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CHAPTER 16

EFFECTS OF ARTIFICIAL NIGHT LIGHTING ON AMPHIBIANS AND REPTILES IN URBAN ENVIRONMENTS

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Abstract — Amphibians and reptiles have evolved with natural lighting cycles. Consequently, alteration of natural variation in diurnal and nocturnal light intensities and spectral properties has the potential to disrupt their physiology, behavior, and ecology. We review the possible effects of night lighting on many species of amphibians and reptiles, noting that few studies of the consequences of artificial lights to amphibians and reptiles have been conducted to date. The one exception is the information available on the negative impacts of artificial lights on hatchling sea turtles, which have received considerable coverage in both scientific and popular media. In many studies that might be relevant, researchers have not recorded the illumination or irradiance at which experiments were conducted. We identify light pollution as a serious threat that should be considered as part of planning and management decisions in the maintenance or conservation of urban areas containing amphibians and reptiles. However, we consider it too early to precisely gauge the effects of artificial night lighting on other taxa found in light-polluted environments or provide specific management recommendations, beyond pointing out the urgent need for more information.

Key words — Activity Pattern, Amphibians, Behavior, Conservation, Ecology, Invasive Species, Light Pollution, Night Lighting, Photopollution, Physiology, Reptiles, Suburban, Urban

Conservation biologists have long been concerned about anthropogenic effects on species and environments. There is good reason for herpetologists to share this concern: both amphibians and reptiles are declining worldwide (e.g., Alford and Richards 1999; Gibbons et al. 2000). Much work has focused on habitat loss and the consequences of water and air pollution, particularly on amphibians. Other anthropogenic impacts, such as light pollution, remain poorly studied and are of concern for urban herpetofauna (defined here as those species that are present within or adjacent to urbanized areas). Light pollution is a by-product of anthropogenic outdoor illumination from sources such as street lighting, sports arenas, and porch lights (e.g., Dawson 1984). When discussed in the context of adverse effects on wildlife, light pollution is also known as photopollution (Verheijen 1985). Its effects on herpetofauna are the focus of this chapter.

Five decades ago, Verheijen (1958) documented illumination patterns produced by lighting devices in urban habitats. The abnormal lighting patterns from these artificial sources resulted in locally elevated contrast in brightness between lighted and background areas which attracted invertebrates, a phenomenon known as "light trapping" (Robinson and Robinson 1950). Artificial lighting has become much more pervasive since 1958, affecting most of the world's urban areas and adjacent habitats (Cinzano et al. 2001; Longcore and Rich 2004). Street and security lights can be more than one million times brighter than natural ambient illumination (S. Wise and B. Buchanan unpubl. data). Additionally, skyglow, caused by

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reflection of artificial night lights from clouds, may increase nocturnal ambient illumination indirectly in less urban areas near cities (Cinzano et al. 2001). Sources of light pollution are often referred to as "night lighting," and the relatively new habitat created by the presence of artificial lights has sometimes been termed the "night-light niche" (Garber 1978).

With the exception of negative consequences for sea turtles, data on the effects of night lighting on amphibians and reptiles are uncommon. A recent book (Rich and Longcore 2006) focuses on many ecological aspects of light pollution. To avoid duplication, this review provides an updated synthesis of information we presented separately there (Buchanan 2006; Perry and Fisher 2006; Salmon 2006; Wise and Buchanan 2006). We focus on what little is known about the relationship between artificial lighting and urban herpetofauna and suggest areas that require further work. Special attention is paid to taxa that appear to be at greatest risk of being effected: species that are edificarian, feed at lights (or are simply positively phototactic), inhabit permanent and ephemeral ponds (parks, ditches), or are found in greenbelts or habitat reserves in or near city limits that are affected by skyglow or glare. Roads that connect urban areas, many of them illuminated by fixed lights in addition to vehicle headlights, may also have effects on species occurring nearby (Outen 2002; Spellerberg 2002), although few papers address this problem (e.g., Baker 1990; Mazerolle et al. 2005). In this chapter, we document the apparently positive (i.e., population-increasing) consequences of night lighting on some species and discuss effects that are clearly or possibly negative for others.

Taxonomic Preface

Information presented in the body of this chapter is arranged by habitat. However, some taxon-specific information pertains across habitats and is presented here. We use standard English names for large, well-recognized clades, but prefer scientific names when discussing specific species.

Salamanders — Salamanders are often nocturnal or crepuscular, with activity patterns regulated by photoperiod (reviewed in Wise and Buchanan 2006). Many species that have been studied are negatively phototropic or phototactic, although some species may show ontogenetic shifts in behavior, exhibiting positive phototaxis as larvae and negative phototaxis as adults (reviewed in Wise and Buchanan 2006). Artificial night lighting may affect physiology and behavior by (1) increasing ambient illumination, (2) lengthening photoperiod, and (3) varying the spectral properties of ambient light. Most studies of the effect of artificial light on salamanders have been conducted in the laboratory and focus on hormone levels or thermoregulation. These laboratory results, the basis for much of the information below, are important for generating field-testable hypotheses that may explain how artificial night lighting affects salamander populations in natural habitats.

Frogs — Frogs may be exposed to extreme changes in natural lighting patterns in urban environments. Few data exist that demonstrate direct effects of lighting on frogs, but many indirect effects are likely (Buchanan 2006). Adults of most taxa conduct the majority of their foraging and reproductive activities under twilight or nocturnal conditions. Eggs and larvae typically develop in aquatic environments, where they may be exposed to artificial illumination. Unfortunately, very few experimental data exist on the effects of artificial illumination on frogs in natural environments. Consequently, most of the data presented in this chapter have been extracted from papers dealing with the general effects of light on the physiology or behavior of frogs.

Caecilians — As with most subterranean taxa, relatively little is known about the biology of caecilians (Gower and Wilkinson 2005). Although many caecilians are of conservation concern, night lighting seems unlikely to be a significant cause of population decline, because these animals spend so little time above-ground and possess such poor eyesight. We have found no information to suggest otherwise and therefore do not discuss caecilians in the sections that follow.

Tuataras — The remaining range of this taxon is limited, and does not overlap major population centers. Thus, night lighting is unlikely to affect populations. The current recovery plan (Gaze 2001) does not refer to lights as a source of concern, and as we have found no information to suggest otherwise, do not discuss tuataras in the sections that follow.

Crocodilians — Relatively few crocodilians occur in abundance in urban areas. When they do, as in parts of Florida, USA, and Darwin, Australia (Nichols and Lentic 2008), they are often considered a source of concern in terms of human safety, rather than a target for conservation efforts. Perhaps because of this bias, we have been unable to locate evidence of possible effects of night lighting on these organisms. Thus, no information on crocodilians is presented in this chapter. Given that most crocodilian species are under some degree of threat and that urban sprawl is likely to bring more of them into contact with humans and night lighting, we feel that studies to explore these effects are urgently needed.

Turtles — Marine turtles are diving specialists (Lutcavage and Lutz 1999) whose vision is adapted to finding food, locating mates, and avoiding predators underwater. Seawater differentially absorbs both the shorter (UV, violet) and longer (yellow to red) light wavelengths, while best transmitting wavelengths between 450–500 nm (blue-green to green). Some turtles have spectral sensitivities that are "tuned" (most sensitive) to the latter; sensitivity declines rapidly as wavelength increases (Witherington 1992a; Lohmann et al. 1997; J. Gocke, M. Salmon, and K. Horch unpubl. data). Negative influences of light pollution on sea turtles, especially those of artificial lights near beaches on the seaward locomotion of hatchlings,

have been well-studied (reviewed in Witherington and Martin 1996), and have led to the only attempts we are aware of to reduce such negative influences. However, the attention given to sea turtles has not resulted in investigations of other turtles. We suggest that field research on non-marine turtles is another area that needs to be addressed.

Lizards — Lizards are often terrestrial and can be either diurnal or nocturnal. More anecdotal information about the effects of night lighting on lizards is available than for any other group (Perry and Fisher 2006). Although this effort has identified some intriguing preliminary patterns (e.g., positive effects for invading species, discussed below), the lack of experimental or systematic observational data is a source of concern.

Snakes — Snakes can be either diurnal or nocturnal, and some species show an ontogenetic switch (Clarke et al. 1996). No studies directly link artificial light to positive or negative effects on snake populations. However, declines have been noted in snake populations in many populated regions, making such work very timely. Perry and Fisher (2006) discussed possible positive predator-prey interactions between snakes and their prey, such as geckos, that are attracted to artificial lights. They also reviewed the probable negative predator-prey interactions associated with prey, such as the apparent decline of heteromyid rodents due to artificial lights, and increased exposure to snake predators. Snakes generally elicit a negative response in the general public, placing them at a special disadvantage in urban areas.

Effects of light in urban habitats

Although irradiance (defined as the density of radiant flux on a surface and typically measured over 180 degrees in units of W/cm^2) is the more appropriate measure of light intensity to use when describing light levels, we often refer to illumination (lux, $lumen/m^2$), because it is more commonly reported in the literature, making for easier comparisons.

Urban Cores — In this section, we focus on species found within or near human dwellings (i.e., edificarian species). Taxa common in urban cores are often familiar to many; some of them have had a long history of co-residence with humans. Although the number of species capable of surviving close to humans is low, edificarian species can reach high densities in their adopted habitat. Responses of edificarian amphibians and reptiles to artificial lights are well documented (Tables 1, 2), but ecological consequences remain much less obvious.

Salamanders — Few salamanders are found in urban cores. However, Garden Slender Salamanders (*Batrachoseps major*), California Slender Salamanders (*B. attenuatus*), and Arboreal Salamanders (*Aneides lugubris*) often occur around houses or along rock walls in California, USA (Cunningham 1960; Petranka 1998). We have not been able to find any information on effects that night lighting might have on such species.

Frogs — Some species of frogs commonly associate with edificarian habitats, including several species that feed on insects at lights (Table 2). Such species are typically only active at night, normally foraging under low ambient illumination (Woolbright 1985; Buchanan 1992). Some nocturnal frogs, such as the widely introduced Cane Toads (*Bufo marinus*), regularly forage under enhanced illumination near buildings (Table 2). Many nocturnal frogs show positive phototaxis (Jaeger and Hailman 1973), and laboratory studies have demonstrated that enhanced lighting can facilitate foraging in edificarian species (Larsen and Pedersen 1982; Buchanan 1998). However, it is unclear whether frogs are attracted to the increased abundance of insects available at lights, the light itself, or a combination of the two. How much light or what illumination differential is necessary to elicit this effect also remains unknown.

Although additional foraging opportunities can be beneficial, frogs aggregating at lights may also experience increased mortality. For example, Baker (1990) suggested that frogs feeding under streetlights are particularly susceptible to being killed by automobiles. In addition, radical and rapid changes in illumination can reduce visual sensitivity and require hours for complete light adaptation (Cornell and Hailman 1984). The frog eye tends to adapt to the brightest available source of light (Fain et al. 2001). Once they are light-adapted, frogs moving through areas with different ambient illuminations may suffer reduced visual capabilities, particularly when moving into shadows cast by artificial lights (Cornell and Hailman 1984; Buchanan 1993; Fain et al. 2001).

Table 1. Non-nocturnal amphibians and reptiles reported to use the night-light niche.

Species	Location	Source
Lizards		
Geckos (Gekkonidae)		
Gonatodes humeralis	Peru	Dixon and Soini 1975
Gonatodes vittatus	Trinidad	Quesnel et al. 2002
Lygodactylus capensis	South Africa	V. Egan unpublished
Phelsuma laticauda	Hawaii	Perry and Fisher 2006
Phelsuma madagascariensis	Madagascar	García and Vences 2002

Table 1. Continued

Species	Location	Source
Sphaerodactylus cinereus	Florida, USA	J. Lazell unpublished
	Haiti	J. Lazell unpublished
Sphaerodactylus elegans	Florida, USA	Meshaka et al. 2004
Sphaerodactylus difficilis	Hispaniola	R. Powell unpublished
Sphaerodactylus macrolepis	Guana Island, BVI	Perry and Lazell 2000
Sphaerodactylus sputator	Anguilla	Howard et al. 2001
Anoles (Iguanidae)		
Anolis aeneus	Grenada	R. Powell unpublished
Anolis bimaculatus	St. Eustatius	R. Powell unpublished
Anolis brevirostris	Hispaniola	Bowersox et al. 1994
Anolis carolinensis	Hawaii	Perry and Fisher 2006
	Mississippi, USA	J. Lazell unpublished
	Texas, USA	McCoid and Hensley 1993
Anolis cristatellus	Dominican Republic	Schwartz and Henderson 1991
	Guana Island, BVI	Perry and Lazell 2000
	Puerto Rico	Garber 1978
Anolis cybotes	Hispaniola	Henderson and Powell 2001
Anolis distichus	Hispaniola	R. Powell unpublished
Anolis gingivinus	St. Maarten	Powell and Henderson 1992
	Anguilla	Hodge et al. 2003
Anolis leachii	Antigua	Schwartz and Henderson 1991
Anolis lineatopus	Jamaica	Rand, 1967
Anolis luteogularis	Cuba	J. Losos, unpublished
Anolis marmoratus	Guadeloupe	Powell and Henderson 1992
Anolis richardii	St. George's, Grenada	Perry and Fisher 2006
Anolis sabanus	Saba	Powell and Henderson 1992
Anolis sagrei	Bahamas	Schwartz and Henderson 1991
	Florida, USA	Meshaka et al. 2004
Anolis schwartzi	St. Eustatius	Powell et al. 2005
Anolis trinitatus	St. Vincent	R. Powell unpublished
	Young Island	R. Powell unpublished
Other iguanids (Iguanidae)		
Agama agama	Cameroon	Böhme 2005
	Gabon	Pauwels et al. 2004
Basiliscus basiliscus	Costa Rica	A. Vega unpublished
Leiocpehalus carinatus	Florida, USA	Meshaka, in preparation
Tropidurus plica (= Plica plica)	Trinidad	Werner and Werner 2001
Skinks (Scincidae)		
Cryptoblepharus poecilopleurus	Cocos Island, Guam	McCoid and Hensley 1993
Lamprolepis smaragdina	Pohnpei	Perry and Buden 1999
Snakes		
Racers (Colubridae)		
Alsophis portoricensis	Guana Island, BVI	Perry and Lazell 2000

Table 2. Nocturnal amphibians and reptiles reported to use the night-light niche.

Species	Location	Source
Frogs		
Toads (Bufonidae)		
Bufo americanus	Oklahoma, USA	J. Lazell unpublished
Bufo bufo	England	Baker 1990
Bufo cognanus	Texas, USA	S. Rideout unpublished
Bufo gutturalis	South Africa	V. Egan unpublished
Bufo maculatus	Cameroon	Böhme 2005
Bufo marinus	Costa Rica	A. Vega unpublished
	Florida, USA	Meshaka et al. 2004
	Guadeloupe	Henderson and Powell 2001
	Hawaii, Fiji, American Samoa	R. Fisher unpublished
Bufo melanostictus	China	Lazell 2002
Bufo terrestris	Florida, USA	W. Meshaka unpublished
Bufo woodhousii	Oklahoma, USA	J. Lazell unpublished
Bufo viridis	Europe	Balassina 1984
Schismaderma carens	Tanzania	V. Egan unpublished
Rain frogs (Leptodactylidae)		
Eleutherodactylus coqui	Puerto Rico	Henderson and Powell 2001
Eleutherodactylus johnstonei	Saba, Netherlands Antilles	Perry 2006
Treefrogs (Hylidae)		
Hyla cinerea	Florida, USA	Goin 1958
	Mississippi and Louisiana, USA	B. Buchanan unpublished
Hyla femoralis	Florida, USA	W. Meshaka unpublished
Hyla gratiosa	Florida, USA	W. Meshaka unpublished
Hyla squirella	Florida, USA	Goin and Goin 1957
	Mississippi and Louisiana, USA	B. Buchanan unpublished
Osteopilus septentrionalis	Anguilla	Henderson and Powell 2001
	Guana, British Virgin Islands	G. Perry, in MS
	Florida, USA	Carr 1940
Scinax eleochroa	Costa Rica	A. Vega unpublished
Old World treefrogs (Rhacophoridae)		
Chiromantis xerampelina	South Africa	V. Egan unpublished
Lizards		
Geckos (Gekkonidae)		
Afrogecko porphyreus	South Africa	E. Baard unpublished
Bunopus tuberculatus	United Arab Emirates	Perry and Fisher 2006
Cosymbotus platyurus	Southeast Asia	Case et al. 1994
Cyrtopodion scabrum	Jordan	Disi et al. 2001
Gekko chinensis	China	J. Lazell unpublished
Gekko gecko	China	J. Lazell unpublished
	Florida, USA	W. Meshaka unpublished
	Thailand	R. Fisher unpublished

Table 2. Continued

Species	Location	Source
Gekko subpalmatus	China	J. Lazell unpublished
	Philippines	J. Lazell unpublished
	Indonesia	J. Lazell unpublished
Gehyra mutilata	China	J. Lazell unpublished
	Hawaii	J. Lazell unpublished
	Sapwuahfik Atoll	Buden 2000
Gehyra oceanica	Sapwuahfik Atoll	Buden 2000
	Pacific Region	R. Fisher unpublished
Hemidactylus brookii	China	J. Lazell unpublished
Hemidactylus bowringi	China	J. Lazell unpublished
Hemidactylus flaviviridis	Egypt	Ibrahim and Ghobashy 2004
	United Arab Emirates	Perry and Fisher 2006
Hemidactylus frenatus	Australia	Cogger 1979:179
	Costa Rica	Savage 2002:484-485
	Florida, USA	W. Meshaka unpublished
	Guam	G. Perry unpublished
	Hawaii	Case et al. 1994
Hemidactylus garnotii	Costa Rica	Savage 2002:484-485
	China	J. Lazell unpublished
	Pacific Region	R. Fisher unpublished
	Florida, USA	Meshaka 2000
Hemidactylus haitianus (recently renamed *H. angulatus*)	Dominican Republic	Bowersox et al. 1994
Hemidactylus mabouia	Anguilla	Howard et al. 2001
	Brazil	Perry and Fisher 2006
	Cameroon	Böhme 2005
	Gabon	Pauwels et al. 2004
	Dutch Antilles	Powell and Henderson 1992
	Florida, USA	Meshaka 2000
	Guana Island, BVI	G. Perry unpublished
	Puerto Rico	R. Powell unpublished
	South Africa	V. Egan unpublished
	Venezuela	Fuenmayor et al. 2005
Hemidactylus persicus	United Arab Emirates	Perry and Fisher 2006
Hemidactylus turcicus	Israel	Werner 1966
	Egypt	A. Ibrahim unpublished
	Jordan	Disi et al. 2001
	United Arab Emirates	Perry and Fisher 2006
	USA: Alabama, Florida, and Mississippi	Nelson and Carey 1993
	Texas, USA	G. Perry unpublished
Hemiphyllodactylus typus	Pacific Region	R. Fisher unpublished
Homopholis wahlbergi	South Africa	V. Egan unpublished

Table 2. Continued

Species	Location	Source
Lepidodactylus lugubris	Costa Rica	Savage 2002:486
	Guam	G. Perry unpublished
	Hawaii	Case et al. 1994
	Sapwuahfik Atoll	Buden 2000
Nactus pelagicus	South Pacific	Perry and Fisher 2006
Pachydactylus bibronii	Namibia	Perry and Fisher 2006
	South Africa	E. Baard unpublished
Pachydactylus turneri	Namibia	Perry and Fisher 2006
	South Africa	V. Egan unpublished
Ptyodactylus guttatus	Israel	Werner 1965
Ptyodactylus hasselquistii	Israel	Y.L. Werner unpublished
	United Arab Emirates	Perry and Fisher 2006
Ptyodactylus puiseuxi	Israel	Y.L. Werner unpublished
Tarentola annularis	Egypt	Ibrahim 2004
Tarentola mauritanica	Egypt	A. Ibrahim unpublished
	Libya	Ibrahim and Ineich 2005
Thecadactylus rapicauda	Anguilla	R. Powell unpublished
	Dominica	J. Lazell unpublished
	Necker, BVI	J. Lazell unpublished
	Trinidad	Kaiser and Diaz 2001
Snakes		
Racers (Colubridae)		
Lamprophis fuliginosus	Namibia	Cunningham 2002
Boiga irregularis	Guam	Perry and Fisher 2006
	Papua New Guinea	Perry and Fisher 2006
	Solomon Islands	Perry and Fisher 2006

Turtles — Some terrestrial turtles, such as Box Turtles (genus *Terrapene*) are known to inhabit urban cores (Dodd 2001). Most of these species are diurnal and could conceivably be affected if night lighting extends their activity period or disturbs their nocturnal rest. Whether such an effect actually occurs remains unknown.

Lizards — Night lighting can benefit some urban lizards. Species that are not normally active after dark, especially anolis lizards, have been observed foraging or being active near artificial lighting at night (Table 1), taking advantage of the "night-light niche" (Garber 1978). Normally nocturnal species, especially members of the family Gekkonidae, have also been documented around night lights (Table 2). At least some of these taxa are also known to occasionally be active during the day (McCoid and Hensley 1993; Teynié et al. 2004). Presumably, the attraction of invertebrates to artificial lights attracts lizards because of the greater quantity of food and the increased predictability of finding prey. Intriguingly, the work of Werner (1990) suggests that artificial lights can also provide basking sites, and thus a second important resource, for lizards (and possibly other amphibians and reptiles). Observations from Egypt (Ibrahim 2004; Ibrahim and Ghobashy 2004) suggest this may be a broad pattern, especially in winter, but additional studies are desirable.

Negative effects of lights on non-introduced urban lizards have not been documented, but some species are more likely to take advantage of the presence of lights, and asymmetric competition can cause locally negative effects for other taxa. The best-documented example is the interaction between two introduced geckos, the Common House Gecko *Hemidactylus frenatus* and the Mourning Gecko *Lepidodactylus lugubris*, in the Pacific. Although *H. frenatus* has negatively affected populations of *L. lugubris* and the Oceanic Gecko *Gehyra oceanica* in some lighted locations (Case et al. 1994), the two species appear to coexist in native and less-disturbed habitats (Case et al. 1994) and on other lighted structures (Perry and Fisher 2006).

Taxa that would not normally interact might nonetheless meet where artificial lights are available. Perry and Fisher (2006) reported a more extreme example from Hawaii.

Hemidactylus frenatus (nocturnal), the Gold Dust Day Gecko *Phelsuma laticauda* (a diurnal gecko), and the green anole *A. carolinesis* (also diurnal) sometimes forage together at the same light source, and may compete for food resources. Ironically, all three are not native to Hawaii, and their ranges do not naturally overlap anywhere. Observations conducted in 2007 indicate that *P. laticauda* was successful in competing for these habitats, at least in the area around Kona, Hawai'i, where it now dominates both the diurnal and nocturnal lizard communities (R. Fisher, unpub.). In a different example, Perry and Lazell (2000) reported that *Anolis cristatellus* forages at artificial lights in the British Virgin Islands. Its predator, the snake *Alsophis portoricensis* (Puerto-Rican Racer), was also observed at the same lights. These species would normally interact during the day, but such additional interactions are of interest for two reasons. First, if common enough, added interactions can exacerbate normal predation effects. Second, and more importantly, this example shows that night lighting can affect more than a single species at a time, perhaps allowing species to interact that would otherwise not do so and possibly creating novel food webs. More severe or pervasive consequences might occur when night lighting exposes native species to competition with or predation by native or introduced species with which they would not normally interact.

Snakes — The effects of night lighting are difficult to separate from other problems that snakes face in urban environments, such as persecution. Only two published reports have been found of nocturnal snakes foraging under lights (Table 2). Other nocturnal species, such as the Brahminy Blind Snake *Ramphotyphlops braminus*, are found near houses in tropical areas and in cities where they have become established, but what effect lights have on their populations is not known.

Urban Water Bodies and Greenbelts

Many cities and towns have areas of natural or semi-natural aquatic or terrestrial habitats, such as city parks and water runoff storage areas, within or just outside their limits. These are typically managed for aesthetics, recreation, and/or flood control. They may be connected to each other by corridors or isolated, and the intensity of management can range from heavy (e.g., channeled streams) to very low. In these areas, skyglow may chronically increase ambient illuminations to levels substantially greater than normal nocturnal light levels (Buchanan 2006; Cinzano et al. 2001). As a result, artificial illumination around urban ponds can be brighter than even the brightest natural nocturnal light levels. For example, nocturnal light intensity around Utica Marsh in Utica, New York was measured at 0.1–1 lux (S. Wise and B. Buchanan unpubl. data), equivalent to illuminations at dawn or dusk. High-density urban cores are typically surrounded by less developed areas (e.g., agriculture, waterways, and greenbelts). In such areas, human density gradually decreases with distance from the core and species absent from the city core are often present here. Despite greater diversity, however, these areas remain influenced by the urban matrix in which they are embedded and the resulting light pollution.

Salamanders — Salamanders, such those of the genera *Ambystoma* (Mole Salamanders) and *Notophthalmus* (Eastern Newts), are commonly found in ponds and surrounding terrestrial habitats within or near urban areas. Completely terrestrial taxa, such as those of the genus *Plethodon* (Woodland Salamanders), may be found in large wooded city parks and greenbelts. Where ponds are located near roadways, salamanders can be subject to very high probabilities of automobile impacts when crossing roads during nocturnal activity (Fahrig et al., 1995; Hels and Buchwald 2001; Mazerolle 2004). Most spotted salamanders (*Ambystoma maculatum*) and blue-spotted salamanders (*Ambysotoma laterale*) respond to disturbance and lights from approaching automobiles by halting their movements, perhaps further increasing the probability of automobile-induced mortality by increasing the time that salamanders spend on the roadway (Mazerolle et al. 2005).

The physiology and behavior of salamanders are influenced by a variety of biotic and abiotic factors, including ambient light. Introduction of artificial light during normally dark periods can disrupt the production of melatonin, a hormone responsible for many aspects of photoperiodic behavior and physiology (Vanecek 1998). Common Mudpuppy (*Necturus maculosus*) aquatic adults kept on a 12L:12D photoperiod exhibited higher plasma melatonin levels during the dark phase than during the light phase (Rawding and Hutchison 1992). When the photoperiod was reversed, melatonin production was also reversed. Aquatic adults of the Eastern Tiger Salamander *Ambystome tigrinum* also had significantly higher plasma levels of melatonin during scotophase (the dark period of a day-night cycle) than during photophase (the light period of a day-night cycle) (Gern and Norris 1979). Gern et al. (1983) found that *A. tigrinum* kept under constant light (a condition that can occur under bright point sources of artificial night lighting) did not show significant differences in plasma levels of melatonin during photophase and scotophase as they would under natural lighting conditions. Although not tested statistically, levels of melatonin during scotophase were similar to levels during photophase for salamanders kept on a regular 12L:12D photoperiod.

Melatonin has multiple effects in amphibians, including reducing tolerance to high temperatures and lowering body temperature (Erskine and Hutchison 1982; Hutchison et al. 1979). One prediction, therefore, is that decreased nocturnal plasma melatonin levels will cause higher metabolic rates. Whitford and Hutchison (1965) compared physiological functions of terrestrial adults of Spotted Salamander (*A. maculatum*) kept on a 16L:8D photoperiod to those kept on an 8L:16D photoperiod. As predicted, animals kept on a 16L:8D photoperiod had significantly higher pulmonary, cutaneous, and total rates of O_2 consumption and higher cutaneous and total rates of CO_2 production (Whitford and Hutchison

1965). Wise and Buchanan (2006) therefore hypothesized that artificially increasing the length of photophase through night lighting may disrupt normal cyclical changes in metabolic rates, changing the energy demands of salamanders. This effect could become problematic during periods of low food availability or when energetic demands are especially high, such as during egg production or periods of drought.

The diel pattern of vertical migration exhibited by larval salamanders (genus *Ambystoma*: *A. jeffersonianum* (Jefferson Salamander), *A. opacum, A. talpoideum* (Mole Salamander), and *A. tigrinum*) is influenced by ambient light, temperature, competition, and predation risk (Anderson and Graham 1967; Stangel and Semlitsch 1987). Anderson and Graham (1967) observed that *A. opacum* exhibited more activity on overcast days and less vertical migration on bright nights. Interruption of vertical migration may reduce size at metamorphosis or survival (Semlitsch 1987).

Changes in light intensity during scotophase as a result of artificial night lighting can also affect other behaviors, such as foraging. Buchanan (unpubl. data) tested adult Red-backed Salamanders (*Plethodon cinereus*) in the laboratory, in the absence of olfactory cues but under a range of illuminations (complete darkness, 10^{-5}, 10^{-4}, or 10^{-3} lux). Salamanders oriented toward prey sooner at higher ambient illuminations, indicating improved visually-based foraging ability with higher light levels. Although increased ambient light may allow salamanders to see prey better, it can also delay the nocturnal foraging activity of *P. cinereus*, which typically emerge from the leaf litter approximately 1–2 h after dark (B. Buchanan and S. Wise unpubl. data; Fig. 1). Buchanan and Wise conducted forest censuses 1–2 h after sunset in six dark (no artificial illumination; 10^{-4} lux) and six lighted (with white holiday lights; 10^{-2} lux, equivalent to bright moonlight) transects. Fewer salamanders were active in the lighted transects than in the unlighted transects during the census. B. Buchanan and S. Wise (unpubl. data) hypothesized that delayed emergence may reduce the length of time salamanders are able to forage, especially on dry nights, when reduced humidity decreases the amount of time spent foraging (Keen 1984).

Agonistic behavior is also affected by nocturnal ambient illumination. Adults of *P. cinereus* are territorial, guarding cover objects that provide access to food, moisture, and potentially mates (Mathis et al. 1995). In the laboratory, B. Buchanan (unpubl. data) examined the threat displays exhibited by territorial residents towards intruding salamanders under different levels of illumination (complete darkness, 10^{-4}, or 10^{-2} lux). Residents used more visual displays as light intensities increased. Presumably, visual threat displays are energetically costly to produce (Wise and Jaeger 1998); thus, increased use of visual displays with increased ambient illumination may negatively affect energy budgets. On the other hand, increased visibility may also allow individuals to assess better the outcome of agonistic interactions, thereby reducing the probability of contests escalating to overt aggression and injury (Jaeger 1981).

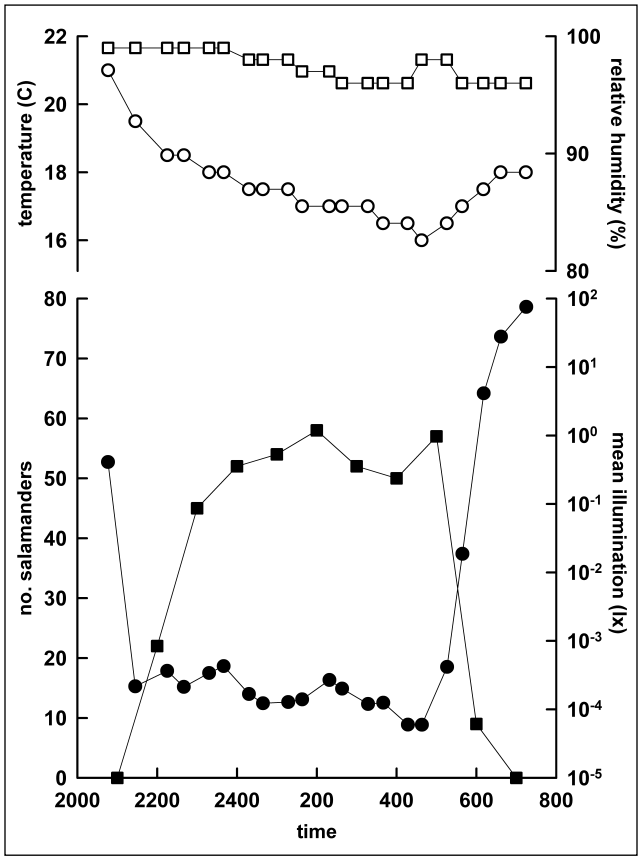

Fig. 1. Activity of *Plethodon cinereus* (Red-backed Salamander) during a representative night census (from dusk until dawn, 2100 – 0700 h, 1-2 July 2003) of two 50 x 1 m transects (Buchanan and Wise, unpubl. data). The study was conducted at Mountain Lake Biological Station, University of Virginia, Giles County, VA. Plotted are the numbers of salamanders detected on the leaf litter or vegetation (■), the mean illumination from the 4 cardinal directions (●), temperature (○), and percent relative humidity (□) for each sampling period.

Spectral properties of light may affect migration to and from ponds. Metamorphosed juvenile Red-spotted Newts (*Notophthalmus viridescens*) migrate from their natal ponds to nearby forests a few months after hatching and return to their natal ponds as adults. Adults also leave the ponds during periods of drought or when ponds freeze (Petranka 1998). These salamanders use a light-dependent magnetic compass (Phillips et al. 1995) involving extraocular photoreceptors (Adler 1970; Deutschlander et al. 1999) for navigation. Phillips and Borland (1992a,b,c, 1994) demonstrated experimentally that orientation and homing behavior were disrupted by monochromatic, long-wavelength light (yellow spectrum, especially 550–600 nm). Common outdoor lights emit light at 540–630 nm (Massey et al. 1990). Their use, therefore, could negatively affect the ability of *N. viridescens*, and perhaps other species of salamanders that use a similar light-dependent magnetic compass, to navigate to home ponds for breeding. Thus, spectral properties of artificial night lighting should be considered as

part of conservation or management efforts in urbanized habitats containing semi-aquatic salamanders.

Frogs — Frogs are typically aquatic breeders, and in urban settings they are likely to use both ephemeral breeding sites (e.g., ditches) and permanent sites (e.g., ponds or streams). Such sites are frequently exposed to increased light levels due to roadway lighting and skyglow (Buchanan 2006). Effects of altered lighting may be seen as early as during embryonic growth and larval development. Decreasing the duration of scotophase slowed growth in larval Painted Frogs *Discoglossus pictus* (Gutierrez et al. 1984) and African Clawed Frogs *Xenopus laevis*, causing the latter to metamorphose at a smaller size (Delgado et al. 1987; Edwards and Pivorun 1991). Conversely, constant lighting accelerated larval development in Northern Leopard Frogs, *Rana pipiens* (Eichler and Gray 1976). Thus, artificial night lighting has the potential to affect time to metamorphosis or size at metamorphosis.

The behavior and physiology of tadpoles may also be affected by night lighting. For example, larval American Toads (*Bufo americanus*) use photoperiodic cues to thermoregulate behaviorally (Beiswenger 1977) and vertical migration in *Xenopus laevis* larvae is dependent upon changes in illumination (Jamieson and Roberts 2000). Exposure at night to artificial light for as little as 1 min can disrupt production of precursors required for larval melatonin production (Lee et al. 1997), which may in turn have important effects on physiological performance (Vanecek 1998). For example, *X. laevis* larvae exposed to constant lighting did not experience normal diel patterns of color change (Binkley et al. 1988).

Adult frogs living in greenbelt or park areas, like those of many species, would traditionally be active at very low environmental illuminations (reviewed in Buchanan 2006), and may thus be affected by artificial night lighting. Species such as the Western Tailed Frog *Ascaphus truei*, normally active only at the darkest natural nocturnal illuminations (Hailman 1982), are likely to be influenced when environmental illuminations increase to levels at which the frogs typically seek refugia. Artificial night lighting can disrupt foraging, fat storage, and growth in adult frogs (e.g., in Fowler's Toad *B. fowleri*, Bush 1963). Reproductive behavior is also sensitive to changes in illumination. For example, calling males of Panamanian Cross-banded Treefrogs *Smilisca sila* exhibit illumination-dependent changes in anti-predator behavior under natural conditions (da Silva Nunes 1988). In another example, females of the Tungara Frog (*Physalaemus pustulosus*) become less likely to exhibit mate choice at higher ambient illuminations (Rand et al. 1997), and vary their oviposition behavior in response to changes in illumination (Tárano 1998). Other nocturnally breeding species, such as the Squirrel Treefrog *Hyla squirella* (Taylor et al. 2007) and the Sarayacu Treefrog *H. parviceps* (Amézquita and Hödl 2004), use visual cues in mate choice and male-male competition. Artificial lighting may allow these and other visually-based behaviors to occur at uncharacteristic times or intensities (Buchanan 2006).

Frogs moving across roadways while foraging or breeding have a high probability of being killed by automobiles (Fahrig et al., 1995; Hels and Buchwald 2001; Mazerolle 2004). Many frogs are primarily active at night, and the moving lights of oncoming cars create cycles of increasing and decreasing illumination that may make dark adaptation difficult. Buchanan (1993) found that rapid increases in illumination similar to that produced by oncoming traffic slow visual foraging in the Gray Treefrog (*H. chrysoscelis*). Mazerolle et al. (2005) similarly found that nocturnally active American toads (*B. americanus*), spring peepers (*P. crucifer*), green frogs (*R. clamitans*), and wood frogs (*R. sylvatica*) are more likely to become immobile on the road when approached by automobile-related stimuli than when left undisturbed. Although their experiment did not completely control for disturbance, making it impossible to separate out the effects of light and disturbance, their results are consistent with the idea that rapid shifts in illumination can alter the behavior of frogs at night.

Physiological consequences are also possible. For example, Leopard Forgs, *Rana pipiens* kept under constant lighting suffered from retinal irregularities (Bassinger and Matthes 1980) and Common Asian Toads *B. melanostictus* show reduced sperm production when maintained in constant light (Biswas et al. 1978). The expression of genes that, in turn, regulate other physiological processes can also be altered by constant illumination (Baggs and Green 2003; Green and Besharse 1996; Steenhard and Besharse 2000). The number of species that may be susceptible to these various effects and the magnitude of change in illumination intensity or duration that is necessary to elicit such responses remain unknown.

Turtles — A number of freshwater turtles survive within urban matrices, perhaps because of their unusual resistance to various pollutants (Gasith and Sidis 1984). Increasingly, species common in the pet trade, such as the Red-Eared Slider *Trachemys scripta elegans*, are also becoming widely established in urban settings (e.g., Lever 2003; Perry et al. 2007), presumably following their release or escape. Information about the ecology of such species in urban and near-urban environments, and on the influence of lights upon them, is lacking. The single exception involves a laboratory study in which Chinese Soft-Shelled Turtles (*Trionyx sinensis*) were shown to have lower food uptakes and growth rates at higher light intensities (Zhou et al. 1998). It is quite possible that species such as softshell turtles (Trionychidae) that sleep on shore at night would also be more exposed to predation due to increased visibility to predators in lighted landscapes.

Lizards — Many lizard species exist in urban peripheries. Nonetheless, we have not been able to find any studies showing effects of lights on these reptiles. Further study on the impacts of night lighting in these habitats is needed.

Snakes — Some aquatic snakes track the lunar cycle in their activity and foraging patterns (Andreadis 1997; Houston

and Shine 1994; Madsen and Osterkamp 1982). The issue of artificial lights disrupting the lunar cycle in natural areas (i.e. biodiversity reserves) adjacent to urban areas is of concern, but studies exploring this potential problem are absent. Increased lighting may affect snake foraging success. Predation success rates for some species that prey on snakes increase with increased illumination (Bouskila 1995), and some snake prey reduce their foraging activity in response to increased illumination (e.g., Bouskila 1995; Bowers 1988).

Urban Beaches and Estuaries

Many of the world's largest cities originated as port towns. Other urban centers have more recently emerged around tourist destinations, and often feature heavily-developed beaches. In many cases, the same sandy beaches treasured by vacationers are also the traditional sites for sea turtle nesting. Sea turtles at such locations probably offer the best case studies of the effects of artificial lighting on any taxonomic group (e.g., Witherington 1992b). Other species, such as the diurnal Fringe-Toed Lizard (*Acanthodactylus scutellatus*) and the nocturnal Leaf-Nosed Snake (*Lytorhynchus diadema*) also inhabit those same dunes (e.g., Perry and Dmi'el 1995) and may be exposed to ambient light from nearby cities.

Frogs — Although no species of frog tolerates the high salinity associated with marine beaches per se, some (e.g., Marine Toads *Bufo marinus*, Crab-Eating Frogs *Rana cancrivora*) are known to breed in brackish water. One of them, *B. marinus*, has been widely introduced around the world (Lever 2003) and is commonly found near urban centers. In Hawaii, Guam, and elsewhere, large numbers will forage under lights, clearly taking advantage of the increased prey abundance (J. Lazell pers. comm.; G. Perry unpubl. data). However, the consequences of lights for amphibian populations inhabiting beaches and estuaries remain unstudied.

Turtles — McFarlane (1963) described how hatchling turtles in Florida, after emerging from their nests, were attracted to street lighting visible at the beach. Many crawled inland, crossed a coastal roadway *en route* to the lights, and were crushed on the road by passing cars. We now know that hatchlings worldwide are commonly attracted to light fixtures (Philibosian 1976; Peters and Verhoeven 1994), and that most turtles attracted to lights die from exhaustion, dehydration, and predation. Other sources of illumination (such as abandoned campfires on land) can also be deadly (Mortimer 1979). Artificial lighting also affects adult turtles by degrading the quality of their rookery sites. Nesting attempts (crawls of gravid females up the beach to nest) each night by Green Sea-Turtles (*Chelonia mydas*) and Loggerheads (*Caretta caretta*) were reduced to almost zero at historically important sites (Melbourne Beach, Florida; Tortuguero, Costa Rica) when these locations were experimentally exposed to lighting (Witherington 1992b). When the lights were turned off, nesting attempts each evening immediately increased. In Florida, the spatial pattern of artificial lighting probably accounts for the present distribution of the "preferred" rookery sites along the East Coast (approximately 75,000 loggerhead nests annually). About 90% of all nests are deposited at five beach sites characterized primarily by their lower exposure to artificial lighting (Salmon 2003). The same sites are also preferentially used by Leatherbacks (*Dermochelys coriacea*), *C. mydas,* and *C. caretta*, which elsewhere tend to nest at different locations. This suggests that the negative effects of coastal development and its associated lighting, rather than features that have traditionally promoted female reproductive success and hatchling survival, currently determine where marine turtles nest.

Lizards — Some species of lizards inhabit beaches, and a few, such as Black Iguanas (*Ctenosaura similis*), may occasionally be seen near human habitation. Slightly further from the beach proper, species such as the Fringe-Toed Lizards *Acanthodactylus scutellatus* and *A. schreiberi* inhabit dune formations nestled within seaside urban communities (Perry and Dmi'el 1995). However, such cases are uncommon, and we are unaware of any studies examining the influence of lights on such species.

Snakes — A number of snake species in the family Elapidae (some authors place them in the families Hydrophiidae and Laticaudidae) spend their lives in the sea and most can at times be found near land, if only briefly. Some of these (e.g. *Laticauda* species) can be quite common along beach-retaining walls in urban south-Pacific cities that are exposed to lights. Another group of snakes, the Homolopsines, primarily occur in mudflats and forage at night. Finally, terrestrial species such as the Sand Snake (*Psammophis schokari*) and *Lytorhynchus diadema* inhabit dune formations nestled within sea-side urban communities in Israel (Perry and Dmi'el 1995). However, we are unaware of studies examining the effects of lights on such species.

Remediation

All of the work conducted to date on light pollution remediation for herpetofauna involves sea turtles. Recent tests on hatchling orientation, conducted in an arena setting, indicated that natural cues and artificial lights "compete." This work offers hope of identifying a technological fix because it shows that a reduction in the perceived "attractiveness" of artificial lighting makes it more likely that hatchling orientation will be based upon natural cues (Tuxbury and Salmon 2005).

A number of studies have examined the feasibility of using alternative lighting methods that would reduce or eliminate the negative influence on sea turtles but that would also be acceptable to humans. Turtle-friendly lights generally emit wavelengths between 540 and 700 nm (amber to red) and can be produced either by designing lights that emit only the longer wavelengths (Fig. 2) or by using filters that exclude the

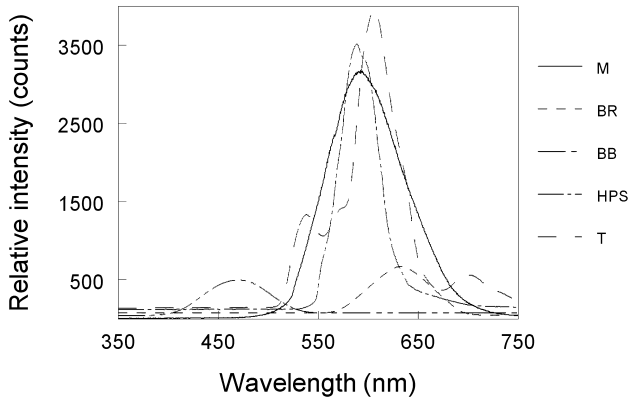

Fig. 2. Spectral energy distributions for four "turtle-friendly" lights (Magnaray, M; filtered High Pressure Sodium vapor, HPS; Twistee, T; and Beeman Red, BR). One short-wavelength light (Beeman Blue, BB) was used as a control. Filtered HPS lights are used on coastal roadway poled streetlights in Florida; the Twistee and Beeman red are lights designed for buildings (residential or commercial) that are visible at marine turtle nesting beaches.

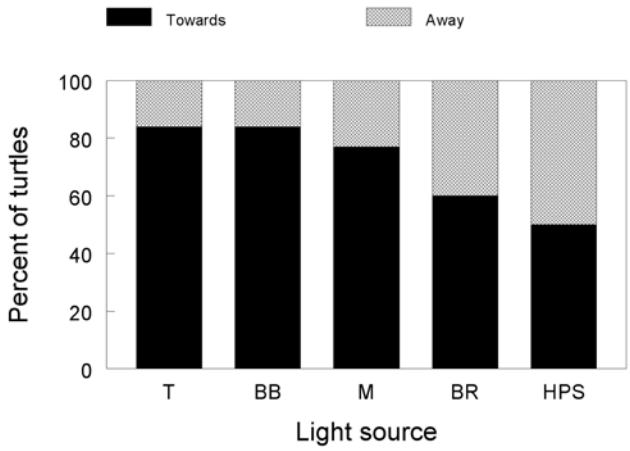

Fig. 3. Choices of hatchling sea turtles (Loggerheads, *Caretta caretta*) presented with various lights. A no-light control was used in each case. Differences among light sources in relative intensities were eliminated through the use of neutral density filters, so that responses shown by the turtles were based upon spectral differences alone. Results show that the turtles are statistically significantly attracted to the Twistee (T, n = 25 turtles), Beeman Blue (BB, n = 25), and Magnaray (M, n = 35) lights, but not to the Beeman Red (BR, n = 45) or Filtered HPS (HPS, N = 46).

shorter wavelengths of "broad-spectrum" lights. Salmon and his colleagues (Halager et al. in press) developed a bioassay that can be used to evaluate the efficacy of "turtle-friendly" lights by giving hatchlings choices between darkness and a light (single light experiments), or pairs of different lights. Using this bioassay, Halager et al. (in press) found that some lights are more attractive to turtles than others and that the strength of attraction declines as spectral energies become more concentrated in, and shifted toward, the longer wavelengths (Figs. 3, 4). Field experiments demonstrate that high-pressure sodium vapor lamps affect marine turtles, but passing such illumination through a filter that excludes wavelengths below 530 nm makes these lights far less attractive to hatchlings (Sella et al. 2006). In fact, when this filtered lighting is visible at nesting beaches, it no longer reduced nesting by adults (Pennell 2000).

The use of spectrally-modified outside lighting should increase the number of hatchlings that successfully locate the ocean, even at urban nesting beaches. Recently, lighting along a coastal roadway in the city of Boca Raton, Florida, was extensively modified. Streetlights placed on posts were turned off during sea turtle nesting season and replaced with light-emitting diodes installed in the pavement. These provided sufficient illumination for traffic safety, but none of the lighting was visible at the nesting beach. Behavioral tests at the beach demonstrated that the seaward orientation of hatchling Loggerheads was normal when the embedded lights were on, but disrupted when the elevated streetlights were on (Bertolotti and Salmon 2005). It remains to be seen to what extent use of similar technologies could help other taxonomic groups.

Discussion

Artificial light, long considered a problem for astronomers but of little concern to biologists, is increasingly viewed as a threat by conservation biologists. A recent volume (Rich and Longcore 2006) illustrated the pervasiveness of the problem of artificial lights, which affect a broad range of taxa. In this chapter, we focused on updating and summarizing the information for amphibians and reptiles, but emphasize that the problems associated with artificial night lighting likely do not stop with a particular group of organisms. It may impact entire communities, and we find it encouraging that solutions to this problem may also simultaneously benefit a broad range of taxa.

There are doubtlessly additional species and populations which use artificial lights and are not listed in Tables 1 and 2. For example, Outen (2002) and Spellerberg (2002), identified lights associated with roads as a potential source of concern, but could find few studies directly evaluating this potentially widespread risk (but see Mazerolle 2004; Mazerolle et al. 2005). The reports collected by Rich and Longcore (2006) also stress the magnitude of the lack of information on effects of artificial night lighting for many taxonomic groups, including amphibians and reptiles (Buchanan 2006; Perry and Fisher 2006; Salmon 2006; Wise and Buchanan 2006). However, there is reason to be concerned about the effects of artificial light on amphibians and reptiles in general: many species are nocturnal and many populations are in serious decline (e.g., Alford and Richards 1999; Gibbons et al. 2000). Unfortunately, the literature demonstrates a lack of information for caecilians, tuataras, and crocodilians, which are primarily nocturnal and could therefore be at risk from changes in light levels.

Urban ecology is a rapidly growing discipline, but herpetological research in urban environments remains notably underrepresented. Studies typically focus on relatively undisturbed habitats, and even herpetofaunal surveys rarely

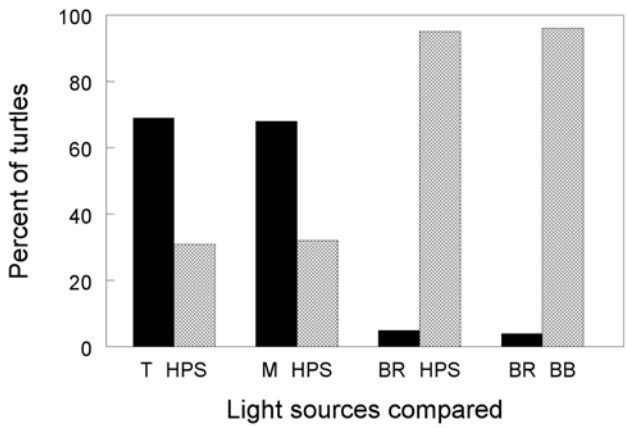

Fig. 4. Choices of hatchling sea turtles (Loggerheads, *Caretta caretta*) in tests in which paired light presentations were made. Turtles are significantly attracted to the Twistee (T) and Magnaray (M) lights when each is matched with a filtered HPS light (n = 29 and 60, respectively, for each test). However, turtles are significantly attracted to the filtered HPS light when it is paired with a Beeman Red light (BR, n = 40), which is also less attractive to the turtles than the Beeman Blue light (BB, n = 25).

explicitly address taxa found in or near human habitation. The biology of edificarian taxa is even more rarely reported (but see Powell and Henderson 2008). We hope that the increased interest in urban ecology will lead to more studies addressing light pollution and their effects on amphibians and reptiles. Although these influences are only beginning to be studied, a few general patterns appear to be emerging:

1) Species vary in their sensitivity to light pollution, which may have no effect, benefit, or negatively affect a particular taxon. Thus, it is important to consider the photobiology of all taxa found in a particular habitat. For example, sea turtle nesting problems may be reduced by shifting the spectra of lights to longer wavelengths. Shifting spectra to longer wavelengths can, however, disrupt migration in newts (which do not, fortunately, share the same habitat). Thus, there may not always be simple solutions to lighting problems other than the removal, reduction of use, or shielding of artificial night lighting.
2) Different aspects of a given species' biology can be affected differently by different lighting conditions at different life history stages.
3) There is a paucity of research available on the negative effects of lighting on herpetofauna. Negative effects of light pollution, such as the disruption of orientation in hatchling sea turtles (e.g., Witherington and Martin 1996) are well documented, but detailed studies for other taxa are not yet available.
4) There is a dearth of studies of the positive effects of lighting on herpetofauna. Positive influences, such as increased prey availability and thermoregulatory opportunities around artificial night lighting are better documented, if only anecdotally, in lizards (Tables 1, 2). We are not aware of studies that have elucidated population-level consequences, what mechanisms are involved, and which species are most likely to be affected.
5) Indirect effects are likely to be common. Benefits to one species may negatively influence another, as demonstrated by Case et al. (1994). However, studies of this phenomenon that do not involve invasive species are only now starting to reach the literature (Rich and Longcore 2006).
6) The ability of artificial light to enhance the invasive potential of some species should be a source of broad concern. Some of the species listed in Table 1 and many of those in Table 2 were observed in areas outside their native range. The ability to use human habitats, which are often characterized by having additional lighting during the night, can be beneficial to invasive species, many of which first colonize urbanized areas. For species that are not only tolerant of such conditions but can also take advantage of the night-light niche, establishment of viable populations may be easier. Almost no information is available on the impacts of invaders such as geckos, which are generally perceived as innocuous, yet it seems likely that at least some native species (particularly invertebrate prey) must be negatively affected. Light-aided invasive species may also spread disease and exotic parasites to native species.

Is it possible to resolve such conflicts of interest between urban residents and urban amphibians and reptiles? New technology, briefly reviewed above, offers some promising options for providing illumination that satisfies human requirements while minimizing effects on other species. However, solving the light pollution problem necessitates light management, including protocols that eliminate the influence of artificial lighting on wildlife by, for example, turning off unnecessary lights, reducing wattage, shielding and lowering luminaires, or creating natural light barriers, such as dune or wooded areas, between light sources and wildlife habitats (Witherington and Martin 1996). However, humans often perceive lighted environments as more pleasing or safe. For example, lighting along roadways and in city parks is often considered necessary for pedestrian and vehicular safety. Thus, there may be resistance to reducing the amount of lighting at urban sites. There is much room for research on the human dimensions of the problem and such work can hopefully help identify technological solutions that benefit wildlife and are broadly acceptable to the public. We hope that such solutions can be incorporated rapidly not just where a particular species of sea turtle or gecko is found, but on a global scale commensurate with the scope of the artificial light problem.

Management Recommendations

The information presented in this chapter clearly indicates the potential for multiple types of effects on amphibians and reptiles resulting from artificial night lighting. Although

the most extensive work has been carried out on sea turtles at urban beaches, preliminary evidence indicates that many species are likely at risk. Although it is clear that much more research is needed in this area before firm conclusions can be drawn, work reviewed above has begun identifying potential problems and solutions to these problems, which we are hopeful can effectively be incorporated into standard practices. We recommend that managers adopt a precautionary approach and attempt to minimize consequences without waiting for researchers to confirm the impacts on a particular species or habitat. It is clear that the best approach for the conservation of native taxa involved is returning habitats as closely as possible to their natural lighting conditions, primarily through the removal of unnecessary lighting and shielding of necessary lighting. It is worth noting that several entities that have experimented with reducing lighting have also recouped their investment in reduced power costs (e.g., International Dark Sky Association: http://www.darksky.org/infoshts/pdf/is191.pdf; accessed May 2006).

Summary

Amphibians and reptiles have not evolved with artificial lighting at night. Thus, alteration of the natural variation in diurnal and nocturnal light intensities and spectral properties of lights has the potential to disrupt their physiology, behavior, and ecology. Our review identified possible effects of night lighting on many species of amphibians and reptiles. However, it also reveals that conclusive data are often lacking. Few studies on the consequences of artificial lights for amphibians and reptiles have been conducted to date, and in many that might be relevant, researchers have not recorded the illumination or irradiance at which experiments are conducted. Thus, it is currently impossible to precisely gauge the effects of artificial night lighting on taxa found in urban, light-polluted environments. The one exception is the information available on the negative impacts of artificial lights on hatchling sea turtles, which has received considerable coverage in both scientific and popular media. With that exception, we believe it is too early to draw sweeping conclusions and to provide broad management recommendations, beyond pointing out the urgent need for more information. However, we identify light pollution as a serious threat that should be considered as part of planning and management decisions in the maintenance or conservation of urban areas containing amphibians and reptiles.

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