced both nesting and nonnesting emergences, it seems that the principal effect of artificial lighting on nesting is to deter turtles from leaving the water. Thus, we cannot rely on a ratio of tracks of nesting turtles to those of nonnesting turtles to reveal effects of artificial lighting. The reason that artificial lighting deters nesting emergences is not known. Turtles may perceive artificial lighting on a beach as daylight, which may suppress a behavior that is usually nocturnal. Once on the beach, sea turtles select a place to make a nest. In the field experiments by Witherington (1992a), artificial lighting had no effect on the distance from the dune at which sea turtles placed their nests. Nest placement on the beach may depend most heavily on nonvisual cues such as temperature gradients (Stoneburner and Richardson, 1981; Salmon et al., 2005) or beach slope (Wood and Bjorndal 2000).

The illumination of sea turtle nesting beaches can be considered a form of habitat loss. When lighting deters sea turtles from approaching nesting beaches, they may select less appropriate nesting sites. Worth and Smith (1976) reported that loggerheads deterred from nesting reemerged onto beaches outside their typical range. Murphy (1985) found that loggerheads, repeatedly turned away as they made nesting attempts, chose increasingly distant and inappropriate nesting sites in subsequent nesting attempts. If we assume that sea turtles choose nesting sites based upon favorable conditions for safe nesting and the production of fit offspring, then light pollution can be said to force some turtles into suboptimal nesting habitat. In the Caribbean, adult female turtles held in pens during the nesting season often drop their eggs without nesting (A. Meylan, personal communication).

NESTING BEHAVIOR ABANDONMENT AND ABBREVIATION

Sea turtles that emerge onto beaches often abandon their nesting attempts before putting their clutches of eggs into the sand. Nesting success (the number of nests divided by attempts) varies among beaches and among species. Among 28 Florida nesting beaches surveyed in 1994, nesting success for loggerheads was 53% (n = 52,275 nests), 52% for green turtles (n = 2,804 nests), and 83% for leatherbacks (n = 81 nests) (Florida Department of Environmental Protection, Index Nesting Beach Survey Program). Nesting success for Florida loggerheads in 1994 was 61% (n = 3,704 nests) at the undeveloped beaches of the Canaveral National Seashore and 45% (n = 6,026 nests) at the residential and heavily armored beaches of Jupiter Island. The Florida Statewide Nesting Beach Survey data for the 2012 season reported a total of 98,601 loggerhead nests statewide with 99,535 non-nesting emergences (50% nesting success). Green turtles created 9,617 nests and 11,312 nonnesting emergences were documented (46% nesting success). The numbers for leatherback turtles were 1,712 and 350, respectively, indicating 83% nesting success. Similar to the trend reported above for 1994, nesting success for loggerheads at the relatively darker beaches of Brevard County was 60% (n = 24,630) and 46% (n = 16,986) for the Palm Beach County beaches.

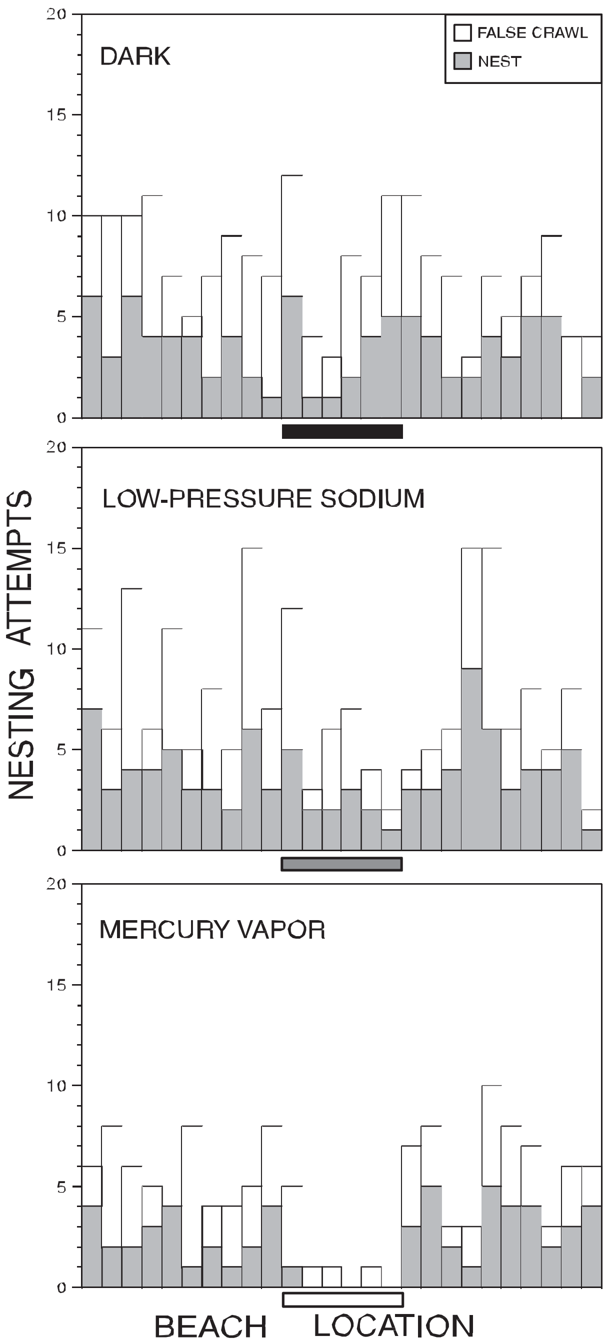

Figure 1. The distribution of loggerhead nesting attempts on a 1,300-m stretch of beach at Melbourne Beach, Florida. The beach locations were divided into 50-m sections. The horizontal bars show the section of beach where luminaires were set up—either lighted mercury-vapor luminaires (open bar), lighted low-pressure sodium-vapor luminaires (shaded bar), or luminaires that were not lighted (dark bars). Data are from Witherington (1992a).

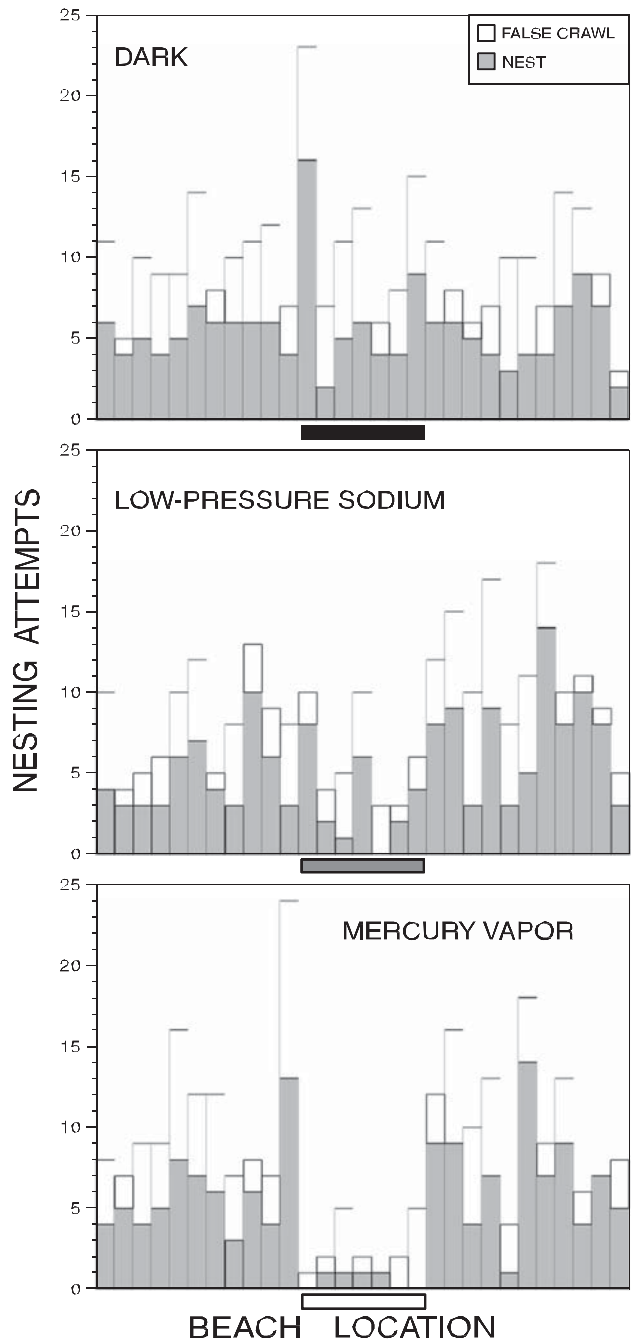

Figure 2. The distribution of green turtle nesting attempts on a 1,450-m stretch of beach at Tortuguero, Costa Rica. Identifications are as in Figure 1.

Sea turtles will abandon nesting attempts when they encounter digging impediments, large structures, unsatisfactory thermal cues, or human disturbance; when there are injuries to the rear flippers; or when other influences recognized thus far only by the turtles deter them (B. Witherington and R. Martin, unpublished data; Stoneburner and Richardson, 1981; Fangman and Rittmaster, 1993).

Sea turtles are most vulnerable to human disturbance during the initial phases of nesting (i.e., from emergence from the sea through egg-cavity excavation; Hirth and Samson, 1987), and during this period, green turtles are reported to be deterred by people with flashlights (Carr and Giovannoli, 1957; Carr and Ogren, 1960). For nesting loggerheads and green turtles, the presence of people moving within the field of view of a turtle may cause abandonment just as often as—and perhaps more often than—hand-held lighting, but this has yet to be studied experimentally.

Witherington (1992a) reported that stationary lighting did not cause loggerheads and green turtles to abandon their nesting attempts on the beach. In that study, however, so few turtles emerged onto the mercury vapor–lighted portion of the beach that too few nesting attempts were recorded to allow a proper test of nesting success.

Although sea turtles are less likely to abandon nesting attempts once they have begun to deposit eggs, the normal post-oviposition behavior of covering the eggs and camouflaging the nest site can be abbreviated if a turtle is disturbed. Johnson et al. (1996) measured the behavior of loggerhead turtles observed by turtle-watch ecotourism groups and found that watched nesting turtles had shorter-than-average bouts of nest covering and camouflaging. During similar observations of turtles watched by unorganized groups of people with flashlights, a green turtle illuminated by a bright flashlight covered its eggs, cast sand, and began a return to the sea less than five minutes after oviposition (green turtles normally take approximately 50 minutes for these behaviors; B. Witherington, personal communication; Hirth and Samson, 1987). No studies have attributed an abbreviation of nesting behavior to the effects of stationary lighting near nesting beaches.

DISRUPTION OF SEA-FINDING

After a sea turtle has camouflaged her nest, she must orient toward the sea and return there. Experiments with blindfolded green turtles that had finished nesting (Ehrenfeld and Carr, 1967; Ehrenfeld, 1968), experiments with blindfolded immature green turtles (Caldwell and Caldwell, 1962), and observations of orientation in nesting leatherbacks (Mrosovsky and Shettleworth, 1975) indicated that these turtles rely on vision to find the sea. The blindfolding experiments allowed Ehrenfeld (1968) to determine how the light reaching each eye of an adult turtle influenced the direction it would turn and which way it would travel relative to the sea. The mechanism for this phototropotaxis—literally, turning and movement with respect to light—seemed to match the way that other, much simpler, organisms orient toward light. In essence, the turtles appeared to turn so that perceived light intensity was balanced between their eyes, a balance that seemed to guarantee orientation toward the brightest direction.

Given an adult sea turtle's reliance on brightness for correct seaward orientation, it is not surprising that artificial lighting disrupts this sea-finding behavior. But it is surprising how rarely this occurs. Turtles attempting to return to the sea after nesting are not misdirected nearly as often as are hatchlings emerging on the same beaches. In the lighted-beach experiments described by Witherington (1992a), few nesting turtles returning to the sea were misdirected by lighting; however, those that were (four green turtles and one loggerhead) apparently spent a large portion of the night wandering in search of the ocean. An unprecedented number of misoriented female leatherback turtles and hatchlings were reported during the 2006–2007 nesting season on a beach in Gabon, on the west-central coast of Africa. The misoriented females and hatchlings were found in the nearby savanna away from the ocean. This was considered a direct impact of increased artificial lighting from new coastal construction. The same study also reported that the influence of artificial lights was often offset by silhouettes created by logs (lost during commercial timber transport) and escarpments resulting from beach erosion. Artificial and natural cues are precariously balanced. Overall the attraction to artificial lights was greater than the effect of landward silhouette cues. The landward silhouette cues were more effective during a full moon (Bourgeois et al., 2009).

Because misdirected nesting turtles may not be able to re-enter the ocean because of topography and obstacles, disruption of sea-finding may mean much more than a simple delay. At Jumby Bay, Antigua, a hawksbill that had nested was found far from the beach and crawling toward distant security lighting (C. Ryder, personal communication). At Hutchinson Island, Florida, adult loggerheads have left the beach and been found crawling toward parking lot lights near a busy highway or floundering in shallow ponds near condominium lighting (R. Martin, personal observation). At Melbourne Beach, Florida, a green turtle wandered off the beach in the direction of mercury-vapor lighting and was found in a roadside parking lot (B. Witherington, personal observation). Observers believed that none of these turtles would have been able to return to the sea without help. A number of nesting females have been struck and killed by vehicles after wandering onto the road. At Patrick Air Force Base, Florida, assistance came too late for a nesting loggerhead that had wandered toward a high-pressure sodium-vapor floodlight and onto a nearby highway, where it was struck and killed by a passing car (S. Johnson, personal communication). In 2014, a female loggerhead was struck and killed by a car at Gulf Islands National Seashore after moving away from the beach toward landward lights (R. Trindell, personal communication).

Hatchling Sea Turtle Orientation

THE ACT OF SEA-FINDING

One of the most critical acts a sea turtle must perform takes place immediately after it views the world for the first time, as a hatchling. From one to seven days after hatching beneath the sand (Demmer, 1981; Christens, 1990), hatchlings emerge from their nest en masse and in normal circumstances quickly orient toward the sea. This emergence of hatchlings and subsequent sea-finding takes place principally at night (Hendrickson, 1958; Carr and Hirth, 1961; Bustard, 1967; Neville et al., 1988; Witherington et al., 1990; Moran et al., 1999; Bourgeois et al., 2009; Berry et al., 2013; Peterson et al., 2013), although some early-morning (Chavez et al., 1968) and late-afternoon (Witzell and Banner, 1980) emergences have been reported. Loggerhead hatchlings in Florida emerge between dusk and dawn, with peak emergence near midnight (Witherington et al., 1990), Figure 3.

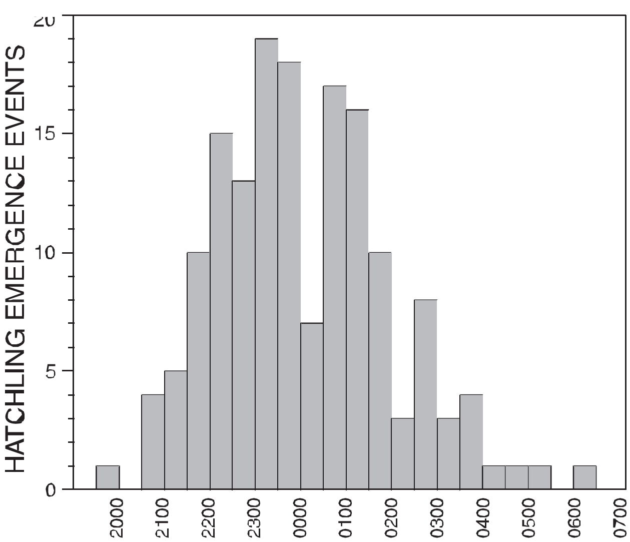

Figure 3. *The timing of 157 loggerhead hatchling emergence events from natural nests at Melbourne Beach, Florida, between 29 July and 1 September 1988. An emergence event was defined as the movement of 10 or more hatchlings from nest to sea. Data are from Witherington et al. (1990).*

Hatchlings emerge at night, which allows them to avoid predation and to prevent overheating. The most probable thermal cue controlling hatchling emergence is change of temperature at superficial sand depth (Moran et al., 1999; Glen et al., 2006). Hatchling emergence is inhibited when subsurface temperatures are increasing. So long as night is relatively cooler than day, this mechanism ensures predominantly nocturnal hatchling emergence regardless of sand albedo (proportion of incident light or radiation reflected by a surface), seasonality, or latitude (Glen at al., 2006).

Under natural conditions, hatchling sea turtles that have just emerged from the sand crawl in a frenzy directly from nest to sea. The zeal characterizing this seaward crawl is justified given the consequences of delay—death. Hatchlings that are physically kept from the sea or whose sea-finding is disrupted by unnatural stimuli often die from exhaustion, dehydration, predation, or other causes (McFarlane, 1963; Philibosian, 1976; Hayes and Ireland, 1978; Mann, 1978; Glen et al., 2006; Bourgeois et al., 2009; Berry et al., 2013; Peterson et al., 2013).

HOW HATCHLINGS RECOGNIZE THE OCEAN

The first authors to study the sea-finding behavior of sea turtle hatchlings focused on associations between observed behavior and potential environmental cues (Hooker, 1907, 1908a, b) and later verified which of a hatchling's senses were necessary for sea-finding (Hooker, 1911; Parker, 1922; Daniel and Smith, 1947a, b; Carr and Ogren, 1960). A major conclusion of these early studies was that hatchlings rely almost exclusively on vision to recognize the sea. There are a number of supporting observations:

1. Hatchlings with both eyes blindfolded circle or remain inactive and seem to be unable to orient directly to the sea (Daniel and Smith, 1947a; Carr and Ogren, 1960; Mrosovsky and Shettleworth, 1968, 1974; Mrosovsky, 1977; Rhijn, 1979).

2. Visual stimuli such as light shields (Hooker, 1911; Parker, 1922; Carr and Ogren, 1959, 1960; Mrosovsky and Shettleworth, 1968, 1975) and artificial lighting (Daniel and Smith, 1947a; Hendrickson, 1958; McFarlane, 1963; Mann, 1978) greatly interfere with hatchling sea-finding performance.

3. Placing hatchlings where the ocean horizon cannot be seen but where other, nonvisual, cues should be detectable typically prevents seaward orientation (Hooker, 1908b; Daniel and Smith, 1947a; Carr and Ogren, 1960; Carr et al., 1966; Mrosovsky, 1970).

Although studies suggest that hatchlings may be able to respond to beach slope, such nonvisual cues appear to have a small influence on directional movement and probably do not come into play when light cues are available (Rhijn, 1979; Salmon et al., 1992).

BRIGHTNESS CUES

A great deal of evidence suggests that brightness is an important cue used by hatchlings in search of the ocean. Hatchlings move toward bright artificial light sources in both laboratory and field settings (Berry et al., 2013; Daniel and Smith, 1947a; Harewood and Horrocks, 2008; Hendrickson, 1958; Lorne and Salmon, 2007; Mrosovsky and Shettleworth, 1968) and toward reflective objects on the beach (Carr, 1962).

The role of brightness in sea-finding has two basic aspects. The first aspect is the mechanism by which hatchlings use their eyes and brain to point themselves in the brightest direction—how they turn toward brightness. The second aspect is a model that describes the properties of brightness of importance to a hatchling—how we might predict where a hatchling will go.

TURNING TOWARD BRIGHTNESS

Two mechanisms have been proposed to explain how hatchling sea turtles turn toward the brightest direction. Evidence for the first mechanism comes from experiments that have capitalized on the odd turning or "circus movements" made by partially blindfolded hatchlings (Mrosovsky and Shettleworth, 1968). In this mechanism, hatchlings are described as having many light-intensity comparators within each eye that would give them a way to compare the light intensity reaching them from different directions. Thus, if the comparator aimed posteriorly within the left eye of a hatchling (a comparator that would be near the nasal margin of the curved retina of the left eye) detects the brightest input of light, the hatchling would "know" to turn left in order to orient in the brightest direction. Similarly, after turning toward the brightness until the light-intensity inputs between the eyes are balanced, the hatchling would "know" that it has reached an orientation in the brightest direction. This mechanism has been called a complex phototropotaxis system (Mrosovsky and Kingsmill, 1985). *Complex* refers to the many comparators involved, and *phototropotaxis* (photos = light, tropos = a turning, tasso = to arrange) refers to a turning and movement toward light.

In a second proposed mechanism, hatchlings are described as having an integrated array, or "raster system," of light sensors within both eyes that would allow them to instantaneously interpret the brightest direction. Rather than sensing detail, this hypothesized raster system would integrate a measure of brightness over a broad area. This mechanism is referred to as a telotaxis system (Verheijen and Wildschut, 1973; Mrosovsky and Shettleworth, 1974; Mrosovsky et al., 1979). *Telotaxis* (telopos = seen from afar, tasso = to arrange) refers to a fixation on and movement toward a target stimulus.

Unfortunately, the differences between these proposed mechanisms are too subtle to allow them to be separated by the experimental evidence at hand. The more "complex" a phototropotaxis mechanism becomes, the more it functionally resembles a telotaxis mechanism (Schöne, 1984). The actual visual-neural system that hatchlings use to turn toward the brightest direction and maintain that orientation may incorporate aspects of each of the proposed mechanisms.

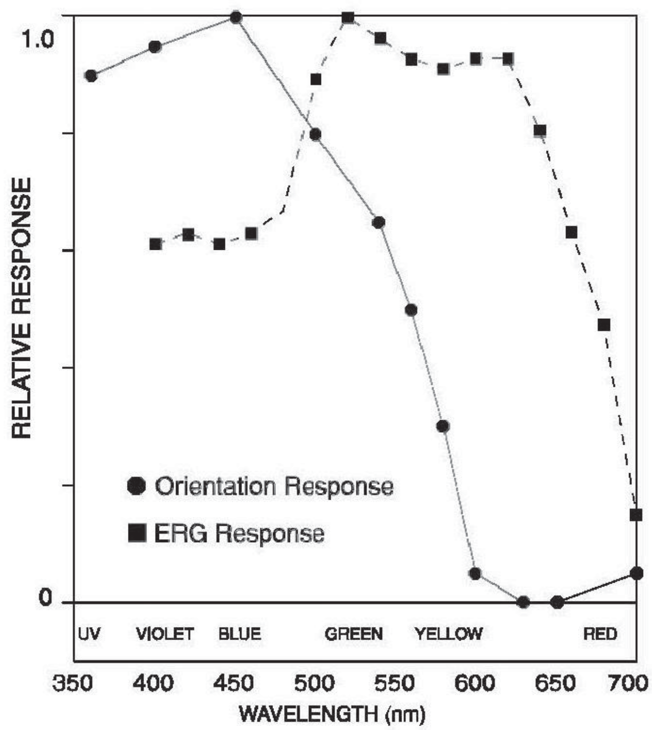

***Figure 4**. A comparison of the orientation and physiological (ERG) responses of green turtle hatchlings to colored light. The orientation response curve shows how attractive the light is to green turtle hatchlings, and the ERG response curve gives an approximation of how bright the light appears to them. Orientation data are from Witherington (1992b), and ERG data are adapted from Granda and O'Shea (1972). Figure adapted from Witherington (1997); used with permission.*

A MODEL FOR MEASURING BRIGHTNESS

To determine the brightest direction, hatchlings must be able to "measure" brightness. Knowing the properties of the "brightness detector" used in this measurement is essential to our understanding a hatchling's response to its world. Although simplistic, modeling hatchlings as biological brightness detectors is a useful way to introduce the properties of light that most affect hatchling orientation.

Spectral properties of the brightness detector.—The spectral properties of a detector—or an eye—reveal its sensitivity to different wavelengths of light. In bright light, we see different wavelengths and combinations of wavelengths as colors. But independent of color, some wavelengths appear brighter to us than others, just as there are some wavelengths that we cannot see.

The term "brightness" is often used in the sea turtle orientation literature and generally refers to the intensity and wavelength(s) of light relative to the spectral sensitivity of an individual (Ehrenfeld and Carr, 1967; Mrosovsky, 1972; Rhijn, 1979; Mrosovsky and Kingsmill, 1985). Brightness is undoubtedly in the eye of the beholder. The different-colored photopigments and oil droplets within the retina of a sea turtle's eye (Granda and Haden, 1970; Liebman and Granda, 1971; Granda and Dvorak, 1977) provide a unique set of conditions that influence how sea turtles make their determination of brightness. Researchers have learned much about sea turtles' perception of brightness by using a procedure called electroretinography (ERG) to measure the relative electrical potential across retinas of turtles exposed to different wavelengths of light. ERG data show that green turtles are most sensitive to light in the violet to orange region of the visible spectrum, from 400 to 640 nm (Figure 4; Granda and O'Shea, 1972; Levenson et al., 2006). In daylight, green turtles show a greater spectral sensitivity within the shorter-wavelength (blue) region of the spectrum than humans do.

Although ERG data provide important physiological information, the most direct way to determine the effects of spectral light on orientation is to conduct behavioral experiments. The earliest studies on hatchlings' responses to light wavelengths employed broadband (multiple wavelength–transmission) filters to vary the wavelengths that reached orienting hatchlings (Mrosovsky and Carr, 1967; Mrosovsky and Shettleworth, 1968). Although reactions to specific wavelengths could not be determined, the green turtle hatchlings studied were clearly more strongly attracted to blue light than to red light.

In later experiments, researchers used narrowband (monochromatic) filters to vary the wavelengths reaching loggerhead, green turtle, hawksbill, and olive ridley hatchlings (Witherington and Bjorndal, 1991a; Witherington, 1992b, Fritsches, 2012). The use of monochromatic filters allowed a simple measure of light intensity so that researchers could determine the responses of hatchlings to a set number of photons at each of several wavelengths. As in previous experiments, hatchlings showed a preference for short-wavelength light. Green turtles, hawksbills, and olive ridleys were most strongly attracted to light in the near-ultraviolet to yellow region of the spectrum and were weakly attracted or indifferent to orange and red light (Figure 5). Loggerheads were most strongly attracted to light in the near-ultraviolet to green region and showed an unexpected response to light in the yellow region of the spectrum. At intensities of yellow light comparable to a full moon or a dawn sky, loggerhead hatchlings showed an aversion response to yellow light sources (Figure 5: Lohmann et al., 1996; Witherington, 1997), although subsequent assays for Australian loggerheads did not find a similar aversion to yellow light (Fritsches, 2012). At low, nighttime intensities, logger-

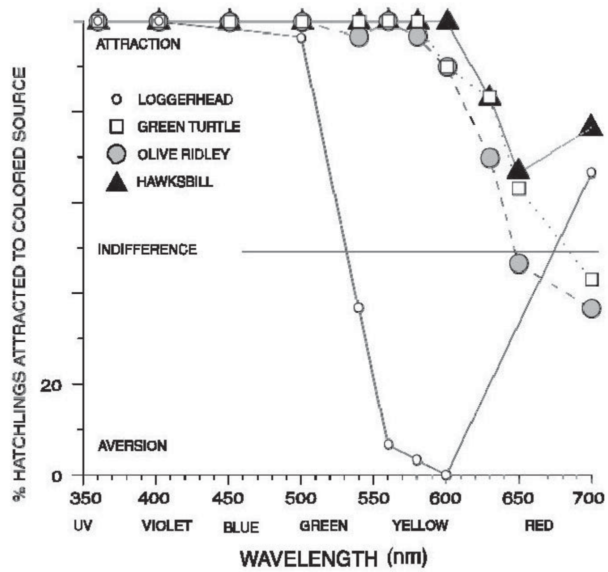

Figure 5. *Orientation responses of four species of sea turtle hatchlings to colored light sources. Responses were measured as the proportion of hatchlings that chose a window lighted with a colored light source over a similar but darkened window (Witherington, 1992b). The loggerhead differed from the other species in that it showed an aversion to light in the yellow region of the spectrum. Figure adapted from Witherington (1997) and Lohmann et al. (1996); used with permission.*

heads were weakly attracted to yellow light (Figure 6). It may be that the hatchlings cannot discriminate color at low light levels. This is common for animals (such as turtles) that have rod-and-cone retinas (Granda and Dvorak, 1977).

Figure 12 (on page 17) presents the human range of photopic and scotopic vision and the range of wavelengths suited for human vision. Figures 5 and 6 show the range of wavelengths suited for vision in sea turtles. It should come as no surprise that humans and sea turtle hatchlings see the world differently. For most of their lives, sea turtles see the world through a blue ocean filter (water selectively absorbs reddish, long-wavelength light), so it makes sense that sea turtles would be most sensitive to short-wavelength light.

Because sea turtle hatchlings respond to ultraviolet light that humans cannot see and are only weakly sensitive to red light that we see well, instruments that quantify light from a human perspective (such as most light meters) cannot accurately gauge brightness from the perspective of a sea turtle. Humans also cannot assess color exactly as a sea turtle would. Although we can see colors, we cannot tell what assortment of wavelengths may make up those colors. For example, a light source emitting both

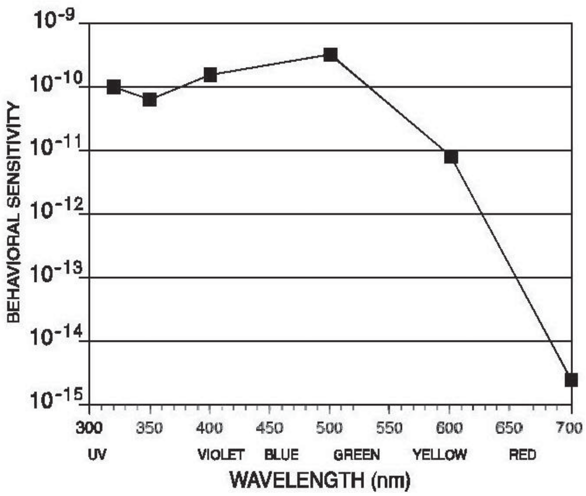

Figure 6. *Behavioral sensitivity of loggerhead hatchlings to low-intensity colored light, represented as the inverse of the light-source radiance required to evoke significantly directed orientation in groups of hatchlings (n = 30 per wavelength). At the low light levels represented here (approximately the radiance of the sky on a full-moon night, and dimmer), there was orientation toward the light source at all wavelengths. The ordinate is a log scale of the units (photons/s/m2/sr)-1. Data are from Witherington (1992b). Figure adapted from Witherington (1997) and Lohmann et al. (1996); used with permission.*

525-nm (green) and 645-nm (red) light, a source highly attractive to hatchlings, appears to a human observer to emit yellow light comparable to a 588-nm monochromatic source, which would be only weakly attractive to hatchlings (Rossotti, 1983).

Directional properties of the brightness detector.—Just as a hatchling has sensitivity to specific light wavelengths, it is also sensitive to light direction. The directional properties of a detector determine how much of the world the detector measures at any one instant. These properties are described by a specific "cone of acceptance" or by bi-dimensional (horizontal and vertical) "angles of acceptance." The height and breadth of a detector's acceptance cone critically influences brightness measurements and the determination of brightest direction (Figure 7). This conceptual acceptance cone may be only a portion of a turtle's complete field of view.

The horizontal component of the acceptance cone for green turtle and olive ridley hatchlings (Verheijen and Wildschut, 1973) and for loggerhead hatchlings (Witherington, 1992b) has been deduced from the way hatchlings orient in controlled-light fields. In these studies, light fields were artificially controlled so that detectors with different acceptance-cone widths measured different brightest directions. Hatchlings of each species typically oriented in the brightest direction as it would be measured with a wide acceptance cone, approximately 180° horizontally.

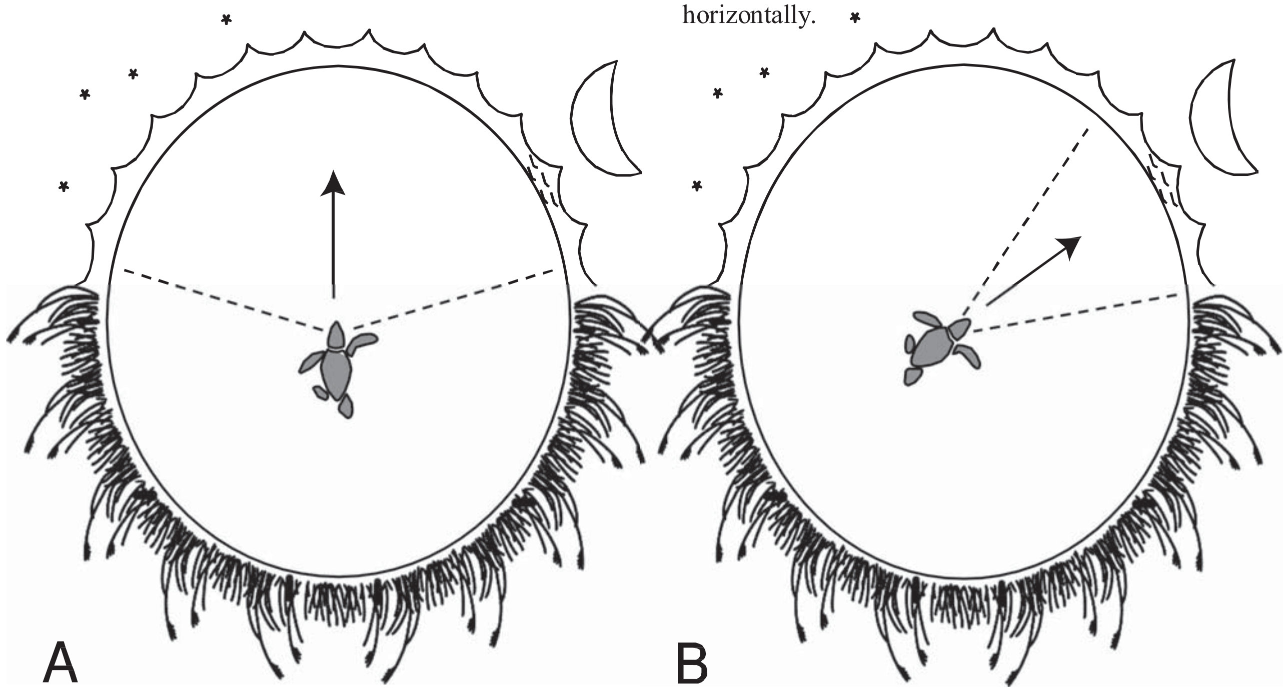

Figure 7*. The consequences of measuring the brightest direction with a wide (A) or a narrow (B) angle of acceptance. Hatchlings A and B both orient toward the center of the brightest portion of the horizon within their angle of acceptance (shown by dotted lines). Hatchling B's path to the water would be considerably longer. Figure adapted from Witherington (1997); used with permission.*

To determine the vertical component of the acceptance cone, the same researchers measured the orientation of hatchlings presented with light sources positioned at various vertical angles. The angular height of this vertical component was approximated to be “a few degrees” for green turtles and olive ridleys (Verheijen and Wildschut, 1973) and between 10° below and 30° above the horizon for loggerheads (Salmon and Wyneken, 1990; Witherington, 1992b). Although the measures are approximate, it is clear that light closest to the horizon plays the greatest role in determining orientation direction. In field assessments of brightness, silhouette, and elevation on hatchling movement, test animals oriented to the lowest horizon visible but chose the lowest, brightest horizon if multiple cues were present (Limpus and Kamrowski, 2013).

The detector model for hatchling orientation predicts that hatchlings measure brightest direction by integrating the light they detect over a broad and flat acceptance cone (Figure 8). Again, we see that the attributes of this hypothetical detector differ from those of most light meters. The most commonly found light meters, illuminance meters, measure light with an acceptance cone that is less flattened and not as wide as the acceptance cone that the hatchlings use. Another type of light meter, a luminance or “spot” meter, measures light with a very narrow acceptance cone. Most light measuring instruments are not useful in determining the impact of distant lights on sea turtle orientation.

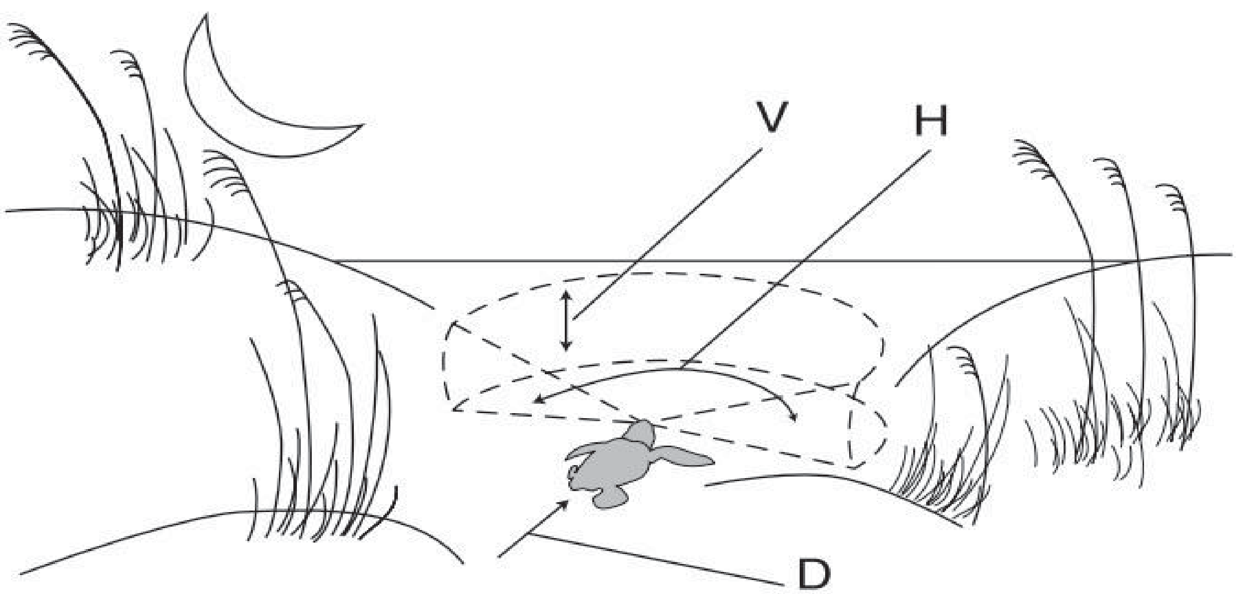

Figure 8. *A hypothetical cone of acceptance that describes the assessment of brightness by a sea turtle hatchling. The vertical angle of the cone (V) is 10°–30° from the horizon, and the horizontal angle of the cone (H) is approximately 180°. Light within this cone of acceptance is integrated into an assessment of brightness for the direction D. This description is based on data from studies of green turtles, olive ridleys, and loggerheads (Verheijen and Wildschut, 1973; Witherington, 1992b). Figure adapted from Witherington (1997); used with permission.*

COLOR CUES

In addition to brightness cues, color may influence the direction in which a hatchling orients. Color discrimination (the ability to identify colored light) is different from spectral sensitivity. An animal may be able to detect many light wavelengths that it cannot tell apart. The fact that sea turtles have cones in their retinas is not sufficient evidence that they can distinguish colors, but there is some behavioral (Piovano et al., 2013) and physiological evidence (Horch et al., 2008; Levenson et al., 2006) that sea turtles can see colored light, and color may play some limited role in sea-finding. ERG assessments of hatchling loggerhead and leatherbacks found both species could detect a wide range of wavelengths, which may provide additional evidence for color perception by these species (Horch et al., 2008).

In one of the first published discussions of sea-finding cues in hatchlings, Hooker (1911) suggested that the blue of the ocean itself may provide attraction. The evidence used to test this hypothesis should be weighed carefully. Green turtle hatchlings do tend to prefer the directions illuminated with blue light over directions illuminated with red light (Mrosovsky, 1972), but is this truly a color choice? Do hatchlings prefer the color blue, or are they simply selecting the brightest direction as determined by a detector that is most sensitive to blue wavelengths? The answer may be that both are true.

Conditioning experiments have shown that loggerheads do have some ability to discriminate colors (Fehring, 1972). Whether loggerheads can and do use this ability in sea-finding, however, can best be determined by comparing the wavelengths a hatchling can detect best (as might be measured with ERG) with those it prefers in orientation experiments. ERG data for the green turtle show that red light must be approximately 100 times more intense than blue light for the two colors to elicit a similar magnitude of response at the retina (Granda and O’Shea, 1972). Yet in a series of behavioral experiments using broadband colors, Mrosovsky (1972) found that red light had to be approximately 600 times more intense than blue light in order for green turtle hatchlings to show an equal preference for the two colors. Such a bias against long-wavelength light was also demonstrated by behavioral studies using monochromatic light (Figure 4; Witherington and Bjorndal, 1991a). In this study, the greatest disparity between ERG response and color preference was found in the yellow-orange region of the spectrum, near 600 nm. Although it is apparent that green turtles see yellow light well, light of this color is relatively unattractive to orienting hatchlings.

Loggerhead hatchlings’ behavior toward some colored light sources indicates that they too may use color cues in sea-finding. Their aversion to yellow light, or xanthophobia, sets them apart from other sea turtle species. Loggerhead hatchlings are weakly attracted to low-intensity yellow light sources but show an aversion to higher-intensity yellow light. Similar increases in the light intensity of near-ultraviolet, violet, and green light sources do not elicit a change in response from attraction to aversion, which indicates that the aversion to yellow light is related to color rather than brightness. Additional experiments with loggerheads have shown an interesting relationship between attraction to short-wavelength light and aversion to yellow light: the two responses appear to be additive. In evidence of this, Witherington (1992b) showed that adding high-intensity yellow light to an otherwise attractive light source (thereby making the light source brighter) will decrease its attractiveness to loggerhead hatchlings.

No empirical evidence suggests why both loggerhead and green turtle hatchlings show little or no attraction to sources that are rich in yellow light. One hypothesis is that a reduced attraction to yellow-rich light sources ensures hatchlings will not be misdirected by the sun or the moon. Because the rising or setting sun or moon lies within a hatchling’s vertically flat acceptance cone, it can affect hatchling orientation to some degree. However, a universal characteristic of celestial light sources is that they become yellower and redder when they are near the horizon (a sunset appears yellowish red because the blue light from the sun at dusk is attenuated by the thickness of the atmosphere that the light must pass through to reach an observer). Actually, some controversy exists as to whether the rising sun does affect sea-finding in hatchlings. Whereas Parker (1922), Ehrenfeld and Carr (1967), and Rhijn (1979) reported that loggerheads, green turtles, and hawksbill turtles are affected insignificantly by the sun on the horizon, Mrosovsky (1970), Mrosovsky and Kingsmill (1985), and Witherington (1992b) reported that loggerhead, green, and hawksbill turtles are affected. By all accounts, given its brightness, the effects of the sun on hatchling orientation seem small.

SHAPE CUES

Many authors have suggested that the patterns of light and shadow associated with visible shapes help sea turtle hatchlings find the sea. On beaches, hatchlings tend to orient toward open areas and open horizons and away from silhouetted horizons, dune profiles, and vegetation (Hooker, 1911; Parker, 1922; Mrosovsky and Shettleworth, 1968; Limpus, 1971; Salmon et al., 1992, 1995b; Tuxbury and Salmon, 2005).

Hatchling sea turtles’ response to shape cues has been studied less extensively than has their response to brightness. To be sure, there is some debate as to how well hatchlings on a beach can discriminate shape. Based on the optical characteristics of a sea turtle’s eye, one would expect it to see most clearly in sea water and to be relatively myopic on land (Ehrenfeld and Koch, 1967; Bartol et al., 2002). But because hatchling eyes are small and their depth-of-focus is large, hatchlings may be able to distinguish shape well (Northmore and Granda, 1982). In fact, the most recent evidence from laboratory studies suggests that sea turtle eyes may be able to distinguish shape well enough to resolve individual stars in the sky (Northmore and Granda, 1991).

Both Limpus (1971) and Salmon et al. (1992) have presented convincing evidence that loggerhead and green turtle hatchlings tend to orient away from silhouettes. On most beaches this tendency would direct hatchlings away from the profile of the dune and toward the ocean. But do hatchlings respond to the shape of the dune itself or to the way the dune influences the brightest direction? By their nature, dune silhouettes darken the horizon and would be expected to influence brightest direction as hatchlings measure it. Hatchlings oriented preferentially toward the lowest visible horizon and not necessarily the brightest horizon in a recent field assessment, although tall silhouettes and brightness were also found to influence orientation (Limpus and Kamrowski, 2013). Although some effects of shape and silhouette may be independent of brightness, isolating these effects is not a straightforward process. In fact, our confidence in distinguishing shape-cue orientation from brightness-cue orientation should be only as great as our confidence in our ability to measure brightness as hatchlings do.

Determining the specific roles of shape and brightness in hatchling orientation has been attempted in cue-conflict studies. In these studies, both green turtle (Rhijn and Gorkom, 1983) and loggerhead (Witherington, 1992b, c) hatchlings tended to orient away from sets of alternating black and white stripes and toward a uniformly illuminated direction, even when the striped direction was brightest. Orientation away from a horizon that has spatial patterns of light and shadow (i.e., shapes) could assist sea-finding by directing hatchlings away from the structure associated with the dune (e.g., vegetation) and toward the comparatively flat and featureless ocean. However, the demonstration that hatchlings can orient with respect to shape cues does not necessarily mean that hatchlings require them for sea-finding.

The necessity of shape cues for sea-finding has been studied by depriving hatchlings of form vision (i.e., the ability to discern shape). Mrosovsky and Kingsmill (1985) disrupted the form vision of loggerhead hatchlings by fitting them with wax-paper goggles and concluded that because the animals still oriented seaward, shape was not a primary cue in sea-finding. In a similar test, Witherington (1992b) placed loggerhead hatchlings within transparent cylinders that were covered with wax paper or not covered. These hatchlings were observed as they attempted sea-finding under what might be considered challenging conditions—at moonset on an east-facing beach. Under these conditions, hatchlings with a clear view of their surroundings oriented seaward, whereas hatchlings whose form vision was disrupted by wax paper oriented in the general direction of the setting moon.

OTHER LIGHT CUES

In addition to intensity, wavelength, shape, and direction, light can vary in time (have a certain periodicity) and in space and time (display motion) and can have a unique composition of polarized light. Motion has not yet been explored as a potential sea-finding cue. Periodicity has been examined and found to have some influence on hatchling orientation, but only as it relates to a brightness measure. Evidence for this comes from a study (Mrosovsky, 1978) in which green turtle hatchlings preferred a constant light source over a flashing one only when the off-time of the flashing source was very long. This implies that hatchlings may integrate their measures of brightness over time.

Because water tends to polarize light reflected from it, richness of polarized light has the potential to indicate the ocean direction. However, the experiments in which hatchlings viewed their world through wax paper but maintained a seaward orientation showed that hatchlings depend little, if at all, on polarity cues (Mrosovsky and Kingsmill, 1985). Wax paper, in addition to obliterating form, would also have depolarized the light that hatchlings saw. Additional laboratory evidence shows that, at least among loggerhead hatchlings, there is no orientation preference between sources that are polarized and those that are unpolarized (Mrosovsky, 1978) or have different directions of polarity (e-vector direction; Witherington, 1992b).

WHEN CUES CONFLICT

Brightness cues, shape cues, and color cues (under high illumination only) all provide information to orienting sea turtle hatchlings. Because a hatchling's environment is complex and variable, having a compound set of cues to guide even the simplest of tasks makes sense. Any single cue could, under some conditions, be misleading. But do conflicting cues present a real problem in nature, and if so, how do hatchlings balance the information from these cues in order to make a correct orientation decision?

In nature, cues do conflict. Brightness measurements made on nesting beaches where hatchlings orient to the sea show that the seaward direction is often brightest, but sometimes it is not (Rhijn, 1979; Wibbles, 1984; Witherington, 1992b). Measurements made under various conditions show that, although the ocean is brightest on clear, moonless nights, the direction of the moon is brightest near moonrise and moonset (Witherington, 1992b).

Although it is not completely clear how hatchlings balance the information from conflicting orientation cues, experimental evidence indicates that this balance may be based on the comparative strengths of the cues. In the cue-conflict experiments (Witherington, 1992b), influences of both brightest direction and shape were seen in some cases. Hatchlings tended to orient away from contrasting stripes even when the striped direction was twice the brightness of the uniformly lighted direction. But, when the striped direction was made three times brighter than the opposing direction, hatchling orientation became undirected, and when the striped direction was five times brighter, most hatchlings oriented toward the stripes. It seems then that orientation either away from contrasting shapes, irrespective of brightest direction, or toward the brightest direction, irrespective of contrasting shapes, depends on how strong the brightest direction happens to be. This strength of the brightest direction is known as directivity. As the directivity of the light field a hatchling sees increases, the brightest direction becomes more pronounced, less ambiguous perhaps, and seemingly a greater orientation stimulus.

Are shape cues more important than brightness cues to orienting hatchlings? To answer this question, researchers will need to measure and compare the strengths of the two types of cues. At present, there is no common unit of measurement that can be used in making a comparison. For now, we can say that both shape and brightness cues are important for correct seaward orientation in a variably lighted world.

DISRUPTION OF SEA-FINDING

OBSERVATIONS OF SEA-FINDING DISRUPTION

Accounts in the literature of the disruption of sea-finding do not properly represent the vast extent of the problem. Only the most conspicuous cases are observed and reported, such as when hatchlings have been crushed on roadways (McFarlane, 1963; Philibosian, 1976; Peters and Verhoeven, 1994; R. Martin and B. Witherington, personal observations), burned to death in an abandoned fire (Mortimer, 1979), or led onto the playing field of a baseball game in progress (Philibosian, 1976).

More often than not, lost hatchlings are preyed upon by beach crabs or shorebirds or become exhausted and dehydrated deep in nearby dune vegetation (R. Martin and B. Witherington, personal observations). The discovery of hundreds of dead loggerhead hatchlings beneath a mercury-vapor light at Melbourne Beach, Florida, serves as one indication of the cryptic nature of the problem (L. M. Ehrhart, personal communication). The number of hatchlings found in this case indicated that the light had been left on and had attracted hatchlings over many nights. The discovery of the pile of dried hatchlings came as a complete surprise to the caretaker of the property.

Disruption in sea-finding has been documented whenever sea turtles nest and hatchlings emerge at beaches affected by artificial lighting. Thevenard Island, off the coast of northwestern Australia, a known nesting site for green turtles, also supports an oil-production facility. The facility includes a flare tower built to shield the flame from nearby nesting beaches. A second pit flare exists for short-term use (e.g., when the primary shielded flare is undergoing maintenance). Surveys and routine inspections indicated that both the flares and the facility lights were potential sources of impact on the sea-finding success of green turtle hatchlings. Experiments were carried out to determine whether the light sources were disorienting hatchlings emerging in the vicinity of the flares and over what distance the influence might extend. The results suggested that although the flares emitted light in a spectral range outside of that visible to green turtles, it caused disorientation of hatchlings during nights of a new moon, but this impact was reduced with distance from the source and as the moon phase progressed toward full (Pendoley, 2000).

MISORIENTATION AND DISORIENTATION

Newly emerged sea turtle hatchlings crawl almost incessantly. For the most part, the effect of artificial lighting on hatchling behavior is not to alter latency, frequency, or intensity of crawling, but rather to alter its efficacy—hatchlings on artificially lighted beaches tend to crawl in the wrong direction. The duration of crawling also increases as hatchlings seek the ocean.

Hatchlings that are oriented away from the most direct ocean path are said to be “misoriented.” Hatchlings on lighted beaches are frequently misoriented, sometimes as entire groups. These groups of hatchlings leave relatively straight tracks that often stream across the beach parallel to the surf line toward an artificial light source.

Hatchlings that are “unsure” about orientation direction demonstrate their uncertainty by frequently changing direction and circling. Hatchlings lacking directed orientation are said to be “disoriented.” Similar “orientation circles” are also seen in hatchlings that have been blindfolded (Mrosovsky and Shettleworth, 1968) or placed in complete darkness (except for an infrared observation source; B. Witherington, personal observation). Hatchlings often become disoriented by overhead light sources. Frequently, hatchlings that are misoriented toward an artificial light source become disoriented as they reach the source. Hatchlings also appear to become disoriented when they reach a boundary between an artificially lighted area and a shadow on the beach. Turtles in this situation exit the shadow and move toward the lighted beach sand, become exposed to the light from the artificial source, and move toward the light source back into the shadow, and they may repeat this cycle until they become exhausted. This often explains the curious circling tracks that observers find in the center of the beach berm, away from any overhead light source.

DIFFERENCES BETWEEN NATURAL AND ARTIFICIAL LIGHTING

Why are sea turtle hatchlings misdirected to such an extent by artificial lighting? Given the importance of light cues to hatchlings, the intuitive answer to this question is that light from artificial sources interferes with the "natural" light cues that hatchlings depend upon to orient seaward. Although hatchlings may possess a marvelous sea-finding mechanism that functions under almost any set of natural lighting conditions, this mechanism is rendered ineffective on an artificially lighted beach. But why does artificial lighting have a far greater effect on orientation than do bright celestial light sources like the sun or moon? Much of the answer to this can be found in the differences between artificial and celestial light fields.

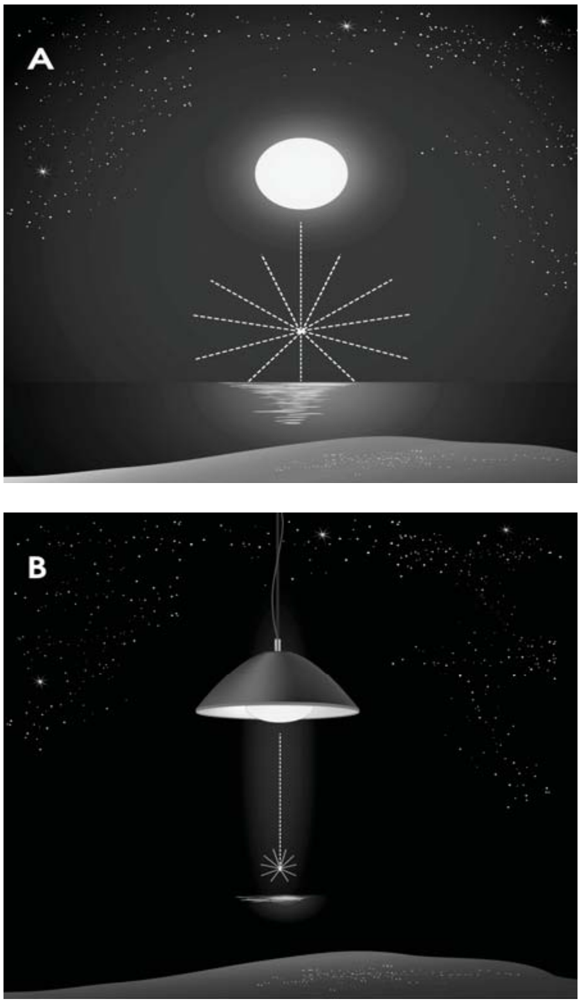

__Figure 9.__ The directional brightness of a natural light field (A, one dominated by celestial sources) and an artificial light field (B, one dominated by a lighted luminaire) from the perspective of an observer on a beach. The length of each radiating line is proportional to the brightness of the direction. In the natural light field, the moon is conspicuous as a bright source, but it also illuminates the sky, water, and other objects. In the artificial light field, a glaring luminaire appears bright because of its closeness to the observer but does not provide enough light to illuminate other features. The luminaire produces a highly directed light field that has an overwhelming brightness in one direction.

A light field is produced by a light source (or sources) but is measured from the perspective of an observer. In essence, it is a directional picture of all the light an observer can detect. An important characteristic of light fields produced by celestial sources is that they are only moderately directed (Figure 9), which means that although there may be only one brightest direction, this direction is not tremendously brighter than other, competing, directions. These natural light fields are moderated because both the observer and the illuminated features that the observer can see are a similar distance from the light source(s). Celestial light has a distant origin and reaches an observer not only directly but also indirectly as it is scattered in the atmosphere and reflected from the features on the Earth's surface (other competing directions). As a result, an observer experiencing a celestial light field can see brightness from many directions.

Artificial light fields are produced by sources that are less intense than celestial sources, although they can appear very bright to an observer close to the light source (Verheijen, 1958, 1978). Other features that could contribute to the brightness of the light field (sky, clouds, landscapes, etc.) are relatively distant, and the light reflected from them is dim when compared to the brightness of the source. Consequently, an observer near an artificial light source experiences a highly directed light field that is overwhelmingly dominated by the light source. For a hatchling near a lighted luminaire on a beach, the overwhelming brightness of the light source provides a supernormal stimulus that overrides tendencies to orient to other visual cues.

Consequences of misorientation and disorientation are grim for hatchlings. With limited nutritional reserves, they quickly become dehydrated, exhausted, or victims of predation. While predation by raccoons, foxes, feral cats, ghost crabs, and birds occurs between the nest and the sea, quantification of hatchling depredation is rarely attempted. Available estimates report a varying number. On Sinai beaches, 45% to 99% of all hatchlings are consumed by ghost crabs. An experimental study on the developed Onslow Beach, North Carolina, reported that 24% of loggerhead hatchlings emerging from the nest on the beach were preyed upon by ghost crabs. In experimental trials (using freshwater sliders as a substitute for sea turtle hatchlings), a 2.6-fold density increase in ghost crab population resulted in a five-fold increase in hatchling predation (Peterson et al., 2013).

Risk of mortality by predation does not abate when hatchlings reach the ocean (Harewood and Horrocks, 2008). A study of near-shore predation rates on loggerhead hatchlings at three locations in Florida reported a 5% predation level during the first 15 minutes of swimming in the ocean away from the nesting beach. Predation rates were higher on Florida's southeast coast than on the southwest coast and increased toward the end of the hatching season (August/September) (Whelan and Wyneken, 2007).

Any increased time spent on land as a result of disorientation induced by artificial light also uses residual yolk energy reserves, so that when hatchlings do eventually reach the sea, they have less energy available for fueling the offshore swim. Additionally, when there are no waves on the beach, hatchlings use the direction of their beach crawl to direct their swimming offshore and out to sea (Lorne and Salmon, 2007). A prolonged disoriented land crawl disrupts the initial orientation process, which then decreases hatchlings' ability to swim directly offshore in the absence of waves (Berry et al., 2013).

EFFECTS OF MOON PHASE AND MOONLIGHT

Some of the myths regarding the moon's effect on hatchling emergence and sea-finding are not valid. For the most part, hatchling sea turtles do not emerge from nests according to a lunar cycle. The date of emergence is determined by the date eggs were deposited in the nest and the length of the incubation period. Although nesting cycles correlated with specific moon phases have been detected in olive ridleys (Cornelius, 1986) and to a lesser extent in loggerheads (Burney et al., 1991), the timing of these cycles allows for hatchling emergence during all phases of the moon. Because hatchlings may emerge when the moon is not visible, they must not depend on the moon to lead them seaward. Perceptions that hatchlings emerge only during the full moon and are led seaward by its light probably originated because hatchlings are most readily observed on bright, full-moon nights.

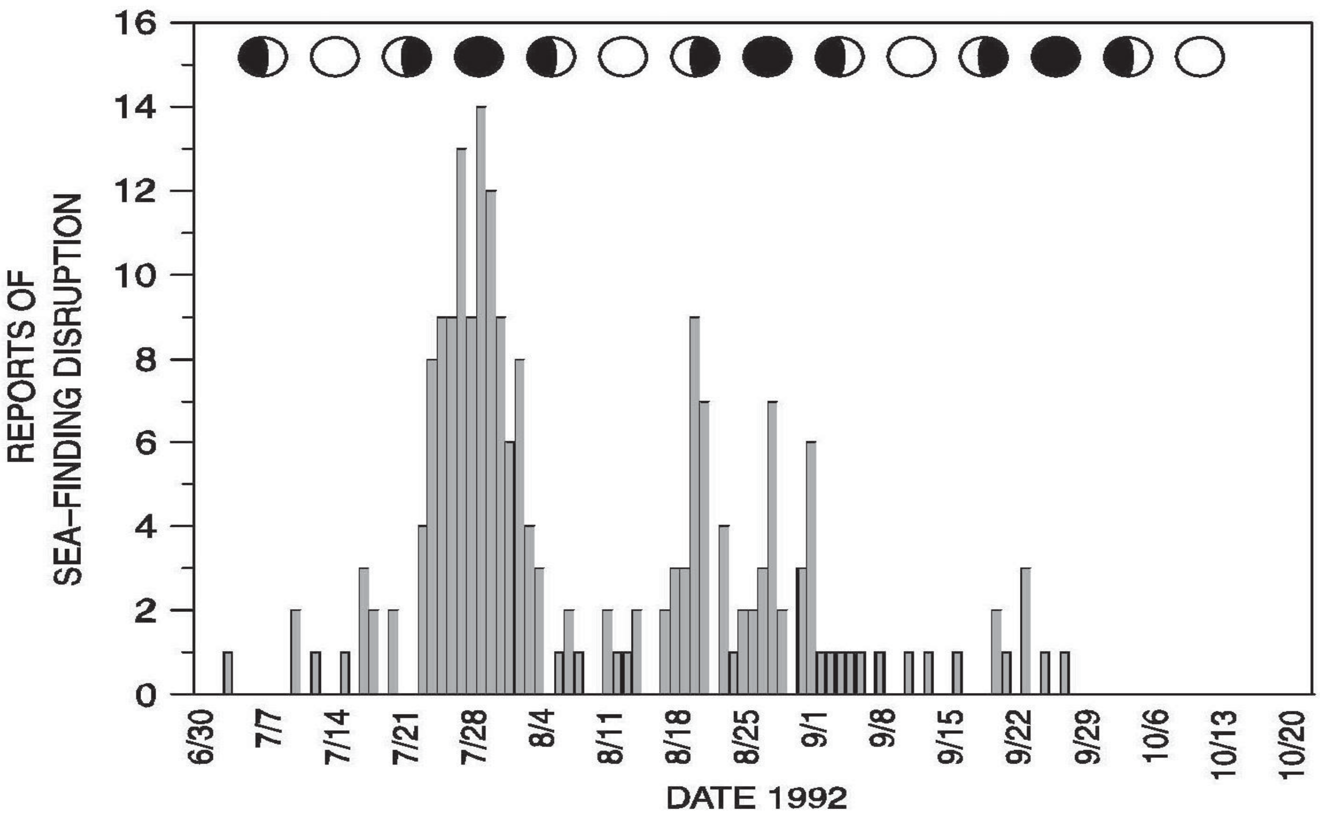

Figure 10. *The timing of 201 reported cases of hatchling disorientation on Florida beaches in 1992. The circles above the histogram bars show the phases of the moon. Most cases occurred on nights on or near the new moon. The decrease in cases in September and October probably represent reduced survey effort at the end of the nesting season. Data are from Salmon and Witherington (1995).*

The light of the moon does, however, affect the degree of sea-finding disruption caused by artificial lighting. Reports of hatchling disorientation events (including misorientation and disorientation) in Florida are most common on nights surrounding the new moon (Figure 10; Salmon and Witherington, 1995; Adamany et al, 1997; Lohmann et al., 1996; Tuxbury and Salmon, 2005; Berry et al., 2013). Compared to darker nights, higher levels of ambient light on moonlit nights may lessen the relative contribution of artificial light sources to the light fields that hatchlings perceive. By reducing light-field directivity, moonlight may allow hatchlings to rely on shape cues that correctly reveal the seaward direction.

SWIMMING ORIENTATION

A hatchling's best chance to survive its first few hours is to escape from the beach and swim directly out to sea, away from the predator-rich waters near the shore (Frick, 1976; Ireland et al., 1978; Salmon and Wyneken, 1987; Witherington and Salmon, 1992). Once in the open ocean, hatchlings can conserve energy by remaining inactive, and, because of their distance from shore, the risk of their being swept back onto land is small.

How artificial lighting affects swimming hatchlings is not well known. Hatchlings have been observed to exit the surf and return to land where there is nearby lighting (Daniel and Smith, 1947a; Carr and Ogren, 1960; Witherington, 1986), but it is not clear how long those hatchlings had been in the water. Limpus (1991) reported that "thousands" of green turtle hatchlings were seen swimming in circles next to a brightly lighted boat anchored off the nesting beach at Raine Island, Australia. Hatchlings affected by such lighting may linger in the lighted water and be preyed upon by fish that are also attracted to the lighted area. There may be little or no evidence of these incidents.

In laboratory settings with other cues absent, loggerhead hatchlings will swim toward an artificial light source (O'Hara, 1980; Salmon and Wyneken, 1990). It is apparent from other laboratory work, however, that once hatchlings have entered the water they depend less on light cues and more on sea-wave and magnetic cues (Salmon and Lohmann, 1989; Lohmann et al., 1990; Salmon and Wyneken, 1990; Wyneken et al., 1990: Lorne and Salmon, 2007). Witherington (1991) observed that loggerhead hatchlings swimming from a lighted beach had a wider pattern of dispersal than did hatchlings from unlighted beaches, but he did not see evidence of disrupted orientation comparable to that seen on land. Further work is needed to determine how lighted ships and platforms may affect the survivorship of hatchlings and their dispersal from beaches.

Evidence of similar use of visual cues to specific wavelengths of light has been investigated in an attempt to protect sea turtles from being caught on long fishing lines. Blue and green chemiluminescent lightsticks are commonly used in longline fisheries to attract targeted fish species. Though not targeted, sea turtles are also attracted to these lightsticks. Laboratory experiments have shown that juvenile loggerhead turtles significantly orient toward chemiluminescent blue (peak 400 nm), green (peak 510 nm), and yellow (peak 550 nm) lightsticks as well as flashing orange (peak 600 nm) LED lightsticks in the water (Wang et al., 2007).

Artificial Lighting and Humans

OPTIMAL LIGHT FOR HUMAN VISION

Humans use a different vision system during the day than at night. A brief description of how human vision works is necessary to understand how much light we need (see Figure 11).

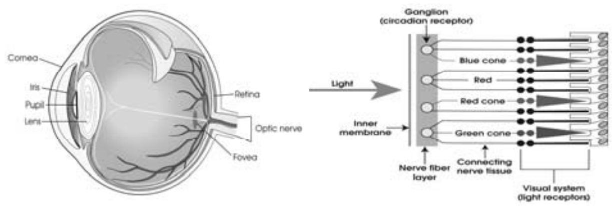

***Figure 11**. (a) Cross section through a human eye. (b) Schematic view of the retina, including rod and cone light receptors (adapted from Encyclopaedia Britannica, 1994).*

Human vision consists of the physical components of the eyeball—the cornea, lens, iris, retina, and optic nerve. The retina, the light-sensitive part of the eye, lines the inside of the eyeball. It contains the light-sensitive rod and cone cells and the ganglion cells and nerve fibers that transmit visual information to the brain. The abundant rod cells are more light-sensitive than the cone cells and operate over the entire visible spectrum. The three types of cone cells, which are sensitive in the red, green, and blue spectral ranges, contribute to color perception as well as to visual acuity.

Human vision consists of three different regimes, photopic, scotopic, and mesopic. Photopic vision occurs at high ambient light levels (e.g., during daylight conditions) and is mediated by the cones. Photopic vision occurs under luminance levels >3 cd/m^2 (0.3 cd/ft^2). (The candela [cd] is the basic international unit for luminous intensity. A common candle emits light with a luminous intensity of roughly 1 cd.).

Scotopic vision occurs at low ambient light levels (e.g., at night) and is mediated by rods. Rods have a much higher sensitivity to low light levels than the cones. But the sense of color is essentially lost in scotopic vision. At low light levels, human eyes cannot perceive color, and objects appear in grayish hues. The scotopic vision range applies to luminance levels <0.001 cd/m^2 (0.0001 cd/ft^2).

Mesopic vision relates to light levels between the photopic and scotopic vision regime (0.001 cd/m^2 < mesopic luminance < 3 cd/m^2). This is a combination of scotopic and photopic vision with both the rods and the cones contributing to the visual response. The majority of exterior night-lighting conditions fall in the mesopic vision range. Mesopic lighting applications include road and street lighting, outdoor area lighting, and other night-time traffic environments (IESNA RP 33, 1999). Figure 12 shows the range of human vision regimes.

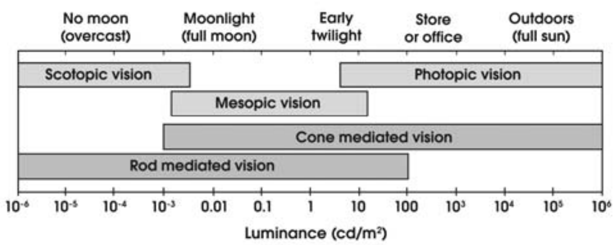

***Figure 12**. Approximate ranges of vision and receptor regimes. (Source: Osram Sylvania 2000).*

The question of optimal exterior lighting for human vision is tricky. Humans see light wavelengths between 390 and 780 nm, and the sensitivity of the human eye to light of a certain intensity varies strongly over that range. During the day, humans are most sensitive to light at a wavelength of 555 nm (Pittendrigh, 1993). A predominance of green light at this wavelength produces a stronger impression of brightness when compared with light of other wavelengths. In low light conditions (with brightness at levels below 0.003 cd/m^2), where vision is mainly scotopic, maximum sensitivity is at 507 nm (in the blue-green region). Red light at a wavelength around 700 nm, while clearly visible to the human eye, has minimum impact on sea turtles and other animals.

Since exterior lighting at night primarily falls in the mesopic vision regime, luminance in the 0.001-cd/m^2 to 3-cd/m^2 range works best for human vision at night. Within this range, the type of light source and the intensity (brightness) depend on the intended use and community goals. Standard industry recommendations (IESNA Lighting for Exterior Environments RP-33-99 [IESNA, 1999] and AASHTO Roadway Lighting Design Guide [AASHTO, 2005]) apply to exterior lighting as well as state and local standards or codes. But often these standards are applied uniformly across diverse landscapes with different ambient lighting conditions, from highly illuminated urban cores to more natural beachfront areas, even though the uniform application of these standards may not be the best option for maximizing human vision.

A measure of how a light source is perceived under daytime and nighttime conditions is the scotopic-to-photopic (S/P) ratio. An S/P ratio is independent of light level and expresses a property of the light's or lamp's spectrum. In general, a light source with a higher S/P ratio provides better overall lighting for conditions with ambient light.

The intensity of light color, also referred to as the color temperature, and its color rendition quality are other important considerations in the selection of appropriate light sources for environmentally sensitive areas, including nesting beaches. Color temperature of a light source is temperature of an ideal black-body radiator that radiates light of comparable hue to that of the light source. It is measured in degrees Kelvin (K). Common household (tungsten incandescent) lamps have a color temperature of 2900K that appears to be warm and yellow in color. Household fluorescents emit cool white light and have a color temperature range of 4300 to 4700K. LED lamps are available in the 3000–7000K range, with light color varying from warm yellow to cool (bluish) white. For comparison, noon sunlight has a color temperature of 5800K.

Color rendition quality of a light source is its ability to reveal the colors of various objects faithfully in comparison with an ideal or natural light source. The lighting industry uses a color rendition index (CRI) to measure color rendition quality of a light source on a scale of 1-100, with 100 being the best possible rating. The current practice is to employ sources having a CRI of at least 70 for most applications. LED light sources typically are available in the CRI range of 70 and above, and the CRI is higher as the color temperature goes up. Before the advent of amber and red LEDs, low-pressure sodium (LPS) was one of the primary sources for sea turtle–friendly lights. But LPS light sources do not provide good color rendition; LED light sources do.

EFFECTS OF ARTIFICIAL LIGHTING ON HUMAN HEALTH

Human sleep cycles are linked to daily shifts between day and night corresponding to the presence and absence of light. Only recent advances in technology have made it possible to keep our surroundings very brightly lit during nighttime. But the presence of bright lights during nighttime hours results in behavioral and nonbehavioral responses in humans. These responses may include resetting of the circadian clock and disruption of the sleep cycle. Exposure to artificial white light at night can also affect biochemical and behavioral processes that impact alertness, performance, and the immune system (Redwine et al., 2000).

Melatonin is a hormone that controls human sleep and waking periods. Low levels of white fluorescent light can disrupt or suppress melatonin secretion. Potential health issues related to melatonin suppression include cancer, especially breast cancer. Laboratory models suggest that melatonin suppresses tumor growth, which may decrease cancer risk. Other diseases that may be exacerbated by circadian disruption include obesity, diabetes, depression and other mood disorders, and reproductive problems (AMA, 2012). Yet few epidemiological studies have investigated the impact of nighttime lighting on sleep cycles, cancer risk, and other diseases or conditions, including obesity (AMA, 2012).

It is no longer just the environmentalist, the sea turtle conservation community, and the dark-sky promoters who recognize the impacts of nighttime lighting on human health. The American Medical Association (AMA, 2012) concluded that:

> Exposure to excessive light at night can disrupt sleep or exacerbate sleep disorders, especially in children and adolescents. This effect can be minimized by using dim red lighting in the nighttime bedroom environment.

and;

> There is a need for developing and implementing technologies to reduce glare from vehicle headlamps and roadway lighting schemes, and developing lighting technologies at home and at work that minimize circadian disruption, while maintaining visual efficiency.

EFFECTS OF ARTIFICIAL LIGHTING ON HUMAN SAFETY

The primary human safety concern with nighttime lighting includes glare, which affects drivers and pedestrian safety. Close to a strong light source, we may feel completely blinded, but even farther away our visual performance can be notably hampered. This experience, well-known to drivers, is called *disability glare*. *Discomfort glare* is caused by a level of light that is intense enough to result in a measurable level of subjective pain or annoyance to the observer.

Disability glare is stray light scattered within the eye that reduces the contrast of the primary image on the retina. This contrast reduction can be thought of as a veil of luminance over the objects, thus the term veiling luminance. Glare from streetlights, pedestrian lights, floodlights, and landscaping lights contributes to veiling luminance, as do extremely bright surfaces. While the negative impact of glare on human vision and on the ability to respond to visual cues increases with age (Vos, 2003), disability glare from bright light sources (e.g., high beams) occurs across all age classes (van den Berg et al., 2009).

Discomfort glare does not necessarily reduce the ability to see an object, but it produces a sensation of discomfort. It is caused by the high contrast or non-uniform distribution of luminance in the field of view. Discomfort glare can be reduced by decreasing the luminance of the light source or by increasing the background luminance around the source to reduce contrast. These considerations led to the Texas Department of Transportation's requiring lower nighttime luminance for pedestrian signals than the prevailing industry standards specified by the Institute of Transportation Engineers (ITE). Historically, pedestrian signal heads have been internally illuminated using incandescent lamps. But with the widespread use of LEDs in pedestrian signals, concerns regarding the visibility of LED devices have emerged. Research funded by the Texas Department of Transportation determined that the ITE-proposed minimum luminance values would cause discomfort glare for approximately 60% of the study participants. The researchers recommended that pedestrian signal indications be dimmed at night to reduce glare. The lower luminance values match the ITE minimum dimmed luminance requirements (Finley et al., 2003).

LIGHTING AND AN AGING POPULATION

An area of particular concern is the impact of lighting on the elderly. The U.S population, as well as that of most other industrialized nations, is undergoing dramatic shifts toward older age. The population of people 65 years or older was over 40 million in 2010. The number of Americans over the age of 65 is estimated to be 72 million by 2030 and 88.5 million by 2050 (Vincent and Velkoff, 2010).

As people age, many aspects of their sensory and cognitive functions deteriorate. With respect to visual capabilities, older adults experience reductions in visual acuity and contrast sensitivity, as well as increased sensitivity to glare, and therefore are more severely affected when exposed to bright short-wavelength light.

Several changes in visual sensation and perception have been noted as a result of the aging process. The yellowing of the lens interferes with color rendition and makes discrimination of short-wavelength colors such as violet, blue, and green quite difficult. Older adults are more vulnerable to the impact of glare and have somewhat reduced visual acuity (particularly in the periphery) and increased visual blur. Therefore, ambient and task lighting must be carefully considered to provide the most appropriate lighting environments for older eyes. Light and dark adaptation takes longer, and the average scene appears darker for older people (Burdick, 2005).

Disability glare and discomfort glare caused by poorly designed, overly bright lighting are serious issues, particularly for the elderly. The impact of disability glare for people over 70 (compared to those under 35 years of age) may be 2 to 3 times worse. To address this, the Commission Internationale de l'Eclairage (CIE) has introduced a new age-sensitive formula (Vos, 2003) requiring better control for disability glare in areas with a significant senior population like Florida.

Discomfort glare also affects older people worse than others. A Texas Department of Transportation study reported that ITE-proposed minimum luminance values would cause discomfort glare to approximately 60% of people older than 55. Based on these results, the department specified that pedestrian signal indications should be dimmed at night (Finley et al., 2003).

ECONOMIC COST OF WASTED LIGHT

In addition to the health and safety aspects discussed here, light pollution exacts an economic toll, in terms of wasted energy. Light pollution caused by bad lighting design gives rise to undesirable and harmful effects including glare, sky glow, and light trespass. Often such problematic lighting is perceived to provide safety and improve visibility—with little or no evidence to substantiate this perspective. Excessive, misdirected, or otherwise obtrusive lighting contributes to light pollution that affects wildlife, sleep habits, and professional astronomy. In addition, light pollution also wastes a significant amount of energy which in the U.S. alone, amounts to nearly $7 billion annually. While there are no dollar estimates for wasted energy worldwide, a strong relationship exists between population growth, especially urban population growth, and the extent of light pollution (Gallaway et al., 2010).

CONCLUSION

Reducing exposure to artificial lighting at night in coastal areas is critical for the survival of sea turtles. Managing artificial lighting at night also benefits humans by promoting safety and good health and by saving energy. Light-management options, such as the use of low-energy, long-wavelength lighting focused only where needed, reduces the potential for impacts to sea turtles and ensures adequate light for nighttime human activities without increasing the risk of health hazards and harmful situations due to overly bright nighttime lighting.

Assessments: Discerning Problems Caused by Artificial Lighting

Lighting Inspections

WHAT IS A LIGHTING INSPECTION?

The goals of a lighting inspection are to locate lighting problems and to identify the property owner, manager, caretaker, or tenant who can resolve any lighting problems found. During a lighting inspection, a complete census is made of the number, types, locations, and custodians of artificial light sources that emit light visible from a beach.

WHICH LIGHTS CAUSE PROBLEMS?

Although the attributes that can make a light source harmful to sea turtles are complex, a simple rule has proved useful in identifying problem lighting under a variety of conditions:

An artificial light source is likely to cause problems for sea turtles if its light can be seen by an observer standing anywhere on the nesting beach.

If light can be seen by an observer on the beach, then the light is reaching the beach and can affect sea turtles. If any glowing portion of a luminaire (including the lamp, globe, or reflector) is directly visible from the beach, then this source is likely to be a problem for sea turtles. But light may also reach the beach indirectly by reflecting off buildings or trees that are visible from the beach. Bright or numerous sources, especially those directed upward, will illuminate sea mist and low clouds, creating a distinct glow visible from the beach. This urban skyglow is common over brightly lighted areas. Although some indirect lighting may be perceived as nonpoint-source light pollution, contributing light sources can be readily identified and include those that are poorly directed or are directed upward. Indirect lighting can originate far from the beach (Kyba et al., 2011).

Although most of the light that sea turtles can detect can also be seen by humans, observers should realize that some sources, particularly those emitting near-ultraviolet and violet light (e.g., bug-zapper lights, white electric-discharge lighting) will appear brighter to sea turtles than to humans (Kawamura et al., 2009). Even though humans are considerably taller than hatchlings, an observer on a dry beach who crouches to the level of a hatchling may still not see some lighting that will affect turtles. Because of the way some lights are partially hidden by dunes, a standing observer is more likely to see light that is visible to hatchlings and nesting turtles in the swash zone.

HOW SHOULD LIGHTING INSPECTIONS BE CONDUCTED?

Lighting inspections to identify problem light sources may be conducted either under the purview of a lighting ordinance or independently. In either case, goals and methods should be similar.

GATHER BACKGROUND INFORMATION

Before walking the beach in search of lighting, it is important to identify the boundaries of the area to be inspected. For inspections that are part of lighting ordinance–enforcement efforts, the jurisdictional boundaries of the sponsoring local government should be determined. It will help to have a list that includes the name, owner, and address of each property within the inspection area so that custodians of problem lighting can be identified. Plat maps or aerial photographs will help surveyors orient themselves on heavily developed beaches.

PRELIMINARY DAYTIME INSPECTIONS

An advantage to conducting lighting inspections during the day is that surveyors will be better able to judge their exact location than they would at night. Preliminary daytime inspections are especially important on beaches with restricted access at night. Property owners are also more likely to be available during the day than at night to discuss strategies for dealing with problem lighting at their sites.

A disadvantage to daytime inspections is that fixtures not directly visible from the beach will be difficult to identify as problems. Moreover, some light sources that can be seen from the beach in daylight may be kept off at night and thus present no problems. For these reasons, daytime inspections are not a substitute for nighttime inspections.

Descriptions of light sources identified during daytime inspections should be detailed enough so that anyone can locate the lighting. In addition to a general description of each luminaire (e.g., “HPS floodlight directed seaward at top northeast corner of the building at 123 Ocean Street”), photographs or sketches of the lighting may be necessary. Advancements in technology including digital photography and the ease with which digital photos can be taken (even high-resolution photos with cell phones) make this task easier. Standardized camera settings should be used and listed in the report. Similarly, with advancements in and the easy availability of GPS and mapping platforms (e.g., Google Earth street views), it is easier to locate features of interest even in remote areas. Keeping track of the information gathered at each property covered during the lighting inspection with GIS is easy and helpful for future references.

Descriptions should also include an assessment of how the specific lighting problem can be resolved (e.g., "needs shielding"; "should be redirected 90° to the east"). These detailed descriptions will show property owners exactly which luminaires need what remedy.

NIGHTTIME INSPECTIONS

Nighttime inspections require visual assessments of the lights most likely to harm sea turtles. While instruments such as light meters can measure the amount of light reaching the beach, they do not measure light characteristics—wavelength, brightness, or direction—in a manner analogous to that of sea turtles. Any light visible from the beach can impact adult and hatchling sea turtles.

Surveyors orienting themselves on the beach at night will benefit from notes made during daytime surveys. During nighttime lighting inspections, a surveyor walks the length of the nesting beach looking for light from artificial sources. There are two general categories of artificial lighting that observers are likely to detect:

Direct lighting.—A luminaire is considered to be direct lighting if some glowing element of the luminaire (e.g., the globe, lamp [bulb], reflector) is visible to an observer on the beach. A source not visible from one location may be visible from another farther down the beach. When direct lighting is observed, notes should be made of the number, lamp type (discernible by color; Appendix A), style of fixture (Appendix E), mounting (pole, porch, etc.), and location (street address, apartment number, or pole identification number) of the luminaire. If exact locations of problem sources were not determined during preliminary daytime surveys, this should be done during daylight soon after the nighttime survey. Photographing light sources (using long exposure times) is often helpful.

Indirect lighting.—A luminaire is considered to be indirect lighting if it is not visible from the beach but illuminates an object (e.g., building, wall, tree) that is visible from the beach. Any object on the dune that appears to glow is probably being lighted by an indirect source. When possible, notes should be made of the number, lamp type, fixture style, and mounting of an indirect-lighting source. Minimally, notes should be taken that would allow a surveyor to find the lighting during a follow-up daytime inspection (for instance, which building wall is illuminated and from what angle?).

WHEN SHOULD LIGHTING INSPECTIONS BE CONDUCTED?

Because problem lighting will be most visible on the darkest nights, lighting inspections are ideally conducted when there is no moon visible. Except for a few nights near the time of the full moon, each night of the month has periods when there is no moon visible. Early-evening lighting inspections (probably the time of night most convenient for inspectors) are best conducted during the period of 2–14 days following the full moon. Although most lighting problems will be visible on moonlit nights, some problems, especially those involving indirect lighting, will be difficult to detect on bright nights.

A set of daytime and nighttime lighting inspections before the nesting season and a minimum of three additional nighttime inspections during the nesting–hatching season are recommended. The first set of day and night inspections should take place just before nesting begins. The hope is that managers, tenants, and owners made aware of lighting problems will alter or replace lights before they can affect sea turtles. A follow-up nighttime lighting inspection should be made approximately two weeks after the first inspection so that remaining problems can be identified. During the nesting-hatching season, lighting problems that seemed to have been remedied may reappear because owners have been forgetful or because ownership has changed. For this reason, two midseason lighting inspections are recommended. The first of these should take place approximately two months after the beginning of the nesting season, which is the approximate time that hatchlings begin to emerge from nests. To verify that lighting problems have been resolved, another follow-up inspection should be conducted approximately one week after the first midseason inspection.

WHO SHOULD CONDUCT LIGHTING INSPECTIONS?

Although no specific authority is required to conduct lighting inspections, property managers, tenants, and owners are more likely to be receptive if the individual making recommendation represents a recognized conservation group, research consultant, or government agency. When local ordinances regulate beach lighting, local government code-enforcement agents should conduct lighting inspections and contact the public about resolving problems.

WHAT SHOULD BE DONE WITH INFORMATION FROM LIGHTING INSPECTIONS?

Although lighting surveys serve as a means of assessing the extent of lighting problems on a nesting beach, the principal goal of those conducting lighting inspections should be to ensure that lighting problems are resolved. To resolve lighting problems, property managers, tenants, and owners should be given the information they need to make proper alterations to light sources. This information should include details on the location and description of problem lights, as well as on how the lighting problem can be solved. One should also be prepared to discuss the details of how lighting affects sea turtles. Understanding the nature of the problem will motivate people more than simply being told what to do.

TECHNICAL ADVANCES IN RECORDING, STORING, AND SHARING SPATIAL INFORMATION ABOUT LIGHTS

Social media have begun to play an increasingly important role in sharing and spreading information. Forums like Facebook and Twitter have large followings. Effective use of these forums can be helpful in early identification of problem lights and timely reporting of inappropriate lighting in coastal areas.

Technological advances in the areas of data storage and sharing include the development of flash drives and several commercially available software programs (e.g., Newforma) for easy transfer of large data files.

Monitoring Sea Turtle Behavior.

In part, the behavior of nesting sea turtles and their hatchlings on the beach can be monitored by studying the tracks they leave in the sand. This evidence can reveal how much and where nesting occurs and how well oriented hatchlings are as they attempt to find the sea from their nest. Monitoring this behavior is one way to assess problems caused by artificial lighting, but it is no substitute for a lighting inspection program as described above. Many lighting problems can affect sea turtles and cause mortality without the turtles' leaving conspicuous track evidence on the beach.

SEA TURTLE NESTING

On many beaches, sea turtle biologists make early-morning surveys of tracks made the previous night in order to gather information on nesting. With training, one can determine the species of sea turtles nesting, the success of their nesting attempts, and where these attempts have been made. These nesting surveys are one of the most common assessments made of sea turtle populations. Because many factors affect nest-site choice in sea turtles, monitoring nesting is a not a very sensitive way to assess lighting problems. But changes observed in the distribution or species composition of nesting can suggest that serious lighting problems exist and should be followed with a program of lighting inspections if one is not already in place.

HATCHLING ORIENTATION

Although hatchlings are more sensitive to artificial lighting than are nesting turtles, the evidence they leave behind on the beach is less conspicuous. Evidence of disrupted seafinding in hatchlings (hatchling disorientation) can vastly underrepresent the extent of a lighting problem, but this evidence can be useful in locating specific problems between lighting inspections. There are two ways to use hatchling-orientation evidence to assess lighting problems: using hatchling orientation surveys and hatchling disorientation reports.

HATCHLING ORIENTATION SURVEYS

Of the two methods, the hatchling-orientation survey is the more accurate and involves measuring the orientation of hatchling tracks at a sample of sites where hatchlings have emerged. Because the jumble of hatchling tracks at most emergence sites is often too confused to allow individual tracks to be measured, simple measures of angular range (the width that the tracks disperse) and modal direction (the direction in which most hatchlings seem to have gone) are used instead. If the sampling of hatchling emergence sites is distributed appropriately across a specific stretch of beach or a particular time of the lunar cycle, data from these samples can be an accurate index of how well hatchlings have been oriented (Witherington et al., 1996).

HATCHLING DISORIENTATION REPORTS

Although hatchling disorientation often goes unnoticed, some cases are observed and reported. Evidence of disorientation includes numerous circling tracks, tracks that are directed away from the ocean, and carcasses of hatchlings that have succumbed to dehydration and exhaustion. Because reporters often discover this evidence while conducting other activities, such as nesting surveys, it is often only the most conspicuous cases that are reported. Despite such bias, such reports can still yield valuable information, though they do not provide accurate numerical estimates of the impact of inappropriate lighting on individual animals.

Reports of hatchling disorientation can help researchers immediately identify light-pollution problems. Although not every hatchling that is misled by lighting may be observed and reported, each report constitutes a documented event. When reports are received by management agencies or conservation groups, action can be taken to correct the light-pollution problem at the specific site recorded in the report. FWC provides a form—(http://myfwc.com/media/418156/Seaturtle_Guidelines_A_LDIR_FillIn.pdf)—for reporting disorientations.

Laws, Regulations, and Standards for Lighting

Lighting in Florida is regulated by multiple rules and regulations including Florida statutes, the Florida Building Code and local lighting ordinances. In addition, the Florida Department of Transportation (FDOT) and local governments have adopted lighting-design standards developed by professional organizations including the Illuminating Engineering Society of North America (IESNA) and the American Association of State Highway and Transportation Officials (AASHTO). These myriad rules, regulations and standards are not always consistent. A detailed discussion of these laws, regulations and standards and specific examples of the inconsistencies among them is presented in Appendix F.

NEED FOR IMPROVEMENTS

Regulating human behavior is difficult. Instead of relying on recent technological developments, approximately 70% of local sea turtle lighting ordinances in Florida primarily seek to regulate behavior (Barshel et al., 2013). Some of these ordinances require that residents close their curtains, move interior housing lights away from windows, and even turn off exterior lights during turtle nesting season. But proper design guidelines and new lighting technologies can eliminate much of the need for such behavioral regulation.

Recently, 82 local ordinances enacted to mitigate the effects of artificial lighting on sea turtles in Florida were evaluated for their legal and functional effectiveness. The ordinances were analyzed for regulatory and enforcement contents, applicable to existing and new properties. The following recommendations were included in this report:

Improve requirements for existing developments.—In many cases the requirements for existing developments tended to be less restrictive than for new development.

- Most ordinances require shielding lights, more often for new developments than for existing developments.
- Fewer than half of the ordinances require that lights not be visible from the beach for existing developments, whereas most (90%) do so for new developments.

Require lower lumens.—Researchers and the sea turtle–conservation community has been advocating the need for lower lumens for better lighting regulation near nesting beaches, but few ordinances mandated low lumens.

Mandate long-wavelength light.—Research has established that light sources with longer-wavelength light (560 nm or more) have less impact on sea turtles. Only Walton County's lighting ordinance *requires* that lights be exclusively long wavelength.

Require compliance inspections.—Regular lighting inspections are believed to improve compliance with lighting regulations. Only a few ordinances require mandatory compliance inspection, though most have penalties for noncompliance.

Emphasize public education.—There is growing consensus that public education helps achieve better compliance with laws and regulations, including lighting ordinances, but only 20% of existing local lighting ordinances have provisions for educating the public.

EFFECTIVE TRAINING AND CODE ENFORCEMENT

Many local governments in coastal areas have adopted lighting ordinances, and a number of those lack the funding to properly enforce them. As a result, many important nesting beaches in Florida still have inappropriate beachfront lighting, which affects nesting and hatchling sea turtles.

Improving the implementation of lighting regulations requires training programs for those who enforce local code governing lighting on and near sea turtle nesting beaches. To be effective, such programs need to be hands-on and field-oriented to train personnel to identify types of lighting sources and fixtures that can negatively impact sea turtles. Such training will enable code-enforcement officers to educate property owners and recommend sea turtle friendly lighting alternatives while meeting the safety and visibility needs of the public. The training should include field trips to view coastal properties with problematic lighting and to assess lighting retrofits that eliminate impacts to sea turtle nesting habitat.

Since new coastal developments are required to adhere to stringent State-approved lighting plans for the protection of sea turtles, the ability to systematically fix lights at older, existing developments presents an important opportunity to achieve long-lasting conservation benefits for Florida's sea turtle nesting populations. Replacing or retrofitting problem lights can be expensive, and owners are often unaware of the options.

SPECIAL CONSIDERATIONS FOR LIGHTING IN COASTAL AREAS

Lighting professionals and public agency staff involved in designing, reviewing, and issuing permits for lighting projects need to be familiar with the need to consider sea turtles when designing projects adjacent to coastal nesting beaches. Laws, regulations, and standards developed to regulate lighting primarily in noncoastal areas should be applied to coastal areas with caution. Not only is it inconsistent, but legal issues are also involved. While it is important to comply with lighting requirements of the Florida Building Code, compliance must be done in a way that does not violate local lighting ordinances or the Endangered Species Act (see discussion in Appendix F). Those designing, installing, and operating lighting along Florida's sea turtle nesting beaches face the challenge of ensuring that their plans do not violate those environmental laws, especially when applying other lighting standards (such as IESNA recommendations) that are not required by law.

The good news is that there are ways to provide lighting that ensures safety, security and efficiency without causing harm to sea turtles. First and foremost, there is simply *no substitute for naturally dark habitat.* Removing unnecessary lights is the simplest, most effective, and most energy-efficient solution to this issue. But when artificial lighting is absolutely required for safety and security, the Florida Fish and Wildlife Conservation Commission (FWC) and the U.S. Fish and Wildlife Service (USFWS) recommend a simple and effective approach which requires that the elements of lighting design and luminaire should:

1. *Keep it low.* Mount the fixture as low as possible to minimize light trespass, and use the lowest amount of light needed for the task.
2. *Keep it shielded.* Fully shield the light so that bulbs or glowing lenses are not visible, minimizing light trespass.
3. *Keep it long.* Use long-wavelength light sources (ambers and reds) in appropriate lighting fixtures. FWC and USFWS have teamed up to develop the Wildlife Lighting Certification Program. This program was designed to educate the public, the building industry, and government officials on how to minimize impacts of artificial light on wildlife by using proper lighting methods and identifying appropriate lighting fixtures, shields, and lamps.

SEEKING A VARIANCE

Sometimes a lighting design meets all the noted recommendations for sea turtle protection yet still does not meet the lighting requirements of the Florida Building Code, the Florida Department of Health, or the Florida Department of Transportation. Most agencies have a process for such situations that involves seeking a variance from the standards due to irresolvable constraints.

FLORIDA BUILDING CODE

Certain requirements in the current versions of Florida Building Code 2010 (with amendments in 2012 and 2013) pertaining to the illumination levels for egress points may cause unintended impacts to nesting and hatching sea turtles. Section 1006.1.3 of the code requires a minimum illumination level of 10 foot-candles for new stairs and 1 foot-candle for the floors and other walking surfaces in an exit and exit access and discharge areas. Where exits open onto a beach, maintaining this high level of illumination may negatively impact the nesting beaches. In this situation, property owners may seek a variance to the code.

In compliance with Florida Department of Environmental Protection (FDEP) requirements, a large number of coastal governments in Florida have beach lighting ordinances that require no lighting or low levels of lighting near nesting beaches. Efforts to comply with the building code, disregarding the special status it grants to structures in coastal areas, require illumination levels that may constitute a violation of the local lighting ordinance. Section 3109 refers to the requirement of obtaining an environmental permit for structures in coastal areas and states that:

> . . . the environmental permit may condition the nature, timing and sequence of construction activities to provide protection to nesting sea turtles and hatchlings and their habitat, including review, submittal and approval of lighting plan.

The Illuminating Engineering Society of North America develops national lighting standards for North America including “IESNA G-1-03: Guidelines for Security Lighting for People, Property, and Public Spaces.” The following excerpt from these guidelines points to another aspect of such security lighting:

> Impact on Surrounding Area. Stray light from a security installation may be considered as light trespass by neighbors. Stray light or over-lighting may also have effects on safety on nearby roads and railroads. Where signal lights are used to control traffic on roads, railroads, rivers, or at sea, care should be taken to avoid confusion caused by disability glare from the security lighting system. Lighting can also have an environmental impact on nocturnal animals, migratory birds and nesting sea turtles. Local lighting ordinances should be consulted prior to design work for any limitations on mounting height, source type, wattage, shielding, and other local requirements that must be followed. Permission for variances should be obtained from the authority having jurisdiction.

MEETING CODE REQUIREMENTS WITHOUT AFFECTING SEA TURTLES

Even though the Florida Building Code’s requirements regarding illumination levels are stringent and not supported by national and local standards, these levels can be achieved for new buildings, in some cases without affecting sea turtle populations on nearby nesting beaches. This requires the use of innovative lighting design and appropriate luminaires and fixtures.

For example, it is essential that stairs for new buildings be kept indoors behind doors or other opaque elements that obstruct light spillage. The luminaires for such stairs should be located such that the light is focused on the stairs, landings, and immediate surrounding areas and with minimal spread of light. Light fixtures recessed in the slabs or walls and equipped with luminaires that have desirable spectral distribution help meet these objectives. Stairways (and elevator shafts) within sight of the beach should be fully enclosed with no glass windows or walls. If glass is required, inside-to-outside light transference should not exceed 10–15%.

Installation of motion sensor–equipped lights helps reduce the amount and duration of exposure to lighting when complete control of stairway lighting is not feasible.

When conflicts arise between the requirements of the building code and lighting to reduce impacts to sea turtles, designers can seek a declaratory statement or a variance to ensure that there are no impacts for sea turtles. A declaratory statement is the administrative process by which the Commission resolves controversy or answers questions concerning the applicability of a statute, rule, or order, to the petitioner's particular situation per Florida Administrative Code—Chapter 28-105. Under certain strictly defined conditions, the Florida Building Commission can authorize local governments to amend requirements such that they are more stringent than stated in the code. The Florida Building Commission may issue official code clarifications using procedures of Chapter 120, Florida Statutes. To obtain such a clarification, a request for a declaratory statement must be made to the Building Commission in a manner that establishes a clear set of facts and circumstances and identifies the section of the code in question. Requests are analyzed by staff, reviewed by the appropriate technical advisory committee, and sent to the commission for action. Approval has been granted to both administrative and technical amendments. For such a process to be followed, lighting design professionals must work with local government officials who have a responsibility to implement both the commission's rules and the local sea turtle–protection lighting ordinance.

FLORIDA DEPARTMENT OF TRANSPORTATION

The Florida Department of Transportation also has a design variation and exception process. If compliance with FDOT lighting-design criteria could harm sea turtles, the FDOT design variation process may be used. A detailed analysis is required to demonstrate that using the lower illumination level necessary to protect sea turtles will have no negative impact on pedestrian and driver safety and traffic operations. (FDOT Plans Preparation Manual, Ch. 23, 2014). While this process requires a rigorous analysis and may involve several rounds of review, FDOT has issued such variances for roadway lighting in coastal areas. At least one FDOT district (District 4) has developed alternative lighting–design standards for coastal roadways along sea turtle nesting beaches (FDOT D4, 2009).

Those involved in lighting design and permitting need to know about alternatives. National and local lighting standards and rules also must be met. At a minimum, any conflict the code's requirements may have with these national and local standards must be brought to the attention of local permitting agencies. This may be followed by offering an alternative design that meets local or national standards. When necessary, variances from the appropriate agency may be requested.

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SOLUTIONS: Solving Problems Caused by Artificial Lighting

Light as a Pollutant

Light pollution has widespread effects. The terms light pollution and photopollution were originally used by astronomers (Dawson, 1984; Eakin, 1986) to describe light that obliterates our scientific and recreational views of the night sky. Many of the same light sources that interfere with our enjoyment of the heavens on nightly beach walks also deter nesting and disrupt orientation in sea turtles. The biological effects of light pollution are just beginning to be realized and are not limited to sea turtles. Many animals—such as migrating birds and night-flying insects—depend on the natural night sky for cues that guide their orientation; these species are well-known victims of artificial lighting (Verheijen, 1985; Witherington, 1997; Rich and Longcore, 2013; Davies et al., 2013; Davies et al., 2014). Impacts from artificial lighting are not limited to wildlife and vegetation, and photopollution can have profound impacts on humans as well.

Solving problems caused by light pollution can be very different from solving problems caused by other pollutants. For instance, in theory, harmful light can be eliminated instantaneously by flipping a switch at the source. Light does not linger in the environment as do many polluting substances. But some difficulty lies in recognizing light pollution and in agreeing upon which artificial lighting constitutes problem lighting. One person's environmental threat may be another person's safety and security.

It may help to think of light pollution as artificial light that is out of place. More often than not, light that is located in the area it was meant to illuminate causes little harm. This is certainly true for sea turtle nesting beaches: artificial light that illuminates dune properties without reaching the nesting beach is not a threat to sea turtles.

The most readily accepted strategy for solving light-pollution problems is to manage light rather than prohibit it. In most cases, light that causes problems for sea turtles has spilled over from the sites it was intended to illuminate; this light spillage does not serve a useful purpose and should be managed. A program of light management can make it possible to solve light-pollution problems without resorting to "just say no" policies that may be intimidating to the public.

USING THE BEST AVAILABLE TECHNOLOGY

Light management for conserving sea turtles must have an identifiable goal; that is, light must be managed to some level that can be recognized. Unfortunately, there is no single level of light intensity that one may use as a criterion. The level of artificial brightness necessary to deter nesting or misorient hatchlings varies greatly with the level of ambient light (moonlight) and the availability of other visual cues (e.g., the amount of dune). Consequently, there is no one acceptable level of light for every sea turtle nesting beach under every set of lighting conditions.

Given the uncertainty over how to measure acceptable light, it is most productive to simply minimize light pollution as best we can. This is the concept behind the use of best available technology (a common strategy for reducing other forms of pollution by using the best of the pollution-reduction technologies available). Best available technology forms the basis of light management methods that reduce the effects of artificial lighting to the greatest extent practicable. Although there is no single turtle-friendly luminaire that would be best for all applications, there are methods one can use and a set of characteristics that light sources should have that will minimize the threat of light pollution for sea turtles. As presented below, these light-management tactics include removing lights not needed for safety and security, retrofitting necessary lights with appropriate fixtures and lamps, controlling light so that the level of light reaching the beach is minimized, and ensuring that the light that does reach the beach is of the least disruptive color. Turning lights off when not in use is also important, but clearly, extinguishing lights for the entire nesting season is not the best option if the light is necessary for human security and safety.

Effective Methods for Managing Light

CURRENT STATUS

Considerable progress has been made in regulating lighting in coastal areas since the first version of this manual was published in 1996, when the concept of lighting ordinances for the protection of sea turtles was in its infancy. A total of 82 municipalities in Florida have adopted lighting ordinances to minimize the impact of lighting on adjacent sea turtle nesting beaches. Advances in our understanding of sea turtle biology, coupled with advances in lighting technology, reinforce the need to update the existing ordinances including the statewide Model Lighting Ordinance (Florida Administrative Code Rule 62B-55).

During 2014, the Florida Department of Environmental Protection (FDEP) has begun to promulgate an updated set of best management practices for the lighting of beachfront buildings, other structures, and parking lots to better protect nesting sea turtles and hatchlings from artificial light pollution. Once adopted, the DEP guidelines will be implemented as a condition of the department's Coastal Construction Control Line (CCCL) permitting program for development along Atlantic, Gulf of Mexico, and inlet beaches. But the proposed guidelines apply only to new construction and CCCL permitting does not cover all development that could contribute to illumination on the beach at night (Barshel et al., 2013).

More than 82 local governments in Florida that have adopted beach lighting ordinances have based them on the 1993 DEP Model Lighting Ordinance. Yet, many turtle disorientation events are documented annually on Florida beaches. In 2012, 2,101 disorientations were reported to the Florida Fish and Wildlife Conservation Commission.

LESSONS LEARNED

Regulating artificial lighting can incorporate two approaches: mandating sea-turtle-friendly lighting technologies and addressing human behavior.

In 2010–2012, problem lights on 65 large beachfront properties were replaced with more appropriate lights and bulbs, darkening approximately 45,000 linear feet of beach. Disorientations from artificial lighting reported during the 2011 nesting season decreased significantly and remained low on that beach during the 2012 nesting season. In addition to the ecological benefits, some retrofitted property owners reported significant savings on their outdoor electricity bills as a direct result of the retrofit, which included very energy-efficient LED lights (Barshel et al., 2013).

ADDRESSING PROBLEM LIGHTS

Any strategy for reducing light pollution should begin with identifying the problem light sources (as defined previously in "Assessments"). Unnecessary lights should be eliminated. Lights necessary for human safety should be retrofitted or replaced with turtle-friendly fixtures. Many light sources illuminate areas that do not need to be lighted. These unnecessary light sources include the following:

1. Light sources that illuminate areas that require no security. This includes the beach itself in most cases. Ocean beaches are more often in public, not private ownership, and are not areas where property should normally be stored.
2. Light sources that illuminate areas that are vacant or have no foot traffic.
3. Decorative lighting that has limited use other than aesthetic enhancement. Decorative lighting near nesting beaches may be much more harmful to sea turtles than it is useful to people.
4. Light sources that provide more than adequate illumination for a particular function.

The amount of light needed depends on its appropriateness in the context of the overall environment and surrounding community. Lighting for commercial and residential areas in an urban setting has different requirements than that in rural and environmentally sensitive areas where glare and light trespass can affect adjacent natural communities.

The Illuminating Engineering Society of North America recommends using appropriate environmental zones that range from intrinsically dark (E1) to high ambient brightness (E4). Most parks, beaches, and natural areas fall in the category of zone E1. Due to strict light trespass requirements for such areas, the recommended illuminance level is 1.0 fc (IESNA, 1999). In other areas, illuminance levels necessary for safety and security are also rather low (0.2–1.0 fc or 2–11 lux, recommended for areas with security fencing and for parking areas) (Kaufman and Christensen, 1987).

Unnecessary light sources near sea turtle nesting beaches should be eliminated, and the number and brightness (lamp intensity, typically expressed in watts) of light sources that provide more than adequate illumination should be reduced. Lighting that is necessary for safety or security can be used when needed during early evening and switched off for the remainder of the night (see notes on timers and motion detectors below). Items valuable enough to require security lighting should be removed from the beach.

Switching lights off when not in use can be the simplest, cheapest, and most straightforward way to solve lighting problems. Turning off lights will result in energy and sea turtle conservation. Usually, property owners are able to switch lighting off on their own, but large outdoor luminaires mounted on poles are sometimes leased from a power company and must be extinguished by authorized company personnel at the request of the customer who pays the electricity bill.

Despite being simple and straightforward, successfully managing beachside lights by regulating human behavior—turning lights off or drawing the curtain—has proved to be difficult. But light management strategies with proper design guidelines and new lighting technologies can help achieve desired results without the need for much behavioral regulation. Where pedestrian activity requires some lighting, low-mounted (preferably bollards, path lights, or embedded lights) and low-wattage lights in the acceptable long-wavelength range, as described in the following section, and color can be provided. Internally illuminated pavement-embedded markers can be installed along roadway lane lines to help delineate the pavement. Apps that run on cell phones and other personal electronic devices to control home appliances and lights remotely (at a scheduled time or on demand) are available at a modest price.

USE ALTERNATIVE, LONG-WAVELENGTH LIGHT SOURCES

Where efforts to dim, redirect, or block light have not been entirely effective, some errant light may reach the beach. An additional strategy for reducing effects of artificial lighting is to ensure that the spectral qualities of any light that does reach the beach make it minimally disruptive to sea turtles. Minimally disruptive light sources have a spectral distribution that excludes short-wavelength (ultraviolet, violet, blue, and green) light. These long-wavelength light sources will have a minimal effect on sea turtles but, because they are not completely harmless, they should not be used without light-management techniques (e.g., shielding, cutoff, or directional fixtures). Unfortunately, long wavelength lights alone do not eliminate the risk to see turtles, but a low wattage, long-wavelength lamp in a fully shielded, downward-directed fixture provides the best option available for lighting along the nesting beach. The following section describes types of long-wavelength light sources available in the market.

LONG-WAVELENGTH LEDs

Light-emitting diode (LED) lamps are one of the best available technologies that can work well for humans and sea turtles. LEDs are highly directional and can be manufactured to produce long-wavelength light in the amber, orange, and red color range. As these LEDs become more widely available, costs are decreasing, making them an attractive option for beachfront property owners.

From airports to headlights, the small size, faster response time and durability of LEDs make them a viable replacement for variety of light sources. Initially LED lights were available only in a small wattage range, limiting their use to smaller areas. But in the past 10 years the technology has developed significantly, and LED lamps are available in an increasing range of wattages. The unique quality of LED lamps to produce light in a wide spectrum of colors and wavelengths makes it particularly suitable for various uses, including near sea turtle nesting beaches. LED lamps producing amber, red, or yellow lights are available that produce light consistently in the narrow band of wavelength around 560 nm. Lights in amber/red /yellow colors with 560 nm or longer wavelength are less disruptive to sea turtles. In addition, LED lights in the above colors do not degrade the night vision of people visiting the beach. As people walk to the beach along a pathway lighted with amber/red/yellow LED lamps, their eyes can adjust to the darkness, leaving them better able to see by moonlight and starlight once they reach the unlighted beach.

LOW-PRESSURE SODIUM VAPOR

The spectral properties of low-pressure sodium-vapor (LPS) lighting make this type of lamp minimally disruptive to sea turtles for applications requiring a high-intensity-discharge light source, such as parking lots, roadways, and parking garages. Light from this lamp type is widely dispersed across a broad area. While light emanating from an LPS fixture tends to reduce or eliminate shadow zones, making it suitable for security lighting, the widely scattered light also tends to illuminate any nearby vertical surface or object. This increase in indirect lighting can reduce the benefits of using a long-wavelength light source in many beachfront applications where lights are installed adjacent to other structures.

The determination that LPS lighting can, in certain situations, have minimal impact on sea turtles comes from studies of nesting and hatchling loggerhead and green turtles, along with limited evidence from studies of hatchling hawksbills and olive ridleys. Because light from LPS sources is not completely ignored by sea turtles, LPS should be considered as a substitute for more disruptive light sources rather than as a replacement selected for beach-darkening efforts.

LPS light has greater effects on some species than on others. Sea-finding in loggerhead hatchlings has not been observed to be substantially disrupted by LPS lighting in the field, whereas green turtle hatchlings are substantially affected under some conditions. Although LPS lighting is predicted to have a minimal effect on loggerhead hatchlings, mere presence of LPS lights does not reduce the attraction of other, adjacent, lights on the nesting beach.

YELLOW FILTERS AND GEL COATINGS

Lamps that are tinted yellow to reduce the emission of insect-attracting short-wavelength light (bug lights) have been found to be disruptive to sea turtles. There are no standard spectral requirements for the term bug bulb. Thus, while these lamps appear yellow or amber, most still contain significant amounts of short-wavelength light. The Best Available Technology (BAT) for sea turtle protection currently does not include incandescent or compact fluorescent bug lights. There are some long-wavelength tubes available (http://www.myfwc.com/conservation/you-conserve/lighting/certified/bulbs/) that do produce predominately long-wavelength light; these can be used instead of white fluorescent tubes, in conjunction with proper shielding, when other replacement options are not available.

Research on white incandescent or fluorescent lamps covered with filters or gels has shown that the filters and gels are not effective in filtering out short-wavelength light or reducing impacts to sea turtles. With the increased availability of better quality LED lamps that produce pure amber, red, or yellow light, they have become the most commonly recommended light source for use near sea turtle nesting beaches.

MINIMIZE BEACH LIGHTING FROM OUTDOOR SOURCES

Beach lighting from outdoor sources can be managed in a number of ways that allow the function of the lighting to be retained or even enhanced. When considering appropriate lighting adjacent to a sea- turtle nesting beach, it is appropriate to "Keep it low, keep it long, and keep it shielded," as follows.

Keep It Low

- Reduce the wattage of problem lighting. For a given lamp type, reducing the wattage of the luminaire will reduce the amount of light emitted. When changing lamp types or fixture styles, the manufacturer's data on luminance (typically given in lumens) should be consulted. A table outlining efficiency (lumens/watt) of various light sources is given in Appendix B.
- Use lower pole-mounted luminaires or low-mounted luminaires (such as louvered, bollard-type fixtures or path-light fixtures) as a substitute for pole-mounted lighting. Low-mounted luminaries that are better focused concentrate light where it is most needed; the lower a light source is mounted, the smaller the area it will illuminate. In addition, sources mounted lower will tend to have a greater degree of shielding from the beach by objects on the dune (vegetation, buildings, etc.). Sources mounted high on poles near the beach can be difficult to shield from the beach. The post-like stature of bollard luminaires with light-directing louvers is ideal for keeping light focused on the ground and off the beach.

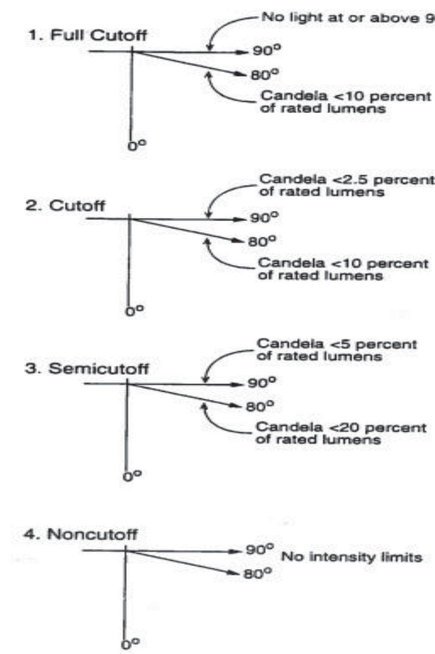

***Figure* 13**. *Cutoff classifications for standard outdoor or roadway luminaires*

Figure 13 graphically depicts light distribution characteristics of luminaires. *Candela* is the basic, international unit for measuring luminous intensity. *Lumen* is a unit of light output or flux. Cutoff luminaires control upward spread of light. Full cutoff luminaires, in addition to controlling upward spread, also reduce the spread of light on the back and sides of the luminaire. Non-cutoff luminaires have no such controls, allowing light to stray.

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Keep It Long

- While not invisible to sea turtles, long- wavelength light in the orange to red color range is less likely to impact nesting females and hatchlings. Monochromatic long-wavelength light sources such as amber or red LEDs that produce light at 560 nm or longer are less likely to impact sea turtles.

Keep It Shielded

- Replace unshielded fixtures with full-cutoff, fully shielded luminaires to focus light where it is most needed.
- Replace higher-wattage multidirectional luminaries with lower-wattage directional luminaires. Luminaires should not be directed onto the nesting beach or any object visible from the beach (see Appendices C–E). Many fixtures have beach or house-side shields that block light on one or more sides and focus it where needed for human safety.

- Shield existing light sources from the nesting beach. To be effective, light shields should be opaque, sufficiently large, and positioned so that light from the shielded source does not reach the beach. Replace poorly shielded fixtures with full-cutoff, opaque shields. Light shields can be fashioned from inexpensive and easily obtained materials. Good shielding should provide a cutoff angle of 90° or more (Figure 13). Shields for many light fixtures are commercially available. Customized light shields are often needed because luminaires come in so many different designs. However, changing a light fixture to a more directional style is almost always a more efficient and permanent solution than shielding.
- Install louvers or baffles to direct light away from the beach and focus it where needed for human safety.
- Recess luminaires into the underside of architectural features of the roof such as a beam, arch, ceiling, or vault, where available. Recessed sources will be more directional and, if directed downward, will be less visible from the beach than multidirectional lighting (see Appendices D and E).
- Shield light from the beach by redirecting luminaires away from the nesting beach. Even sources that are poorly directional can be redirected so that most of their brightness is pointed away from the beach.
- Reposition luminaires to take advantage of natural light screens. Necessary luminaires should be positioned on the landward side of any buildings or vegetation and the light focused so it does not reflect off walls, structures, or vegetation.
- Create natural light shields by planting native dune vegetation as a light screen. Planting light-blocking vegetation on the primary dune can alleviate problems caused by light that is not managed by the techniques outlined above. To be most effective, vegetation should be near the crest of the dune closest to the beach, which is where woody, well-established vegetation normally grows. Salt-tolerant, bushy, densely leaved native plants are the most suitable.

METHODS FOR REDUCING LIGHT TRESPASS FOR SPECIFIC OUTDOOR LIGHT SOURCES

POOL LIGHTING

Outdoor swimming pools pose some unique beach-lighting issues. The Florida Department of Health (DOH) sets lighting standards for public swimming pools. DOH has a "no light swimming" category implying no use of the pool after daylight hours. But if this option is used, the pool must be closed at night, with posted notices and often locked gates to prevent entry.

For properties that choose to allow nighttime use of their pools or pool decks, DOH requires both deck and underwater lighting. The required illumination level for the deck surface within four feet of the pool is 3.0 fc. Underwater lights are required at 0.5 watt per square foot. These required lights, especially the underwater lights, can pose a problem for sea turtles, particularly if white halogen light is used, as the glow from such lights can reflect onto adjacent structures and be seen from the beach. Because shielding these underwater luminaires would block light from areas where it is needed for human safety, using multiple lower-wattage luminaires that produce light at greater than 560 nm wavelength can reduce the impact of pool lighting on adjacent nesting beaches. But this will not eliminate the light's spreading out from the underwater luminaires.

Similarly, using low-mounted fixtures such as bollards, step lights, embedded lights, and pathway lights can reduce visibility from the nesting beach while providing the required amount of lighting on the pool deck. Using lower-wattage lights that produce light in long-wavelength range and with distribution focused down helps reduce uplighting. Pole lights are not required and should not be used to light any pool on the landward side of a building or within sight of the beach. Pool lights often reflect up the side of adjacent structures, so screens and other light-blocking options should also be used.

If meeting the DOH lighting requirements while using the above options still results in an unacceptable level of lighting on the nesting beach, a design variation can be submitted for DOH processing. The documentation for the design variation should include an analysis of the safety, security, and functional impacts of the desired lower levels of illumination. It should also include a reference to the implications of potential violations of the local lighting ordinance and state and federal laws protecting sea turtles as a result of compliance with the DOH lighting requirements.

PARKS

Several public parks are located close to the beach in Florida. Most of these parks are open to the public during the day only, but some are also open at night. These parks require lighting only when public access to trails, pathways, or bikeways is required. If not absent entirely, artificial lighting for maintenance rooms, restrooms, and adjacent parking lots should remain at very low levels. If lighting is provided, the luminaires should be well shielded, taking full advantage of existing natural vegetation. Even if natural vegetation provides adequate visual shielding from the beach, luminaires should be shielded with commercially available fixtures to minimize their contribution to sky glow. Much of the discussion provided below for piers, sidewalks, walkways, and bikeways is also applicable to parks.

PIERS, SIDEWALKS, WALKWAYS, AND BIKEWAYS

Most public beaches have one or more piers, sidewalks, walkways, or bikeways where lighting may be needed for safety and security. National, state, and local lighting standards for these facilities are available, but most do not address constraints for lighting near sea-turtle nesting beaches. With the exception of commercial areas, the following illumination levels are recommended, but not required, for these facilities, and vary from 0.5 to 0.2 fc (IESNA, 1999).

Table 1. *Recommended maintained illuminance levels for walkways and bikeways (IESNA, 1999)*

Classification	Minimum average horizontal illuminance levels (fc)
Sidewalks (roadside); Type A bikeways	
Commercial areas	1.0
Intermediate areas	0.5
Residential areas	0.2
Walkways distant from roadways and Type B bikeways	
Walkways and bikeways	0.5
Pedestrian stairways	0.5
Pedestrian tunnels	2.0

Other options for minimizing impacts of artificial lighting on nearby or adjacent beaches include the following:

- Restrict use of these facilities to daylight hours only, if feasible.
- Control amount of light. If access is provided at night, the amount of lighting should be proportional to the distance of the facilities from the beaches and take into account the presence of dunes and vegetation cover between these facilities and the beach.
- Avoid pole-mounted lights. Pole mounted lights are not a good choice for pathway or pedestrian crossings near beaches. Pavement-embedded LED markers, low-height bollards, step lights, and low pathway lights are preferred.
- Keep mounting height low. If the desired illumination levels cannot be achieved without pole-mounted lights, the mounting height should be kept to a minimum, not exceeding 12 ft.
- Reduce wattage. Luminaires should be of lower wattage, fully shielded, preferably amber or red LEDs with a wavelength of 560 nm or more. Occupancy or motion sensors can be used to minimize the duration of unnecessary illumination. Some sensors also adjust amount of light based on available ambient light.

STREETLIGHTS

Roadways in Florida fall under state (FDOT), county, or municipal jurisdiction. FDOT has its own lighting-design criteria. Most counties and local governments use the *Manual of Minimum Standards for Design, Construction and Maintenance of Streets and Highways,* commonly known as the *Florida Greenbook* (Greenbook, 2011) for street design, including lighting. Both FDOT and *Florida Greenbook* standards of street lighting are based on standards of the American Association of State Highway and Transportation Officials, which, in turn, are derived from IESNA standards. Due to their high intensity (wattage) and mounting height, pole-mounted street lights can be difficult to shield from the beach. The recommended approaches to dealing with street lighting are:

- Minimize new or additional lights. Unless justified for safety by rigorous crash analysis, clearly establishing that the absence of lighting is contributing to a number of accidents greater than the statewide average for a comparable section of road, no new or additional street lighting should be allowed near beaches.
- Consider a lighting calendar. Many coastal areas observe a lighting calendar, requiring that all pole-mounted lights be turned off during the sea-turtle nesting season. Low-height and low-intensity bollards and internally illuminated, pavement-embedded LED markers are more appropriate solutions in such areas. In other areas, replacing existing pole-mounted fixtures with lower, fully shielded, long- wavelength LED lights may be appropriate.
- Use lowest acceptable illumination levels. If new or additional lighting is justified for safety considerations, as discussed above, the FDOT (or county or local) standards must be reviewed carefully. For roadways under FDOT's jurisdiction, the lighting standards do not consider limitations and constraints along sea-turtle nesting beaches.

- Seek Variance. In most cases, lower illumination levels can be requested for FDOT roadways. To request this, a design variation must be prepared by a lighting design professional and submitted to FDOT. For roadways under local government jurisdiction, a wider array of land-use and intensity-of-use combinations must be considered. In these cases, a variance may be available from the local government.
- Keep mounting height low. Mounting height for luminaires is another important consideration. The minimum pole height per FDOT standards is 25 ft. This is based primarily on economics. But poles as short as 17.5 ft. can be used for lighting without creating safety issues. A design variation from FDOT is required to allow use of shorter poles.
- Use low-wattage luminaires. Low-wattage luminaires (90 watts or less) are preferred near nesting beaches, although 150-watt luminaires are often used. Luminaires in such areas should be full cut-off and completely shielded, preferably also with a vegetative screen if facing the beach. As has been stated, LED luminaires are fast gaining acceptance in the industry as they are highly efficient. When used near the beach, LED luminaires must emit light in the 560 nm or greater wavelength range to minimize the impact on sea turtles.
- Provide buffer zones. Dunes and taller vegetation such as sea grapes provide an essential buffer between streets and beaches and should be provided and maintained wherever possible.

PARKING FACILITIES

These facilities may be open parking lots or unenclosed areas in buildings. In coastal areas, parking lots and garages located close to the beaches are not uncommon. Lights from these facilities are often directly visible from the beach and pose a serious risk to marine-turtle nesting.

- Parking lot lights are, in general, regulated under local ordinances. For example, parking lot lights in Miami-Dade County are regulated by the Miami-Dade Parking Lighting Ordinance. Illumination levels required by the ordinance vary depending upon the land-use of adjacent areas and the type of facility (open parking lot or unenclosed building) and range from 0.5 to 1.0 fc. The ordinance allows for reducing these illumination levels 50% on nonbusiness days, commencing 30 minutes after closing on business days.
- Although required light levels are typically low, achieving these levels through overhead lighting sometimes results in light-trespass that is not eliminated despite the use of full-cutoff luminaires when the parking lots are located very close to the beach. Lowering pole heights, strategically placing poles with fully shielded, long-wavelength luminaires, or using multiple low-height (2–4 ft.) bollards instead of pole-mounted lights may reduce impacts to nesting beaches. Internally illuminated amber LED markers are good for pedestrian path lighting in the parking lots.
- Use of long-wavelength, full-cutoff, and fully shielded fixtures; motion sensors; and screens are all options, but when possible parking garages should not be placed in sight of a beach.
- Parking spaces should be oriented along the beach so that headlights do not shine directly toward the water. Spaces should be placed behind dunes and vegetation to block headlights.

SPORTS FIELDS

In some cases, such as athletic fields, lowering the lights or using long-wavelength light is not an option. Stadium lighting—intense broad-spectrum lighting that is typically mounted as multiple units on tall poles—can pose lighting problems that are particularly difficult to solve. This type of lighting should not be used near sea-turtle nesting beaches during the nesting–hatching season. Because stadium lighting tends to be both outwardly directed and intense, it can produce a glow that affects nesting beaches many kilometers away. These lights can be shielded and the glow can be reduced by fitting individual luminaires with louvers or visors that reduce the amount of light shining upward and laterally.

DECORATIVE LIGHTING

Decorative lights are not necessary for improvement of nighttime vision. These nonessential light sources are not required for security and safety or to help people perform routine nighttime functions. They include accent lights, uplights, many rope lights, and string lights. One way to address this issue is to use full-cutoff, fully shielded, long-wavelength fixtures. Functionality and attractiveness need not be mutually exclusive. For example, path lights may provide required light levels for a walkway but can also be an attractive part of the overall aesthetic.

Because lights installed solely for aesthetic purposes can and do impact sea turtles, they should not be installed on the seaward or shore- perpendicular sides of buildings near nesting beaches or at other locations from which they may be visible from the beach. For example, light from decorative uplights is often visible from the beach, even when the fixture is on the landward side of the building. Limited decorative lighting may be acceptable behind (i.e.

landward of) taller structures provided the fixture and any illuminated surface is not directly or indirectly visible from the beach and the light does not contribute to glow. All such fixtures should be long-wavelength, red or amber, fully shielded, low-wattage, and low-mounted. Examples of such limited decorative lights include tree-strap amber LED downlights mounted low and pointed toward the ground on the landward side of the trunk.

SIGN LIGHTING

Illuminated signs, especially in urban areas, are a significant part of the night skyline. Billboards and neon and other lighted signs are commonly installed on buildings or poles for advertising or identification and can be difficult to shield from the beach. While an important part of the commercial activity in such areas, these lights, like any other visible light source, can interfere with sea-turtle nesting and hatchling activity.

- Use amber, orange, or red LEDs and true red neon for exit and emergency signs that cannot be hidden from the beach.
- Install illuminated signs landward of existing structures where they are not within sight of a nesting beach.
- Use low-mounted illuminated signs if they are in sight of a beach. They should be close to the ground, with full cutoff fixtures mounted above the sign and shining downward with long-wavelength amber, orange, or red directional LEDs. Backlighting using long-wavelength sources is preferred.
- Use a dark background with light text to improve visibility. Minimizing the amount of light or using reflective lettering on a sign can also reduce impacts to marine turtles.
- Provide no external lighting to signs. Signs on FDOT roadways may use retroreflective sheeting (FDOT, 2013) eliminating the need for external lighting. Signs along sharp horizontal curves where visibility may become an issue due to line-of-sight obstructions must still have external lighting.

MINIMIZE BEACH LIGHTING FROM INDOOR SOURCES

Light from indoor sources can also cause problems for sea turtles. The criteria for identifying problems caused by indoor lighting are the same as those for identifying problems caused by outdoor lighting. Indoor light is a problem if it is visible from the beach. Indoor lighting from buildings that are close to the beach, are very tall, or have large seaside windows causes the greatest problem for sea turtles. Because indoor lighting is usually not meant to light the outdoors, its unwanted effects can be eliminated without compromising its intended function by doing the following:

- Turning off lighting in rooms that are not in use. Reminder notices placed on switches in oceanfront rooms can help in this effort.
- Relocating movable lamps away from windows visible from the beach.
- Tinting or applying window treatments to windows visible from the beach so that light passing from inside to outside can be substantially reduced. A good tinted glass or window-tinting treatment will reduce visible light from the inside to 45% or less (transmittance $\leq$ 45%). Tints are now available that reduce light transmittance 85%. Window glass may be either tinted during its manufacture or tinted later with an applied film. Window treatments (shading materials) are less permanent and can reduce light transmittance more than tints and films can. Complete blockage of light is ideal. See Appendix G for companies offering tinted glass and window treatments.
- Closing opaque curtains or blinds after dark to completely cover windows visible from the beach. Most windows have curtains or blinds to provide privacy to the occupants. Reminder notices on windows or sliding glass doors in oceanfront rooms can help in this effort.

HOW TO CHOOSE AN ALTERNATIVE LIGHT SOURCE

For example, which would be least harmful to sea turtles and more cost effective, a 15-watt white bulb or a 35-watt LPS luminaire? Unfortunately, we have no reliable formula for calculating how much a light source will affect sea turtles. We do know, however, that if spectral emissions are equivalent, reducing intensity will reduce effects, and if intensities are similar, substituting less attractive sources (like LPS) will also reduce effects. A sound strategy, therefore, would be to reduce effects on sea turtles by manipulating both intensity and color. As few lights as practicable should be used, and for lighting applications that are deemed essential, long- wavelength light sources (e.g., LEDs) should replace more disruptive light sources, and intensity should be reduced by using lamps of minimal wattage housed within well-directed fixtures aimed down and away from the beach.

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USE LIGHT SCREENS AND ENHANCE THE DUNE PROFILE

Both laboratory and field experiments have suggested that the dune silhouette can influence sea-finding in hatchlings (Limpus, 1971; Salmon et al., 1992), and it is clear that sea-finding problems are exacerbated where the dune profile is low or the dune is sparsely vegetated (Ferris, 1986; Witherington, 1990; Reiners et al., 1993). Whether by providing visual cues, blocking light, or both, enhancing the silhouette of the dune can reduce lighting problems. Methods include the following:

- Planting native vegetation on the dune. Unlike artificial light screens, vegetation will grow and enhance the dune habitat for other animals, and it may provide more natural orientation cues for hatchlings.
- Erecting artificial light screens on the dune where immediate, short-term light blocking is needed. Artificial screens should be positioned so that they do not impede nesting. Sturdy shade cloth and privacy fencing can make effective light screens. Artificial light screens can be used to block light until planted vegetation thickens to fill in gaps.
- Filling in and replanting dune cuts, pathways, and washout areas. Misoriented hatchlings and adult turtles often exit the beach through these lighted gaps in the dune.

A COMPREHENSIVE STRATEGY FOR MINIMIZING EFFECTS OF ARTIFICIAL LIGHTING

There are many options for lessening the effects of artificial lighting on sea turtles, but in order to employ them, a comprehensive strategy is needed to educate stakeholders, pass legislation, enforce laws, and monitor the nesting beach.

1. Education. Efforts should begin with making those able to solve lighting problems (individuals, corporations, or governments) aware of the problems and possible solutions. Public awareness is a prerequisite for legislative action and can encourage results that exceed what can be mandated by government. Many of the organizations listed in Appendix H are authorities on educating the public on conservation issues. Stories in the news media, distribution of pamphlets or fliers presentations at community gatherings, and door-to-door campaigns can make the public aware of the need for darker nesting beaches (Limpus et al., 1981; Witherington, 1986).

   Well-rounded and long-term educational efforts should include the next generation of sea turtle conservationists. Nurturing appreciation of sea turtles and other features of the natural world in school-age children is a vital conservation investment.
2. Legislation. While public awareness is important in beginning beach-darkening efforts, light-management legislation is often necessary to complete the task. Light-management laws represent serious commitment to protecting sea turtles from artificial lighting and ensure that this conservation effort will be communitywide.
3. Prevention and enforcement. It is far easier to solve light-pollution problems during preliminary planning, before projects are constructed and before lighting is installed. Legislation should require that a central, knowledgeable authority review development plans so that any new lighting near a nesting beach does not become a problem for sea turtles. Solutions to existing lighting problems should also be sought and implemented. Where existing lighting problems are complex or difficult to solve, grace periods can be granted, but flagrant lighting problems caused by easily identifiable sources should be remedied quickly. Issuing warnings and levying fines can ensure that lighting problems are solved promptly. Ideally, warnings should be issued before the nesting and hatchling seasons so that problems can be solved before nesting is deterred and hatchlings are killed.
4. Assessment. Lighting problems can be detected more quickly if observers are familiar with the activities of sea turtles and humans on the beach. Results of lighting inspections, nesting surveys, and hatchling disorientation reports should be assessed regularly.

Overview: Current Status and Future Strategy

Assessment of Past Efforts

NESTING TRENDS

As part of the State's program for promoting the recovery of sea turtles, the Florida Fish and Wildlife Conservation Commission (FWC) oversees the statewide collection of data on nesting sea turtles. The monitoring program was initiated by the Fish and Wildlife Research Institute (FWRI), then the Florida Bureau of Marine Research, in 1979. FWRI has two separate but complementary sea turtle monitoring programs: the Statewide Nesting Beach Survey (SNBS) and the Index Nesting Beach Survey (INBS).

The SNBS program was initiated in 1979 to document the total distribution, seasonality, and abundance of sea turtle nesting in Florida. Nesting data are collected for all species of sea turtles, the loggerhead, the green turtle, and the leatherback that nest regularly on Florida beaches, as well as the rare Kemp's ridley and the hawksbill.

The latest available statewide nesting data for 2012 and 2013 are summarized in Table 2:

Table 2. Updated Statewide Nesting Data

Year	Loggerhead	Green	Leatherback
2012	98,602	9,617	1,712
2013	77,975	36,195	896

Source: FWC Unpublished. Data (http://myfwc.com/research/wildlife/sea-turtles/nesting/).

Since 1989, the INBS has coordinated a detailed monitoring program in conjunction with SNBS. This program was established to measure trends in nest counts. Of the 207 SNBS-surveyed areas, 32 are included in the INBS program.

Since the inception of the INBS program, annual observed loggerhead nest counts on these beaches varied from a peak of 59,918 in 1998 to a low of 28,074 in 2007. Green turtle nest counts have increased approximately 100-fold since counts began in 1989, a trend that differs from that of the loggerhead. The INBS green turtle nest count for 2013 (25,553) was more than twice the count from the next highest year. Surveyors counted 322 leatherback nests on core index beaches in 2013. Similar to nest counts for green turtles, leatherback nest counts have been increasing exponentially.

The overall nesting trend for three species has been positive. Despite the decrease in nest numbers documented in 2007, loggerhead nest counts have kept a generally upward trend since, while previously there were concerns about a possible decline in loggerhead nest counts (Witherington et al., 2009).

COMMUNITIES WITH LIGHTING ORDINANCES

More than 82 municipalities and counties in the state of Florida have adopted lighting ordinances to regulate lighting on sea-turtle nesting beaches (http://www.myfwc.com/conservation/you-conserve/lighting/ordinances/). Areas with ordinances include the entire east and west coasts of Florida with the exception of the Big Bend area, which has few sandy beaches available for nesting. While each local lighting ordinance is unique in its requirements and the degree to which sea turtles are protected (Barshel et al., 2013), they all provide a framework by which local governments can manage artificial lighting harmful to sea turtles. The number and size of beachfront buildings and infrastructure-related development has increased steadily in Florida's coastal counties and municipalities. It is not difficult to imagine that, without these ordinances, impacts to marine turtles, including disorientation, could have been much greater than is being documented.

SUCCESS STORIES

While new coastal developments are required to install lighting appropriate for the protection of sea turtles, lights at older developments present an important challenge. Fixing these lights provides an opportunity to achieve long-lasting conservation benefits for Florida's sea turtle nesting populations.

LIGHTING RETROFIT PROGRAMS

A number of projects around Florida have worked to retrofit problematic lights with shielding or replace them with sea turtle–friendly fixtures. In the past few years a number of projects have received funding earmarked for helping property owners identify appropriate options for retrofitting lights. Table 3 provides a summary of these programs. Lighting retrofit programs focus on identifying problematic lights, then developing a plan for reducing their visibility from the beach.

TABLE 3 - Summary of Lighting Retrofitting Programs

Project Name	Year	County	Organization	Funding Entity	Amount
St. George Island Sea Turtle Friendly Lighting Project	2001	Franklin	Apalachicola Bay and River Keeper	Sea Turtle License Plate Grant	$1,500
Sarasota County Roadway Lighting Replacement Project	2002	Sarasota	Sarasota County	Sea Turtle License Plate Grant	$2,850
Lighting Modifications and Educational Sea Turtle Walks in Palm Beach County	2003	Palm Beach County	Palm Beach County	Sea Turtle License Plate Grant	$12,500
South Lido Lighting Improvement Project	2004	Sarasota County	Sarasota County	Sea Turtle License Plate Grant	$10,008
Florida Artifical Light Mitigation/ Minimizing Light Impacts on Sea Turtles: Shield Loan Program	2006	Brevard, Charlotte, Collier, Indian River, Lee, Martin St. Lucie Counties, Town of Jupiter	Florida Fish and Wildlife Commission	National Fish and Wildlife Foundation	$1,160.12
Street Light Pollution - Reduction	2006	Brevard County	City of Cape Canaveral	Sea Turtle License Plate Grant	$8,920
Sarasota County Partnership for Lighting Improvement	2006	Sarasota County	Sarasota County	Sea Turtle License Plate Grant	$8,617
Sarasota County Partnership for Lighting Improvement - Phase II	2008	Sarasota County	Sarasota County	Sea Turtle License Plate Grant	$10,900
Embedded Roadway Lighting Program Enhancements	2008	Palm Beach County	City of Boca Raton	Sea Turtle License Plate Grant	$13,910
City of Venice Artificial Light Abatement	2009	Sarasota County	City of Venice	Sea Turtle License Plate Grant	$5,647
Bonita Beach Roadway Lighting Improvement	2010	Lee County	Lee County	Sea Turtle License Plate Grant	$1,702
Priority Nesting Beaches in Deerfield Beach and Venice Municipalities of Broward and Sarasota Counties in Florida.	2010	Broward, Sarasota	Wildlife Foundation of Florida/ City of Deerfield Beach and Venice Beach	National Fish and Wildlife Foundation/Recovered Oil Fund	$450,000
Maximizing Florida Sea Turtle Nesting Success by RetrofittingPproblem Beachfront Lights on FL Nesting Beaches	2010	Statewide	Sea Turtle Conservancy	National Fish and Wildlife Foundation-Recovered Oil Fund for Wildlife	$371,377
Reducing Light Pollution on Florida's Sea Turtle Nesting Beaches by Retrofitting Lights on Problem Properties	2011	Statewide	Sea Turtle Conservancy	National Fish and Wildlife Foundation-Recovered Oil Fund for Wildlife	$344,512

TABLE 3 Cont'd- Summary of Lighting Retrofitting Programs

Project Name	Year	County	Organization	Funding Entity	Amount
Shell Marine Habitat Program	2012	Florida's Golf coast, from the Western Panhandle to Tampa Bay	Sea Turtle Conservancy	National Fish and Wildlife Foundation	$150,000
Reducing Light Pollution on Florida's Sea Turtle Nesting Beaches by Retrofitting Lights on Problem Properties	2012	Select Counties	Sea Turtle Conservancy	USFWS	$18,961
Maximizing Florida Sea Turtle Nesting Success by RetrofittingPproblem Beachfront Lights on FL Panhandle Nesting Beaches	2013	All Counties from Panhandle to Tampa Bay	Sea Turtle Conservancy	National Fish and Wildlife Foundation- Shell Marine Habitat Program	$81,912
Eliminating Light Pollution by Retrofitting Lights on Private Beachfront Properties (FL Panhandle)	2014	Franklin, Gulf, Walton and other Gulf Counties	Sea Turtle Conservancy	National Fish and Wildlife Foundation- Gulf Environmental Benefit Fund	$722,500

Source: Florida Fish and Wildlife Commission

Overly bright and unshielded lights, directly visible from the beach. An example of bad lighting on one Florida beach. (Photo provided by B. E. Witherington)

Shielded fixtures with minimum light directly visible from the beach. An example of appropriate lighting on another Florida beach. (Photo provided by B. E. Witherington)

These and other retrofit programs have corrected lighting problems at single family homes, large multi-family condos and resorts, and commercial sites around Florida, creating darker beaches for sea turtle nesting.

SR A1A BOCA RATON

In an experimental project in 2001, the Florida Department of Transportation installed lighting for sea-turtle protection on a small (<0.25 mi) section of State Road (SR) A1A just south of Spanish River Boulevard in the city of Boca Raton. The roadway section, which is adjacent to a nesting beach, has pole mounted street lights with some light spilling over to the beaches. The City agreed to turn off the pole-mounted lights for the nesting season, March 1– October 31, and FDOT funded installation of pavement-embedded LED markers. The experimental section also included low-mounted bollards installed on the edge of unpaved shoulders.

In 2004 the City of Boca Raton and FDOT decided to extend the turtle-friendly embedded roadway lighting to approximately 1.25 miles. The internally illuminated LED markers installed on the roadway lane lines in place of standard retroreflective pavement markers provide good delineation for motorists. This project has been well received by local residents and roadway users. It won the Florida Institute of Consulting Engineers Excellence in Engineering Design Award for 2009.

SR A1A, Boca Raton, Florida: Internally illuminated LED pavement markers provide delineation at night when pole mounted lights are turned off during sea turtle nesting season (Photo by Erdman Anthony & Associates, Inc.).

No hatchling disorientations were reported from the adjacent beach the year after the embedded lights were installed and street lights were extinguished during nesting season (Rusenko et al., 2003).

Future Strategy

OUTREACH AND EDUCATION

Community outreach and education have always been a tool in sea turtle conservation efforts worldwide. In Florida, these efforts range from contacting and educating coastal property owners to FWC-authorized sea turtle walks for the community at large. Many coastal communities host festivals to celebrate sea turtle days and highlight the community's role in conservation. Typically a conservation agency and interested citizens prepare the program, provide the venue, and contact sponsors for various events. Local marine turtle conservation groups develop and implement programs specific to their communities and beaches. These programs include hosting booths at local events, presenting educational programs at schools, and hosting social media programs.

The Sea Turtle Conservancy has developed and implemented a number of educational initiatives in Florida and the wider Caribbean basin (http: //www.conserveturtles.org/education.php).These efforts include development and distribution of outreach materials, lesson plans, and distance-learning programs.

EXPLORING NEW TECHNOLOGIES

Technology continues to impact every aspect of our lives. Sea turtle conservation and sea turtle–friendly lighting have benefited and will continue to benefit from such technological advancements.

The rapid pace of progress in smart phones and tablets offers a particularly promising field. While such devices are valuable for recording information on nests, disorientations, and lights observed in the field, the light associated with the devices must be managed if used on the beach at night. Still, the ability to transmit information in real time has positive implications for marine turtle conservation. Programs in Florida and other states are using smart phones and tablets for sea turtle conservation efforts (Davis, 2013). Such devices, along with social media, are invaluable in allowing conservation volunteers to collect and store nesting, stranding, and disorientation data.

INFORMATION FOR LIGHTING DESIGN PROFESSIONALS

Good lighting design must address lighting requirements for humans as well as economic and environmental issues. This includes the requirement that design meet local, state, and federal laws prohibiting adverse impacts to marine turtles and their hatchlings, nests, and nesting habitat. Impacts on nesting or hatchling sea turtles from light visible from or illuminating a nesting beach from a beachfront building could be considered a violation of the laws protecting threatened and endangered sea turtles.

While a detailed discussion of the lighting design process and requirements is not the objective here, lighting professionals must be able to develop designs that address both sea turtles and safety standards. National, state, and local governments and professional organizations like IESNA and AASHTO standards include specific illumination levels for ordinary circumstances. Lighting design professionals may have concerns about meeting these standards using the luminaires, fixtures, and techniques recommended for lighting near nesting beaches. Designing outdoor lighting poses a particular challenge. Improperly designed lights contribute to light trespass, a form of light pollution. In such cases light travels from one property to another where it is unwanted. Using technology that is already available, and a growing understanding of the special lighting requirements in environmentally sensitive areas including nesting beaches, it is possible to design lighting systems that focus light properly to address human safety while limiting impacts to natural areas (Gaston et al., 2012), including adjacent sea turtle nesting beaches.

Advancements in lighting technology have made it easier to design a lighting system satisfying all of the above objectives using low wattage luminaires. LED luminaires have a much better lumen to watt ratio, producing more light for a given amount of energy (watt) than incandescent and CFL luminaires. LED luminaries are capable of producing light in the more desirable yellow-amber color and wavelength range.

For outdoor lights, keeping the mounting height low may require the use of additional fixtures or luminaires, which creates a conflict with the most economical design.

Lighting designers are expected to provide recommended illumination levels to ensure desirable quantity of light. The other aspect of lighting design that plays a significant role in the selection and placement of luminaires is the quality of light. Quality of light provided, to a great extent, depends on the purpose for which lights are to be used. For exterior lights, visual acuity—a measure of the ability to distinguish fine details—is often cited as a desirable feature. Typically white light sources that produce light in shorter wavelength ranges, closer to the blue color spectrum, work better for that. However, that does not work well near nesting beaches as sea turtles are sensitive to the short- wavelength light produced by these sources. Lighting designs that employ light sources with lower wattage, producing light in a longer wavelength (> 560nm) range and installed at low to medium mounting heights, work better in such environments. This may result in a relatively greater number of lights for the desired illumination levels and a little less visual acuity than is achievable in other situations, but that is considered to be an acceptable tradeoff.

In most cases an optimal lighting design complying with all requirements is feasible. In situations where lighting design standards conflict with designs that limit impacts to sea turtles, a variance from the lighting design standards can be requested.

An acceptable lighting system for these areas can have lights that provide illumination levels that meet applicable codes and standards as long as no light reaches or is directly visible from the nesting beach. There is no acceptable amount of light that can actually be allowed to shine on the nesting beach (less than 0 footcandles is the goal). Several steps can be taken to avoid or minimize light trespass and light pollution:

- Plan development along nesting beaches so that areas that require higher levels of light for safety are appropriately sited. When outdoor lighting next to the nesting beach is unavoidable, utilize low overall light levels and optics that reduce or confine the light to critical areas. Implement the FWC's recommendations to keep it low, keep it shielded, and keep it long.
- Use night lighting only when and where necessary. Design exterior lighting to meet, but not exceed, IESNA lighting standards when possible, understanding that the standards are recommendations. Seek variances from local requirements where necessary to avoid impacts to sea turtles while lighting for human safety. Use the minimum amount of light needed. Provide uniform lighting with good distribution that avoids wasteful hot spots. Over-lighting directly contributes to light pollution and is often tied to light trespass.
- Use luminaires with BUG ratings appropriate for the area. BUG, an abbreviation for Backlight, Uplight and Glare refers to a measuring system developed by IESNA to compare and evaluate outdoor luminaires.

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APPENDICES

APPENDIX A

The following is a list of artificial light sources grouped by the level of disruption they are likely to cause sea turtles. The criteria used to group the sources came from studies of physiological spectral sensitivity (Granda and O'Shea, 1972), hatchling orientation with respect to laboratory light sources (Mrosovsky and Carr, 1967; Mrosovsky and Shettleworth, 1968; Mrosovsky, 1972; Witherington and Bjorndal, 1991a; Witherington, 1992b), and commercial light sources (Dickerson and Nelson, 1988, 1989; Witherington, 1989; Witherington and Bjorndal, 1991b; Ferreira et al., 1992; Nelson, 1992; Witherington, 1992b), and spectral profiles of commonly used lamps (Anonymous, 1983; Rossotti, 1983; Anonymous, 1989; Witherington and Bjorndal, 1991b). Effects are described as being extremely disruptive, highly disruptive, moderately disruptive, or minimally disruptive.

White, broad-spectrum, short-arc lighting (*extremely disruptive*).—These light sources include xenon and mercury arc lamps and are the brightest and highest-energy light sources commonly used. They emit wavelengths rather evenly across the visible spectrum (which is why they appear white) and in the ultraviolet spectrum as well. They are used principally for temporary, intense lighting needs.

White, broad-spectrum, electric-discharge lighting (*extremely disruptive*).—Mercury-vapor, metal-halide, and fluorescent-tube lighting are included in this group. Like sources in the preceding group, these sources emit wavelengths across the visible spectrum. They are used both indoors and out- doors. Fluorescent-tube lighting is becoming more common as an indoor source and is frequently used to light porches and outdoor signs.

Color-phosphor and tinted-fluorescent lighting ("blacklight" ultraviolet, violet, blue, green, and mixtures of these colors) *(extremely disruptive)*.—As revealed to some extent by their colors, these electric-discharge tube lamps emit light principally in the short-wavelength end of the visible spectrum. The so-called blacklight-type of fluorescent tubes, however, emit much of their light in the near-ultraviolet region. These blacklight tubes appear as a dim violet color to humans but are very disruptive to sea turtle hatchlings. Blacklights are often used as insect attractants in insect-electrocuting bug zappers. Tubes of other colors are used principally for decorative applications.

White, broad-spectrum, LED lighting (*extremely disruptive*).—White LEDs are created either by mixing several different-colored light sources, including short-wavelength blue or green, or by combining shorter-wavelength blue light with phosphors. The latter method is preferred for better color rendition but produces a higher proportion of energy in the short-wavelength range, i.e., around 450 nm. LEDs produce directional lighting that can be very bright and disruptive to marine turtles.

White, broad-spectrum, incandescent lighting (*extremely disruptive*).—Light emitted from incandescent sources comes from a glowing filament. This group includes quartz–tungsten–halogen and simple tungsten-filament sources. Without tinting, these sources emit wavelengths throughout the visible spectrum but less short-wavelength light than the sources described above. Incandescent sources are commonly used as outdoor floodlights, as indoor lighting (i.e., the common light bulb), and as transient lighting (e.g., flashlights, lanterns, electric torches).

Color-tinted incandescent lighting (blue and green) (*extremely disruptive*).—These colored sources are tinted so that they emit principally short-wavelength light; they are often used in decorative applications.

White, pressurized-fuel, glowing-element lanterns (*extremely disruptive*).—These portable lanterns are used for camping, fishing, and other transient nighttime activities.

High-pressure sodium vapor (HPS) lighting (*highly disruptive*).—HPS sources emit light with minor wavelength peaks in the blue and green regions and major peaks in the yellow and orange regions of the visible spectrum. The color of HPS sources is whitish golden to peach. Although less disruptive than the broad-spectrum white sources listed above, HPS is one of the most commonly used outdoor light sources in the United States and many other countries and is one of the most common causes of hatchling misorientation and mortality.

Open fires (*moderately to highly disruptive*).—Although fires are temporary light sources and emit less short-wavelength light than the sources mentioned above, they have been documented as a significant source of hatchling mortality. Unlike other attractive light sources, fires can kill hatchlings quickly (hatchlings are known to crawl into fires and die). The size and temperature of a fire determine how attractive it is to hatchlings. Gas-flame applications vary widely in color temperature (1800 – 3000 K) but in general bare flames are redder than most HID lamps (HPS, MH, MV). Flames are inefficient in terms of both energy converted to visible light and in terms of light control, making them difficult to impossible to shield. Almost none of the conventional "good" light fixtures are usable for flame light.

Yellow-phosphor and amber-tinted fluorescent lighting and red tubes (*moderately disruptive*).—Yellow and amber fluorescent tubes emit principally red, yellow, and green wavelengths but do not exclude light in the blue region of the spectrum so well as do yellow incandescent bulbs. Yellow and amber fluorescent tubes are not generally marketed as bug lights. Although they are more disruptive to sea turtles than yellow incandescent bulbs, yellow and amber fluorescents are far better than white or other colored tubes for use near nesting beaches. But the hue of these yellow fluorescent lamps varies with manufacturer and so yellow florescent can have a range of effects on sea-finding in hatchlings. Red tubes are typically used for decoration and can be of two types: red (or reddish) phosphor-fluorescent tubes and red neon tubes. Reddish or red-purple fluorescent tubes can be very disruptive, depending upon the amount of short-wavelength light that they emit (purplish lights emit both blue and red light). Neon tubes are covered below.

Lamps with yellow or orange dichroic long-pass filters (*minimally to moderately disruptive*).—Because these filters are very good at attenuating short wavelengths, the type of lamp used with them matters little. Consequently, these filters may allow the use of lamps like metal-halide and HPS that have small and easily focused elements *i.e.,* part of the lamp actually producing light. These lamps can be used in more directional fixtures to reduce stray light. Dichroic filters are not standard off-the-shelf accessories for commercial fixtures but they have been used in some outdoor applications near nesting beaches.

Color-tinted incandescent lighting (yellow and red) (*minimally to moderately disruptive*).—Yellow or amber incandescent light bulbs (bug lights) are generally only weakly attractive to hatchlings for the same reason that they attract few insects—they emit low amount of light, in short-wavelength range. Although they are minimally disruptive for the most part, bug lights can interfere with sea-finding if they are numerous, of high wattage, or close to the nesting beach. Red-tinted incandescent sources are more variable in color than bug lights. Some red sources can turn purple or pinkish over time and become more attractive to hatchlings.

Low-pressure sodium vapor (LPS) lighting (*minimally disruptive*).—LPS is by far the least disruptive light source among those commonly used. LPS sources emit a light that is pure (i.e., monochromatic) yellow, a region of the spectrum that is only weakly attractive or even aversive (for loggerheads, and only at greater intensities) to orienting hatchlings. Because LPS sources have poor color rendition, they are used principally for outdoor applications.

Amber- and red-LED) lighting (*minimally disruptive*).—LED lamps are now available for a variety of exterior uses, from embedded roadway lights, to pathlights, to bollard and pole lights. Red LEDs come close to being ideal for use near sea turtle nesting beaches. Red LEDs emit a pure-red light that does not vary in color over the life of the lamp. Amber LEDs are also available, but some may emit short-wavelength light. Only amber LED lamps that emit light in the 560-nm range or greater are appropriate for use adjacent to a sea turtle nesting beach when used in a full cut-off, well-shielded downward-directed fixture. LEDs are small and directional and typically light only a limited area. They are easy to hide from the beach and have a very long life. Green and amber LEDs are marketed but are much less strongly preferred than red.

Neon tubes (*minimally disruptive*).—True neon tubes (not tinted tubes) are a pure-red light source. Neon is used almost exclusively for decorative purposes. Neon tubes can be difficult to shield, but their color makes them minimally disruptive. Potential applications include pathway and ground- level lighting.

Transient light sources (flashlights, electric torches, flash photography) (*disruptive characteristics vary*).—This lighting is placed in a separate category because it is generally in use for relatively short time periods. Most of these sources have white incandescent lamps and can be expected to affect sea turtles as the incandescent sources above do. Transient sources are well-known disruptors of sea-finding behavior in hatchlings and adults, but researchers are less certain about how transient sources may affect nesting turtles or those emerging from the ocean to nest. Many workers in the field believe that flashlights and flashes from cameras can turn emerging turtles back to the sea and alter the behavior of nesting turtles. Until additional evidence suggests otherwise, transient light sources should be used sparingly on sea turtle nesting beaches. If hand-held lighting is to be used, red LED flashlights should be used during nesting season and only when ambient light is not sufficient for human vision. As an alternative, deep-red filters can be fastened over the lens of the source. Red light appears much brighter to humans than it does to sea turtles and does not degrade the night vision of people using it. People using red light can acclimate to the dark, and most are surprised by how well they can see by starlight and moonlight alone.

APPENDIX B

A table of lamp types and their efficiency. Information sources were the lighting manufacturers and distributors listed in Appendix G. General suitability is based upon the lamp characteristics that may affect sea turtle nesting and hatchling orientation.

Lamp Type	General Suitability for Sea Turtle Nesting Beaches	Efficiency (lumens per watt, lamp only)	Common Wattages	Directional Control of Light	Initial Fixture Cost
White incandescent (including tungsten halogen)	poor	15–25	15–1,500	excellent	low
Red or amber LED	good	17-98	4-28	excellent	moderate high
White fluorescent	poor	55–100	9–219	fair	moderate
Metal-halide	poor	80–100	70–1,000	good	high
Mercury-vapor	poor	20–60	40–1,000	good	moderate high
High- pressure sodium vapor	poor–fair	67–140	35–1,000	good	high
Low-pressure Sodium vapor	good	180	18-180	fair	high

APPENDIX C

ACCEPTABLE LAMPS, BULBS AND OTHER LIGHT SOURCES

Long wavelength lamps, e.g., those that produce light at 560 nm or greater, are appropriate for use adjacent to sea turtle nesting beaches. In general, the following types of lamps can be used in full cut-off, well shielded downward directed fixtures mounted as low as possible in coastal areas adjacent to sea turtle nesting beaches.

ACCEPTABLE LAMPS

- Red, orange or amber LED (true red, orange or amber diodes, *not* filters)
- True red neon
- Low Pressure Sodium (LPS) 18W, 35W
- Other lighting sources that produce light of 560 nm or longer

FWC-recommended lamps are listed at http://www.myfwc.com/conservation/you-conserve/lighting/certified/bulbs/. Lamps are properly employed if they are not visible from the beach. Many amber or red LED bulbs can be used in place of white light bulbs in egress fixtures (*e.g.,* porch, balcony, doorway, walkway, stairway, and security lighting) and can be used in conjunction with motion-detecting fixtures.

Bright white–light lamps (metal halide, halogen, fluorescent, mercury vapor, and incandescent lamps) are extremely disruptive to adult and hatchling sea turtles and should not be used either directly adjacent to the beach or in areas where even their glow might be visible from the beach. Filters and other types of lenses placed over full-spectrum white lights are unreliable and do not reduce the potential of impacts on nesting and hatchling marine turtles. Incandescent lamps, including yellow, bug-light bulbs, are not suitable for use near nesting beaches, because yellow or amber color alone does not ensure protection for hatchling orientation.

APPENDIX D

ACCEPTABLE FIXTURES

The following table describes common styles of light fixtures that may be suitable for use near sea turtle nesting beaches if they are employed properly. Fixtures are properly employed if their light is not directly or indirectly visible from the beach. Low-pressure sodium lamps are considered conditionally acceptable for use near nesting beaches if they can be positioned so that their light is not directly or indirectly visible from the beach. In all cases, LPS fixtures are greatly preferred to comparable incandescent or HID (high-intensity discharge) fixtures if red or amber LEDs are not available for an application.

All exterior fixtures on the seaward side and on the sides of the building perpendicular to the shore (and on the landward side of the building if they are visible from the beach) should be well shielded, full cut-off, downward directed fixtures. All exterior fixtures on the landward side of the building should be downward directed only.

Fixture type	Mounting type and height	Location	Comments
Ceiling mount cylinder (with interior black baffles)	Ceiling surface	If located on the side of structure perpendicular to or facing the beach, use on *ground floor* only.	Matte-black non-reflective interior baffles are recommended.
Wall mount cylinder down light (with interior black baffles)	Wall mount downward directed 8 ft. from floor.	If located on the side of structure perpendicular to or facing the beach, use on *first habitable floor* only.	Matte-black non-reflective interior baffles are recommended. Hex-cell (honeycomb) louvers may be required to decrease wall wash.
Recessed-ceiling canister	Recessed ceiling	If located on the side of structure perpendicular to or facing the beach, use on *ground floor* only.	Interior black baffles Hex-cell (honeycomb) louver.
Recessed and wall-mounted step lights (louvered or downward directed)	Wall mount maximum height 24 in. on ground floor only; above ground floor maximum height 12 in.	Ground floor and second level, and pool deck.	If on perimeter of pool deck, must be mounted directed away from beach.
Bollard (with downward-directed non-reflective louvers)	Maximum height 42 in,	Parking areas, commercial walkway, landscape, pathway and pool deck.	180° to 270° external beach side shields on any fixture on perimeter of pool deck or immediately adjacent to beach.

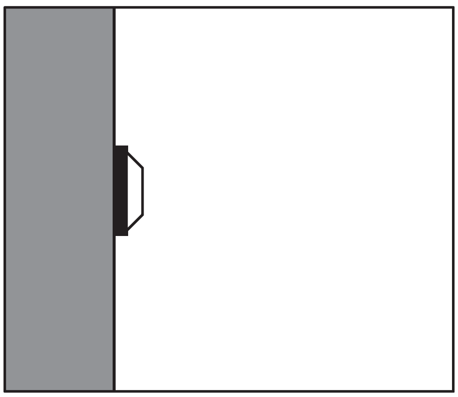
Fixture type	Mounting type and height	Location	Comments
HID full cutoff pole lights	Pole, maximum height 12 ft.	Parking area, landward side of structure only.	Beach side shields or louvers for any fixture within line of sight of beach.
Paver lights	In-ground mount	Parking areas, driveways, pathways, pool decks.	
Landscape/pathway lighting	Ground mount at 12 in.	Ground level, landscape	
Signage	Must be mounted with light directed down onto sign; or, use backlit channel lettering.	Sign should be on landward side of structure when possible and mounted perpendicular to the beach.	
Garage lighting	Garage ceiling	Garage	If parking garage is open so that the interior is visible from any section of beach, only LPS or amber/orange LED lamps may be used. Additional shields may be necessary if parking is above ground level.
Water feature lighting	Light must be downward or horizontally directed and not directed up.	Submerged lights are only recommended on landward side of structure and only if fully shielded from beach by structure.	
Emergency egress lighting			Short-wavelength-lamped emergency egress fixtures should be on a separate circuit that will illuminate fixtures only during a power outage.
Channel/rope lighting	Must be mounted recessed under steps, bar, etc., and directed downward.	Rail lighting and Tivoli lighting can be used for lighting stairways, steps, pool decks, pool bars and handrails.	

Remarks:

- All fixtures should be positioned so that vegetation, topography, or buildings screen the light from the beach, or the fixture should be equipped with shields so that light sources are not visible from the beach.
- For illuminating stairways and walkways, lighting hidden within hand rails or recessed at foot to waist level within walls is generally preferred over elevated lighting.
- Linear strip lighting mounted at foot level along walking paths or stairways is greatly preferred over elevated lighting.
- HID (high-pressure sodium, metal halide) fixtures are not recommended for applications within 50 m of a nesting beach or for which luminaires are visible from a nesting beach. Red- or amber-LED and LPS fixtures are greatly preferred over HID fixtures for applications near nesting beaches.
- Full-cutoff luminaires are preferred to less-directional luminaires that include globe-style, cube-style, and cobra-head lighting.
- Specific reflectors can be used with any fixture to still better direct light.
- Arm-mounted LPS fixtures are greatly preferred over HID fixtures for the same applications.
- Floodlighting should only be used where absolutely necessary for crowd control or other high-usage areas. Floodlighting is properly directed if it faces away from the beach and is mounted at an elevated position facing downward rather than mounted low and facing upward. All floodlights must be fully shielded and downward directed.
- In all cases, care should be taken not to brightly illuminate buildings and other large objects visible from the nesting beach.
- Lighting fixtures outfitted with a motion detector illuminate when approached by a moving object and remain on for a specified time, which can be set at the fixture. This specified time should be 30 seconds or less for a fixture near a nesting beach. To maximally reduce impacts to sea turtles, long-wavelength bulbs, such as red or amber LEDs, should be used with these fixtures.

APPENDIX E

Diagrams of common lighting fixtures showing mounting position, light distribution, and overall suitability for use near sea turtle nesting beaches. For purposes of recommending suitable mounting distances from nesting beaches, the crest of the primary dune is considered to be the landward limit of the beach. Fixtures are assessed for their suitability in minimizing direct and indirect lighting of the beach. For all fixtures, glowing portions of luminaires (including reflectors and globes) should not be visible from the nesting beach.

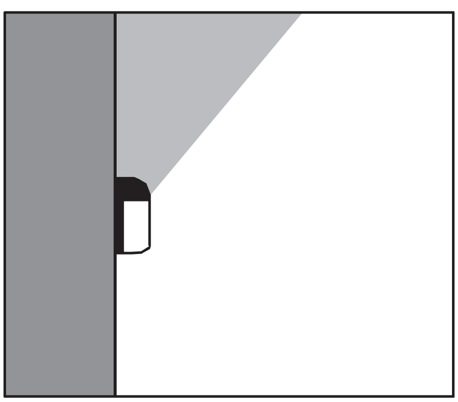


WALL-MOUNTED AREA LIGHTING

MOUNTING SUITABILITY
Poor; very poor when mounted on upper stories.

DIRECTIONAL SUITABILITY
Poor.

OVERALL SUITABILITY
Poor; not suitable for the beach sides of buildings.

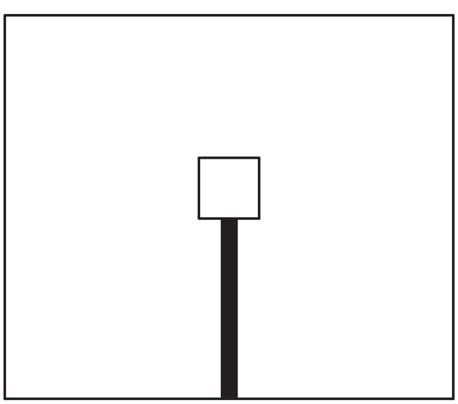


WALL-MOUNTED AREA LIGHTING; WALL PAK

MOUNTING SUITABILITY
Poor; very poor when mounted on upper stories.

DIRECTIONAL SUITABILITY
Poor.

OVERALL SUITABILITY
Poor; not suitable for the beach sides of buildings.



DECORATIVE CUBE LIGHT

MOUNTING SUITABILITY
Fair if mounted at heights lower than 6 ft.; poor if mounted higher.

DIRECTIONAL SUITABILITY
Very poor.

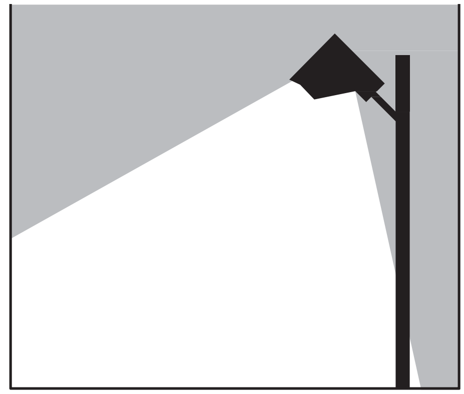
OVERALL SUITABILITY
Very poor. This fixture is difficult to shield and should not be used near nesting beaches.

POLE-MOUNTED FLOODLIGHTING WITH FULL VISOR

MOUNTING SUITABILITY
Good if directed downward and away from the beach.

DIRECTIONAL SUITABILITY
Good.

OVERALL SUITABILITY
Good if directed downward and away from the nesting beach and if light does not illuminate objects visible from the beach.

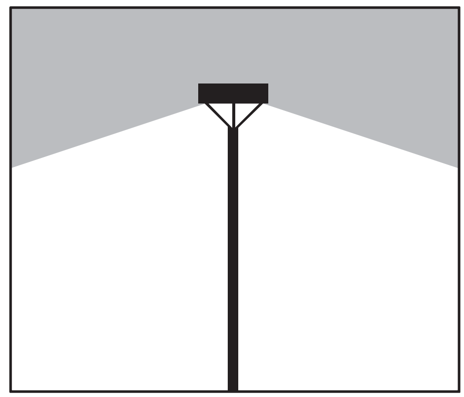


POLE TOP-MOUNTED CUTOFF LIGHTING, SHOEBOX FIXTURE

MOUNTING SUITABILITY
Good to poor, depending on mounting height. Mounting height should be no more than 15 ft. within 300 ft. of a nesting beach.

DIRECTIONAL SUITABILITY
Fair to good, as determined by reflectors.

OVERALL SUITABILITY
Fair to good when mounting heights are low.

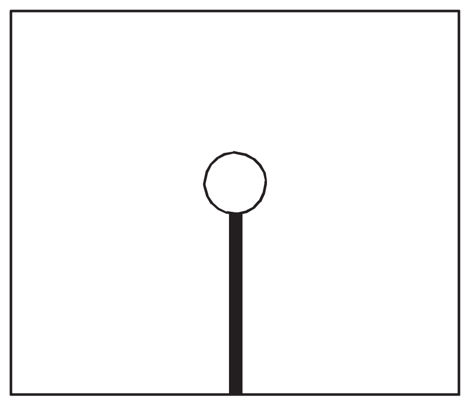


DECORATIVE GLOBE LIGHT

MOUNTING SUITABILITY
Fair if mounted at heights lower than 6 ft.; poor if mounted higher.

DIRECTIONAL SUITABILITY
Very poor.

OVERALL SUITABILITY
Very poor. This fixture is difficult to shield and should not be used near nesting beaches.

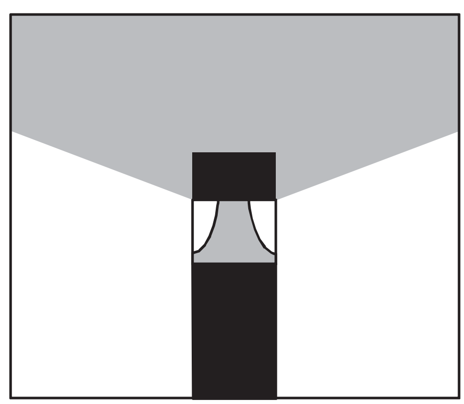


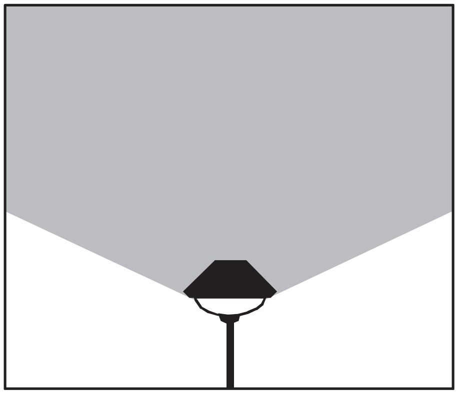
LIGHTING BOLLARD WITH HIDDEN LAMP

MOUNTING SUITABILITY
Good if mounting height is near 3 ft.

DIRECTIONAL SUITABILITY
Poor to fair.

OVERALL SUITABILITY
Fair; good if additional shields on the beach side of the fixture are used.



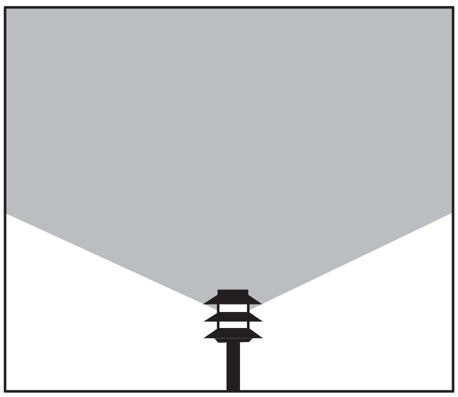


LOW-HEIGHT (SHORT) MUSHROOM LIGHTING

MOUNTING SUITABILITY
Good if mounted at foot level.

DIRECTIONAL SUITABILITY
Poor.

OVERALL SUITABILITY
Fair; good to excellent if used so that vegetation and topography block its light from the beach.

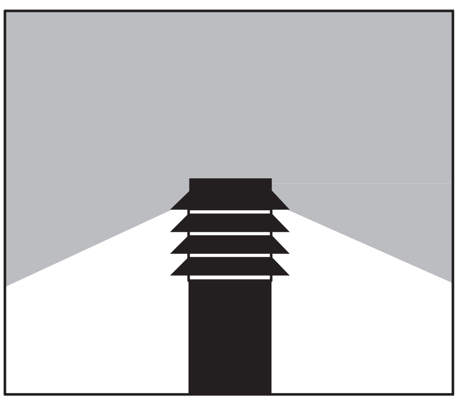


LOW-HEIGHT (SHORT) TIER LIGHTING

MOUNTING SUITABILITY
Good if mounted at foot level.

DIRECTIONAL SUITABILITY
Poor but can be good if the fixture has louvers that eliminate lateral light.

OVERALL SUITABILITY
Fair; good to excellent if used so that vegetation and topography block its light from the beach.

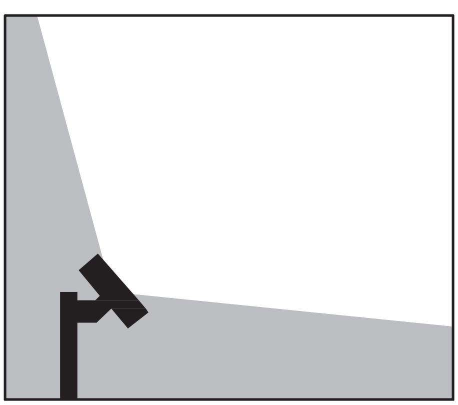


LIGHTING BOLLARD WITH LOUVERS

MOUNTING SUITABILITY
Good if mounted at foot level.

DIRECTIONAL SUITABILITY
Poor but can be good if the fixture has louvers that eliminate lateral light.

OVERALL SUITABILITY
Fair; good to excellent if used so that vegetation and topography block its light from the beach.



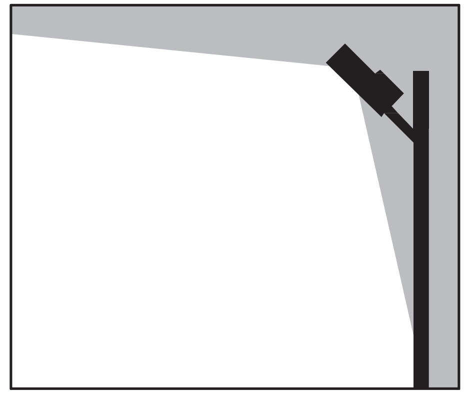
GROUND-MOUNTED FLOODLIGHTING

MOUNTING SUITABILITY
Poor, because of its upward aim

DIRECTIONAL SUITABILITY
Fair to good.

OVERALL SUITABILITY
Fair to poor if directed away from the beach, very poor if directed toward the beach.

POLE-MOUNTED FLOODLIGHTING

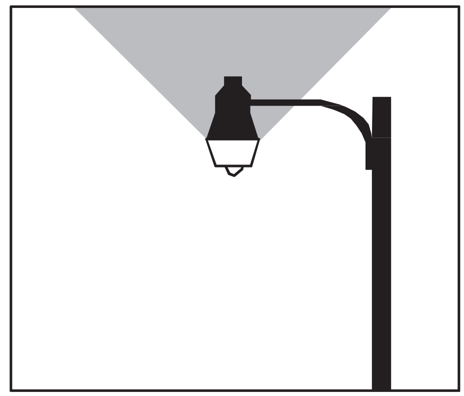


MOUNTING SUITABILITY
Fair if directed downward and away from the beach.

DIRECTIONAL SUITABILITY
Fair to good.

OVERALL SUITABILITY
Fair to good if aimed downward and directly away from the nesting beach and if light does not illuminate objects visible from the beach. Otherwise, poor to very poor.

ARM-MOUNTED AREA LIGHTING, OPEN-BOTTOM OR BARN-LIGHT FIXTURE

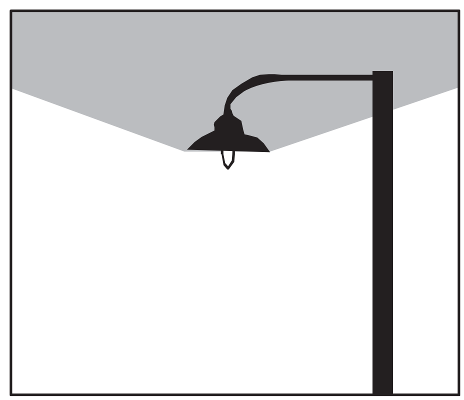


MOUNTING SUITABILITY
Poor to very poor, depending upon mounting height. Should not be mounted higher than 15 ft. within 500 ft. of a nesting beach.

DIRECTIONAL SUITABILITY
Poor if unshielded; fair if shielded.

OVERALL SUITABILITY
Poor.

ARM-MOUNTED AREA LIGHTING; DECORATIVE PENDANT FIXTURE

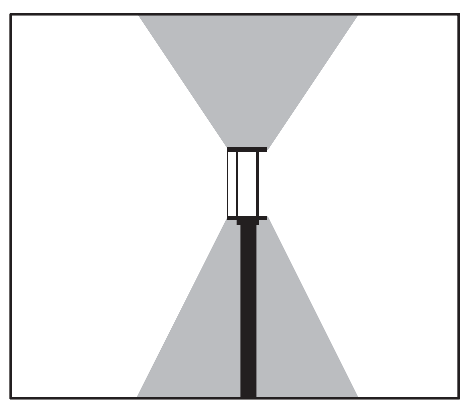


MOUNTING SUITABILITY
Poor to very poor, depending upon mounting height. Should not be mounted higher than 15 ft. within 500 ft. of a nesting beach.

DIRECTIONAL SUITABILITY
Poor. Difficult to shield properly.

OVERALL SUITABILITY
Poor.

DECORATIVE CARRIAGE LIGHTING



MOUNTING SUITABILITY
Fair if mounted at heights lower than 6 ft; poor if mounted higher.

DIRECTIONAL SUITABILITY
Very poor; fair if properly shielded.

OVERALL SUITABILITY
Poor

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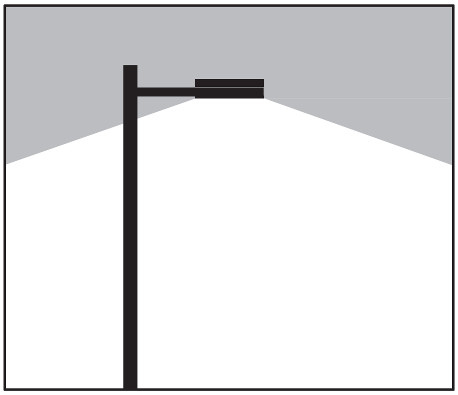
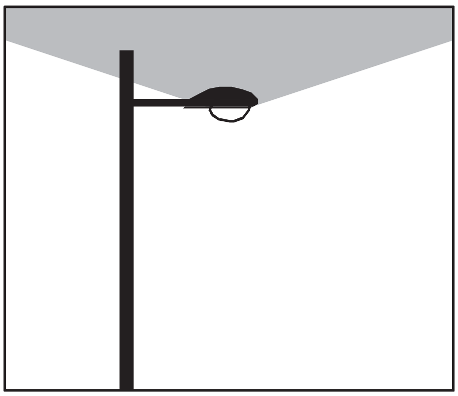


ARM-MOUNTED CUTOFF LIGHTING; SHOEBOX FIXTURE

MOUNTING SUITABILITY
Good to poor, depending on mounting height. Mounting height should be no more than 15 ft. within 300 ft. of a nesting beach.

DIRECTIONAL SUITABILITY
Fair to good, as determined by reflectors.

OVERALL SUITABILITY
Fair to good when mounting heights are low and fixtures are aimed directly downward.

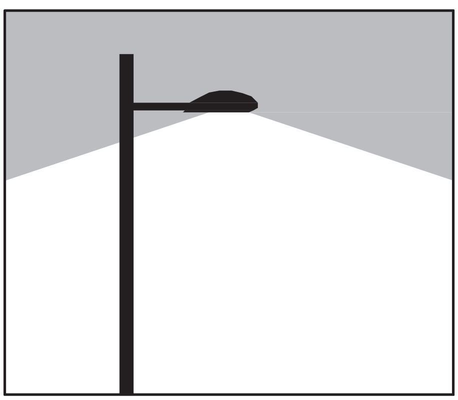


ARM-MOUNTED AREA LIGHTING; COBRA-HEAD FIXTURE

MOUNTING SUITABILITY
Poor to very poor, depending on mounting height. Mounting height should be no more than 15 ft. within 300 ft. of a nesting beach.

DIRECTIONAL SUITABILITY
Poor. Difficult to shield properly.

OVERALL SUITABILITY
Poor.

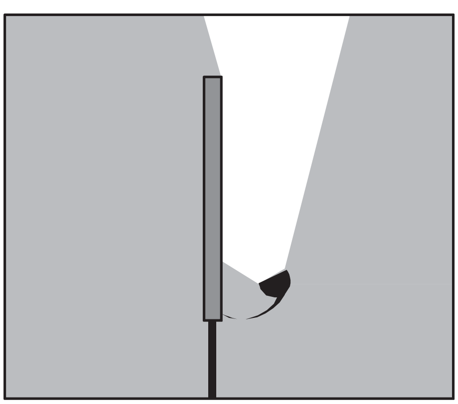


ARM-MOUNTED AREA LIGHTING; FLAT-FACE CUTOFF FIXTURE

MOUNTING SUITABILITY
Good to poor, depending on pole height. Mounting height should be no more than 15 ft. within 300 ft. of a nesting beach.

DIRECTIONAL SUITABILITY
Fair to good, as determined by reflectors.

OVERALL SUITABILITY
Fair to good when mounting heights are low.



SIGN LIGHTING; BOTTOM-UP STYLE

MOUNTING SUITABILITY
Poor, because of its potential for producing uplight scatter.

DIRECTIONAL SUITABILITY
Poor to good.

OVERALL SUITABILITY
Poor. Signs near nesting beaches should be lighted from the top down. In no case should lighted signs be visible from the beach.
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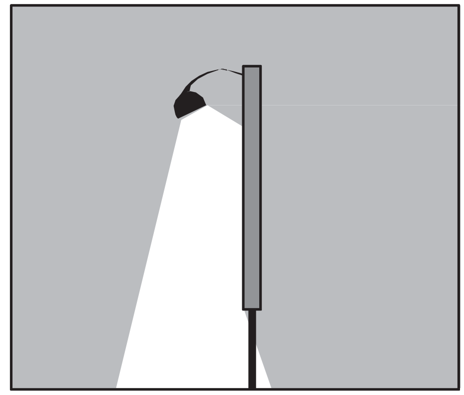
SIGN LIGHTING TOP-DOWN STYLE

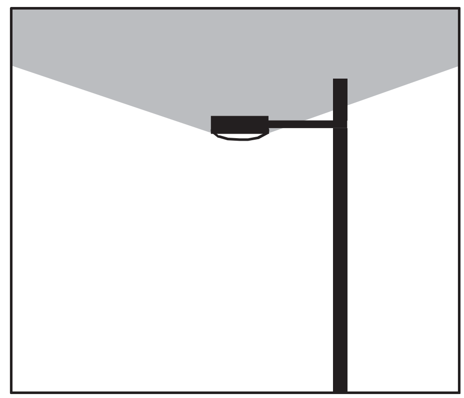


MOUNTING SUITABILITY
Good.

DIRECTIONAL SUITABILITY
Poor to good.

OVERALL SUITABILITY:
Generally good if the sign is not visible from the beach and if the lighting is well aimed.

ARM-MOUNTED AREA LIGHTING, FIXTURES WITH REFRACTING GLOBES OR CONVEX LENSES

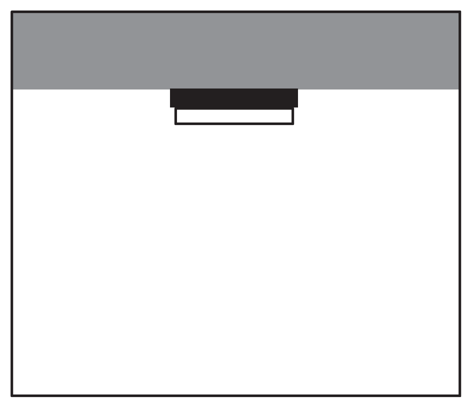


MOUNTING SUITABILITY
Poor to very poor, depending upon mounting height. Mounting height should be no more than 15 ft. within 500 ft. of a nesting beach.

DIRECTIONAL SUITABILITY
Poor. Fair to good if shielded properly.

OVERALL SUITABILITY
Poor.

CEILING-MOUNTED AREA LIGHTING, FIXTURES WITH REFRACTING GLOBES OR CONVEX LENSES

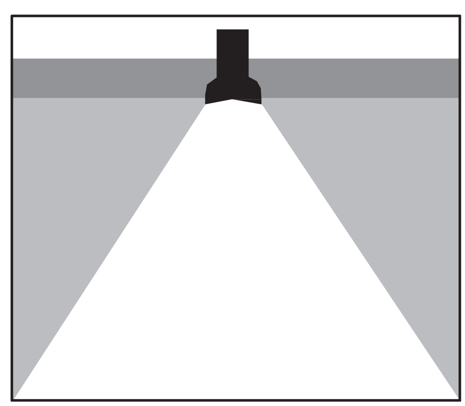


MOUNTING SUITABILITY
Poor if mounted on the beach sides of buildings or on upper stories. Good if shielded from the beach by buildings.

DIRECTIONAL SUITABILITY
Poor.

OVERALL SUITABILITY
Poor to fair, depending upon mounting location.

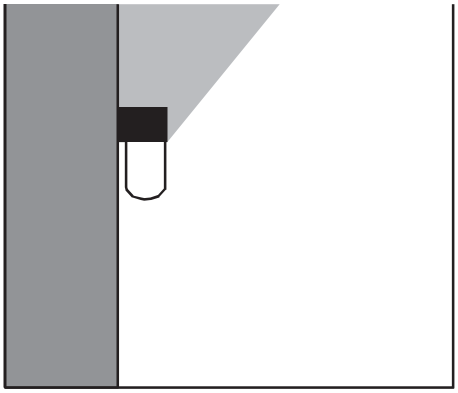
CEILING-RECESSED DOWNLIGHTING WITH BAFFLES TO ELIMINATE LATERAL LIGHT



MOUNTING SUITABILITY
Good to excellent when mounted in lower-story ceilings and soffits.

DIRECTIONAL SUITABILITY
Excellent.

OVERALL SUITABILITY
Good to excellent.

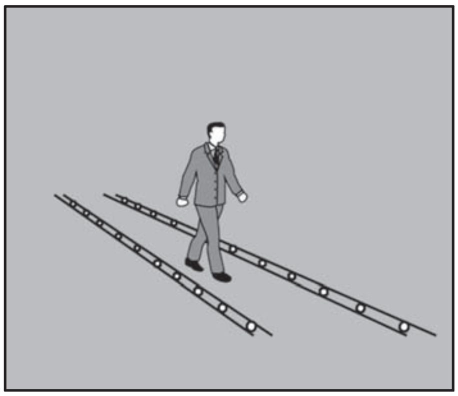


WALL-MOUNTED AREA LIGHTING, "JELLY-JAR" PORCH LIGHT FIXTURE

MOUNTING SUITABILITY
Poor. Very poor when mounted on upper stories.

DIRECTIONAL SUITABILITY
Poor.

OVERALL SUITABILITY
Poor.

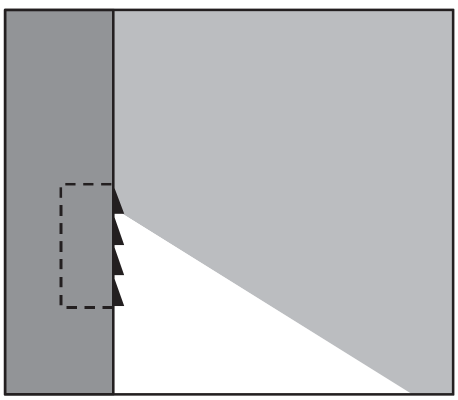


LINEAR TUBE LIGHTING

MOUNTING SUITABILITY
Excellent if mounted at foot level.

DIRECTIONAL SUITABILITY
Fair to poor, but this lighting is of concern only if mounted high or if large numbers of high-wattage (>3 W) lamps are used.

OVERALL SUITABILITY
Excellent if low-wattage strips are used sparingly in recessed areas.

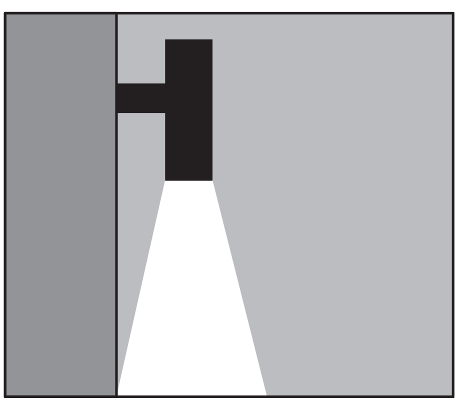


LOUVERED STEP LIGHTING

MOUNTING SUITABILITY
Excellent if mounted at foot level.

DIRECTIONAL SUITABILITY
Excellent.

OVERALL SUITABILITY
Excellent.



WALL-MOUNTED DOWNLIGHTING

MOUNTING SUITABILITY
Good to excellent when mounted on lower-story walls.

DIRECTIONAL SUITABILITY
Excellent.

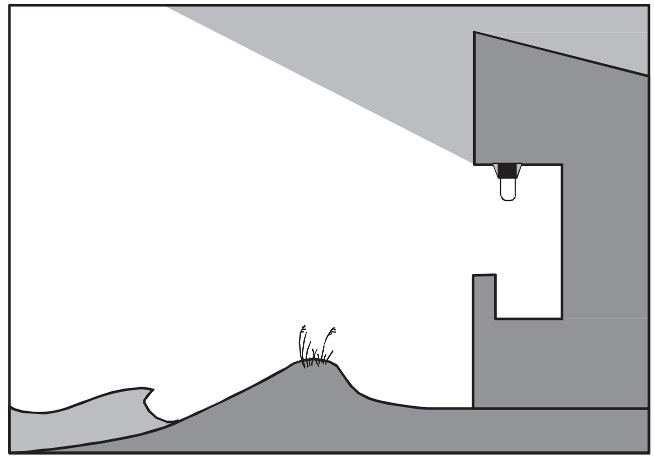
OVERALL SUITABILITY
Good to excellent.

Diagrams depicting solutions to two common lighting problems near sea turtle nesting beaches balcony or porch lighting and parking-lot lighting.

BALCONY OR PORCH LIGHTING

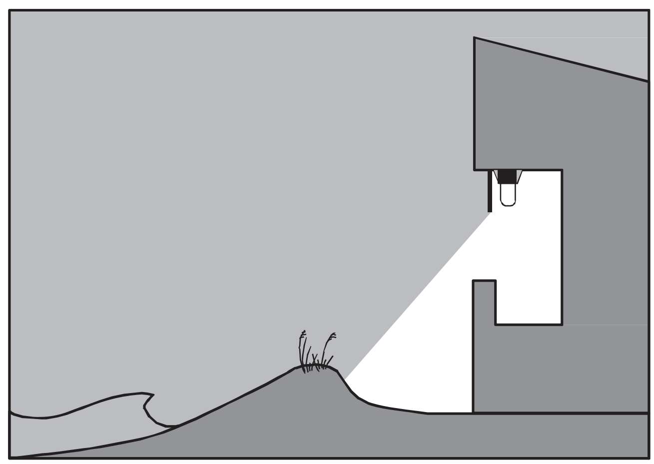
POOR

Poorly directed balcony lighting can cause problems on sea turtle nesting beaches.



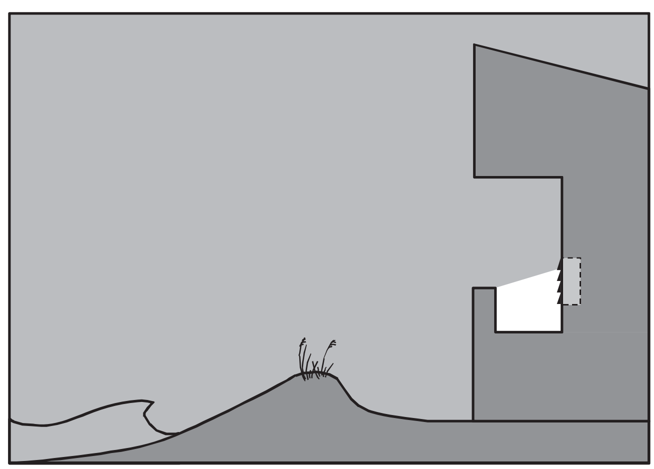
BETTER

Completely shielding fixtures with a sheet of metal flashing can reduce stray light reaching the beach.



BEST

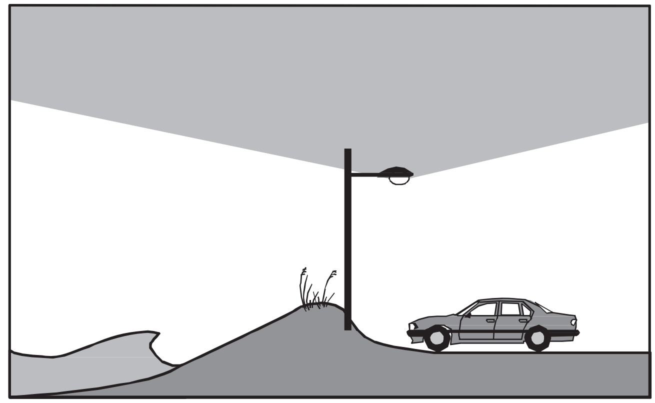
Louvered step lighting is one of the best ways to light balconies that are visible from nesting beaches.



PARKING-LOT LIGHTING

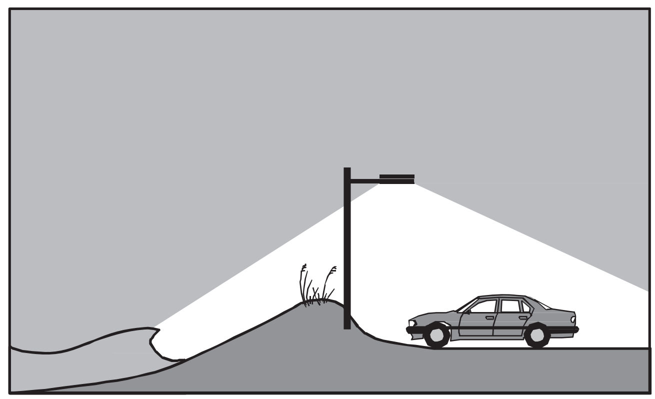
POOR

Poorly directed parking lot lighting can cause problems on sea turtle nesting beaches.



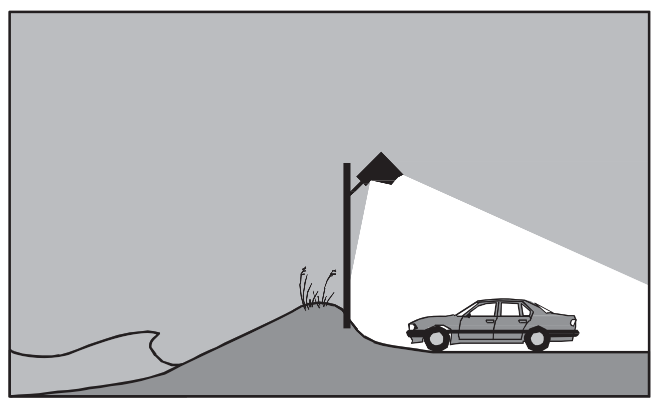
BETTER

Fixtures with 90°cutoff angles can reduce the amount of stray light reaching the beach.

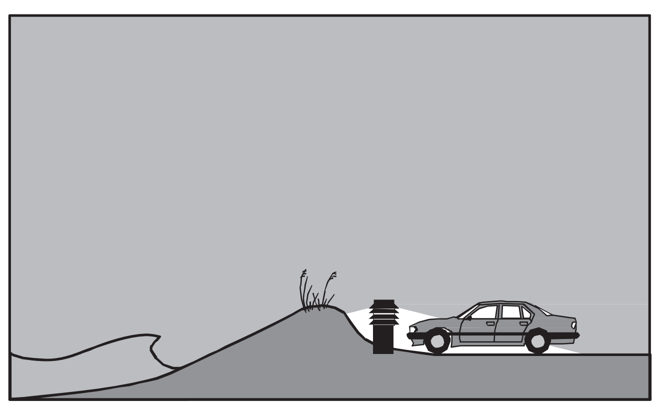


MUCH BETTER

Fully hooded floods can direct light accurately and reduce stray light even more.



BEST



APPENDIX F

LAWS AND REGULATIONS PROTECTING SEA TURTLES

Several local, state, and federal laws and regulations have been enacted to protect sea turtles. Some of these, especially at the local level, specifically address the issue of the negative impact of lighting on the sea turtle nesting and hatching habitats by mandating measures to avoid or minimize these impacts. Current laws and regulations are summarized below.

FEDERAL LAW

The five species of sea turtles found in Florida waters—the loggerhead, leatherback, green turtle, hawksbill, and Kemp's ridley—are all protected under the U.S. Endangered Species Act of 1973 (ESA) as endangered, except the loggerhead, which is listed as threatened. About 90% of all loggerheads nesting in the United States nest in Florida. One of the purposes of the ESA is to enable the preservation of the ecosystems upon which threatened and endangered species depend. The ESA also requires developing a program for the conservation of such species through implementation of recovery plans.

The ESA makes it unlawful to take a listed animal without a permit. *To take* is defined as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or attempt to engage in any such conduct." Through regulations, *harm* is the result of "an act which actually kills or injures wildlife." Such an act may include "significant habitat modification or degradation when it kills or injures wildlife by significantly impairing essential behavior patterns, including breeding, feeding or sheltering." (Federal Register, 1999)

Through the ESA, the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (FWS) have been directed to develop and implement conservation plans, known as recovery plans. A recovery plan has been implemented for each of the five species of sea turtles found in Florida waters. Pursuant to a memorandum of agreement between NOAA and the FWS, the jurisdiction over listed sea turtles is shared: FWS has responsibility for sea turtles primarily in the terrestrial environment, while NMFS has responsibility for sea turtles primarily in the marine environment.

FLORIDA LAWS

Florida has its own Marine Turtle Protection Act (Florida Statutes 379.2431 (1). Following are the excerpts from the law:

379.2431 Marine animals; regulation

(1) PROTECTION OF MARINE TURTLES.

(a) This subsection may be cited as the "Marine Turtle Protection Act."

(b) The Legislature intends, pursuant to the provisions of this subsection, to ensure that the Fish and Wildlife Conservation Commission has the appropriate authority and resources to implement its responsibilities under the recovery plans of the United States Fish and Wildlife Service for the following species of marine turtle

1. Atlantic loggerhead turtle (*Caretta caretta*).
2. Atlantic green turtle (*Chelonia mydas*).
3. Leatherback turtle (*Dermochelys coriacea*).
4. Atlantic hawksbill turtle (*Eretmochelys imbricata*).
5. Atlantic ridley turtle (*Lepidochelys kempi*).

(c) As used in this subsection, the following phrases have the following meanings

A "properly accredited person" is:

a. Students of colleges or universities whose studies with saltwater animals are under the direction of their teacher or professor; or

b. Scientific or technical faculty of public or private colleges or universities; or

c. Scientific or technical employees of private research institutions and consulting firms; or

d. Scientific or technical employees of city, county, state, or federal research or regulatory agencies; or

e. Members in good standing or recognized and properly chartered conservation organizations, the Audubon Society, or the Sierra Club; or

f. Persons affiliated with aquarium facilities or museums, or contracted as an agent therefor, which are open to the public with or without an admission fee; or

g. Persons without specific affiliations listed above, but who are recognized by the commission for their contributions to marine conservation such as scientific or technical publications, or through a history of cooperation with the commission in conservation programs such as turtle nesting surveys, or through advanced educational programs such as high school marine science centers.

h. "Take" means an act that actually kills or injures marine turtles, and includes significant habitat modification or degradation that kills or injures marine turtles by significantly impairing essential behavioral patterns, such as breeding, feeding, or sheltering.

(d) Except as authorized in this paragraph, or unless otherwise provided by the Federal Endangered Species Act or its implementing regulations, a person, firm, or corporation may not:

1. Knowingly possess the eggs of any marine turtle species described in this subsection.
2. Knowingly take, disturb, mutilate, destroy, cause to be destroyed, transfer, sell, offer to sell, molest, or harass any marine turtles or the eggs or nest of any marine turtles described in this subsection.
3. The commission may issue a special permit or loan agreement to any person, firm, or corporation, to enable the holder to possess a marine turtle or parts thereof, including nests, eggs, or hatchlings, for scientific, education, or exhibition purposes, or for conservation activities such as the relocation of nests, eggs, or marine turtles away from construction sites. Notwithstanding other provisions of law, the commission may issue such special permit or loan agree-

ment to any properly accredited person as defined in paragraph (c) for the purposes of marine turtle conservation.
4. The commission shall have the authority to adopt rules pursuant to chapter 120 to prescribe terms, conditions, and restrictions for marine turtle conservation, and to permit the possession of marine turtles or parts thereof.
(e)1. Any person, firm, or corporation that commits any act prohibited in paragraph (d) involving any egg of any marine turtle species described in this subsection shall pay a penalty of $100 per egg in addition to other penalties provided in this paragraph.
2. Any person, firm, or corporation that illegally possesses 11 or fewer of any eggs of any marine turtle species described in this subsection commits a first degree misdemeanor, punishable as provided in §§. 775.082 and 775.083.
3. For a second or subsequent violation of subparagraph 2., any person, firm, or corporation that illegally possesses 11 or fewer of any eggs of any marine turtle species described in this subsection commits a third degree felony, punishable as provided in s. 775.082, s. 775.083, or s. 775.084.
4. Any person, firm, or corporation that illegally possesses more than 11 of any eggs of any marine turtle species described in this subsection commits a third degree felony, punishable as provided in s. 775.082, s. 775.083, or s. 775.084.
5. Any person, firm, or corporation that illegally takes, disturbs, mutilates, destroys, causes to be destroyed, transfers, sells, offers to sell, molests, or harasses any marine turtle species, or the eggs or nest of any marine turtle species as described in this subsection, commits a third degree felony, punishable as provided in s. 775.082, s. 775.083, or s. 775.084.
6. Notwithstanding s. 777.04, any person, firm, or corporation that solicits or conspires with another person, firm, or corporation, to commit an act prohibited by this subsection commits a felony of the third degree, punishable as provided in s. 775.082, s. 775.083, or s. 775.084.
7. The proceeds from the penalties assessed pursuant to this paragraph shall be deposited into the Marine Resources Conservation Trust Fund.
(f) Any application for a Department of Environmental Protection permit or other type of approval for an activity that affects marine turtles or their nests or habitat shall be subject to conditions and requirements for marine turtle protection as part of the permitting or approval process.
(g) The Department of Environmental Protection may condition the nature, timing, and sequence of construction of permitted activities to provide protection to nesting marine turtles and hatchlings and their habitat pursuant to the provisions of s. 161.053(5). When the department is considering a permit for a beach restoration, beach renourishment, or inlet sand transfer project and the applicant has had an active marine turtle nest relocation program or the applicant has agreed to and has the ability to administer a program, the department must not restrict the timing of the project. Where appropriate, the department, in accordance with the applicable rules of the Fish and Wildlife Conservation Commission, shall require as a condition of the permit that the applicant relocate and monitor all turtle nests that would be affected by the beach restoration, beach renourishment, or sand transfer activities. Such relocation and monitoring activities shall be conducted in a manner that ensures successful hatching. This limitation on the department's authority applies only on the Atlantic coast of Florida.
(h) The department shall recommend denial of a permit application if the activity would result in a "take" as defined in this subsection, unless, as provided for in the federal Endangered Species Act and its implementing regulations, such taking is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity.
(i) The department shall give special consideration to beach preservation and beach nourishment projects that restore habitat of endangered marine turtle species. Nest relocation shall be considered for all such projects in urbanized areas. When an applicant for a beach restoration, beach renourishment, or inlet sand transfer project has had an active marine turtle nest relocation program or the applicant has agreed to have and has the ability to administer a program, the department in issuing a permit for a project must not restrict the timing of the project. Where appropriate, the department, in accordance with the applicable rules of the Fish and Wildlife Conservation Commission, shall require as a condition of the permit that the applicant relocate and monitor all turtle nests that would be affected by the beach restoration, beach renourishment, or sand transfer activities. Such relocation and monitoring activities shall be conducted in a manner that ensures successful hatching. This limitation on the department's authority applies only on the Atlantic coast of Florida.

This Statute gives FWC the authority to implement its responsibilities under the recovery plans of the United States Fish and Wildlife Service.

In addition to the above Florida Statute, Chapter 62B-55 of Florida Administrative Code (FAC) directly addresses the issues concerning negative lighting impacts on sea turtles and includes the Model Lighting Ordinance for Marine Turtle Protection. It states that the statute "is intended to guide local governments in developing ordinances which will protect hatchling marine turtles from the adverse effects of artificial lighting, provide overall improvement in nesting habitat degraded by light pollution, and increase nesting activity and production of hatchlings." It also contains model standards for new as well as existing beachfront lighting; this law is being considered for updating to reflect more recent technologies.

LOCAL LAWS

As of July 2013, 21 Counties have adopted lighting ordinances to protect nesting sea turtles and hatchlings from artificial lighting. In addition, 82 municipalities have also passed lighting ordinances.

OTHER FEDERAL and STATE LAWS

Development along coastal regions is regulated by the Coastal Barrier Resources Act (CBRA), which recognizes the importance of coastal habitats to sea turtles and other wildlife and establishes the Coastal Barrier Resources System. The CBRA does not prohibit private development, but restricts federal funding that may directly or indirectly encourage development within these areas. This includes flood insurance, disaster relief, beach renourishement projects, or the construction of new federal highways or other infrastructure.

Through the Coastal Zone Management Act, the federal government supports coastal states in the development and implementation of management programs to achieve the best use of coastal lands. These management plans consider ecological, cultural, historic, and esthetic values and promote compatible economic development.

The Florida Beach and Shore Preservation Act, Florida Statute 161, and the Coastal Construction Control Line (CCCL) program administered by the Florida Department of Environmental Protection (FDEP) also regulates development along the coastline of Florida. The purpose of the CCCL is to protect the coastal system from structures and construction practices that may negatively impact beaches, dunes, sea turtles or other natural resources. Chapter 62B-33.005 (11) and (12), Florida Administrative Code, require protection of dunes, native vegetation, and marine turtles. This includes special conditions for construction activities that include shielding lighting and tinting windows from which lighting might reach the beach and alter sea turtle nesting behavior. General conditions in Chapter 62B-34-050 (4) specify appropriate exterior lighting for single family homes and require protection of dunes and native vegetation.

ENFORCEMENT

The United States Fish and Wildlife Service (USFWS) and the Florida Fish and Wildlife Conservation Commission (FWC) are the two agencies responsible for enforcing the conservation and recovery of sea turtle populations in Florida. USFWS has the authority to pursue civil penalties against the owners of the lights that are identified to harm sea turtles and can refer the case to the Department of Justice to pursue criminal penalties. Although the role of the lighting custodian (typically a private property owner, municipality or private utility) is important, the party ultimately responsible to the USFWS for resolving the problem may be the entity responsible for funding the lighting service, permitting the light, or the owner of the light.

The FWC is responsible for enforcing Florida's Marine Turtle Protection Act and for assisting with national sea turtle recovery efforts through a cooperative agreement with USFWS. Under this agreement, FWC permits qualified individuals to conduct sea turtle conservation activities including those on nesting beaches in the state. Whenever obvious signs of hatchling disorientation are observed, a report including the potential light source that may have caused the disorientation is sent to the FWC by local inspectors. If a lighting ordinance is in effect, either the FWC-authorized permit holder or the FWC furnishes a copy of the report to the local code enforcement department for action. If no lighting ordinance is in effect, the property owner may be notified directly. If the violation is not addressed within a reasonable timeframe, records of such persistent lighting problems may be furnished to the USFWS for federal prosecution under the ESA. Regulating agencies prefer first to work with individual and institutions involved in lighting impacts to resolve the issues. However, failing voluntary compliance, these agencies may proceed with enforcement, including prosecution.

In addition to the state agencies responsible for enforcing the ESA, concerned citizens and other interested groups can also pursue a legal course against state, county, or municipality for failure to act.

LAWS REGULATING LIGHTS IN FLORIDA

Lighting in Florida at the state level is regulated by multiple rules, regulations and agencies. Florida Statute (FS), Chapter 553, Building Construction Standards, applies to buildings and structures not related to transportation. FS Chapter 553, Part IV – Florida Building Code (FBC) contains the bulk of state lighting requirements for non-transportation related buildings and structures. The Department of Health (DOH), under Chapter 514 FS, Chapter 64E-9 FAC and FBC Section 424.1 regulates indoor and outdoor public pools, including lighting.

Florida Statute 334, as part of the Florida Transportation Code, provides the legal basis for lighting for all transportation facilities. Florida Statutes 334.044 (10) (a) and 334.045 establish the legal basis for the Florida Department of Transportation to set criteria and standards for lighting on transportation facilities.

The Florida Building Code is primarily enforced by municipal governments. The Florida Department of Transportation (FDOT) sets lighting standards for all State roads under Sections 20.23(4) a, 334.048(3) of Florida Statutes.

In addition to the laws referenced, the Illuminating Engineering Society of North America (IESNA) recommends guidelines, often considered as standards, for indoor, outdoor, and roadway lighting under the rules and procedures of the American National Standards Institute (ANSI). The American Association of State Highway and Transportation Officials (AASHTO) issues guidelines for roadway lighting design, which primarily rely on IESNA recommendations, but are a little more conservative and cover a greater range of roadway functional classifications. FDOT like the Departments of Transportation in most US states complies with AASHTO standards for lighting. The FBC, in general, complies with ANSI standards. However some FBC standards (especially those concerning egress lighting) are more stringent than and not consistent with IESNA standards.

COMPATIBILITY ISSUES

The myriad rules, regulations and standards discussed previously are not always consistent. Coastal lighting is a good example where consistency is lacking. Most state and professional organization standards are detailed, with specific illumination levels. The Florida Building Code has the Egress Lighting requirements ranging from 1.0 foot candle for the walkway floors to 10 footcandles for the stairs

The DOH requirements for outdoor swimming pools include 3 footcandle of illumination at pool deck surface. For indoor pools 10 footcandle of illumination is required.

Comparing the above FBC and DOH requirements with the illuminance levels for safety recommended by IESNA (IESNA, 2000)), reveals that the FBC minimum illumination requirements are twice as high as the highest recommended by IESNA (5 foot candles for high level of activity at locations with high levels of hazards requiring visual detection). No illumination requirements for outdoor pools are provided by IESNA. For indoor pools, IESNA recommends illumination levels similar to DOH, or higher.

Unlike the specific illumination level requirements for various situations required by FBC, DOH, FDOT, AASHTO, and IESNA, most local sea turtle lighting ordinances do not specify required/desired illumination levels. In most cases, these local ordinances restrict the intensity (wattage), mounting height, light trespass and location/position features for lights provided in these areas and emphasize shielding the luminaires. Very few lighting ordinances specify acceptable illumination levels; Cape Canaveral is perhaps the only example with an ordinance that actually states that "no more than 0.5 footcandles of artificial illumination shall be cast upon the beach". However if the spectral distribution of the light bandwidths is between 560 and 620 nanometers, the ordinance allows artificial illumination levels of "no more than two (2.0) foot candles on the beach". (no endorsement of these illumination levels is implied here). Unfortunately allowing any illumination on the beach is likely to harm nesting marine turtles or their hatchlings.

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APPENDIX G

The following is a list of lighting and window-treatment manufacturers and distributors. For current information, go to www.myFWC.com/seaturtle.

AFG Industries Inc.
(tinted glass)
1400 Lincoln Street
P.O. Box 929
Kingsport, Tennessee 37660 USA
TEL: 423-229-7200 or 800-251-0441
FAX: 423-229-7459
WEBSITE: www.afgglass.com
E-MAIL: (access through website)

General Electric
(lamps)
GE Lighting
1975 Noble Road
Cleveland, Ohio 44112 USA
TEL: 216-266-2653; 800-435-4448
FAX: 216-266-8437
WEBSITE: www.gelighting.com

Genlyte Thomas
(lamps, fixtures)
10350 Ormsby Park Place, Suite 601
Louisville, Kentucky 40223 USA
TEL: 502-420-9500
FAX: 502-420-9540
WEBSITE: www.genlytethomas.com
E-MAIL: (access through website)

Heath-Zenith
(lamps, fixtures)
Desa International
2701 Industrial Drive
P.O. Box 90004
Bowling Green, KY 42101 USA
TEL: 270-781-9600
FAX: 270-781-9400
WEBSITE: www.desaint.com
E-MAIL: (Access through Web site)

Hubbell Lighting Inc.
(lamps, fixtures, shields)
2000 Electric Way
Christiansburg, Virginia 24073-2500 USA
TEL: 540-382-6111
FAX: 540-382-1526
WEBSITE: www.hubbell-ltg.com

Hydrel
(lamps, fixtures)
12881 Bradley Ave Sylmar, California 91342 USA
TEL: 818-362-9465
FAX: 818-362-6548
WEBSITE: www.thelightingcenter.com

Intermatic Inc.
(lamps, fixtures)
Intermatic Plaza
Spring Grove, Illinois 60081-9698 USA
TEL: 815-675-2321
FAX: 815-675-7055
WEBSITE: www.intermatic.com

Janmar Lighting
(lamps, fixtures)
730 W. Golden Grove Way
Covina, California 91722 USA
TEL: 626-858-6776
FAX: 626-967-0314
WEBSITE: www.janmar.com
E-MAIL: sales@janmar.com

LEDTronics
(lamps)
23105 Kashiwa Court
Torrance, California 90505 USA
TEL: 310-534-1505; 800-579-4875
FAX: 310-534-1424
WEBSITE: www.ledtronics.com

Lithonia Lighting
(lamps, fixtures)
P.O. Box A
Conyers, Georgia 30012 USA
TEL: 770-922-9000
FAX: 770-483-2635
WEBSITE: www.lithonia.com
E-MAIL: lithonia@lithonia.com

Osram Sylvania Inc.
(lamps)
100 Endicott St.
Danvers, Massachusetts 01923-3623 USA
TEL: 978-777-1900 or 800-544-4828
FAX: 978-777-2152
WEBSITE: www.osram.co.za
E-mail: webmaster@osram.de

Patch Works
(shields)
216 NE 14th Ave.
Pompano Beach, Florida 33060 USA
TEL: 954-784-2314
FAX: 954-946-6052

Phifer Sunscreen
(window light shades)
P.O. Box 1700
Tuscaloosa, Alabama 35403 USA
TEL: 205-345-2120 or 800-633-5955
FAX: 205-391-0799

PPG Industries
(tinted glass)
Flat Glass Technical Services
P.O. Box 11472
Pittsburgh, Pennsylvania 15238 USA
TEL: 412-820-8500
FAX: 412-820-8025

Quality Lighting
(lamps, fixtures)
11500 Melrose Avenue
P.O. Box 1389
Franklin Park, Illinois 60131 USA
TEL: 847-451-0040 or 800-545-1326
FAX: 800-545-8250
WEBSITE: www.qualitylighting.com
E-mail: sales@qlty.com

SOL, Solar Outdoor Lighting Inc.
(solar lighting)
3210 SW 42nd Ave.
Palm City, Florida 34990 USA
TEL: 561-286-9461; 800-959-1329
FAX: 561-286-9616

Solargard
(window tint)
2400 W. Copans Road, Suite 7
Pompano Beach, Florida 33069 USA
TEL: 800-282-9031
FAX: 954-960-0297

Southwall Technologies
(tinted glass)
1029 Corporation Way
Palo Alto, California 94303 USA
TEL: 650-962-9111
FAX: 650-967-8713
WEBSITE: www.southwall.com
E-mail: webmaster@southwall.com

Spaulding Lighting
(lamps, fixtures)
1736 Dreman Ave.
Cincinnati, Ohio 45223 USA
TEL: 513-541-3486
FAX: 513-541-1454

Starfire Lighting
(lamps, fixtures)
7 Donna Drive
Wood Ridge, New Jersey 07075-1915 USA
TEL: 201-438-9540 or 800-443-8823
FAX: 201-438-9541
Website: www.starfirelighting.com

Sterner Lighting Systems Inc.
(lamps, fixtures)
351 Lewis Ave. West
P.O. Box 805
Winsted, Minnesota 55395-0805
TEL: 320-483-2148 or 800-328-7480
FAX: 320-485-2881
Website: www.sternerlighting.com
E-mail: adman@sternerlighting.com

Supreme Lights
(fixtures)
812 NW 8th Ave.
Fort Lauderdale, Florida 33311 USA
TEL: 954-768-0044
FAX: 954-768-0645

Synergy Lighting
(LED and solar lamps)
6015 28th Street East
Bradenton, Florida 34203
TEL: 877-220-5483
FAX: 941-756-4866
WEBSITE: www.synergylightingusa.com

Thomas Industries, Gardco Lighting
(lamps, fixtures)
2661 Alvarado St.
San Leandro, California 94577 USA
TEL: 510-357-6900 or 800-227-0758
FAX: 510-357-3088
WEBSITE: www.sitelighting.com
E-mail: webmaster@sightling.com

Voigt Lighting
(lamps, fixtures)
135 Fort Lee Road
Leonia, New Jersey 07605 USA
TEL: 201-461-2493
FAX: 201-461-7827
E-mail: voigtlight@aol.com

APPENDIX H

The following is a list of conservation organizations, government agencies, and other groups that may be able to assist in resolving light-pollution problems on sea turtle nesting beaches.

ARCHELON
Sea Turtle Protection Society of Greece[4]
Rescue Center
3rd Marina, GR-166 75 Glyfada
Athens, GREECE
TEL/FAX: +30-210-89-82-600
E-MAIL: rescue@archelon.gr
WEBSITE: www.archelon.gr/eng/whois.php

Sea Turtle Conservancy[1]
4424 NW 13th Street, Suite B-11
Gainesville, Florida 32609 USA
TEL: 352-373-6441
E-MAIL: STC@Conserveturtles.org
WEBSITE: www.Conserveturtles.org/

Ecological Associates, Inc.[1]
P.O. Box 405
Jensen Beach, Florida 34958 USA
TEL: 772-334-3729
FAX: 772-334-4925
E-MAIL: info@ecological-associates.com
WEBSITE: www.ecological-associates.com/

Florida Power and Light Company[2]
Juno Beach, Florida USA
Environmental Information
WEBSITE: www.fpl.com/environment/wildlife/sea_turtles.html

Florida Fish and Wildlife Conservation Commission[1, 2, 4]
Tequesta Field Laboratory
19100 SE Federal Highway Tequesta,
Florida 33469 USA
TEL: 561-882-5975
FAX: 561-743-6228
E-MAIL: seaturtlelighting@MyFWC.com
WEBSITE: www.MyFWC.com/seaturtle

FWC Fish and Wildlife Research Institute[1, 2, 4]
Florida Fish and Wildlife Conservation Commission Wildlife Research, Marine Turtles
100 8th Avenue SE
St. Petersburg, Florida 33701 USA
TEL: 727-896-8626
FAX: 727-823-0166
WEBSITE: http://myfwc.com/research/

FWC Imperiled Species Management[1, 2]
Florida Fish and Wildlife Conservation Commission
Habitat and Species Conservation
620 South Meridian Street
Tallahassee, Florida 32399 USA
TEL: 850-922-4330
FAX: 850-922-4338
WEBSITE: www.MyFWC.com/seaturtle

International Dark-Sky Association[5]
3225 North First Avenue Tucson,
Arizona 85719 USA
TEL: 520-293-3198
FAX: 520-293-3192
E-MAIL: ida@darksky.org
WEBSITE: www.darksky.org

Ogasawara Marine Center [4]
Sea Turtle Association of Japan
Byobudani, Chichi-jima
Ogasawara-mura, Tokyo, JAPAN 100-21
E-MAIL: info@bonin-ocean.net
WEBSITE: www.elna.or.jp/

[1]May be able to assist in education and legislation efforts.
[2]Offers a pamphlet for distribution entitled “Sea Turtles and Lights” and a booklet on general sea turtle biology (Van Meter, 1992).
[3]Maintains worldwide contacts with sea turtle researchers and conservationists.
[4]Compiles national or regional data gathered at sea turtle nesting beaches.
[5]Compiles and distributes information on causes and effects of light pollution; offers list of approved fixtures.

Projeto Tamar/ICMBio[1, 4]
Praia do Forte, Base Mãe
Caixa Postal 2219, CEP 41950-970
Rio Vermelho, Salvador, Bahia, BRASIL
TEL: (71) 3676-1020/1045
FAX: (71) 3676-1067
E-MAIL: protamar@tamar.org.br
WEBSITE: www.tamar.com.br

PRONATURA—Península de Yucatán, A.C.[4]
Calle 32 No. 269
Colonia Pinzón II
Mérida, Yucatán—MEXICO C.P. 97207
TEL: 999-988-4436, 999-988-4437
E-MAIL: informacion@pronatura-ppy.org.mx
WEBSITE: www.pronatura-ppy.org.mx

Queensland National Parks and Wildlife Service [4]
Department of Environment and Resource Management
160 Ann Street
P.O. Box 155, Brisbane Albert Street
Queensland 4002 AUSTRALIA
TEL: +61 (7) 3227 8186
FAX: +61 (7) 3227 8749
WEBSITE: www.derm.qld.gov.au/wildlife-Ecosystems/wildlife/watching wildlife/turtles/index

The Ocean Conservancy[3]
1300 19th St. NW.
8th Floor, Washington DC 20036 USA
TEL 800 519 1541
E-MAIL: info@oceanconservancy.org
WEBSITE: www.oceanconservancy.org

United States Fish and Wildlife Service[4]
National Sea Turtle Coordinator
7915 Baymeadows Way, Suite 200
Jacksonville, Florida 32256 USA
TEL: 904-731-3032
FAX: 904-731-3045 or 904-731-3048
E-MAIL: seaturtle@fws.gov
WEBSITE: www.fws.gov/northflorida/SeaTurtles/seaturtle-info.htm

WIDECAST[1]
1348 Rusticview Drive Ballwin,
Missouri 36011 USA
TEL: (314) 954-8571
E-MAIL: keckert@widecast.org
WEBSITE: www.widecast.org

WIDECAST Latin American Office
Didiher Chacón Chaverri Director
Apdo. 2164-3000
Heredia, Costa Rica
TEL: (506) 2 241-7431
MOBILE: (506) 8 838-9480
FAX: (506) 2 241-7149
E-MAIL: dchacon@widecast.org
WEBSITE: www.latinamericanseaturtles.org/

World Wildlife Fund[1, 3]
1250 24th Street NW.
P. O. Box 97180
Washington, DC 20090-7180 USA
TEL: 800-225-5993; 202-293-4800
E-MAIL: through Web site
WEBSITE: www.worldwildlife.org

[1]May be able to assist in education and legislation efforts.
[2]Offers a pamphlet for distribution entitled "Sea Turtles and Lights" and a booklet on general sea turtle biology (Van Meter, 1992).
[3]Maintains worldwide contacts with sea turtle researchers and conservationists.
[4]Compiles national or regional data gathered at sea turtle nesting beaches.
[5]Compiles and distributes information on causes and effects of light pollution; offers list of approved fixtures.

APPENDIX I

Comments and responses to common questions about sea turtles and lighting.

When do hatchling sea turtles emerge from their nests?

The first hatchlings of the season emerge from nests approximately eight weeks after the first nesting of the season. Thus, hatchlings continue to emerge approximately eight weeks after the final nesting. Outside the tropics, hatchlings generally emerge throughout the summer and early fall. In the southeastern United States, hatchlings emerge throughout the months of June, July, August, September, and October. It is a myth that hatchlings emerge only around the time of the full moon. Hatchlings ready to emerge wait just beneath the sand surface until conditions become cool. This temperature cue prompts them to emerge primarily at night, although some late-afternoon and early-morning emergences have been documented.

How do hatchling sea turtles know where the ocean is when they emerge from their nests?

Sea turtle hatchlings tend to move in the brightest direction. On a natural beach, the brightest direction is most often the open view of the night sky over, and reflected by, the ocean. Hatchlings also tend to move away from darkly silhouetted objects, such as the dune profile and vegetation. This sea-finding behavior can take place during any phase and position of the moon, which indicates that hatchlings do not depend on lunar light to lead them seaward.

Why do artificial light sources attract hatchling sea turtles?

Hatchlings that crawl toward artificial light sources are following the same instinctive response that leads them seaward on naturally lighted beaches. The apparent brightness and glare of artificial lighting is what often leads hatchlings astray. To a hatchling on a beach, an artificial light source appears bright because it is relatively close by, yet it is not intense enough to brighten the sky and landscape. The resulting glare makes the direction of the artificial source appear overwhelmingly bright—so much brighter than the other directions that hatchlings ignore other visual cues and move toward the artificial light no matter where it is relative to the sea.

There are other lights near my beachfront property that are visible from the beach. Why should I modify my lights?

Any reduction in the amount of artificial light reaching the nesting beach helps sea turtles. Efforts need to be made to minimize existing artificial lights reaching nesting beaches and certainly not allow any new lights to add to the problem. As lighting is reduced, hatchlings emerging on moonlit nights and at locations far from the lighted property will have a better chance of finding the sea.

Can hatchlings be protected by increasing the number of lights on a nesting beach in order to prevent turtles from nesting?

Although artificial lighting tends to deter sea turtles from nesting, many do nest on lighted beaches. Apparently, the level of artificial lighting necessary to misdirect hatchlings is well below the level necessary to deter nesting. But even if beaches were lighted to the extent that no nesting occurred, hatchlings on adjacent beaches would be harmed. Regardless, chasing sea turtles away from nesting beaches means that important habitat is lost to them; therefore, it is not a beneficial conservation strategy.

How bright can a light be without affecting hatchlings or adult sea turtles on the beach?

Unfortunately, no simple measure of light intensity can reveal whether a light source is a problem. The effects of artificial lighting on sea turtles may actually increase as ambient light levels decrease on darker, moonless nights. Because any visible light from an artificial source can cause problems, the most reliable “instruments” to use when making judgments about problem lighting may be the eyes of a human observer on the nesting beach. Any light source producing light that is visible from the beach is likely to cause problems for nesting sea turtles and their hatchlings.

What should be done with misdirected hatchlings found on the beach?

Hatchling sea turtles found wandering away from the ocean should be taken to a darkened portion of beach and allowed to walk into the surf on their own. Those that do not crawl vigorously can be placed in the water and allowed to swim away. In all cases, local natural resource or environmental protection agencies should be notified. Consult Appendix H for a list of governmental and nongovernmental conservation organizations.

Whom should I notify about a light that is visible from a sea turtle nesting beach?
Contact the owner or resident of the property where the light source is located. In most cases, people are simply unaware rather than uncaring. Local government conservation agencies should also be notified. A growing number of coastal communities have adopted ordinances that prohibit lighting on the beach during the nesting season and have offices that enforce them. If there is inadequate regulation of beach lighting in your area or if lighting problems persist, private conservation organizations may be able to help. Consult Appendix H for a list of governmental and nongovernmental conservation organizations.

I do not have the ability to turn off a problem light that is located on my property. What can be done?
Luminaires that do not have convenient on–off switches are most often controlled by the utility company. Property owners should contact the entity to whom electricity bills are paid or to whom lighting lease payments are made.

Will lighting on a pier affect sea turtles on the adjacent beach?
Yes. Lighting on piers is very difficult to shield from the beach. Hatchlings on adjacent stretches of beach may crawl for great distances in the direction of the lighted pier. Hatchlings that enter the water near the pier may linger in the glow beneath the lighted structure and fall prey to fish, which are also attracted to the light, rather than disperse offshore.

Will placing bright lights on platforms offshore guide hatchlings into the water off lighted beaches?
Apart from being an overly expensive and complicated solution, lighting the ocean to draw hatchlings offshore would probably create additional problems. Lighting on the water can interfere with hatchling dispersal and increase mortality from predation by fish.

There is not enough sea turtle nesting on this beach to justify beach-darkening efforts. Why is light-management legislation needed?
Beaches on which small numbers of turtles nest can be important. The entire nesting range of a population may be made up of sparsely nested beaches. Hawksbill turtles, for instance, one of the most highly endangered sea turtles, never nest in great numbers. Moreover, any group of nesting turtles may constitute a genetically unique and vulnerable unit, and losing even a small population may mean the permanent loss of diversity. The irony in disregarding lighting problems at sparsely nested beaches is that artificial lighting may have caused the nesting to be so rare on those beaches. They may again attract more nesting turtles once they are darkened.

Crime will increase if the beach is not lighted.
Generally, beaches are not areas where there is a great need for crime prevention. Little valuable property is stored on beaches, and there is seldom much nighttime human activity to require security. Fortunately, areas adjacent to nesting beaches where people reside, work, recreate, and store valuables can be lighted for protection without affecting turtles on the nesting beach. Where this type of light management was legislated in Florida coastal communities, the Florida state attorney's office has found no subsequent increase in crime.

Implementing a beach-darkening program will be prohibitively expensive.
Darkening nesting beaches for sea turtles is one of the least expensive ways we can benefit the environment. The simplest solution to the problem—turning off lights visible from the beach during the nesting season—costs little or nothing and may actually save money in electricity costs. Most of the essential lighting that remains can easily be shielded so that the light performs its intended function without reaching the beach. Proper shields can be fashioned from inexpensive metal flashing and fastened with screws. Replacing fixtures is more expensive but is necessary only when an owner decides that greater lighting efficiency or aesthetics are a concern. Choosing well-designed fixtures and incorporating light-management techniques into the plans for coastal development are the most effective ways to fulfill lighting needs while protecting sea turtles.

Are there disadvantages to using sea turtle–friendly lights?

Advancements in LED lighting technology offers sea turtle–friendly lights with little or no disadvantage, and LEDs provide better light quality, use less energy, and have a lighter environmental footprint than most other light sources. Before the advent of LEDs, low-pressure sodium lights were preferred for the purpose. LPS lights had some disadvantages including poor color rendition. As is true for any light source, there are both advantages and disadvantages to using LED lighting. The following is a list of issues specific to LEDs.

Expense. The initial costs of LEDs are greater than for incandescent and fluorescent sources but are only slightly greater than costs for high-intensity discharge lighting (e.g., High Pressure Sodium). Operating costs, however, are generally much lower for LEDs because LED lamps are very efficient and produce significantly more light per watt of energy consumed than any other commercial source.

Color. LEDs can produce light of many colors, and all of them have excellent color rendition. LEDs producing lights in amber or yellow shades are preferred as sea turtle–friendly lights because sea turtles are less sensitive to these lights

Disposal. LED lamps, like most other commercially available lights, contain low amounts of lead, arsenic, nickel, and some other toxic materials, but, according to federal standards, they are not hazardous except for low-intensity red LEDs, which, after disposal (in landfills), leach lead at levels exceeding regulatory limits. LEDs contain no mercury.

Availability. Low-wattage LED luminaires are readily available in retail stores, and a variety of LED fixtures are available from a number of manufacturers (see Appendices D and G).

Sea turtle nests on our beach are moved to darker areas to protect hatchlings from lighting. Are our lights still a problem?

Yes. Although it may seem that moving nests out of harm's way will solve the problem, doing so only partially solves the problem and may create new ones. In moving nests, nothing is done to prevent lighting from deterring nesting turtles and interfering with their orientation on the beach. Moving nests also has its own negative consequences that stem from the limitations of this technique.

1. In nearly every effort to find nests, some are missed. Hatchlings from missed nests will suffer the effects of beach lighting.
2. Moved clutches of eggs often have poorer hatching rates. Moving eggs kills at least some of them, and often many die, depending upon how skillfully the moving is done.
3. Putting eggs in places other than those chosen by the nesting turtle can be detrimental. A specific nest environment is critical, both for the survivorship of eggs and for the determination of the hatchlings' sex ratio.

How can the sacrifice of human safety and security to save a few sea turtles be justified?

Thankfully, no such choice is necessary. The safety and security of humans can be preserved without jeopardizing sea turtles. The goal of any program for reducing harassment and mortality of sea turtles caused by lighting is to manage light so that it performs the necessary function without reaching the nesting beach. Still, some may contend that any inconvenience is too much and that the concerns of humans should always outweigh those for turtles. People insistent on this generalization should not ignore the large and resolute constituency that values sea turtles. Sea turtles are valuable to people both ecologically and for pure enjoyment. In many ways, the protection of sea turtles is in our own best interest.

What good are sea turtles?

Measuring the true worth of anything is difficult, but it is especially difficult to make this measurement of a common resource. Although some may appreciate sea turtles more than others, sea turtles are of value to all. Short of a thorough discussion on the ecological place of sea turtles, suffice it to say that the world would be a poorer place to live without them. We just don't know how much poorer. With regard to sacrificing the diversity of life, Aldo Leopold wrote in his *Sand County Almanac:*

> *"The last word in ignorance is the man who says of an animal or plant:* 'What good is it*?'... If the biota, in the course of aeons, has built something we like but do not understand, then who but a fool would discard seemingly useless parts? To keep every cog and wheel is the first precaution of intelligent tinkering."*

APPENDIX J

Glossary

A19 base: The most common size and shape of residential light bulbs used in most household fixtures. An A19 base bulb is pear-shaped and typically has a metal thread, or E, (Edison screw light base) type base.

Acceptance cone: A solid angle that describes the apex of a geometrical cone containing the range of directions from which light can be measured by a detector (and perceived to be detected by an animal).

Angle of acceptance: An angle, usually specified as horizontal or vertical, that describes the range of directions from which light can be measured by a detector (and perceived to be detected by an animal).

Anthropogenic: Originating from the actions or devices of humans.

Artificial lighting: Light sources produced by humans.

Baffle: A structure used to reduce or deflect light or glare escaping from a fixture. Baffles can also reduce visibility of the lamp in a fixture.

BAT: A common strategy for reducing pollution using the best available (pollution-reduction) technologies to reduce effects of lighting as much as practicable. Includes many light-management options used by lighting engineers to protect sea turtles.

Beach: Dynamic coastal areas of sedimentary deposits, usually sand, between the primary dune and the water.

Bollard lighting: A type of lighting fixture within a waist-level post or bollard. Bollard fixtures are generally designed to illuminate only the immediate area around the bollard.

Brightest direction: The direction in which the perception or measurement of brightness is greatest.

Brightness: The perception or measure that describes light intensity with respect to a specific spectral sensitivity and angles of acceptance.

BUG: A luminaire classification system that classifies backlight (B), uplight (U) and glare (G).

Bug light: An incandescent lamp that is tinted yellow to attenuate its emission of short-wavelength visible light and thus reduce its attractiveness to insects.

Candela: The basic, international unit for measuring luminous intensity.

Clutch: The group of eggs deposited in a nest.

Color rendering: The effect of a light source on the color appearance of an object.

Color: The sensation resulting from stimulation of the retina by light of certain wavelengths.

Cone: A photoreceptor cell in the eye that is sensitive to color.

Cone of acceptance: *See* **Acceptance cone**

Crawl: The tracks and other disturbances left on a beach by a sea turtle that has attempted to nest.

Cut-off angle: The angle between a vertical line through a luminaire and the first line of sight at which the glowing elements of the luminaire are no longer visible.

Dichroic filter: A multi-layer coating that transmits certain wavelengths and reflects those not transmitted.

Diffuser: Made of a translucent material, the part of a luminaire through which light is diffused. One of the elements of a luminaire that appears to glow. Also called a lens or globe.

Direct lighting: Any combination of artificial lighting that includes a luminaire with a glowing element visible to an observer on the beach.

Directional lighting: A luminaire that can be aimed so that its light reaches only specific areas.

Disorientation: Loss of orientation. The inability to maintain constant directional movement.

Downlighting: Generally canister or cylinder-shaped lighting fixtures that direct light predominately downward and that possess baffles to reduce lateral light.

Efficiency: For a lamp, the ratio of light output (lumens) to electrical power (watts) consumed.

Electroretinography (ERG): A method of determining spectral sensitivity in which the relative electrical potential is measured across a retina exposed to light at specific wavelengths and intensities.

ERG spectrum: As measured by electroretinography, the spectral sensitivity of an animal.

False crawl: An aborted nesting attempt (emergence onto a beach) by a sea turtle.

Fixture: The device that holds, protects, and provides the optical system and power connections for a lamp.

Floodlighting: High-intensity lighting that can be directed at various angles to illuminate large areas or objects.

Fluorescent: An electric-discharge lamp containing argon, neon, mercury, and in some cases krypton, that is coated inside with phosphors that determine color appearance (most commonly, white) when lighted.

Footcandle: The English unit for measuring illuminance; the illumination of a surface uniformly one foot from a point source of one candela; one lumen per square foot; equal to 10.76 lux.

Globe: A diffuser, usually hemispherical, of a luminaire. One of the elements of a luminaire that appears to glow.

Halogen: A type of incandescent lamp that combines a halogen gas and a tungsten filament to produce light.

Hatching success: The proportion of eggs in a nest that produce living hatchlings.

Hatchling: A newly hatched sea turtle.

High-pressure sodium vapor (HPS) lamp: An electric discharge lamp containing an amalgam of sodium and mercury, and rarefied xenon, that appears whitish golden or peach-colored when lighted.

High-intensity discharge (HID) lamp: A type of lamps that emits high intensity light and includes high-pressure sodium-vapor, mercury-vapor, and metal-halide lamps.

Illuminance: The density of luminous flux on a surface. Luminous flux includes only visible light. Measured in footcandles or lux.

Incandescent: A lamp that produces light by means of an electrically heated glowing metal filament and that appears white when lighted. Includes quartz tungsten halogen (or simply tungsten halogen) sources. May be tinted to vary color (e.g., yellow bug lights).

Indirect lighting: Lighting that is visible to an observer on the beach only after it is reflected by objects near the beach or scattered by mist.

Irradiance: The density of radiant flux on a surface. Radiant flux may include light throughout the spectrum.

Lamp: The source of light within a luminaire.

LED: A light-emitting diode (LED) is a semiconductor device that emits visible light when an electric current passes through it. The light is not particularly bright, but in most LEDs it is monochromatic, occurring at a single wavelength. The output from an LED can range from red (at a wavelength of approximately 700 nanometers) to blue-violet (about 400 nanometers). LEDs are now increasingly being used in lighting products because of their low power consumption, high efficiency and long life.

Lens: *See* **Diffuser.**

Light: 1) Visible or near-visible radiant energy. 2) A term often used in place of “luminaire” or “light fixture.”

Light color: *See* **Color**.

Light fixture: *See* **Fixture**.

Light shield: Any opaque material fastened to a luminaire that makes the luminaire produce more directional lighting.

Light meter: A detector used to measure levels of visible light, typically luminance or illuminance.

Light pollution: The introduction of detrimental artificially produced light into the environment. Similar to light trespass, i.e., the emission of light into areas where it is unwanted.

Louver: One of a series of light-blocking baffles used to direct light coming from a luminaire.

Low-pressure sodium vapor (LPS) lamp: An electric discharge lamp that contains sodium, neon, and argon and that appears amber yellow when lighted.

Lumen: A unit of light output or flux, equal to the amount of light flow from one candela through a unit solid angle.

Luminaire: A device that artificially produces and distributes light, including all parts, such as fixture, ballast, mounting, and lamps.

Luminance: The luminous flux from a surface or light source, per unit area of the surface. Luminous flux includes only visible light.

Lux: The metric unit for measuring illuminance; the illumination of a surface uniformly one meter from a point source of one candela; one lumen per square meter; equal to 0.0929 footcandle.

Mercury-vapor lamp: An electric-discharge lamp that contains mercury and argon and is sometimes coated with phosphors; appears whitish when lighted.

Metal-halide lamp: An electric-discharge lamp that contains mercury, argon, sodium iodide, scandium iodide, and scandium; appears white when lighted.

Misorientation: Orientation in the wrong direction. For hatchling sea turtles on the beach, travel in any direction other than toward the general vicinity of the ocean.

Monochromatic: The description of a light source emitting a very narrow set of wavelengths (*i.e.*, a single color).

Mounting height: The vertical distance between a luminaire and the surface to be lighted.

Nest: The area of disturbed sand on a beach where a sea turtle has buried a clutch of eggs.

Nesting success: The proportion of nesting attempts by a sea turtle (emergences onto the beach) that result in the deposition of eggs.

PAR: Parabolic Anodized Reflectors that collect and reflect light in a fixture via a shiny *U*-shaped piece of metal. PAR lights are described by the diameter of the bulb measured in eighths of an inch.

Photobiology: The science that investigates and describes the impact of light on living organisms.

Phosphors: Materials used in a light source to produce or modify its spectral emission distribution.

Photometer: *See* **Light meter**.

Photopigments: The light-absorbing chemicals within the rod and cone cells of the retina.

Photopollution: *See* **Light pollution**.

Phototropotactic: Pertaining to phototropotaxis.

Phototropotaxis: Directional movement governed by a weighing of sensory excitation from stimuli received by separate light-sensing structures.

Primary dune: Coastal areas of elevated sandy deposits closest to the water; generally has well-established vegetation if it has not been artificially cleared.

Radiance: The radiant flux from a surface or light source, per unit area of the surface.

Radiometer: An instrument that measures radiant energy (e.g., visible light).

Recessed: (In this manual's context), a term describing a luminaire mounted within a ceiling opening in such a way that the glowing elements of the luminaire are hidden from view.

Reflector: An element of a luminaire that directs light from the luminaire by reflection.

Retina: The membrane lining the vertebrate eye that contains the pigmented cells (rods and cones) that are sensitive to light.

Rod: A photoreceptor cell in the retina that is sensitive to low levels of light.

Sea-finding behavior: The tendency to move in the direction of the ocean.

Sex ratio: The proportion of females to males. Sex ratios of sea turtle hatchlings are determined by the environmental conditions (mostly temperature) under which the eggs incubate.

Shield: *See* **Light shield**.

Skyglow: The glow of light scattered by mist and clouds over densely lighted areas.

Spectral light: Light composed of specific wavelengths.

Swash zone: The beach zone in which advancing waves wash up the beach and recede.

Tier lighting: Small light fixtures with louvers that restrict light to the immediate area around the fixture; generally mounted at ground level.

Up-lighting: Lighting fixtures that are directed upward, usually onto objects (flags, monuments, signs, buildings, etc.).

Urban skyglow: *See* **Skyglow**.

Visible spectrum: The range of wavelengths visible to humans, generally between 380 (violet) and 760 (red) nm.

Wavelength: The property of a photon of light that determines its energy and color, usually expressed in nanometers.

Xanthophobia: The tendency to orient away from sources rich in yellow light. A type of orientation seen in loggerhead hatchlings.