From: Mike Murray
To: Margaret Carfioli
Cc: Abra C Zobel; Britta Muiznieks; Darrell Echols; Michelle Baker; Thayer Broili
Subject: Re: Fw: CAHA night skies & lighting guidelines
Date: 12/18/2008 09:16 AM
Attachments: NPS wildlife guidelines.doc

In practical terms, I'd like to run whatever we come up with for turtle friendly lighting by FWS and WRC before we finalize it. I've had discussions with Pete Benjamin and the Director of WRC about turtle lighting and am trying to leverage the RegNeg process to encourage Dare County to enact turtle friendly lighting requirements for the villages. That would have far greater impact than just us dealing with our buildings and the fishing piers. To make that happen, we will need WRC, in particular, to be on board with our standards (or need them to develop standards that we could adopt, whichever approach happens first).

Mike Murray
Superintendent
Cape Hatteras NS/ Wright Brothers NMem/ Ft. Raleigh NHS
(w) 252-473-2111, ext. 148
(c) 252-216-5520
fax 252-473-2595

▼ Margaret Carfioli/CAHA/NPS

Margaret Carfioli/CAHA/NPS

12/18/2008 08:29 AM

To Mike Murray/CAHA/NPS@NPS, Darrell Echols/CAHA/NPS@NPS, Thayer Broili/CAHA/NPS, Britta Muiznieks/CAHA/NPS, Michelle Baker/CAHA/NPS@NPS, Abra C Zobel/CAHA/NPS

cc

Subject Fw: CAHA night skies & lighting guidelines

FYI -
Sandy Hamilton asked where we stand on the lighting guidelines and to make sure the ORV Mgmt Plan contractor(s) had all the info. The documents generated by Chad and his team (e.g., summary report on night skies at CAHA; draft lighting guidelines; draft lighting zones maps) were provided to Sandy. All of these documents are available to view on the Shareall here: I:\DIVISION FOLDER-RES MNGT\Night Skies

Below is Chad's summary of where we are on the lighting guidelines....

Thanks,
Meghan

----- Forwarded by Margaret Carfioli/CAHA/NPS on 12/18/2008 08:22 AM -----

Chad Moore/FTCOLLINS/NPS

12/17/2008 09:30 PM

To Margaret Carfioli/CAHA/NPS@NPS
cc Sandra Hamilton/DENVER/NPS@NPS
Subject CAHA night skies & lighting guidelines

Meghan,
My sincere apologies for letting this project lapse. It has been challenging to reestablish my program within WASO and there have been many issues regarding a servicewide lighting guideline that have distracted me. Additionally, we have funds rescinded and have yet to get FY09 funds, Kate Magargal has resigned in lieu of being extensively furloughed, and I have to furlough my lead scientist for 2-4 months this winter. We got overextended with several projects, yours being one of them. But I'm negligent for not communicating.

We are in the final edits and appendix of a document called Wildlife Friendly Lighting for Parks. It does not have specific engineering specifications (footcandles, watts, etc), though we are thinking about throwing one in there as an example. It is more of a general discussion biome by biome. As I am learning the hard way, in order to change the minds of people who think the old way of outdoor lighting is good enough, I need a step by step logic trail. Some parks are lucky enough to have a superintendent that says "make it so," but that is the exception. I've attached a recent draft of that document.

When some engineers in Denver and Shawn Norton found out about the efforts of the Night Sky Team to define lighting guidelines, they started sort of a parallel effort. Unfortunately, this was driven mostly by energy efficiency with little or no regard for wildlife. I've been trying to interject myself into their process, but it has been slow. My first phone conference with them is tomorrow. I'm hoping I can get them to agree to a "NPS Mission" driven document that takes the multitude of issues, such as wildlife, into consideration. If I can't get that concession, I have a huge fight on my hands. Clearly this is an important issue for me, but not one that should hinder your needs especially since they were dictated by USF&W.

I have another email that I use for large attachments- moore@cira.colostate.edu. I cannot find a relevant document on the FTP server you indicated below; could you repost or send to my alternate email?

I would like to complete my recommendations to CAHA. The modeling of the sea turtle spectral sensitivity is completed, and I have amassed all the literature I need on light spectra. What remains is about 5 pages of text to be written and delineation of recommended lighting levels- a task that will require much deliberation. I will be working on this immediately following completion of the draft wildlife friendly guidelines (attached) which should only take another week.

NPS wildlife guidelines.doc

Chad Moore
NPS Night Sky Program
Colorado State University- CIRA
1375 Campus Delivery
200 W. Lake Street (shipping)
Fort Collins, CO 80523. USA.
970-491-3700
www2.nature.nps.gov/air/lightscapes

"There are certain values in our landscape that ought to be sustained against destruction or impairment, though their worth cannot be expressed in money terms. They are essential to our life, liberty, and pursuit of happiness, this Nation of ours is not so rich it can afford to lose them, it is still rich enough to afford to preserve them."
Newton B. Drury
Director NPS 1940-1951
▼ Margaret Carfioli/CAHA/NPS

Margaret Carfioli/CAHA/NPS

12/04/08 02:11 PM EST

To Chad Moore/FTCOLLINS/NPS@NPS
cc Sandra Hamilton/DENVER/NPS@NPS, Kate Magargal/BRCA/NPS@NPS
Subject Fw: CAHA night skies & lighting guidelines

Hi Chad,

Sandy and I wanted to check in with you about the status of lighting zone guidelines for CAHA. The contractors for the ORV Management Plan/EIS would like to make sure that they have the most current versions of documents. Since the email delivery failed, I went ahead and posted the documents I have to the NPS' FTP site....

URL: ftp://63.220.43.40/CAHA/

username: npsftpwin

password: FTP04npswin

Please let us know if any additional documents are relevant or have since been updated. Thanks!

Thanks,
Meghan

Meghan Carfioli
Natural Resource Manager
NPS - Outer Banks Group
1401 National Park Drive
Manteo, NC 27954

Tel: (252) 473-2111 x 135
Cell: (252) 475-8346
Fax: (252) 473-2595
Margaret_Carfioli@nps.gov

----- Forwarded by Margaret Carfioli/CAHA/NPS on 12/04/2008 02:04 PM -----

Your document: CAHA night skies & lighting guidelines

Chad Moore/FTCOLLINS/NPS

Error delivering to Chad Moore/FTCOLLINS/NPS; Router: Database disk quota exceeded

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NP018ATLANTA/MAIL/NPS, NP002BDENVER/MAIL/NPS, NP002BDENVER/MAIL/NPS, NP018ATLANTA/MAIL/NPS

To: Chad Moore/FTCOLLINS/NPS@NPS

cc: Sandra Hamilton/DENVER/NPS@NPS

Date: 01:53:57 PM Today

Subject: CAHA night skies & lighting guidelines

Hi Chad,

Sandy and I wanted to check in with you about the status of lighting zone guidelines for CAHA. The contractors for the ORV Management Plan/EIS would like to make sure that they have the most current versions of documents. Attached are the most current files I have on this subject.

Please let us know if any additional documents are relevant or have since been updated. Thanks!

Thanks,
Meghan

Meghan Carfioli
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Wildlife Friendly Lighting for National Parks

Travis Longcore

Catherine Rich

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Wildlife Friendly Lighting for National Parks

Americans have long considered their national parks as places to be able to see and enjoy the solitude of unspoiled nature and as places where the natural rhythms of life are allowed to flourish with minimal disturbance from human interference. Park managers therefore must balance the need to provide visitor infrastructure with its impacts on the environment. Although night lighting is considered an essential element for visitors in many circumstances, recent research has shown a range of adverse ecological consequences of night lighting on ecosystems and wildlife. With some planning, however, the effects of lighting on species and ecosystems can be reduced and in some instances avoided altogether. This report provides the scientific basis for assessing the impacts of artificial night lighting on wildlife and presents options to retrofit and design lighting that minimizes impacts to wildlife and the nocturnal environment.

Extensive outdoor (and indoor) electric lighting is an extremely recent phenomenon in the history of the world. Thomas Edison commercialized the electric light bulb in the late 1880s, but outdoor use was largely limited to cities until well into the 1900s. Electric lights were introduced in city centers as replacements for gas lamps in the late 1880s, with almost immediate adverse effects on wildlife. Nearly 1,000 migratory birds were killed in collisions after being attracted to an electric light tower in Decatur, Illinois in 1886 (Gastman 1886). Significant outdoor lighting spread with the rural electrification programs of the 1930s and 1940s. Other significant sources of outdoor lighting have similarly spread across large swaths of the globe. Mining and oil and natural gas drilling is usually accompanied by extensive lighting, along with flaring of excess natural gas. These flares illuminate large areas of the ocean in regions with significant offshore oil resources. Light-induced fisheries light up oceans in many regions, with 30,000-Watts of lights per boat to attract fish for capture and ocean-going freighters and passenger ships introduce mobile light sources along oceanic routes. Together these light sources, and others, introduce novel sets of lighting conditions that have no historical precedent into natural ecosystems.

These guidelines have two main sections. The first section reviews the adverse effects of artificial night lighting on natural ecosystems and is divided into major habitat types. As quickly becomes obvious, no single solution is available to minimize adverse effects of light at night. We therefore attempt to generalize the concerns that typify each biome. The second section provides recommendations for best practices to minimize impacts from lighting. It addresses the characteristics of lights in terms of spectrum, duration, and directionality with reference to biomes in which each method of control would be applicable. It then reviews the issues that arise from a range of potential lighting contexts, including night hikes and mountain biking, vanity lighting, communication towers, and light-induced fisheries. Finally, we provide examples of lighting projects in national parks designed to protect the nighttime environment.

1 Effects of Artificial Night Lighting on Natural Ecosystems

1.1 Natural Patterns of Light at Dark

In the natural world, sources of light are either very predictable, or exceedingly ephemeral. The dominant and structuring source of light is the sun, through daylight and the reflected light of moonlight. Patterns and intensity of sunlight and moonlight vary with geographic location, weather, and time, but they have certain predictably characteristics. For example, the daily, monthly, and seasonal patterns of moonlight and sunlight incident upon the Earth's atmosphere are only rarely interrupted (e.g., by a solar eclipse), but they never violate certain rules. Once the sun has set, the brightest possible constant light source is a full moon until the sun rises again. The length of the night varies by season and latitude but these patterns are, in the timescale of biological activity, fixed. Weather can darken a bright day, but prior to human activity, it did not turn the nighttime into day. Fires, lightning, bioluminescence, and starlight also produce light under natural conditions, but these are by and large of short duration, intermittent or exceedingly dim in comparison with sunlight and moonlight.

Light is often measured in lux, which summarize two characteristics of light, the absolute energy represented by the photons incidence upon a receiver and the wavelengths of that energy. Lux is a measure of brightness as perceived by humans and so the calculation is weighted to place more value on wavelengths of light to which the human eye responds, and less on those wavelengths to which humans are less sensitive. Lux measurements can be customized for the optic responses of different species by re-weighting the calculations to emphasize different wavelengths.

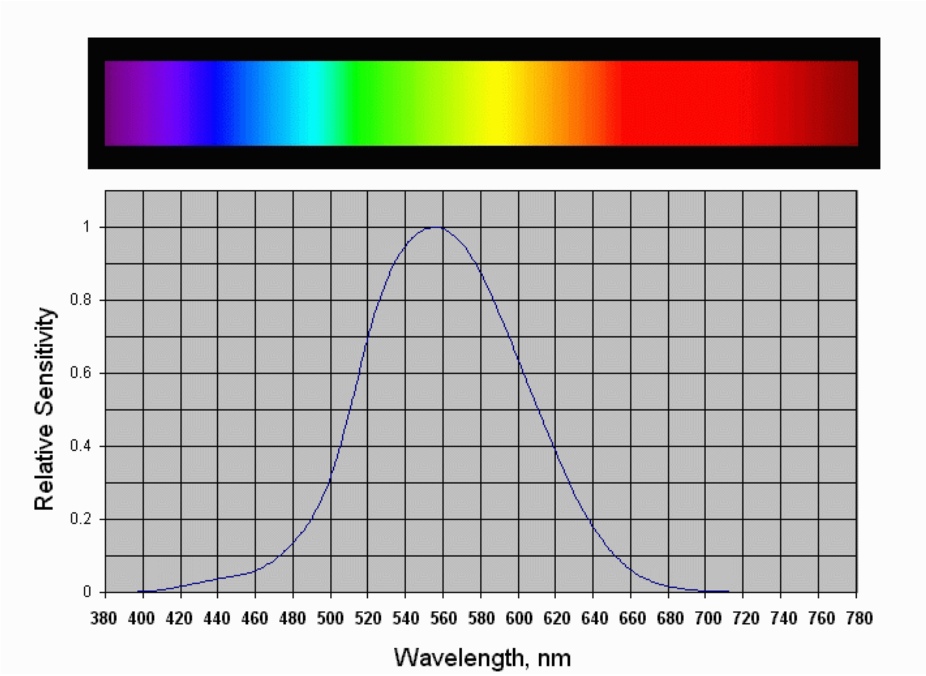

Figure 1. Sensitivty of human eye to light by wavelength.

Outdoor light during the day ranges from 1,000 lux on a cloudy day to over 100,000 lux in full sunlight (Figure 2). At dawn and dusk there is a transition into and out of much darker conditions. This transition, in addition to experience changes in illumination, is also characterized by predictable changes in the dominance of the wavelengths of light present. As dusk falls, more and more red light is present in the ambient light. Organisms use the natural light regime to trigger many behavioral and physiological processes. Circadian, circannual, and circalunar rhythms are linked to the predictable changes in the light environment. Light triggers can be at different illuminations depending on the environment. What is extraordinarily dim in one environment may be bright in another. For example, the illumination at which activity takes place on a forest floor is on average dimmer than the same activity for similar organisms in open grassland. Illumination that is within the natural range of variation on a beach may be far brighter than anything experienced at night at ground level in a boreal forest.

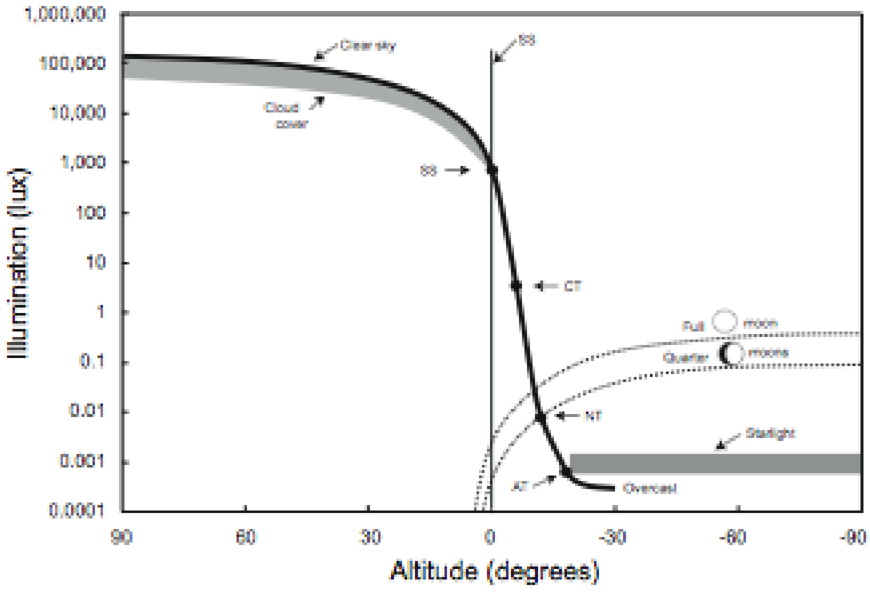

Figure 2. Natural illumination during the day, sunset, and at night (Beier 2006). Illumination in log nits on the y-axis, x-axis shows altitude above the horizon for the sun and moon. SS = sunset, CT= civil twilight, NT = nautical twilight, AT = astronomical twilight. Reprinted with permission.

Light is a critical component in the natural rhythms of nearly all living organisms. Life evolved with predictable daily, monthly, and seasonal patterns of light and dark. Artificial light has long been known to affect these patterns: Aristotle’s moths drawn to a flame, fire used to defend against predators large and small. Concern about adverse effects of lighting dates to descriptions of the “destruction” of birds at lighthouses in the late 1800s (Allen 1880) and even the first electric urban lighting (Kumlien 1888). Mortality of hatchling sea turtles at lights was identified as a conservation issues in the 1960s (McFarlane 1963). Verheijen coined the term “photopollution” in 1985 (Verheijen 1985), which was followed by Ken Frank’s classic review of the effects of lighting on moths (Frank 1988), and a series of unpublished reports (Outen 1998), conference proceedings (Schmiedel 2001), and research reports from Europe (De Molenaar et al. 2000, Kolligs 2000). We described the adverse effects of lighting as “ecological light pollution” (Longcore and Rich 2004) and released the edited book *Ecological Consequences of Artificial Night Lighting* in 2006 (Rich and Longcore 2006).

Reviews of the effects of artificial night lighting on different taxonomic groups can be found in Rich and Longcore (2006). Managers dealing with questions about specific plants or animals should consult this text, which contains chapters on mammals, birds, reptiles and amphibians, fishes, invertebrates, and plants. Taxon-specific information is essential to devise lighting systems that minimize impacts on sensitive species when lighting is necessary.

In the sections that follow, we present short reviews of the recorded and potential effects of artificial night lighting in different habitat types, highlighting research conducted in these systems that has relevance to other similar habitats. These habitats are: dune and shorelines, deserts and scrublands, wetlands, islands and oceans, grasslands, forests, alpine and tundra, and urban environments.

1.2 Dunes, Beaches, and Shorelines

Dunes and beaches are generally open environments with low vegetation that is adapted to moving sand. Because they present unique environmental conditions that are often quite distinct from their surroundings, dunes are often populated by endemic species adapted to these conditions. These species are often the focus of management concern because of the development pressure on coastal ecosystems in the United States and their increasingly imperiled status (Schlacher et al. 2007b). Dunes are also often the focus of interaction with lakes and oceans; light from development in coastal dunes illuminates adjacent waterbodies, and species such as sea turtles use sandy beaches for nesting.

Low vegetation allows light to spread across dune environments where topography is low. Sky-glow from coastal development increases ambient illumination in many dune environments (Salmon 2006). Many dune and beach species are active at nighttime. Many shorebirds forage at night (Dugan 1981, Burger and Gochfeld 1991), which has been attributed to increased invertebrate activity at night (Dugan 1981). Small mammals, snakes, and other prey species also forage predominately at night (see e.g., Bird et al. 2004).

As a general rule, additional light, whether moonlight or artificial light, increases foraging efficiency of predators and reduces activity of prey (Longcore and Rich 2004, Rich and Longcore 2006, Seligmann et al. 2007). This phenomenon has been shown many times in different habitats. On dunes, Bird et al. (2004) investigated the effects of lighting on foraging behavior of beach mice. Bird et al. used low pressure sodium lights and “bug” lights, which are commonly employed on beaches in Florida because they do not disorient sea turtle hatchlings. They found that foraging by beach mice was significantly decreased in proximity of both types of turtle friendly lights. Similar behavior by prey species has been shown for both natural and artificial light. For example, Ghost crabs active only at night, and avoid activity under both the full moon (Schlacher et al. 2007a) and artificial light (Christoffers III 1986).

Artificial lighting has dramatically adverse consequences for sea turtles. Female sea turtles avoid beaches that are lit as nest sites and hatchings are fatally affected by lights visible from beaches (Salmon 2003, 2006). This phenomenon was first recorded by MacFarlane (1963) and aversion of females to lights was confirmed experimentally by Witherington (1992). Habitat degradation by lights is caused both by lights adjacent to dunes and beaches and by regional sky glow (Salmon 2006).

Effects from lights on beaches and shorelines may also affect aquatic ecosystems. For example, the predator-prey dynamics of fish and marine mammals are affected by lights (Hobson 1965, Hobson et al. 1981, Yurk and Trites 2000, Nightingale et al. 2006). In general, additional light provides benefits for predators, except when their prey are schooling species, in which case the predator defense mechanism of a school is enhanced (Nightingale et al. 2006).

Shorebirds sometimes forage at night (Rohweder and Baverstock 1996), probably as a defense against predation (Robert et al. 1989, McNeil et al. 1992, Thibault and McNeil 1994) and slightly higher invertebrate activity on beaches at night (Evans 1987). Predator defenses of shorebirds are different during the night compared to the day; in an observational study some proportion of dunlins freeze and limit vocalizations as a defense at night while all individuals in a flock fly away in response to predators during the day (Mouritzen 1992). Owls are the major nocturnal predator of shorebirds and are aided by additional light when foraging (Clarke 1983).

Artificial night lighting on dunes and beaches can therefore have a variety of adverse effects on species and habitats. Predator-prey relations are disrupted and key reproductive behaviors can be inhibited. Beaches and dunes also provide the gateway to adjacent water bodies, which have no barriers to block the propagation of light. Because there is usually less light pollution offshore, park visitors often use beaches and dunes to gaze at the night sky. Beaches and dunes should be kept as free from the influence of artificial lights as possible, with special attention paid to ensuring negligible increases in overall illumination and that no lights are visible from the beach and points offshore as glare.

1.3 Deserts and Scrublands

Deserts and scrublands are open habitats with few barriers to the spread of light. Furthermore, in hot deserts and many scrublands, many animals are nocturnal to conserve water and avoid day-time temperature maxima. Consequently, artificial night lighting has the potential to dramatically change the ecology of these environments by disrupting the natural patterns of light and darkness used by a large proportion of the fauna.

Desert animals can have very particular preferences for illumination levels. These preferences may be related to particular foraging opportunities, predation risk, or physiological requirements. For example *Leucorchestris arenicola*, a trapdoor spider endemic to the Namib desert, exhibits extremely nocturnal activity patterns (Nørgaard et al. 2006). Males are active only during really dark moonless nights, when they are able to navigate hundreds of meters across dune environments using starlight alone (Nørgaard et al. 2006). For a species such as this, which is never active before the end of civil twilight, addition of illumination from any source in its habitat would likely eliminate the species.

Desert rodents also exhibit specific illumination preferences to manage their risk of becoming prey (Grigione and Mrykalo 2004, Beier 2006). Some species are active at twilight, others after twilight, and some during the darkest periods during moonless nights (Grigione and Mrykalo 2004). Artificial light can disrupt these patterns, even the light from a camp lantern equivalent to a quarter moon was sufficient to substantially inhibit foraging by a suite of rodent species (Kotler 1984). Those species vulnerable to this disruption lack other predator avoidance abilities such as exceptional hearing (Kotler 1984, Kotler 1985). Because of the well-documented lunar patterns in activities of many desert animals, especially predaceous arthropods such as scorpions (Skutelsky 1996, Tigar and Osborne 1999) and granivorous small mammals (Price et al. 1984, Daly et al. 1992), any artificial light that produces light equivalent to even a quarter moon can alter these patterns.

Scrubland environments share many characteristics with deserts, especially in Mediterranean climates. Many species are nocturnal and the open vegetation structure of drier scrublands allows for light to propagate.

Perry and Fisher (2006) describe the decline of nocturnal snake species in the scrublands of southern California. Long-nosed snake, a nocturnal species, showed a pattern of decline consistent with the gradient of light pollution (Fisher and Case, unpub. data). Otherwise suitable scrub habitats, which supported other diurnal species of snakes, lacked long-nosed snake. Presumably increased predation risk (from owls) or decreased activity in the snakes small-mammal prey was responsible for the decline (Perry and Fisher 2006).

1.4 Wetlands

In some places, wetlands and lakes are the last refuges of night on the landscape. The difficulty of developing wetlands often leaves them as the only remaining unlighted sites in urban and suburban regions. The evidence is strong that many aquatic organisms depend on daily cycles of light and dark. Furthermore, artificial lights disrupt critical behaviors in many species (Moore et al. 2006).

Aquatic invertebrates are important components of wetland ecosystems and provide an example of the sensitivity of wetlands to lighting levels. Many aquatic invertebrates migrate up and down in wetlands during the course of a night and day. This “diel vertical migration” presumably results from a need to avoid predation during lighted conditions, so many zooplankton forage near water surfaces only during dark conditions. Light dimmer than that of a half moon ($<10^{-1}$ lux) is sufficient to influence the vertical distribution of aquatic invertebrates, and indeed diel vertical migration follows a lunar cycle. When constant light from human development is added to the natural nocturnal illumination of the moon and stars, the darkest conditions are never experienced, and the magnitude of diel migrations (both range of vertical movement and number of individuals migrating) is decreased. The effect of artificial light on the diel migration of zooplankton has been shown experimentally using *Daphnia* as a study animal (Moore et al. 2000). Moore et al. also showed that the amount of light incident on lakes from sky glow is sufficiently large to affect aquatic invertebrates. Disruption of diel vertical migration by artificial lighting may have significant detrimental effects on ecosystem health. Moore et al. conclude that “[decreases in] vertical migration of lake grazers may contribute to enhanced concentrations of algae in both urban lakes and coastal waters. This condition, in turn, often results in deterioration of water quality (i.e. low dissolved oxygen, toxicity, and odor problems).”

Amphibians found in nearshore and wetland habitats also are particularly vulnerable to artificial light. Amphibians are highly sensitive to light to light and can perceive increases in illumination that are impossible for humans to detect (Hailman and Jaeger 1975). A rapid increase in illumination causes a temporary reduction in visual acuity, from which the recovery time may be minutes to hours (Buchanan 1993, Buchanan 2006). In this manner a simple flash of headlights can arrest activity of a frog for hours. Amphibians are also sensitive to changes in ambient illumination from sky glow. Frogs in an experimental enclosure ceased mating activity during night football games when lights from a nearby stadium increased sky glow (Buchanan 2006). In an experiment to invetigate the effects of intermittent artificial light, male green frogs called less and moved more when exposed to the light of a handheld flashlight (Baker and Richardson 2006)

In natural communities some amphibians will forage only at extremely low light levels, and foraging times are partitioned among species with different lighting level preferences (Jaeger and Hailman 1976). The squirrel treefrog (*Hyla squirrela*) orients and forages at lighting levels as low as 10^{-6} lux and stops foraging at illumination above 10^{-3} lux (Buchanan 1998). The western toad (*Bufo boreas*) forages only at illuminations between 10^{-1} and 10^{-5} lux, while the tailed frog (*Ascaphus truei*) forages only during the darkest part of the night below 10^{-5} lux (Hailman 1984).

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decompressor
are needed to see this picture.

QuickTime™ and a
decompressor
are needed to see this picture.

Figure 3. These two tadpoles are of the same age kept in 12:12 L:D. A was kept in the equivalent of very dark night (0.0001 lux) in the dark phase, while B was exposed to artificially bright illumination in the dark phase and is not yet metamorphosing (Wise 2007).

Laboratory experiments indicate that the development of amphibians is influenced by artificial light (Wise and Buchanan 2006, Wise 2007). Light interferes with the production of the hormone melatonin, which is involved in regulating many important functions, including sexual functions, thermoregulation, adaptation of eyes to the dark, and skin coloration (Wise and Buchanan 2006, Wise 2007). Current research shows artificial lighting slows larval amphibian development in the laboratory (Figure 2). The influence of artificial lighting on such physiological processes in the field is currently unknown, but the potential for lighting to harm amphibians and other wetland species is evident.

1.5 Islands, Oceans, and Reefs

Light propagates unimpeded across open water, and its reach is extended beyond the curvature of the Earth by fog and clouds. Island, ocean, and reef environments are affected by a range of artificial light sources that range from light-induced fisheries, to urban skyglow to offshore hydrocarbon facilities.

In 1999, Xantus's murrelets (*Synthliboramphus hypoleucus*) nesting on Santa Barbara Island off the coast of southern California were dying at twice the average annual rate. Park managers suspected the recent increase in fishing boats equipped with dusk to dawn floodlights to attract squid. Squid boats typically have 30,000 watts of light, per boat. If pointed upward, this amount of light would be visible from the moon with the naked eye. The number of squid boats increased dramatically in the 1990s, and in 1999 intense squid fishing occurred during murrelet nesting season (spring, while previous fishing was during fall and winter), and near important murrelet breeding islands. The mangers believed that the nesting seabirds, without the safety of darkness, were subject to increased predation from predators, especially barn owls (*Tyto alba*). Indeed, during the 1999 season an unprecedented 165 dead Xantus's murrelets were found on Santa Barbara Island. Most of the dead were killed by barn owls, while five were victims of western gulls (*Larus occidentalis*). Researchers also recorded high nest abandonment closest to the most intensive squid boat activity. Faced with these observations, NPS managers put the areas around the islands off limits to squid fishing, and death rates for the birds returned to normal. The excluded areas were subsequently incorporated into a permanent marine preserve with no fishing allowed to allow for replenishment of fish stocks. Also, the California Fish and Game

Commission listed Xantus’s murrelet under the California Endangered Species Act, citing artificial light lighting as one of the major threats to the species.

Nearly all seabirds are nocturnal, and an adverse response to decidedly unnatural conditions such as that suffered by Xantus’s murrelets should not be surprising (Montevecchi 2006). Years of studies have shown that nocturnal seabirds are less active during moonlit nights, and those that are active suffer more predation during those times. Seabirds are attracted to lights; they naturally cue in on bioluminescent plankton to find prey (Montevecchi 2006). They have therefore long suffered from collisions with lights in and adjacent to the ocean — lighthouses, cruise ships, fishing vessels, lighted buoys, and oil derricks. All of these may be major cumulative sources of mortality for oceangoing species. Where lights correspond with feeding or breeding areas, or migratory routes, lights at sea have the potential to tip the scales against bird species already suffering from centuries of human insults.

Other sources of artificial light threaten the nighttime environment of the oceans. Cruise ships are becoming more common, and are often brightly illuminated. Ships in the path of bird migrations, or near undersea food sources may attract both migratory birds and foraging sea birds, which collide and are stunned or die. Anecdotal accounts have emerged where cruise ship staff frantically work to clear the decks of dead birds before passengers awake in the morning. Offshore oil platforms are also significant sources of light, and attract and kill birds through collision, exhaustion, and even incineration in flares burning off natural gas. Many of these birds are long distance migrants, and the losses at oil platforms may affect regional and global breeding populations.

Coral reefs are also threatened by artificial night lighting. Lighting has been used as a proxy for other impacts (urban development, intense fishing, hydrocarbon extraction) to assess risk to coral reefs on a global scale (Aubrecht et al. 2008). We also illustrated how artificial lighting would adversely impact reefs directly and repeat that summary here (Aubrecht et al. 2008).

> Corals are highly photosensitive; many species synchronize their spawning through detection of low light intensity from moonlight (Jokiel et al. 1985, Gorbunov and Falkowski 2002) and coral reef structure is strongly influenced by illumination (Wellington 1982). Seaweeds in coral reefs, signaled by lighting levels, can grow at night to reduce herbivory (Hay et al. 1988). Many coral reef anthozoans (e.g., corals, gorgonians, sea anemones, sea pens) expand and contract on a daily basis to conserve nutrients (Sebens and DeRiemer 1977, Levy et al. 2001). Other marine invertebrates in coral communities synchronize reproduction by monthly patterns of lunar illumination (Bentley et al. 2001).
>
> Zooplankton in coral reefs undergo diel vertical migration upwards at night to forage and downwards at dawn to avoid predation (Yahel et al. 2005b, Yahel et al. 2005a). Planktivorous coral reef fish also exhibit diel vertical migration (Leis 1986). For fish larvae, the direction and timing of these migrations differ between species and larvae age (Leis 1986). Such extensive structuring of this community by light is undoubtedly disrupted by artificial lighting, which has no ecological analog — moonlight, starlight, and bioluminescence are the only sources of light to which marine organisms are adapted (Hobson et al. 1981).

The synchrony of coral spawning breaks down under artificially simulated continuous full moon conditions (Jokiel et al. 1985). Because corals can detect illumination in the ranges caused by the moon, they are sensitive to even minor increases in nocturnal illumination, especially in the shorter wavelengths (Gorbunov and Falkowski 2002). Streetlights and other dim photopollution are sufficient to disrupt the spawning cycles of polychaete worms (Clark and Hess 1940, Hauenschild 1960, Franke 1990, 1999).

Just as the diel vertical migration of zooplankton has been shown in freshwater systems to be suppressed by sky glow from distant cities (Moore et al. 2000, Moore et al. 2006), Zooplankton in coral reef communities are almost certainly similarly affected, which would influence overall community structure (Wellington 1982, Yahel et al. 2005a).

Many coral reef fish are highly phototropic (Choat et al. 1993) and lights can be used to attract fish to new reefs (Munday et al. 1998). Introduction of light to these environments would alter natural distribution patterns. Furthermore, some species are nocturnal specialists that forage efficiently in the dark (Holzman and Genin 2003, 2005) and could be adversely affected by increased lighting. Settlement of coral reefs by larvae of some species of fish is maximized at night and during the new moon. Increased settlement under dark conditions is interpreted to be a mechanism to minimize predation (Victor 1986, Kingsford 2001).

The central importance of light regimes to marine life, and the apparent ease with which behaviors linked to light can be disrupted should be a cause of concern for park managers of these ecosystems.

1.6 Grasslands

Like other open habitats, light has few barriers in grasslands. Lights can thereby influence both illumination and direct glare over hundreds of meters or more, depending on topography. Artificial night lighting can be expected to influence habitat use and behavior of grassland species.

The lights of a road bisecting wet grassland in the Netherlands were shown to influence the spatial distribution of a rare ground-nesting bird (Black-tailed Godwit) (De Molenaar et al. 2000, De Molenaar et al. 2006). Turning road lights for a breeding season on caused birds to nest slightly farther away from the road, with the effect extending 300 m from the lights. Birds that arrived first to the breeding area, nested farther from the lights while those arriving later nested closer (De Molenaar et al. 2000, De Molenaar et al. 2006). The same research group investigated the behavior of mammals in wet grasslands and showed that some species (polecat, *Mustela putorius*, stout, *Mustela erminea*, weasel, *Mustela nivalis*, and fox, *Vulpes vulpes*) were more likely to take paths near lights, while other species were not influenced or preferred darker areas (De Molenaar et al. 2003). Such differences in habitat use have the potential to change predation rates and distribution of prey species as well (Lima 1998).

Fireflies are another example of grassland species that could be adversely affected by artificial night lighting (Lloyd 2006). Because light is used for firefly communication, both for sexual behavior and in some interspecific interactions (where females attract males of other species to capture and eat them), any disruption of the ability to see light will have adverse effects. Artificial light washes out the signals used for communication and potentially contributing to the decline of fireflies and other organisms that rely on bioluminescent communication (Lloyd 2006).

1.7 Deciduous and Evergreen Forests

Although the structural complexity of forests blocks light and reduces its propagation, species that inhabit the forest floor are sensitive to illumination at levels appropriate to the darker nighttime environment there. A review of the research on forest species shows some general patterns that illustrate the potential for lights to affect wildlife behavior.

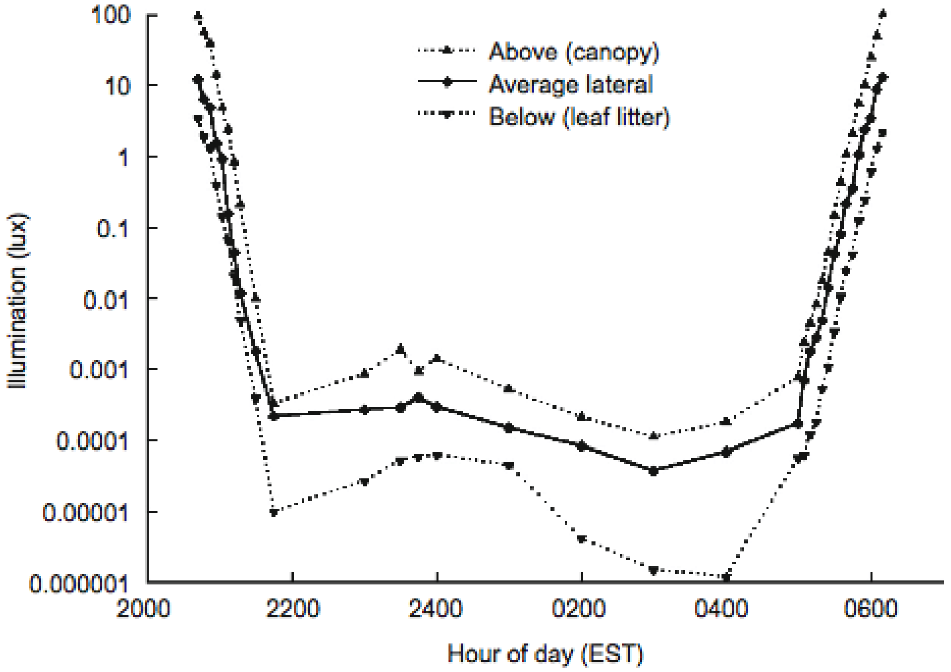

Figure 4. Illumination in deciduous forest (Buchanan 2006). Reprinted with permission.

As in many other ecosystems, salamanders in forests exhibit reactions to light equivalent to moonlight, under which foraging is reduced or delayed (Wise 2007). This has been shown experimentally with dim artificial lights installed in a forest environment (Wise 2007). In two different experiments lighting delayed the emergence time of nocturnal mammals (DeCoursey

1986, Barber-Meyer 2007) and reduced foraging activity (Barber-Meyer 2007). For sugar gliders, a nocturnal forest mammal native to Australian, light equivalent to street lighting (7–12 lux) reduced the time individuals were active at night (Barber-Meyer 2007).

In other instances, reproductive behavior can be affected. The leafcutting ant *Atta texana* usually undertake nuptial flights approximately 15 minutes before dawn but in instances where security lights from homes and businesses were visible, the colonies flew 15 minutes after dawn (Moser et al. 2004). The lights are also very attractive to the flying ants, which may decrease mating success and increase exposure to predation at the lights (Moser 2000).

1.8 Alpine and Tundra

National Parks have alpine and tundra habitats disproportionately represented. The are on average less developed than other habitat types but can and are used for visitor-serving facilities or may be sites for various types of infrastructure. Control of artificial lighting in these habitats is import to avoid disruptions of predator-prey relationship and potential influences on circannual rhythms.

As in other habitats, predator-prey relationships in alpine environments are mediated by illumination. For example, small species of rocky outcrops typical of alpine regions are often nocturnal, foraging in open areas at night and retreating to the safety of outcrops for shelter (Kramer and Birney 2001). In experimental conditions one such species foraged less under 1.5 and 3.0 lux treatments (up to bright moonlight) when compared to a 0 lux control (Kramer and Birney 2001). Similar results have been found for snowshoe hares (Gilbert and Boutin 1991), are subject to more predation under brighter nocturnal conditions, especially during the winter (Griffin et al. 2005). Such small mammals depend on natural darkness for foraging to keep up body weight (Vasquez 1994).

Circannual rhythms are found in most animals, but the environmental conditions that influence them are less well understood because of the long period necessary to conduct experimental research (Beier 2006). For research that has been completed, light appears to have a large influence in setting these cycles, although temperature is also important (Beier 2006). Light can be important in determining when species react to the seasons (e.g., hibernation, Hock 1955) and consequently disrupting these signals has the potential to put species out of phase with climate. In alpine and tundra environments where conditions change so dramatically between the seasons, appropriate synchronization of activities is important.

1.9 Urban Environments

Even though urban environments have many sources of artificial light at night, variations within this already light-polluted environment still make a difference to wildlife. For example, American crows choose roost sites in urban areas that are on average more brightly illuminated than non-roost sites (Gorenzel and Salmon 1995). Presumably, this allows the communal predator response behaviors of the flock to operate more efficiently, reducing predation from owls. Elevated populations of this native species has adverse consequences for other native species for which the crows are predators. In another example, urban-tolerant bat species are influenced by the degree of illumination on the exit hole of their roosts. Nightly emergence is delayed by illumination of the exit hole which reduces fitness of individuals in the colony and can indeed eliminate the colony altogether (Boldogh et al. 2007). Because of the importance of bats as consumers of insects, and their conservation status, such adverse impacts are of grave concern.

Figure 5. Townsend's Big-eared bats (*Corynorhinus townsendii*) on Santa Cruz Island. This roost could be imperiled if the exterior of this building were to be illuminated.

Cities are also sites for mortality of nocturnally migrating birds, which are attracted to lights. They die either in collisions with buildings at night or during the day when they attempt to regain their orientation and continue migration. This phenomenon is well documented in Chicago, Toronto, New York, and Washington, D.C. A notable example in a national park is the ongoing mortality of nocturnal migrant birds killed at the Washington Monument, starting when it was illuminated (Overing 1938).

The profusion of light in urban areas also has spillover effects on surrounding natural areas and opens species within cities. For example extremely high levels of ambient light are measured in the Santa Monica Mountains National Recreation Area in Los Angeles. Although it is difficult to address the multitude of sources of such lights, it is worthwhile for parks to incorporate lighting and the night sky as part of their education, outreach, and community engagement in such areas.

The evidence from across habitat types indicates that artificial lighting at night is either proven to, or has the potential to, disrupt the natural behavior of wildlife species, sometimes with lethal consequences. From this context we can identify practices that can reduce and minimize the effects of lighting in our national park units.

2 Best Management Practices for Lighting in National Parks

Knowledge about the effects of lighting on wildlife is growing. All indications are that lighting can have cumulative and additive consequences, which could be especially important for vulnerable species. Although there are general trends in the effects of light on wildlife, the wide range of different reactions by species to lighting types means that mitigation strategies must be based on the characteristics of target species. In the following two sections, the considerations for developing such mitigation measures are considered. First we discuss the attributes of light that might be manipulated — spectrum, intensity, direction, and duration — and how different groups of species might be affected by them. Then we review the many contexts in which light is used (e.g., security lighting, vanity lighting, communication towers, etc.) and identify preferable mitigation strategies for them.

2.1 Lighting Characteristics

Four characteristics of lighting can be manipulated to reduce the impacts to wildlife: spectrum, intensity, direction, and duration. For some of these characteristics, a single recommendation applies in all instances. For others, the recommendation depends upon the context of use or the species that might be affected.

2.1.1 Spectrum

It is tempting to believe that a certain spectrum of light will be a "silver bullet" that minimizes the impact of lighting in all situations. Unfortunately, no one-size-fits-all solution exists. Rather, it is possible to identify spectra of light that have shown to affect wildlife less in certain contexts.

One general rule is to avoid any light that has any emission in the ultraviolet spectrum and nearby short wavelengths. Ultraviolet light is not visible to humans and should be avoided entirely because it is visible to other species. Insects are highly attracted to ultraviolet light and their attraction and mass death at lights would be dramatically reduced by eliminating ultraviolet light from use (Frank 1988, Eisenbeis and Hassel 2000, Eisenbeis 2006, Frank 2006). Mercury vapor lamps are high in ultraviolet radiation, while other commonly used outdoor lamps have some ultraviolet as well (e.g., metal halide, fluorescent). Insects are attracted to light in the short wavelengths (e.g., blue) as well, so so-called full-spectrum lighting that allows good color rendering for human vision, is not advisable from the standpoint of ecological effects. All lights heavy in the blue spectrum, such as fluorescent and metal halide lights, and full-spectrum LED lights, will have greater impacts on insects than lights with longer wavelengths (e.g., low pressure sodium vapor and even high pressure sodium vapor). This also reduces impacts on bats by avoiding the competitive advantage given by lights to bats that forage at them (Rydell 2006).

Blue light is the most biologically active for physiological processes such as the production of hormones and the circadian clock and consequently is of significant concern in that respect (Beier 2006). This concern has been best expressed relative to human health (Pauley 2004), but blue light is also important to wildlife. To minimize disruption to circadian rhythms, shorter wavelengths such as blue and violet should be avoided. They might also be avoided to minimize influence on species that are phototactic to blue light. Many frog species have a "blue light preference" whereby they move toward blue light preferentially, presumably as an escape mechanism that leads them away from vegetation (and into water) in times of danger (Hailman and Jaeger 1974, Buchanan 2006) although these preferences can vary depending on the intensity of illumination (Buchanan 2006).

Figure 6. Green light designed to minimize attraction of birds developed by Philips. Shell is using this light on a new oil platform in Alaska and Philips is adding the lights to their regular catalog. These lights elminate the red and yellow light associated with

disorientation of birds under experimental conditions. Photograph courtesy of Joop Marquenie.

For birds, illumination by monochromatic blue or green light does not affect magnetic orientation, while such navigational ability is disrupted by light from longer wavelengths (red and yellow). For this reason, Dutch researchers have been experimenting with the use of specially designed lamps that contain blue and green light on coastal locations and on offshore platforms to see if the number of attracted and disoriented birds is decreased (van de Laar 2007, Poot et al. in review). Preliminary results show blue and green lights influence birds less than red and full-spectrum (white) light, although the effects on other species has not been research.

Light that includes longer wavelengths appears to be preferable in that it attracts few insects and does not disrupt orientation of sea turtle hatchlings. For this reason, yellow lights are commonly identified as wildlife-friendly. However, these same lights reduce the foraging activity of native beach mice (some species of which are endangered) along the Florida coastlines where turtle-friendly lighting is recommended (Bird et al. 2004). Fireflies are vulnerable to impacts from yellow light because it is this part of the spectrum that is used by species flying after dusk (Lloyd 2006).

Red light appears to disrupt the orientation capabilities of birds, but it seems to have the least effect on other species. Few insects are attracted to red light and dark-adapted eyes are not bleached by red light, making it the spectrum of choice for stargazers. In low-light environments in national parks, red light might be preferable where lights are needed for safety reasons (Figure 6).

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decompressor
are needed to see this picture.

QuickTime™ and a
decompressor
are needed to see this picture.

Figure 7. Illumination of a stairway with two 4-W red bulbs instead of by a bright white spotlight (Wagner et al. undated).

2.1.2 Intensity

Land and facility managers have great latitude on the intensity and quantity of lighting used. From a wildlife perspective, discretion should be exercised to only use the absolute minimum amount of light for the required purpose when absolutely necessary. This can be accomplished by drastically decreasing the luminous output commonly used by lighting designers. Land managers should not rely on standards promulgated by professional societies to guide lighting levels for natural areas. Rather, every effort should be made to reduce the intensity of lights and still achieve the desired function.

Reduction in lighting intensity benefits species in the vicinity of lighting, but also greatly reduces the reflection of light in the atmosphere. The glow of lighted areas can thereby be reduced, reducing impacts to natural systems and park visitor experience in wildlands. Often illumination levels can be reduced without adverse consequence. In fact, reducing the contrast between light and dark areas actually increases the ability of humans to see. The human eye adapts to the brightest light in view. As the eye adapts to bright lights, acuity in darker areas is lost. Bright lights plunge the surrounding areas into darkness, while with dimmer lights the eye is able to retain some of its ability to see in darker areas.

2.1.3 Direction

Shielding lights is a common mitigation measure to reduce impacts to natural lands and species. Usually this involves shielding the lights so that little or no light is emitted above the horizontal plane, and less than 10% of the light is emitted within 10 degrees below the horizontal plane, which is “full cut-off” lighting. Shielding in this manner greatly reduces (but does not eliminate) sky glow. Light still reflects and scatters, so reduction in intensity should be combined with shielding to address sky glow. Downward directed lights may also have adverse ecological consequences. They still attract insects and species that feed on the insects (bats, frogs, birds). They may be directed downward into sensitive habitats such as wetlands and rivers even if they are full cut-off.

Managers of natural lands should endeavor to shield lights beyond the conventional understanding of full cut-off, to ensure that light falls only on the intended surfaces. This will minimize direct glare, which can affect the orientation of organisms across distances (Longcore and Rich 2004) as well as minimizing the area that is artificially illuminated.

Figure 8. A full cut-off shield being installed on an existing light on the lodge at Yellowstone National Park. This previously unshielded light was visible across the lake and from the backcountry.

2.1.4 Duration

Impacts from lighting can be reduced by changing the duration of illumination. This approach reduces some impacts but it may have some adverse consequences and so should be implemented with these limitations in mind. For example, one common way to reduce the time a light is on is to install a motion detector so that it is only illuminated when there is activity in a particular area. Lights that go on and off at irregular intervals may disrupt the nocturnal behavior of some species. In particular, green frogs reduce calling behavior and move when a light is shined on them (Baker and Richardson 2006) and return to a dark-adapted state can take hours in frogs (Buchanan 2006). So this might not be an appropriate choice next to a wetland.

Another restriction on duration is setting a time for lights to be extinguished each night. For example, the lights that illuminate Mount Rushmore are only on for a few hours each night. This approach reduces impacts by allowing darkness during the late night and early morning hours. If the lights are on during dusk, however, it may eliminate specific lighting conditions required by species. Rather than a smooth range of illumination conditions occurring as the sun goes down and darkness falls, sites will experience a single illumination level until the lights are turned off. Many groups of species share resources across lighting levels; that is, one species may forage at dusk, another right after dusk, and another in the dark of night (Hailman 1984). Increased illumination, even on a temporary basis, reduces the time available for critical behaviors and could eliminate it altogether if the species prefers the transitional lighting levels of dusk when lights are illuminated. If artificial lighting eliminates a significant period of potential breeding time for a species, the long-term consequences will be negative.

Reduction of lighting after activity is completed is, however, superior to leaving it on. The Dutch government has done this with roadway lighting through wet grassland habitat. Roadway lighting is turned off at 11 p.m. and replaced with 7-Watt incandescent bulbs halfway up the light standards (De Molenaar et al. 2006). These lights allow for wayfinding and have not changed the number of accidents occurring on the road.

2.2 Lighting Situations

In addition to considering spectrum, intensity, direction, and duration, mitigation measures can be devised for many different situations in which lighting might be installed in National Parks.

In the sections that follow, we discuss the issues involved with mitigating impacts from a series of different situations that might be faced by a park manager.

2.2.1 Communication towers

All towers that are greater than 200 feet tall must have obstruction lighting in accordance with Federal Avian Administration guidelines. Lighting is a primary factor resulting in the attraction and mortality of nocturnal migrants at towers. Review of previous work (Longcore et al. 2008) and recent studies (Gehring and Kerlinger 2007) have shown that mortality can be reduced by using a lighting system that has flashing lights only, whether these are strobe lights or red-flashing lights. White strobe lights are already approved as lighting on towers and the FAA is considering allowing red flashing lights. It is also important that towers do not have ground-level lighting around them because these lights could attract birds that then collide with tower guy wires (Longcore et al. 2008).

2.2.2 Night hikes and biking

Night hikes and night mountain biking have become popular activities in natural areas. The lights used in these activities, especially mountain biking, have become brighter in recent years. For examples, websites advertise full-spectrum LED lights that emit 720 lumens (approximately the same as a 60-Watt incandescent bulb) and bikers often use multiple lights. Activities such as these expose wildlife to unnatural disturbance at night, this affects behaviors both because of the disturbance itself and because of the potential bleaching of eye pigments (“blinding”) from which recovery time can take minutes to hours.

Managers can mitigate the impacts of night hiking and biking through a number of methods. These include:

1. Restrict the time of month when illuminated nocturnal recreation is allowed to ten days surrounding the full moon. In this manner animals are allowed the darkest part of the month as a refuge from disturbance.
2. Restrict the spectrum of lights used in outdoor nocturnal recreation. Red lights would be most preferable because of the limited effect these have on dark-adapted vision.
3. Restrict the total luminous intensity of lights used in these activities (e.g., 40 lumens per participant).
4. Set curfews for illuminated nocturnal recreation.
5. Restrict nocturnal recreation activities to areas that are already disturbed by night lighting, leaving more remote wildland areas protected from nocturnal disturbance.

2.2.3 Campsites

Although "traditional" camping with firelight and flashlights is certainly still a popular activity, more and brighter portable lights are being brought to campsites. Large arrays of lights are readily available and increasingly used by campers. Such lights can degrade the nighttime camping experience for other campers and certainly would have greater impacts on wildlife than a campfire or small personal flashlight. Park managers might consider establishing guidelines for nighttime lighting at campsites, including limits on overall illumination, lighting curfews, and recommendations for use of flashlights instead of area lighting. In especially dark areas, managers could recommend the use of red filters on flashlights. Such actions should be paired with minimizing lighting from the existing infrastructure (e.g., converting lights on bathrooms to low wattage red).

2.2.4 Monuments

Parks with cultural monuments face the challenge of needing to balance the impacts of lighting against the significance of the monument. For example, the Washington Monument (Figure 8) is bathed in white light and known to attract and kill migratory birds. Because the Washington Monument has been illuminated at night since the 1930s and is so powerfully symbolic of Washington, D.C., it is not feasible to propose elimination of lighting. Limitation on the hours of illumination is probably the best management action in such situations.

Figure 9. The Washington Monument stands out because lighting in the surrounding area has been kept low. The tower attracts nocturnally migrating birds, but this effect is minimized by the hours of operation.

2.2.5 Light-induced fisheries

Offshore lighting poses threats both to aquatic and terrestrial ecosystems. Light has a long history of use as a method to attract fish for capture. In artisanal fisheries, dim lamps may be used on small human-powered boats. Current industrial scale fisheries, however, use extremely bright lights (equivalent of 30,000 Watts incandescent) to attract squid and other fish. Even boats that do not use lights to attract their catch operate during the night and are highly illuminated. Illumination in this manner affect behavior of fishes (Nightingale et al. 2006) and other aquatic organisms (Forsythe et al. 2004). It is implicated in the mortality of seabirds in fisheries (Dick and Donaldson 1978, Carter et al. 2000). Spillover light on seabird nesting colonies has the potential to increase predation on vulnerable species (Keitt et al. 2004). As discussed above, park managers should take action to reduce such fishing activity near sensitive island habitats and in marine protected areas. A range of options are possible to do so, including outright bans, limiting light-induced fishing by phase of the moon (to times around the full moon), and limiting total luminance allowed in protected waters.

2.2.6 “Security lighting”

Managers are often faced with pressure to install “security” lighting in hopes of decreasing illegal activity. The evidence that increased illumination reduces crime is equivocal at best (Tien et al. 1977, Sherman et al. 1997). Lighting may be effective in crime reduction in some places and counterproductive in others. Many schools now use a “dark campus” approach, wherein all lights are extinguished at a certain hour. Lights seen after this time are then quickly recognized as unauthorized activity. Schools implementing such programs usually see a decrease in property crime such as graffiti. Park managers should think very carefully about installation of any dusk-to-dawn “security” lighting. It has very little chance of being effective if no staff are on site to observe the location and complete darkness at night for areas that are off-limits and unoccupied is almost always preferable.

2.2.7 Bridges

Bridges can introduce artificial lighting into natural areas through roadway lighting for safety or through architectural lighting (Figure 1). Both of these have the potential to disrupt natural habitats. For example, harbor seals used the lights on the Puntledge Bridge in British Columbia to form a "feeding line" and intercept outmigrating juvenile salmonid smolts (Yurk and Trites 2000). Extinguishing these lights led to a decrease in salmon mortality. Other studies document increased predation on fish under on bridges and docks (Nightingale et al. 2006). For bridges with tall structures, illumination of these towers may result in attraction of migratory birds. Such lighting should be avoided to the maximum degree possible, so that obstruction lighting is limited to flashing red lights (if required by the FAA) and any roadway lighting is carefully directed onto the roadway with no spill into the river. Furthermore, use of yellow light is preferable under most circumstances to minimize the attraction of insects, although this step alone will not eliminate the effects of lighting on foraging behavior of mammals (Bird et al. 2004)

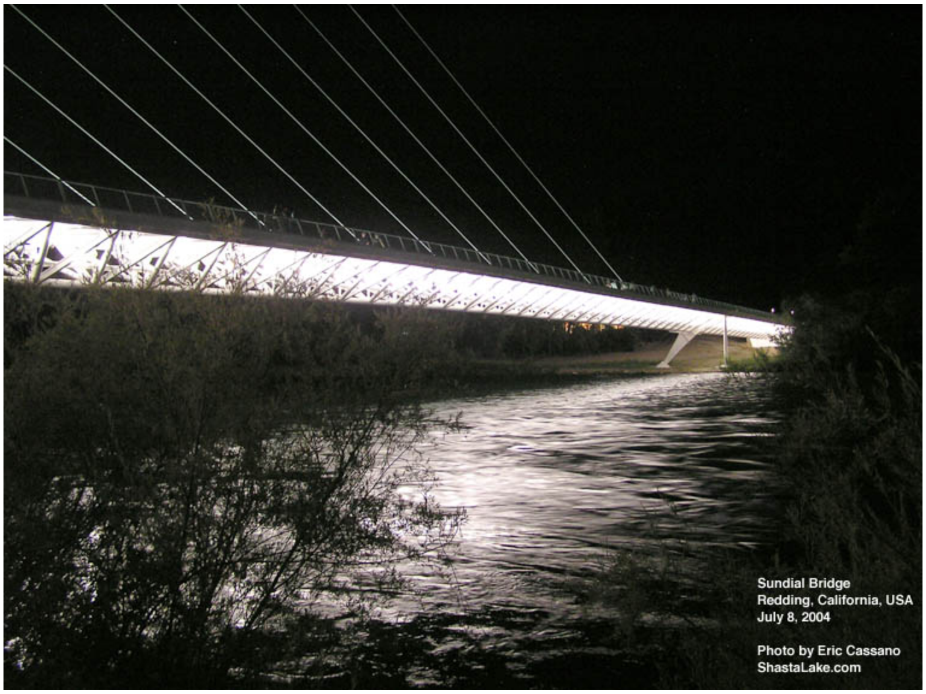

Figure 10. The Sundial Bridge over the Sacramento River is an example of trends in architectural lighting of bridges without concern for impacts to biological resources.

2.2.8 Roadway Lighting

Roadway lighting is a large source of outdoor illumination and contributes significantly to sky glow. Park managers must make the decision whether roadway lighting is necessary in the first place and if so, what characteristics it should have. Certainly there are limited circumstances in which continuous roadway lighting is desirable within natural areas of national parks. To minimize impacts on wildlife, street lighting should be avoided to the maximum degree possible. Where it is essential, fixtures should be full cut-off and directed and shielded to minimize glare from any non-road site, especially those areas with known sensitive species. The best overall choice for spectrum should probably be in the yellow (e.g., low pressure sodium) but technical considerations may lead to use of a broader spectrum (e.g., high pressure sodium).

Other alternatives are available to further reduce the impacts of street lighting. Embedded roadway lighting (Figure 11) has been investigated in Florida as a way to minimize impacts on nesting sea turtles (Bertolotti and Salmon 2005). Such lights may be useful in locations where snow plowing is not necessary and a sensitive species needs protection from lighting. Another alternative is the use of dynamic lighting systems that decrease illumination based on the time of day so that lights are extinguished by a certain time at night.

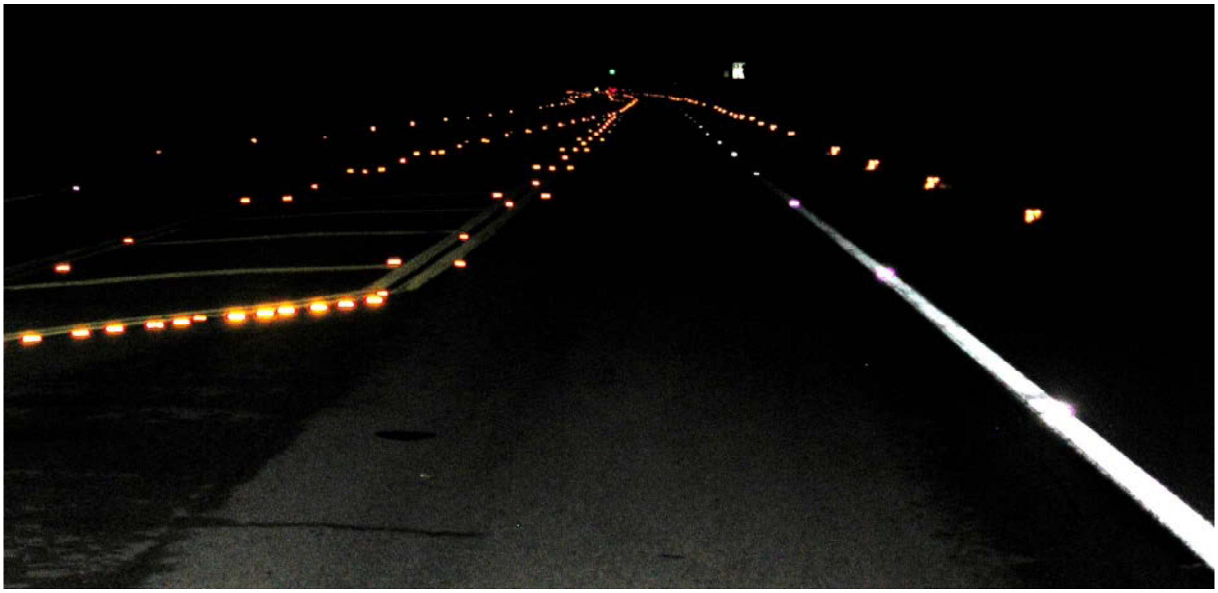

Figure 11. Embedded roadway lighting. These LED lights installed in the pavement are not visible to sea turtles nesting at the adjacent beach and are well-received by motorists and pedestrians (Bertolotti and Salmon 2005). Photograph courtesy of Michael Salmon.

2.2.9 Energy Installations

Efforts to increase domestic energy production have resulted in increased pressure to explore for fossil fuels and develop industrial scale facilities for wind and solar energy in rural locations throughout the country. These locations have the potential to affect natural resources on National Park Service properties that may be found intermixed with other public and private lands approved for such activities. The direct impacts of such activities are of great conservation concern, but are not discussed here. In the event that such facilities are reviewed in the environmental review process, the following recommendations could be made to minimize the impacts of artificial night lighting.

Wind turbines are illuminated with flashing red lights at the corners of the array of turbines. Not all turbines have obstruction lighting. Researchers documenting mortality of animals at wind turbines (both bats and birds) have concluded that these flashing lights do not attract birds, but rather constant illumination of structures on the ground is associated with increased bird mortality at nearby turbines (Kerlinger 2004). Wind turbines currently are estimated to kill 30,000–60,000 birds per year, with this number to grow thirtyfold in the next twenty years to meet federal goals for renewable energy. Ensuring that lighting is only red flashing with no steady-burning lights on any accessory structures would reduce mortality of nocturnal migrant birds, but would not mitigate the significant bat mortality that is associated with wind turbines (Kunz et al. 2007).

Solar arrays are proposed to be constructed in open desert areas in proximity to National Park units. There is no reason for such facilities to be illuminated at night with steady-burning lights. Should “security” lighting be desired, the recommendation should be made that it be fully shielded, low wattage, and on a motion detector.

Oil and natural gas facilities are notoriously for being brightly illuminated at night. This light can have adverse consequences for any habitat in which it is found. For example, offshore oil platforms attract seabirds, usually to their detriment (Wiese et al. 2001, Montevecchi 2006). Terestrial facilities are often the only sources of light in remote open spaces. National Parks can ask that these impacts be reduced through commenting in the environmental review process and working with existing facilities to retrofit lights. For marine facilities, some initially positive data have been collected that suggest that using a "green" light on an offshore platform reduces the number of birds that are attracted to it (van de Laar 2007, Poot et al. in review). These specially designed lights eliminate light in the red part of the spectrum, which has been suggested to be less attractive to birds. By retrofitting the platform from white lights to green lights, Dutch researchers documented a reduction in the number of birds observed circling a platform (van de Laar 2007). The cause of this reduction could have been the wavelength of light used, or an overall decrease in lighting intensity that was a byproduct of the lighting change. The research shows that decreasing illumination and restricting the spectrum of light to avoid the red is a promising method to reduce impacts to biological resources while still maintaining safe operations.

Recommendations about lighting in general apply to energy facilities — minimize wattage, shield lights from sky, off-site, and water, and use spectrum appropriate for environment (see above).

2.2.10 Interior Lights and Buildings

Although outdoor lighting is usually the focus of efforts to reduce impacts on wildlife, indoor lighting should also be considered. Indoor lighting may contribute substantially to ecological light pollution. In extreme example, greenhouses in Germany attract insects and migratory birds (Abt and Schultz 1995, Kolligs 2000). Furthermore, office buildings in urban cores can contribute as much to sky glow as billboards or roadway lighting (Oba et al. 2005). In darker environments, even the lights from a residence may have some effect on local wildlife behavior and affect the experience of natural areas. Managers can be aware of these issues and seek to shield interior lights through provision of curtains. This also gives an additional reason to cluster developments within parks. For urban areas and office buildings guidelines are available to minimize the effects on birds, including through steps to reduce interior illumination (New York City Audubon Society 2007).

2.2.11 Lighthouses

The fatal attraction of birds to lighthouses has been observed for over a century (Dutcher 1884, Miller 1897, Hansen 1954). In the United States, mortality of birds is more commonly reported on the east coast than on the west (Allen 1880, Merriam 1885), although mortality has been recorded on west coast as well (Squires and Hanson 1918). There has been some conflicting research on lighting color and flashing in the early 1900s (see review in Gauthreaux and Belser 2006), but the view is solidifying that mortality can be decreased through the use of a flashing rather than constant light (Baldwin 1965, Jones and Francis 2003, Gauthreaux and Belser 2006). It is important that the light itself flashes, extinguishing completely between flashes, rather than the flashing effect being created by a rotating beam that remains illuminated. Reduction in lighting intensity also reduces bird mortality (Jones and Francis 2003).

2.2.12 Billboards

Billboards and signage can affect wildlife behavior when illuminated. For example, light from a single billboard was sufficient to change the concealment behavior of juvenile salmon in a stream (Contor and Griffith 1995). While the significance of such behavioral changes is unknown, illumination of billboards and signs should be controlled to minimize cumulative effects of lighting on wildlife.

2.3 Examples of wildlife friendly lighting in National Parks

CM: I'd suggest we take a look at individual installations (maybe one building/pathway/whatever that has several lights installed and analyze the pros and cons. We have more examples from the field, and we are in the midst of conducting lighting retrofits in half a dozen parks

3 Elements of a Park Lighting Plan

CM: Finally, can we "pull this all together" and articulate the components of a lighting guideline that protects wildlife. Not necessarily write a full one (although I am working on that) but describe the elements of one?

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