

Effects of Coastal Lighting on Foraging Behavior of Beach Mice

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Abstract: *Introduction of artificial light into wildlife habitat represents a rapidly expanding form of human encroachment, particularly in coastal systems. Light pollution alters the behavior of sea turtles during nesting; therefore, long-wavelength lights—low-pressure sodium vapor and bug lights—that minimize impacts on turtles are required for beach lighting in Florida (U.S.A.). We investigated the effects of these two kinds of lights on the foraging behavior of Santa Rosa beach mice (*Peromyscus polionotus leucocephalus*). We compared patch use and giving-up densities of mice for experimental food patches established along a gradient of artificial light in the field. Mice exploited fewer food patches near both types of artificial light than in areas with little light and harvested fewer seeds within patches near bug lights. Our results show that artificial light affects the behavior of terrestrial species in coastal areas and that light pollution deserves greater consideration in conservation planning.*

Key Words: artificial illumination, foraging behavior, light pollution, *Peromyscus polionotus leucocephalus*, Santa Rosa beach mice

Efectos del Alumbrado Costero sobre el Comportamiento de Forrajeo de Ratones de Playa

Resumen: *La introducción de luz artificial al hábitat de vida silvestre representa una forma de intrusión humana que se expande rápidamente, particularmente en sistemas costeros. Durante la anidación, la polución por luz altera el comportamiento de tortugas marinas; por tanto, para la iluminación de playas en Florida (E. U. A) se requieren luces de longitud de onda larga - luces de vapor de sodio de baja presión y contra insectos - que minimizan impactos sobre las tortugas. Investigamos los efectos de estos dos tipos de luces sobre el comportamiento de forrajeo de ratones de playa de Santa Rosa (*Peromyscus polionotus leucocephalus*). Comparamos el uso de parches y las densidades de rendición de ratones en parches alimenticios experimentales establecidos a lo largo de un gradiente de luz artificial en el campo. Los ratones utilizaron menos parches de forrajeo cercanos a ambos tipos de luz artificial que en áreas con poca iluminación y cosecharon menos semillas en parches cercanos a luces contra insectos. Nuestros resultados muestran que la luz artificial afecta el comportamiento de especies terrestres en áreas costeras y que la polución por luz merece mayor consideración en la planificación de la conservación.*

Palabras Clave: comportamiento de forrajeo, iluminación artificial, polución por luz, ratones de playa (*Peromyscus polionotus leucocephalus*)

Introduction

Alteration of nighttime light levels by artificial illumination is a worldwide phenomenon and a rapidly expanding form of human encroachment on natural environments. Recent global-scale analyses of artificial sky brightness in-

dicates that almost 20% of the Earth's land area is subjected to light pollution, and in many countries light pollution affects 100% of the surface area (Cinzano et al. 2001). Artificial illumination has increased with human population growth, but in some countries, such as the United States, per capita outdoor lighting has risen more dramatically.

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For over three decades, astronomers have called for policies to limit artificial light (Riegel 1973). In contrast, light pollution has received little attention as a threat to ecological systems, perhaps in part because the effects of artificial light on ecological systems are largely unknown.

Light in natural environments influences numerous ecological processes directly and indirectly and, as a result, the effects of light pollution may be significant and widespread. For example, starlight provides essential navigational cues for the long-distance migration of birds (Akeson et al. 2001). Ambient light entrains circadian rhythms, controls diel migrations of pelagic organisms, influences the ability of nocturnal predators to detect and capture prey, and alters the risk environment for prey (Buchanan 1993; Lima 1998; Ringelberg 1999). Studies of sea turtles provide the strongest evidence of impacts of artificial illumination on wildlife (Witherington & Martin 2000). Beachfront lighting deters sea turtles from coming onto beaches to nest and disorients hatchlings (Peters & Verhoeven 1994). Also, lights attract birds and insects that forage and migrate at night, resulting in substantial mortality from collisions with structures in the vicinity of lights (Le Corre et al. 2002).

Because of extensive development, coastal beaches and barrier islands are among the areas most affected by light pollution. Two types of long-wavelength lights—low-pressure sodium vapor lights and incandescent yellow bug lights—are mandated for beach lighting in Florida because long-wavelength lights have spectral properties that reduce orientation problems for sea turtles (Witherington & Martin 2000). The effects of artificial lighting on terrestrial species in coastal habitats have not been addressed, even though these habitats contain species of critical conservation concern, such as beach mice (*Peromyscus polionotus*).

Eight subspecies of beach mice occur in small, isolated populations in the coastal dunes of Alabama and Florida. All extant subspecies, except the Santa Rosa beach mouse (*P. p. leucocephalus*), are threatened or endangered (Humphrey 1992). Beach mice are susceptible to habitat loss and fragmentation from coastal development and hurricanes, and introduced predators pose a serious threat to all populations (Oli et al. 2001). Artificial light can exacerbate these problems. Light modifies predation risk by influencing the visual abilities of predators and prey (Lima & Dill 1990). Natural illumination influences activity levels, foraging behavior, and habitat use by nocturnal rodents (Wolfe & Summerlin 1989; Kotler et al. 1991). Behavioral changes associated with illumination are likely an antipredator response because the perceived risk of predation increases with increasing light (Lima & Dill 1990). We hypothesize that artificial illumination associated with coastal development alters the behavior of beach mice in ways that negatively affect resource acquisition. We conducted field experiments to assess the effects of the types of lighting mandated for sea turtles on

the foraging behavior of Santa Rosa beach mice. Our study provides the first baseline data for evaluation of impacts of lighting policies designed for one species on a nontarget species of conservation concern; to our knowledge, it documents for the first time the effects of artificial light on terrestrial species in coastal systems.

Methods

We compared patch use and giving-up density (GUD), the density of resources in a patch at which foraging ceases (Brown 1988), for beach mice foraging in experimental resource patches (trays with seeds) subjected to low-pressure sodium vapor lights, incandescent yellow bug lights, or only new moon conditions (control). Giving-up density provides an index of foraging costs, including metabolic costs, predation risk, and missed opportunity costs (i.e., lost opportunity to engage in other activities that enhance fitness). If artificial light increases the costs of foraging—by increasing predation risk, for example—mice should cease foraging in patches under light at higher densities of resources than in patches not subject to artificial light. Assumptions of GUDs have been tested on species similar to beach mice (Morris 1997). This method provides a useful assay for anthropogenic impacts on foraging behavior (Bowers & Breland 1996).

We conducted illumination experiments from February to April 2002 at four sites along Santa Rosa Island, Florida. The island is a mosaic of primary dunes (sparsely vegetated dunes adjacent to high tide line), open sand, and vegetation patches, predominately sea oats (*Uniola paniculata* L.), dune panic grass (*Panicum amarum* Ell.), and gulf bluestem (*Schizachyrium maritimum* [Chapman] Nash). Beach mice occur throughout the dunes. At each site, we established two linear arrays of experimental resource patches a minimum of 20 m apart in sparse bluestem. We randomly chose one array to receive low-pressure sodium vapor lights and bug lights, and the other array served as a dark control. We mounted lights on a 3-m pipe at a randomly chosen end of the treatment array to create a light gradient. We used two 40-W bug lights (Phillips Longer Life Bug-a-way) or one 18-W low-pressure sodium vapor light (LPS 1000 Series, Harris Lighting, Monroe, North Carolina) to achieve a 12-m illumination radius. Lights were powered by generators placed 300 m from arrays. We collected data within 3 days of a new moon to standardize natural illumination. We applied each light treatment at each site for 3 consecutive nights with order of treatments determined randomly. Because of generator failure, we collected data at two sites only 2 nights per treatment.

Each array of resource patches contained 18 plastic trays filled with 5 g of oven-dried millet mixed into 3 L of beach sand placed in pairs at 2-m intervals along a 16-m

transect. To allow access to trays by beach mice but not other granivores (cotton rats [*Sigmodon hispidus*] and ghost crabs [*Ocypode quadrata*]), we covered trays with plastic lids, cut small entrance holes (4×4 cm) in lids for mice, and elevated trays approximately 9 cm from the ground. Wooden dowels served as ramps for mice to reach trays. In the light array, we placed the first pair of trays (0 m) beneath the light. We randomly chose one end of the dark array to represent the 0-m distance. Prebaiting preceded each data session for 1–2 weeks to ensure that resource patches were discovered by mice. During experiments, trays were left out overnight and lights were run dusk to dawn. The following day, we removed seeds remaining in trays and rebaited trays. Collected seeds were dried at 65°C , cleaned of debris, and weighed.

To assess patch use, we calculated the proportion of patches at which foraging occurred for each distance along transects by summing the number of trays visited by mice for all nights of the experiment at each distance and dividing by the total number of possible trays foraged (i.e., two trays \times number nights in experiment). We estimated giving-up densities by averaging grams of seeds remaining in each resource patch for all nights that mice foraged in the patch. Seeds remaining in a patch reflect the GUD of the final forager to visit the patch. We excluded patches that did not exhibit signs of foraging by beach mice from GUD analyses. All nights were combined for both analyses because initial analyses did not detect temporal trends in data. Prior to analysis, we also averaged GUDs for the two foraging trays at each distance along the 16-m transects. Sites were replicates ($n = 4$) for all analyses of patch use and GUDs.

We tested for effects of illumination (light or dark), light type, and distance from light source on patch use with logistic-regression analysis (SAS Institute 2000). We examined effects of illumination and distance from the light source on GUDs for each light type with linear mixed models (SAS Institute 2000). Site and site-by-illumination terms were included as random factors to account for the split-split plot design of the experiment. We used Fisher's least-significant-difference (LSD) tests for pairwise comparisons of GUDs along light gradients. Because we predicted a priori, based on field studies of predation risk, that mice would respond negatively to light, we used one-tailed LSD tests.

Results

Patch use was affected significantly by presence of illumination, light type, and distance from light source (Table 1). Mice foraged at a significantly higher proportion of patches in dark arrays than in light arrays, and mice foraged at a higher proportion of patches illuminated by bug lights than at patches illuminated by low-pressure

Table 1. Results of logistic-regression analysis for effects of illumination (present or absent), light type, and distance from light source on proportion of patches foraged by beach mice.*

Parameter	Estimate	SE	Z	p
Intercept	-0.82	0.84	-0.10	0.92
Illumination	2.93	0.88	3.33	0.0009
Light type	1.34	0.47	2.84	0.005
Distance	0.36	0.05	6.63	<0.0001

*Sites are replicates ($n = 4$).

sodium vapor lights (Fig. 1). Effects of lights on visitation of patches were observed only within 4 m of the light source. Over the experimental period, mice visited 82% of the resource patches within 4 m of bug lights and 65% of the patches within 4 m of low-pressure sodium vapor lights.

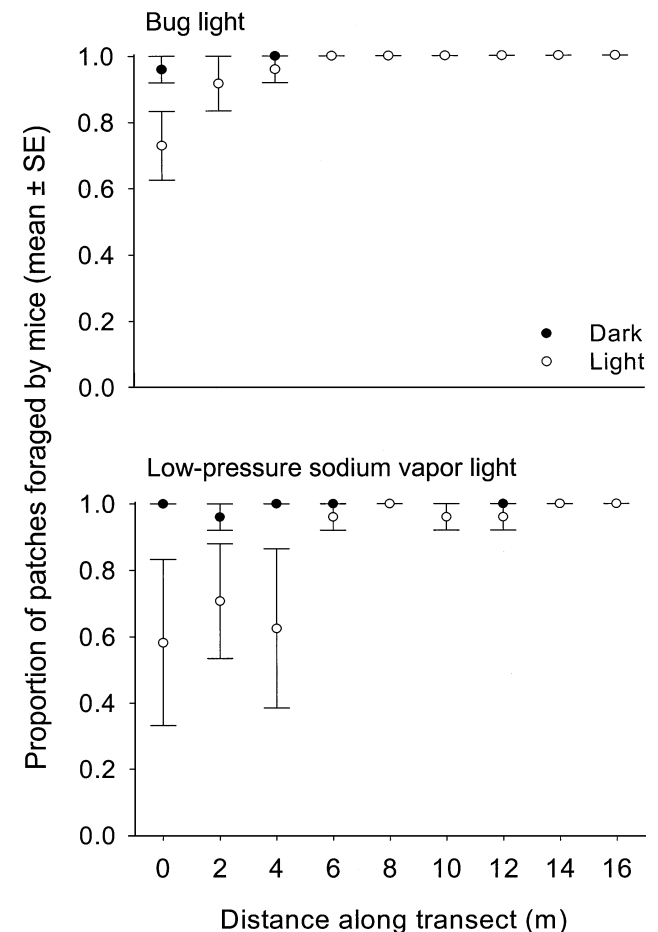


Figure 1. Proportion of experimental resource patches foraged by mice (mean \pm SE) along a light gradient that extended from the base of an artificial light source (0 m) to 16 m (light array) and along 16-m transects with no lights that served as dark controls (dark array). The light symbol is shown for locations where mice foraged similar proportions of patches in dark and light arrays.

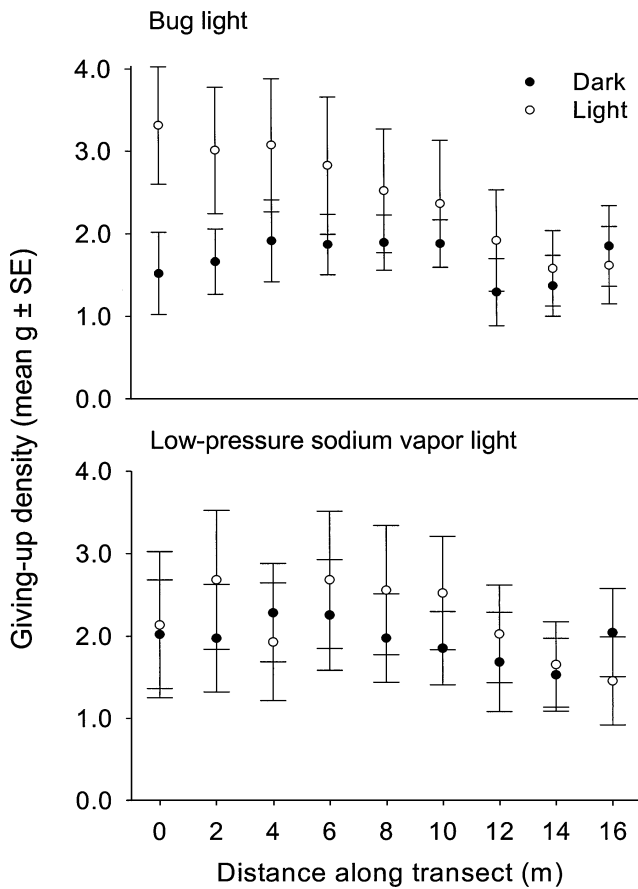


Figure 2. Giving-up density—density of resources in a patch at which foraging ceases (mean \pm SE)—in experimental resource patches located at 2-m intervals along a light gradient extending from the base of artificial lights (0 m) to 16 m (light array) and along 16-m transects with no lights that served as dark controls (dark array).

Mice removed significantly more seeds from resource patches (i.e., GUDs decreased) as distance from the light source increased under the bug light treatment ($F_{8,48} = 2.97, p < 0.009$; Fig. 2a). Giving-up densities from patches located 0–10 m from the bug light were significantly higher than GUDs from patches located 14–16 m from the bug light, and GUDs at 0–6 m also were different from GUDs at 12 m (Fisher's LSD tests, all $p < 0.05$). Giving-up densities were not affected by distance from light source with low-pressure sodium vapor lights ($F_{8,46} = 1.17, p < 0.34$; Fig. 2b). No significant differences were found in GUDs with distance along the dark array for either light type (Fisher's LSD tests, all $p > 0.05$).

Discussion

Foraging decisions represent tradeoffs between immediate benefits associated with intake of energy and nutrients and long-term costs, such as predation risk, that influence

the fitness of organisms (Lima 1998). These decisions are modulated by environmental factors, such as light, temperature, and presence of conspecifics, that modify costs associated with foraging. Consistent with our hypothesis, artificial light altered foraging behavior of beach mice in two ways that affected resource acquisition. First, mice reduced patch use near low-pressure sodium vapor and bug lights. Second, mice harvested fewer seeds from exploited patches near bug lights than from areas with no artificial light. These patterns suggest that beach mice assess risk at two scales, first by choosing which patches to forage and second by deciding how long to forage within a patch.

Under the light regime we used, both light types affected patch choice by mice only within about 4–6 m of the light source, suggesting that the effects of “turtle-friendly” lighting on beach mice could be localized. However, bug lights altered foraging activity within exploited patches up to 10 m from the light. We do not know why the two light types affected mice differently, but spectral properties of the lights differ. Low-pressure sodium vapor lights emit light only in the yellow spectrum; bug lights emit a broader range of wavelengths.

Our research was conducted at the microhabitat scale and may underestimate impacts of artificial lighting on mice at larger scales. First, experiments were conducted in areas with vegetative cover. Mice may perceive heightened predation risk from illumination at greater distances from the source in the absence of vegetation and, as demonstrated under natural illumination (Bowers 1988), may exhibit stronger behavioral responses to light in open areas than in cover. Open areas comprise a large part of beach mouse habitat, particularly following severe storms. Second, mice avoided areas affected by 1–2 low-wattage light bulbs. Taller, higher-intensity lights and multiple light sources are common in substantial portions of beach mouse habitat and may have more pronounced impacts on mouse behavior than the 18- to 40-W bulbs we tested. In addition, negative impacts of artificial lighting may extend beyond alteration of foraging behavior. If beach mice decrease their use of habitat exposed to artificial light, artificial lighting may alter movement of mice between vegetation patches and within open microhabitat and may diminish landscape connectivity.

Because light levels influence predation risk in many species (e.g., fish, Clark & Levy 1988; rodents, Clarke 1983; Kotler et al. 1991; birds, Lima 1998), behavioral responses to artificial light, such as those we detected for beach mice, are likely to be common across a range of taxa. Based on the growing number of taxonomic groups for which detrimental effects of artificial light have been documented, the diversity of impacts, and the continued expansion of light pollution in natural environments, impacts of artificial light on ecological systems clearly deserve more attention than they have received in conservation research and planning.

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