Light Pollution and Its Effects on Biodiversity

Angie Price

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Abstract

Human beings have wrought great changes in landscapes and natural habitats all over the globe. The urbanization of the world has profoundly changed ecosystems and will continue to do so as humanity continues to progress and expand. Anthropogenic changes have included the introduction of massive light pollution into the world of the night. There are many different types of and layers to light pollution. As light pollution increases, changes in the behavior and biodiversity of nocturnal animal species is becoming more and more apparent. All different types of animals are negatively affected by this phenomenon, from invertebrates up to all levels of vertebrates – fish, amphibians, reptiles, birds, and mammals. The negative effects of light pollution are not only found in animals but, in the human population as well. The reasons behind continued light pollution in the face of a growing field of research on its negative effects are varied, from legal to economic to behavioral. Fortunately, all hope is not yet lost. Ways to counter light pollution and motivating factors for doing so are beginning to emerge. However, we as conservationists must work to promote and publicize the issues surrounding light pollution if we want things to change.

Light Pollution and Its Effects on Biodiversity

When humans first discovered electricity and adapted it for their use in the nineteenth century, they also developed the ability light up the night sky. The practice of using electric light during the nighttime hours has only increased as time has gone on. One study found that the greatest increases in nighttime exposure to artificial lighting as a whole were in the Mediterranean and temperate ecosystems (Bennie, Duffy, Davies, Correa-Cano, & Gaston, 2015). However, they also found that some of the areas where the largest increases in exposure had occurred were in localized and fragmented areas that had high levels of biodiversity and endemism. Another even earlier study found that light pollution is not confined to developed countries, but is an issue that affects nations around the globe irrespective of location (Cinzano, Felchi, & Elvidge, 2001). This same study found that 93% of the U.S. and 40% of the world live in what was deemed "perennial moonlight" or ambient-lighted night sky that is so bright it duplicates a perpetually moonlighted landscape (Cinzano, Felchi, & Elvidge, 2001).

Davies, Bennie, Inger, & Gaston (2013) found that artificial light pollution as a form of anthropogenic pollution has one of the largest worldwide distributions. At the same time, their studies found that it is one of the issues about which humans have the least knowledge and concern (Davies, Bennie, Inger, & Gaston, 2013). Lyttimaki (2013) concurs that light pollution is a serious concern that still needs to be addressed as a major challenge in conservation. Light pollution is a problem that will continue to grow and it will continue to have profound effects on ecosystems around the world. The purpose of this paper is to look at exactly what constitutes light pollution, how widespread it is, how it negatively affects wildlife, both at the species level and the ecosystem level, and the actions that are being taken by various organizations to mitigate its effects.

Light Pollution as a Concept

Light pollution is a concept that is fairly new to humanity; the use of electric light itself only started in the 1800s, after all. The idea that there could ever be too much light was inconceivable at that time. However, as electric lights have been improved and amplified over time, they have spread in use to the point where it is now impossible to imagine cities that are not perpetually lit up through the night. The growing use of artificial light at night has not been without consequences, and although the effects of light pollution become more researched and more recognized, the precise level to which the use of artificial light has pervaded our society has not yet been fully understood. Light pollution comes in several different forms. Ścięžor, Kubala, Dworak, & Kaszowski (2010) created a method for measuring light pollution using the average "surface magnitude of the faintest observable comets" as overall representatives of that of the night sky (p. 92). However, even they agreed that light pollution can be highly variable, as light pollution can change in localized areas in a short period of time with a number of factors, such as cloud cover, particle suspensions in the air, and other atmospheric conditions. Other researchers have also attempted to quantify light pollution (Hollan, 2009). There are two general types of light pollution considered, astronomical light pollution and ecological light pollution (Longcore & Rich, 2004). Studies in this paper were more concerned with the latter, since the former deals with the factor of sky glow and obstruction or lack of visibility of the celestial bodies in the nightly skies, whereas ecological light pollution looks at all aspects of disturbance caused by artificial light. Within ecological light pollution, there are different types of pollution, as well as many aspects involved, since entire ecosystems are affected and they are composed of so many different types of living organisms.

One type of light pollution that has been recently defined and introduced is that of polarized light pollution, wherein animals that use the direction of light polarization for activities such as navigation (such as birds and insects) are disrupted by the lack or masking of the natural light polarization of the moon, for instance (Horvath, Kriska, Malik & Robertson, 2009). Results of researchers still do not fully agree on all aspects of what creates and constitutes light pollution. For example, one study found that the use of LED lights would decrease light pollution in the infrared but not in the visible spectrum (Andreić, Andreić & Krešimir, 2012). This could be significant because there are a number of animals that see in the infrared spectrum, such as birds and insects. However, another study looked at the color temperature of LED lights trying to ascertain whether or not certain ones attracted more or fewer insects; they concluded that LED lights negatively impacted the ecology of the systems no matter which lights were used (Pawson & Bader, 2014). It would appear that further studies may be needed on the topic to draw any definite conclusions.

Disrupting Animal Behavior and Biodiversity

Similar to light pollution itself, the extent to which animals are affected by light pollution is another topic that invites further inquiry. Biodiversity decreases in urban areas, both at the species and ecosystem level (Faeth, Bang, & Saari, 2011). Urban areas are also the areas where light pollution most often occurs. Of all effects of urbanization and all forms of anthropogenic pollution (or pollution caused by humans and human activity) researchers agree that light pollution in particular has been shown to have some of the most harmful effects on biodiversity in ecosystems (Deda, Elbertzhagen, & Klussmann, 2007; Holker et al., 2010; Kyba and Holker, 2013). In several different studies, it was found that the presence of light influenced the behavior

of nocturnal species in urban settings far more than the level of noise, for instance (Fure, 2006; Newport, Shorthouse, & Manning, 2014).

The use of artificial light extensively has proven to be harmful to animals at all levels of the biological ecosystem. Bogard (2013) divides the disruption of animal behavior by light pollution into five categories: orientation, predation, competition, reproduction, and Circadian rhythms. Different researchers highlight different aspects of these categories in a number of studies. Orientation echoes polarized light pollution, wherein animals that use light to navigate are confused and dislocated by their misperception of artificial light as a natural light indicator. Several different species have been shown to be affected by this phenomenon. Insects are one of the most well-known groups to be affected; insects congregating at streetlights and porch lights are a common sight. Studies have shown numerous insect species to be negatively affected in the presence of artificial light, both in number and biodiversity (Blaho et al., 2014; Boda et al., 2014; Conrad et al., 2006; Davies, Bennie & Gaston, 2012; Eisenberg and Hanel, 2009; Thancharoen, Branham & Lloyd, 2008). Another group of animal species strongly influenced by light pollution particularly when it comes to orientation are migrating birds. Many birds become confused by night lights and crash into buildings, causing injuries and fatalities (Kerlinger et al., 2010; Poot et al., 2008; Rodriguez et al., 2014). In other cases, birds will become confused and fly around light sources for hours, sometimes to the point of exhaustion (Bogard, 2013). A third set of species that has been strongly affected by orientation and navigation are marine turtles. In the presence of light, sea turtles have difficulty finding their way from the nest to the ocean, and often come to harm when they become disoriented; they may try to cross highways or never make it anywhere near the ocean. Several studies have shown that when they are unable to navigate properly to the

ocean, entire generations of turtles can be harmed (Brei, Perez-Barahona, & Strobl, 2014; Kamrowski, Sutton, & Tobin, 2014).

Harmful behaviors can be found across species lines, and they take many different forms. Increased predation of a particular species can be a result of light pollution; even the perception of the possibility of increased predation can affect some animal species. For example, many bats are lunarphobic, meaning that they are less likely to emerge from their roosts and hunt, or that they hunt for shorter periods of time without flying as far out to hunt during the brighter cycles of the moon (Börk, 2006). This can have negative effects both on the bats' individual health as well as that of their general populations. From this, we can extrapolate that at least some species of bats will be affected by the presence of light in a landscape that mimics perpetual moonlight. In fact, there have been a number of studies that have catalogued all of the negative effects of light pollution on bats alone (Boldogh, Dobrosi, & Samu, 2007; Fure, 2006; Lewanzik & Voigt, 2014; Patriarca & Debernardi, 2010; Stone, Jones, & Harris, 2012; Stone, 2013). Because bats make up about 25% of mammals overall, they can have an extremely significant overall effect on ecosystems. Bats are keystone species that consume millions of insects every night. They also pollinate certain plants and participate in re-seeding activities in various ecosystems. Disruption in their behavior could have far-reaching effects.

Artificial lighting has been shown to upset nearly every aspect of nightly activities that bats carry out; the level and type of disturbance found varied from study to study. For example, Boldogh, Dobrosi & Samu (2007) and Stone (2013) agreed that the presence of brighter light was found to delay the initial emergence of bats from their roosts. Artificial lighting has been shown through a number of studies to significantly inhibit the activity of bats in regard to foraging habits, commuting or transit/flight patterns, and overall activity levels; it also resulted in

roost abandonment, increased arousal from hibernation, an increase in habitat fragmentation as a result of spatial avoidance of lit areas, and poorer food choices. (Fure, 2006; Patriarca & Debernardi, 2010; Stone, Jones & Harris, 2009; Stone, Jones, & Harris, 2012; Stone, 2013). Definitive decreases in both body mass and forearm length (a common measurement used among bat researchers to determine overall size) in the presence of light pollution were found in one study (Boldogh, Dobrosi, & Samu, 2007). Another study found that seed dispersal was compromised in lighted areas that bats avoided (Lewanzik & Voigt, 2014). This could obviously have much larger implications for forest growth in tropical areas, where some bats act as seed dispersers for key plants.

There were a few exceptions found among the literature. In three different papers, bat species have been shown to benefit from foraging at streetlights where many insects congregate (Lacoeuilhe et al., 2014; Matthews et al., 2015; Patriarca & Debernardi, 2010). This shows one possible positive outcome from the presence of artificial light. However, even with these particular papers, most studies seemed to indicate overall negative effects and behaviors among the majority of bat species. In addition, the bat species indicated in the above papers were more common species, and not threatened or endangered at the time of their publishing. This could indicate a number of possibilities in regards to those species, such as the presence of a more robust constitution or a greater adaptive ability; more research would be needed to draw any conclusions.

Combatting Lunar Pollution

From all appearances, light pollution seems to be on the rise while continuing to be one of the lesser-known conservation threats when it comes to the public at large. However, there is some hope among researchers when it comes to searching for and enacting solutions to the

artificial lighting problem. There are an increasing number of researchers and groups looking at the effects of light pollution (such as Urban Wildlands, Civil Twilight, International Dark-Sky Association, Dark Skies Initiative, and Fatal Light Awareness Program). Every year, the research on light pollution grows exponentially.

Some companies are beginning to invest in the idea of diminishing artificial lighting at night as well. One company, Civil Twilight, has created "lunar-resonant streetlights", which are lights that actually alter the light they emit based on the level of moonlight available, thus allowing for more overall balanced light, as well as savings costs in energy (Bogard, 2013). Increasing energy costs may be one of the decisive factors in a change in lighting habits for the future. One economic study was conducted that looked at the costs and waste of the way that artificial night lighting is currently conducted. When they took into account wildlife, health, and energy costs, they estimated a loss of almost 7 billion dollars each year (Gallaway, Olson & Mitchell, 2009). In past instances, economic factors have often proven to be mitigating catalysts when it comes to large-scale behavioral changes. Studies such as the one mentioned can provide a starting point for justifying changes in practices. Additionally, as mentioned many groups are participating in and creating events that promote education about light pollution and its effects. Dark Skies Awareness (2009) provided a number of activities to publicize light pollution during the International Year of Astronomy; other citizen science groups have been getting involved as well.

Conclusion

Light pollution is a topic that has been increasing in prominence, although it is still one of the lesser-known conservation threats. The presence of increasing light pollution has been demonstrated to have profound effects on animal behavior, health, and biodiversity in

ecosystems throughout the world. Different types of light pollution can have different effects on different species and ecosystems, depending on their specific circumstances - the level of light pollution present, the adaptability of the species, whether other factors are present that are affecting ecosystems, and so on. Overall, however, researchers appear to agree that as a general rule most forms of light pollution have negative effects on both animal individuals and populations; studies of many and varied types of animal species have been harmed by light pollution.

There is some hope when it comes to working on solutions to the light pollution issue. Research in the field has been growing and some groups have worked on promoting the cause of educating the public about light pollution. There are still a number of obstacles to overcome when it comes to light pollution, however, simply because nighttime artificial lighting is so pervasive and ingrained within our culture. As mentioned, lack of awareness is one of the largest hurdles for scientists to overcome. Without education of the seriousness of the issues of light pollution and even the basics of light pollution itself, the likelihood of change is minimal. Creating the best possible compromise of lighting which serves both humans and nocturnal animals will be difficult; which light is most harmful to wildlife has not even fully been determined, and levels of "acceptable" lunar pollution for nocturnal wildlife may be a pipe dream. The continued overall increase and diversification of research is encouraging, however, as this will allow for more informed decisions when it comes to presenting analyses for possible legal changes. Additionally, the inclusion of economic studies could prove to be extremely influential in motivating legislators and corporations when it comes to making large-scale changes to our nighttime light usage. It is hoped that as more organizations publicize the plight

of ecosystems in regards to light pollution, awareness will grow and perhaps in time momentum for positive change can be achieved.

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