Practice Evaluating Sources

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Have students look at "Useful questions to ask when assessing a source"

Group Work

- Look at the assigned text for your group and go through the questions from the library website (link given above).
- How useful and reliable is your group's assigned source? Would you use it or not for this class in a researched essay about dark sky issues?

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SEPTEMBER 22, 2021

Aquatic insects are sensitive to light pollution

by Forschungsverbund Berlin e.V. (FVB)

People like to settle near waters—so freshwater systems are strongly affected by light pollution. Credit: Markus Venohr

Light pollution—too much artificial light in the wrong place at the wrong time is one reason for the decline in insect numbers worldwide. New research from the Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB) shows that current strategies for reducing the impact of light pollution do not go far enough in protecting aquatic insect species.

Most people are familiar with the sight of insects swarming around a streetlight at night. This well-known phenomenon shows one of the most severe ecological effects of artificial light at night—disruption of nocturnal insect location and behavior. Such is the attraction of artificial light to nocturnal insects, that the light acts like a "vaccuum cleaner," drawing insects away from their regular habitat and out of their usual behavioral cycles. The effect not only disrupts the insects' behavior and distribution, but has knock-on effects on the ecosystems in which they play a vital part. For example, nocturnal insects play an important role as pollinators. The recent German "Insect Protection Act" (Federal Nature Conservation Act) has anchored the implementation of insect-friendly lighting as a crucial strategy for biodiversity protection.

Insects and larvae are also attracted to light under water

In numerous studies, Dr. Franz Hölker's team has been able to show the influence of artificial light on flying and ground-dwelling insects. Now the researchers have investigated the effect on aquatic insects and insect larvae. Inland waters are particularly affected by light pollution as the shores of rivers and lakes are often densely built-up and brightly lit at night.

To study the effect, the researchers had to go where it is still really dark at night. In the Westhavelland Star Park near Berlin, they set up underwater traps for insects in water ditches and installed lights at different wavelengths. "In the illuminated water areas we found significantly more insects in the traps than in the unlit ones. This demonstrates that the vacuum cleaner effect of artificial light is felt even under water. Affected insects are impaired in their search for food and mates and become easier prey for predatory species," Franz Hölker explained the result of the field study.

Land and water insects: Not on the same wavelength

Many flying insects are particularly sensitive to short-wave, blue light and, as such, campaigns to protect insects against light pollution have focussed on reducing blue light wavelengths in streetlamps. However, the researchers found that aquatic insects don't exhibit this preference, and as such current blue-light mitigation strategies may not be enough. "Most species of aquatic insects seem to be attracted to long-wave light rather than short-wave light," explained Franz Hölker.

Light conditions in water are not the same as on land. The water body acts like an optical filter, altering the light spectrum and intensity. For example, if there is organic material in the water and it becomes more turbid. Short-wave, blue light in particular is attenuated as the distance from the light source increases.

"For the protection of flying insects, we recommend reducing the blue fraction of the light, but this does not help aquatic insects according to our study. Therefore, it would certainly make sense for lighting at water bodies to focus on alternative conservation measures—for example, to generally avoid direct lighting of water surfaces, and to reduce the intensity and duration of lighting in areas close to water bodies," Franz Hölker summarized.

More information: Impact of Different Wavelengths of Artificial Light at Night on Phototaxis in Aquatic Insects, *Integrative and Comparative Biology*, 2021; icab149, doi.org/10.1093/icb/icab149

Provided by Forschungsverbund Berlin e.V. (FVB)

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SMART NEWS

Is Light Pollution Really Pollution?

As countries grow richer, light pollution gets worse–but some are fighting to change that

Kat Eschner

June 1, 2017

Recent research found that fully one third of humanity can't see the Milky Way because of light pollution Pixabay

After all, what harm could light do? It's just light.

The answer is: a lot. The damage of light pollution has only begun to be understand in the last two decades, writes Verlyn Klinkenborg for *National Geographic*. And that's not just because the unpolluted night sky is full of a vast world of celestial lights that has struck humans with awe since the beginning. "Ill-designed lighting washes out the darkness of night and radically alters the light levels—and light rhythms—to which many forms of life, including ourselves, have adapted," she writes. "Wherever human light spills into the natural world, some aspect of life—migration, reproduction, feeding—is affected."

Sea turtles can't figure out where to lay eggs, and hatchlings find the bright roadway instead of the sea. Fireflies can't mate. Migrating birds get confused and fly into brightly lit buildings. In humans, light pollution is associated with depression, sleeplessness and cancer. The darkness of the night is essential for humans and other species, Klinkenborg writes: "We've lit up the night as if it were an unoccupied country, when nothing could be further from the truth."

As humans began to seriously consider the consequences of their light use, countries began to legislate against it. On this day in 2002, the Czech Republic struck back by putting a new law into effect to combat light pollution with a simple (and effective) solution: "From 1 June, all outdoor light fixtures must be shielded to ensure light goes only in the direction intended, and not above the horizontal," wrote Tom Clarke for *Nature* in 2002. It was the first national law of its kind in the world.

Outdoor lights now have to be shielded to keep light from spilling out above a certain height, and flat glass rather than curved has to be used, writes Kate Connolly for *The Guardian*.

The Czech law is still in effect, and other countries and regions have adopted similar measures to the "Protection of the Atmosphere Act." But a 2016 study found that one third of humanity still can't see the Milky Way, and in Europe and the United States, more than 99 percent of people live in light-polluted conditions. Anti-light pollution advocates such as the International Dark-Sky Association say there is more to do.

Founded in 1988, IDA is an U.S.-based education and advocacy group advocating against light pollution. It consults on initiatives like the one in Florida to reduce infant sea turtle deaths, and also certifies places that have worked to reduce light emissions, such as—recently—Cedar Breaks National Monument in Utah. The organization has been on the front lines of the fight for dark-sky legislation.

“Electricity is a modern necessity of life,” Franklin Delano Roosevelt once said. It’s true that artificial light has done many positive things for humanity, but like anything else, it has consequences.

Kat Eschner

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SPECIAL ISSUE ARTICLE

Light pollution is the fastest growing potential threat to firefly conservation in the Atlantic Forest hotspot

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Abstract. 1. In addition to being threatened by habitat loss derived from deforestation and urbanisation, fireflies are further deeply impacted by light pollution, which impairs their unique use of light signals to communicate and track females. The impact of stressors that can lead to declines in firefly populations is poorly known in the southern hemisphere, including the Atlantic Forest where they are especially diverse, associated with lack of knowledge about their distributions.

2. Here, we model the potential distribution of the tracker ghost firefly *Amydetes fastigiata* and investigate whether light pollution, urbanisation and deforestation are increasing over time in this area.

3. We found that light pollution is the stressor with the most prominent increase rates over its distribution. Light pollution is significantly increasing in extent and intensity over time, outpassing urbanisation and deforestation which increased at lower rates. Protected areas successfully buffer effects of urbanisation and deforestation, but are incapable to halt the spread of light pollution.

4. Increasing light pollution is especially concerning due to the spotlighting behaviour of *A. fastigiata* to track females through the night, which is imperilled by overshadowing lights. Light pollution trends are increasing fast and should be considered as a significant stressor even within protected areas – which calls for a reform in regional conservation policies and designation of new areas to be prioritised.

5. We presented a framework for the evaluation of threat rates based on species distribution models that can foster future research and assess vulnerabilities of important species facing global change.

Key words. Artificial Light At Night, Atlantic Forest, conservation, extinction risk, global change, protected areas, urban sprawl.

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Introduction

Several forms of global change stress biodiversity (Irwin, 2018; Owens & Lewis, 2018; Sánchez-Bayo & Wyckhuys, 2019). Habitat loss has always been highlighted as one of the major threats, especially as a consequence of deforestation and urban expansion (Barlow *et al*., 2016; Gonçalves-Souza *et al*., 2020). Light pollution emerges as a relatively recent unprecedented threat to ecosystems as a by-product of urbanisation (Gaston *et al*., 2014), however being less studied so far (Gaston

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et al., 2015b). Natural ecosystems are experiencing significant increases in light pollution exposure worldwide (Bennie *et al*., 2015), altering natural night-sky regimes that once were only brightened by lunar cycles (Kyba *et al*., 2017). However, light pollution can have an impact in ecosystems greater than its concomitance with urbanisation (Kyba & Hölker 2013). Artificial lights can significantly increase sky brightness up to six times compared to rural areas; and mask lunar cycles over time and seasonally deeply impacting biological systems (Davies *et al*., 2013). Thus, artificial lighting is able to reshape ecosystems altering their structure and function (Davies *et al*., 2012).

Although concern about light pollution impacts on biodiversity has increased, there is still a lack of understanding of the proportion and location of species that are prone to be threatened by light pollution (Gaston *et al*., 2014; Correa-Cano *et al*., 2018). A crucial step towards filling this gap is to assess the extent and trends in light pollution along the geographic ranges of species from diverse taxonomic groups (Duffy *et al*., 2015; Correa-Cano *et al*., 2018) – particularly those potentially vulnerable to erosion of natural darkness like nocturnal insects.

Habitat loss and light pollution are known drivers of insect decline (Sánchez-Bayo & Wyckhuys, 2019; Lewis *et al*., 2020; Owens *et al*., 2020). In fact, we already know that different stressors might act in synergy (Miller *et al*., 2017) but the ways in which the interactions between multiple stressors impact biodiversity is still poorly understood. In this context, fireflies are especially threatened worldwide due to their biology associated with bioluminescent communication (Owens & Lewis, 2018).

Sexual communication in fireflies involves emission and perception of bioluminescent signs and/or pheromones, the combination of which varies across species and is fine-tuned according to the different environments and daytime periods in which they occur (Cronin *et al*., 2000; Stanger-Hall *et al*., 2018). In fact, pheromone signalling is more effective in woodlands – where wind if buffered by trees – and light signalling is more effective in dark environments, especially during night-time (Stanger-Hall *et al*., 2018). As such, species relying on these two signals might have narrower niches, and live in habitats that are threatened by anthropisation in multiple dimensions.

Firefly species in which males use light signalling to find females are particularly vulnerable to light pollution. Due to intense luminosity, the firefly activity is reduced (Hagen *et al*., 2015), flashes activity and abundance are compromised (Firebaugh & Haynes, 2016), resulting that males and females that possibly will hardly find and communicate with one another. In fact, it has been shown that females face sexual competition from city lights (Bek, 2015). Further, firefly larvae – often unnoticed in soil – also depend on bioluminescent communication, which they use as an aposematic signal (De Cock & Matthysen, 2003; Long *et al*., 2012). Thus, larvae may also be equally affected by artificial light because it may hamper their defence mechanisms and decrease their effectiveness as predators (Owens *et al*., 2020). Therefore, it is crucial to keep environments safe from artificial light to protect firefly species.

Protected areas (PAs) are the cornerstone of biodiversity conservation and play a key role buffering biodiversity from a wide range of anthropogenic stressors (Margules & Pressey, 2000). However, in several regions of the southern hemisphere high proportions of PAs have experienced recent and significant increases in light pollution (Gaston *et al*., 2015a). Many of these regions are biodiversity hotspots that support high levels of richness and endemism of species, including fireflies.

Key questions about light pollution and insect (particularly fireflies) conservation include: how many species are experiencing darkness erosion somewhere in their geographic range, how extensive this exposure is, how it changes through time, how it interacts with other anthropogenic stressors, and how much can be buffered by PAs. These questions have been addressed only for a few groups of vertebrates (Duffy *et al*., 2015) and plants (Correa-Cano *et al*., 2018). Addressing these questions for insects, especially fireflies, is challenging given that geographic range maps are not available for all or most of the species.

Here, we combined species distribution modelling and threat mapping to assess the spatial extent and trends of light pollution exposure for a range of data-deficient species, like fireflies. We illustrated our approach with a firefly species potentially prone to be vulnerable to light pollution, the tracker ghost, *Amydetes fastigiata*. This nocturnal firefly stands out among lampyrids by their elaborate male antennae, with a huge surface area for chemical receptors, ranging from 14 up to 64 flabellate antennal joints, and large lanterns (Silveira & Mermudes, 2014; Nunes *et al*., 2019), which they use to find females. *Amydetes fastigiata* is endemic to the Atlantic Forest hotspot, a region severely threatened by urban sprawl since more than 60% of the Brazilian population lives within the Atlantic Forest domain (Scarano & Ceotto, 2015). Hence, understanding how the interplay between habitat change and light pollution affects the distribution of *Amydetes* fireflies would provide insight on how multi-modal signallers might respond to future environmental changes and inform conservation policies. However, ecological and conservationist studies on *Amydetes* fireflies have been impaired by severe knowledge shortfalls on their ecological niches, geographic ranges and even taxonomic boundaries, despite recent efforts (Silveira & Mermudes, 2014).

We applied our combined methodological approach to evaluate to what extent light pollution, deforestation and urban sprawl stress areas over the distribution of *Amydetes fastigiata*. This tracker ghost firefly makes a particularly valuable case study, as it occurs throughout the Atlantic Forest in urban forests located inside and outside PAs (Silveira & Mermudes, 2014). Thus, our specific goals were: (i) to predict the potential distribution and environmental suitability for the tracker ghost *Amydetes fastigiata* firefly in the Atlantic Forest, (ii) to assess the exposure of *Amydetes fastigiata* to three anthropogenic stressors – light pollution, urbanisation and deforestation – over space and time and (iii) to evaluate the level of protection coverage and how the different categories of PAs – strictly protection and sustainable use – stands to buffering the three stressors.

Material and methods

Study area and model organism

The Atlantic Forest is a biodiversity hotspot (Myers *et al*., 2000) known for housing an extraordinary richness of fireflies that nevertheless remain largely understudied (Silveira *et al*., 2020). However, its heterogeneous landscape has been increasingly threatened by urban sprawl at least since the 19th century. Only 11–16% (Ribeiro *et al*., 2009) to 28% (Rezende *et al*., 2018) of its 150 million ha original area (Ribeiro *et al*., 2009) remain covered with natural vegetation. This represents less than 15% of its original cover remaining, of which only 1% is within strictly PAs (Ribeiro *et al*., 2011).

Fireflies are the perfect model to study how increased urbanisation in the Atlantic Forest might affect endemic animals in this biome. We chose the firefly *Amydetes fastigiata* to represent small-bodied, nocturnal animals, which would be most significantly affected by changes in air humidity and turbulence (i.e. vegetation cover), levels of ambient light, like a typical firefly. Moreover, *A. fastigiata* is the best sampled, and has the largest geographic range among its congenerics, that are otherwise usually endemic to narrower ranges, often known from a single locality (Silveira & Mermudes, 2014). In fact, the occurrence of *A. fastigiata* in different forest remnants and PAs close to urban centres makes it well suited for our investigation.

Male *A. fastigiata* are easily spotted year-round across its range, although more abundant during the austral winter (June–August), when they can be seen in hundreds within one's field of vision (pers. obs.). They use multimodal signalling: pheromones for the long-range, but light for the close-range. Males fly close to the ground, seldom above a meter, frequently landing to antennate the soil, where supposedly brachypterous females are likely to dwell. Similar brachypterous or apterous, cryptic females are common in lampyrid fireflies, including females that live buried (e.g. *Lucidota luteicollis* – cf. Lloyd, 2018), which we believe might represent the condition in *A. fastigiata*. Such flightless females are expected to have reduced dispersal abilities and thus would be more susceptible to localised threats. While flying, males will display a behaviour called spotlighting (De Cock *et al*., 2014), also known in other glowing fireflies, in which males would point out their glowing lanterns to the ground, contracting the abdomen to various degrees (Fig. 1). Therefore, it is reasonable to believe that *Amydetes* males follow long-range pheromonal plumes, but find females on site by spotting their glow. Because *A. fastigiata* combines light and pheromonal cues in sexual communication, changes in forest cover and ambient light are very likely to impact its occurrence.

We compiled *A. fastigiata* occurrence data in entomological collections, literature and fieldwork. We obtained nearly a total of 200 preserved specimens in the following collections: CEIOC, Coleção Entomológica do Instituto Oswaldo Cruz, Brazil; CLEI, Coleção Entomológica do Laboratório de Ecologia de Insetos, Brazil; DZRJ, Prof. José Alfredo Pinheiro Dutra, Universidade Federal do Rio de Janeiro, Brazil; MNRJ, Museu Nacional, Universidade Federal do Rio de Janeiro, Brazil; MZSP, Museu de Zoologia, Universidade de São Paulo, Brazil. In addition to the entomological collections specimens, we also investigated the recent review of the firefly genus *Amydetes* incorporating its examined material previously studied by comparison to holotype by Silveira and Mermudes (2014). Furthermore, we studied many adults during several field surveys conducted since 2013 in five PAs located in Rio de Janeiro State, southeastern Brazil: Reserva Ecológica do Guapiaçu (REGUA), Parque Nacional da Tijuca (PNT), Parque Nacional da Serra dos Órgãos (PARNASO), Parque Estadual da Pedra Branca (PEPB) and Parque Estadual da Ilha Grande (PEIG).

Fig. 1. The tracker ghost firefly *A. fastigiata* locate their females by tracking pheromones and glows while pointing its lanterns to the ground – a behaviour known as spotlighting. [Color figure can be viewed at wileyonlinelibrary.com]

Species distribution modelling

We built species distribution models (SDMs) from occurrence records to generate the potential distribution of the tracker ghost firefly *A. fastigiata* based on climatic and environmental suitabilities. We used the correlative Ecological Niche Models/Species Distribution Models approach to associate occurrence data for the firefly *A. fastigiata* to environmental predictors, and then identify areas that are ecologically suitable for the species and generate its potential distribution. This important tool can be used to predict the distribution of biodiversity in face of threats that vary spatially and temporally. Thus, SDMs can be used to inform conservation guidelines in consonance with policy to protect forest remnants and fireflies. By combining taxonomic and ecological expertise, we can contribute towards filling important gaps in South American firefly biology.

After filtering all *bonafide* occurrence records compiled from museum collections and literature to eliminate localities with geographic inconsistencies, we were able to retain a total of

80 occurrence records. To reduce spatial autocorrelation and sampling bias, we applied a species occurrence record thinning procedure using the function 'thin' in the package 'spThin' (Aiello-Lammens, 2015) in R (R Core Team, 2016). This spatial rarefaction procedure sequentially removes occurrence records closer to each other than a predefined distance in order to minimise environmental and geographical bias. The 'thin' function returns a data set with the maximum number of records for a specified thinning distance when run for sufficient iterations (see also Aiello-Lammens *et al.*, 2015). We used a minimum distance of 10 km between each occurrence record to prevent model overfit to areas with high density of occurrence (Boria *et al.*, 2014; Boucher-Lalonde & Currie, 2016). The final data set for *A. fastigiata* retained 21 unique localities as occurrence records.

The initial set of environmental data for our analysis included bioclimatic, topographic, and vegetation variables that were selected to represent a spectrum of characteristics that can be related to ecological features of the target species and are often used in distribution models of terrestrial species (Barbet-Massin & Jetz, 2014). Bioclimatic data were obtained from Worldclim 2.1 database (www.worldclim.org) with a spatial resolution of 2.5 arc minutes (approximately 5 km^2). A total of 19 bioclimatic variables, originally derived from monthly temperature and rainfall values collected from weather stations in 1970–2000, were used to depict the current global climate. Moreover, we included nine topographic variables that characterise the shape of the relief such as: aspect cosine and sine, evergreen and deciduous broadleaf trees, elevation, slope, Topographic Position Index and Vector Ruggedness Measure (Amatulli *et al.*, 2018). The vegetation-related variable included was the Normalised Difference Vegetation Index (NDVI), gathered from the ESA database (ESA, 2014). We used the NDVI mean for the year 2000, that represents the middle point in the time period covered by the occurrence data set. To control the negative effects of collinearity among environmental variables in SDMs and to provide a more objective variable selection in the modelling process, we used a principal component analysis (PCA)-derived variables approach (De Marco & Nóbrega, 2018). We performed a PCA in our set of 28 environmental layers using the 'RStoolbox' package (Leutner *et al.*, 2019). The first six components of PCA were retained because they account for about 85% of the total variance, and their derived variables in raster format were used in the models.

To generate potential geographic distributions for *A. fastigiata* in the Atlantic Forest, we used several algorithms combined in a final ensemble model to reduce uncertainties (Araújo & New, 2007; Qiao *et al.*, 2015): generalised boosting model (or usually called boosted regression trees), generalised additive model, classification tree analysis, artificial neural network, surface range envelop (or BIOCLIM), flexible discriminant analysis, random forest, machine-learning MAXENT, and regression methods Generalized Linear Models (GLM). Together these algorithms cover a considerable range of different mathematical approaches and are among the most used and best performing modelling techniques.

We randomly generated 1000 pseudo-absences from the background area, with a minimum distance of 10 km from presence points. We separated presences and pseudo-absences into 80% for calibration and 20% for evaluation, and repeated this procedure 100 times. Model performance was assessed by True Skill Statistics (TSS) (Allouche *et al.*, 2006). Models with TSS > 0.7 are considered potentially useful, good performance models (Capinha *et al.*, 2014). We then produced ensemble models using only the good performance models for each algorithm. The highest ranked models of all algorithms were then combined to generate one final ensemble map of potential distribution of *A. fastigiata*. Modelling procedures were carried out in 'biomod2' package (Thuiller *et al.*, 2013) in R.

We used the final generated map of the potential distribution of *A. fastigiata* within the Atlantic Forest to assess changes in the stressors over time. Additionally, we categorised the potential distribution (varying from 0–100% suitable) into three thresholds of increasing suitability. To do so, we matched the predicted suitability correspondence to the occurrence points in order to establish the lowest value of suitability where any firefly was found in the field. The lowest suitability value found for any occurrence point was 30% suitable, therefore, values below this threshold were considered unsuitable for *A. fastigiata* distribution. We categorised the distribution into lowest suitability (between 30% and 50%), moderate suitability (between 50% and 75%) and highest suitability (>75%). To limit overprediction of SDMs, excluding suitable habitat greatly outside of observed range, we limited the potential distribution to the area encompassed by a buffer of 300 km around the minimum convex polygon around all occurrence records. This buffer represents the mean distance between all records (200 km) plus 1 SD (100 km). This way, we obtained maps for each of the three categories of increasing suitability that fall within the ecoregions where the tracker ghost firefly has been spotted *in natura*. Lastly, the total distribution and each of the three suitability classes were overlapped with maps of potential stressors: light pollution, urbanisation and deforestation.

Light pollution data

The distribution of artificial light from satellite images has been used as a proxy for urbanisation (Sutton, 2003; Li *et al.*, 2013), population density (Amaral *et al.*, 2006), and economic activity (Chen & Nordhaus, 2011), as well as to assess the spatial extent of light pollution itself (Cinzano *et al.*, 2001; Butt, 2012).

In order to analyse trends in light pollution as a stressor over the distribution of *A. fastigiata*, we used a harmonised global night-time light observations data set 1992–2018 from satellites DMSP and VIIRS, following Li *et al.* (2020). The images are standardised at 1 km resolution and each pixel is represented by a digital number (DN) ranging from 0 to 63. Zero represents darkness, whereas very brightly lit urban areas saturate at values of 63.

We defined a threshold for darkness of <10 DN. This value is a conservative threshold for unlit areas (as opposed to others who consider this threshold to be at <5.5 DN such as Gaston *et al.*, 2015a and Duffy *et al.*, 2015) and limits the extent to which dark sites may be classified as lit to avoid calibration errors. We categorised the lighting intensity into 11 classes varying from 0 to 100%. Assuming <10 DN as darkness (0% light intensity), we categorised each class according to subsequent light intensity intervals of 5 DN; for example, 11–15 DN configure 0–10% intensity, 15–20 configure 10–20% intensity and so on. We considered values >56 DN as 90–100% of light intensity.

Urbanisation and forest cover trends data

We used Atlantic Forest maps from MapBiomas Collection 5 (Mapbiomas, 2020) to assess trends in urbanisation and deforestation over the distribution of *A. fastigiata* for the time frame of 1992–2018. We calculated a degree of urban and forest cover per pixel for each map for the corresponding time frame. Then, we calculated the degree of urbanisation and deforestation using the 'Block Statistics' function from 'Neighborhood Spatial Analysis' toolbox from ArcMap version 10.5 (ESRI, 2015). Finally, we calculated an index of urbanisation and deforestation based on how many pixels in the block displayed presence/absence of the referred land cover class and rearranged the spatial resolution to match the one from light pollution data (∼1 km).

The resulting map displayed the percentage of urban or forest cover for a given pixel, varying from 0 to 961. We categorised the range of values into 11 classes varying from 0 to 100%. Urban categories vary from 0% urbanised to 100% urbanised, whereas forest cover categories vary from 0% deforested to 100% deforested. We defined a threshold of >50% deforestation (Andren, 1994; Pardini *et al*., 2010) and a threshold of >30% of urbanisation as a stressors. These thresholds of how much urbanisation and deforestation characterise as stressors are according to *A. fastigiata* biology.

PAs data

We overlapped the maps from light pollution, urbanisation and deforestation trends with the current PAs system within the distribution of *A. fastigiata*. Data about Strictly Protected Areas (IUCN Categories I–IV) and Sustainable Use Protected Areas (IUCN Categories V–VI) were retrieved from online databases (accessed on November 2020), including World Database on Protected Areas (WDPA, http://protectedplanet.net) and Brazil's Ministry of Environment Database (http://mapas.mma.gov.br). We calculated the change in the stressors within and outside Strictly Protected Areas and Sustainable Use Protected Areas in the distribution of *A. fastigiata*.

Assessing changes in the stressors over time

We delimited the maps of the potential stressors for *A. fastigiata* (light pollution, urbanisation and deforestation) by (i) its entire current distribution of climatic and environmental suitability, (ii) the current distribution with different suitability categories (30–50%, 50–75%, and >75% suitable), and (iii) according to the PA systems, comparing changes both within and outside these areas within the entire distribution of *A. fastigiata*.

To assess the changes over the full time frame, we compared the first and last 5 years periods. We calculated mean values for 1992–1996 and for 2014–2018. Within both periods, we transformed the continuous index for luminosity and the continuous land cover of deforestation and urbanisation into categories of intensity varying from 0 to 100%. We used the number of pixels representing each category to calculate statistical significance of change through time. Therefore, we performed a χ^2-test to quantify the difference between two temporal categories groups (1992–1996 and 2014–2018). The χ^2 residuals show the degree of change by category in the amount of pixels of light pollution, urbanisation and deforestation among different intensity categories over time, both inside and outside different types of PAs. Since the number of pixels is too high and thus all tests are likely to be significant owing to effect-size, we performed a Cramér's V test to assess how strong both 1992–1996 and 2014–2018 categorical fields were associated. The maps were created using ArcMap version 10.5 (ESRI, 2015) and the graphs quantifying the difference in number of pixels were created using GraphPad Prism software version 8.0.1 (GraphPad Software, San Diego, CA, USA, www.graphpad.com).

Time series trend analysis

We used a Mann-Kendall trend analysis to test whether an upward or downward trend in the exposure to light pollution, urbanisation and deforestation was occurring in the geographic range of *Amydetes fastigiata*. This is a test for monotonic trend in a time series based on the Kendall rank correlation (Bennie *et al*., 2014). We evaluate the mean number of lit pixels, urban pixels and deforested pixels for each year for the entire time series analysed (27 years, 1992–2018).

Results

Potential distribution of Amydetes fastigiata

The tracker ghost firefly *Amydetes fastigiata* was observed and collected at urban forests within the two biggest economic centres of Brazil, where human population density is high (Rio de Janeiro and São Paulo) (Fig. 2a). It was mostly collected in the Tijuca National Park and Pedra Branca State Park – among the largest urban forests of the world (ICMBio, 2008) – both located at the Rio de Janeiro State. As such, our models suggest that its potential distribution is mostly located in the surroundings of Rio de Janeiro, São Paulo and Espírito Santo (Fig. 2b). However, our models show that the distribution is not only limited to the south-eastern coast where they were observed in the field, but also extends to small parts of north-eastern and south coasts. Its entire distribution is characterised by both Serra do Mar and Bahia Coastal Forest ecoregions at the Atlantic Forest (Supporting Information Fig. S2).

The three suitability categories that we established – low, moderate and high suitability – varied spatially ranging from

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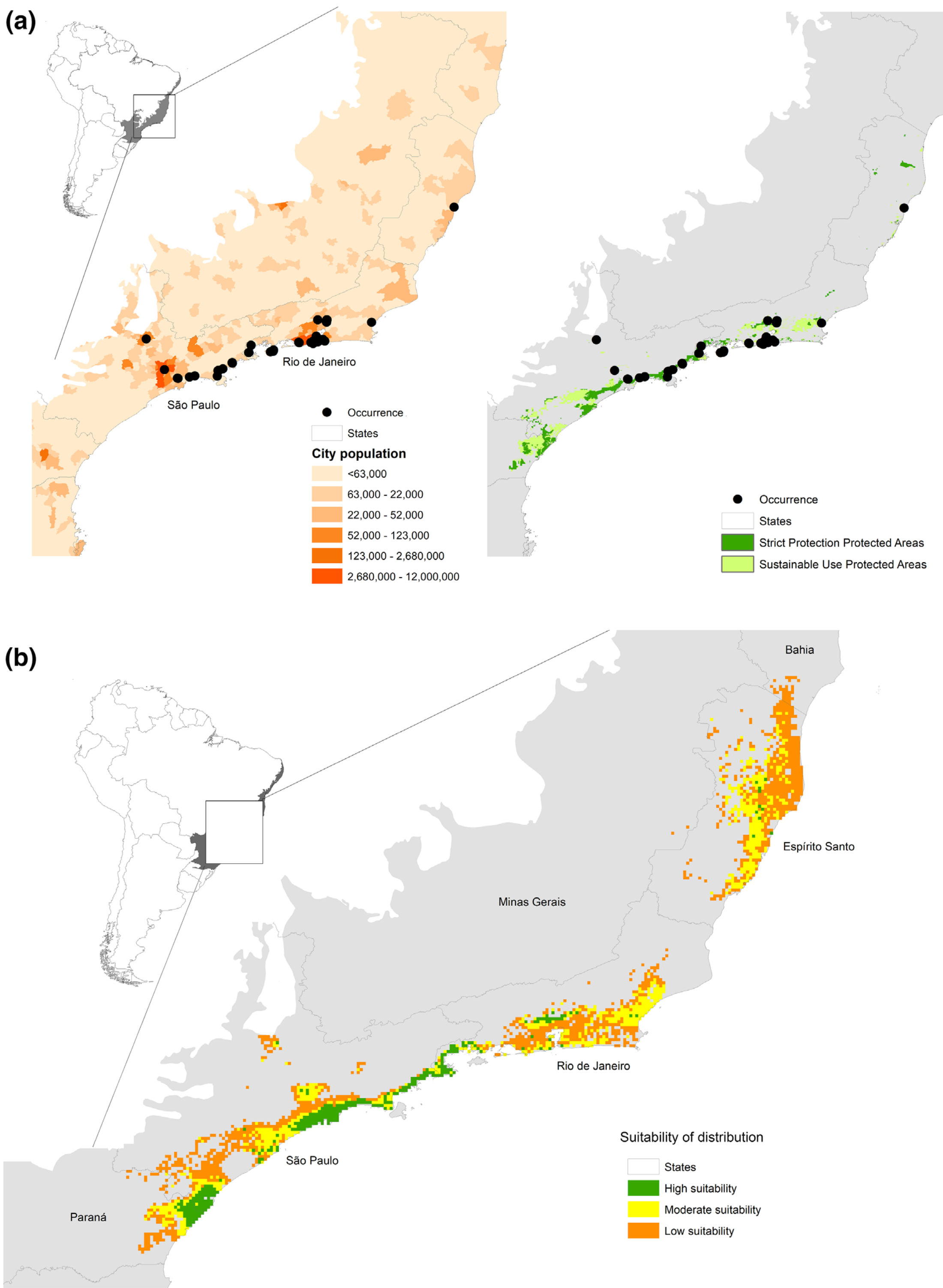

Fig. 2. Occurrences and current distribution of *A. fastigiata* on the Atlantic Forest. (a) The dots represent places where the tracker ghost firefly was observed and collected. On the left, the red colours indicate the population of the cities within the Atlantic Forest (representing a proxy for city size). Population maps obtained from IBGE database in reference to the year of 2010. On the right, green colours represent PAs within the potential distribution of the tracker ghost firefly, divided into strictly protection and sustainable use categories. (b) Current distribution of *A. fastigiata*. The maps for each modelling algorithm can be found on Supporting Information Fig. S1. Distribution classified in high, moderate and low suitability. [Color figure can be viewed at wileyonlinelibrary.com]

south of Bahia State to north of Paraná State coasts (Fig. 2b; Supporting Information Fig. S1). The highest suitability represents 12.8% of their potential distribution and is concentrated to the southern coast of the Rio de Janeiro, São Paulo and Paraná States, corresponding to the north of the Serra do Mar Coastal Forest. However, a few areas could be observed among the north of their distribution (middle of Espírito Santo, represented by Bahia Coastal Forest ecoregion) (Fig. 2b). The potential distribution presents moderate and lowest suitability areas, comprising 32.7% and 54.5%, respectively, extending from south (Paraná state) to north-eastern of the Atlantic Forest (south of Bahia state). Indeed, the total distribution comprehends large distances over the Atlantic Forest; however, the northern of Espírito Santo and Bahia are restricted to less suitable conditions. In the south-eastern, specifically São Paulo State, these areas are more isolated when compared to areas with high suitability (Fig. 2b). Furthermore, the tracker ghost firefly is predicted to be found in different forest remnants inside and outside PAs.

The entire extension of the potential distribution of *A. fastigiata* falls mostly within forest remnants outside PAs (60%), while only 16% and 24% overlap with strictly protection and sustainable use areas, respectively. However, when considering only the areas with highest suitability, the extent of distribution that is protected rises to more than 80% (45% in strict protection and 36% in sustainable use areas). High suitability areas include strictly PAs whose occurrence of *A. fastigiata* has already been reported (e.g. Parque Nacional da Serra dos Órgãos, Parque Nacional da Tijuca, Parque Estadual da Pedra Branca, Parque Estadual da Ilha Grande, Parque Nacional da Serra da Bocaina and Parque Estadual da Serra do Mar) and strictly PAs where it is expected to occur according to SDM results (e.g. Parque Estadual Lagamar de Cananeia, Estação Ecológica de Juréia-Itatins, Parque Estadual Restinga de Bertioga, Parque Nacional de Superagui and Refúgio de Vida Silvestre de Santa Cruz).

The exposure to stressors over Amydetes fastigiata *distribution*

The degree of exposure to deforestation, urbanisation and light pollution on the potential geographic distribution of *Amydetes fastigiata* varied between the three stressors (Fig. 3). Regarding spatial extent of the exposure, deforestation was the most pervasive stressor, affecting more than half of its distribution (Fig. 3c). Light pollution follows, where darkness erosion affects more than a third of its distribution (Fig. 3a). The extent of urbanisation is even smaller, affecting more than 10% of the distribution (Fig. 3b). However, the exposure of the three stressors between the beginning (1992–1996) and end (2014–2018) of the analysed period raises concern about the growth of light pollution. Although the proportion of the degree of exposure remained the same, the difference between the beginning and end of the time series revealed a small decrease in deforestation (55.74–55.68%), an increase in urbanisation (8.63–10.63%) and a higher increase in light pollution (23.26–33.82%).

Light pollution significantly increased between time periods reducing dark areas (0% light intensity) and greatly increasing areas between 0% and 10% and extremely lit areas of 90–100% (Fig. 4; Supporting Information Table S2). All light intensity categories showed a low association (>0.1) change over time (Fig. 4; Supporting Information Table S2), with the categories 0–10% and 90–100% with highest contributions to the Cramér's V effect size of χ^2 test differences (Fig. 4; Supporting Information Table S2). The change sums up to approximately 1.400 km^2 of dark areas impacted to some degree by light pollution over the entire distribution of *A. fastigiata*. Similarly, areas with no urbanisation were also reduced (0% urban intensity), whereas most urbanised areas increased (90–100%). In contrast to light pollution and urbanisation that are localised but significantly growing threats over time, deforestation is widespread over the distribution of *A. fastigiata* (more than half of its distribution suffers some degree of deforestation). However, there were no significant changes in deforestation trends over time, only slightly increasing areas with highest deforestation intensity (90–100%).

The negative effect of the stressors was maintained over areas with the highest suitability over *A. fastigiata* distribution (Supporting Information Fig. S3). Light pollution significantly increased over dark areas (reduction of 0% light) and doubled areas with highest light intensity (Supporting Information Fig. S3). Urbanisation also increased over time, especially reducing areas that were not urbanised and increasing areas with highest urbanisation. Areas with highest deforestation intensity (90–100%) increased between both time periods; however, there was also a slight increase in areas without deforestation (0% deforestation intensity). A similar pattern was observed in areas with moderate (Supporting Information Fig. S3) and lowest suitability (Supporting Information Fig. S3), where light pollution significantly increased over time (Supporting Information Table S2) whereas urbanisation and deforestation changed in lower magnitudes.

Stressors over PAs

Most of the potential distribution predicted for *A. fastigiata* is not protected, but the existing PAs mostly fall into the category of protection that allows sustainable use instead of being designated strictly for biodiversity protection (Fig. 2a).

PAs successfully buffer the negative impacts from deforestation trends (Fig. 3). Strictly protection and sustainable use areas have much lower deforestation intensities than areas without protection. Only one-fourth of the area without protection displays deforestation intensities below 50%, and this trend increases with time. The trend is inverted within sustainable use and strict protection areas, where 75% and 95% of their area are below the threshold of 50% deforestation intensity, respectively. Urbanisation is substantially reduced in areas of strict protection and sustainable use, where <1% of their area is urbanised in intensities higher than 50% (Fig. 3). Urbanisation trends, however, are increasing over time in all intensities.

PAs also buffer the intensity of light pollution, although to a lesser extent (Fig. 3). Although only 1% of PAs' extent has intensive urbanisation levels, the protection is not able to halt

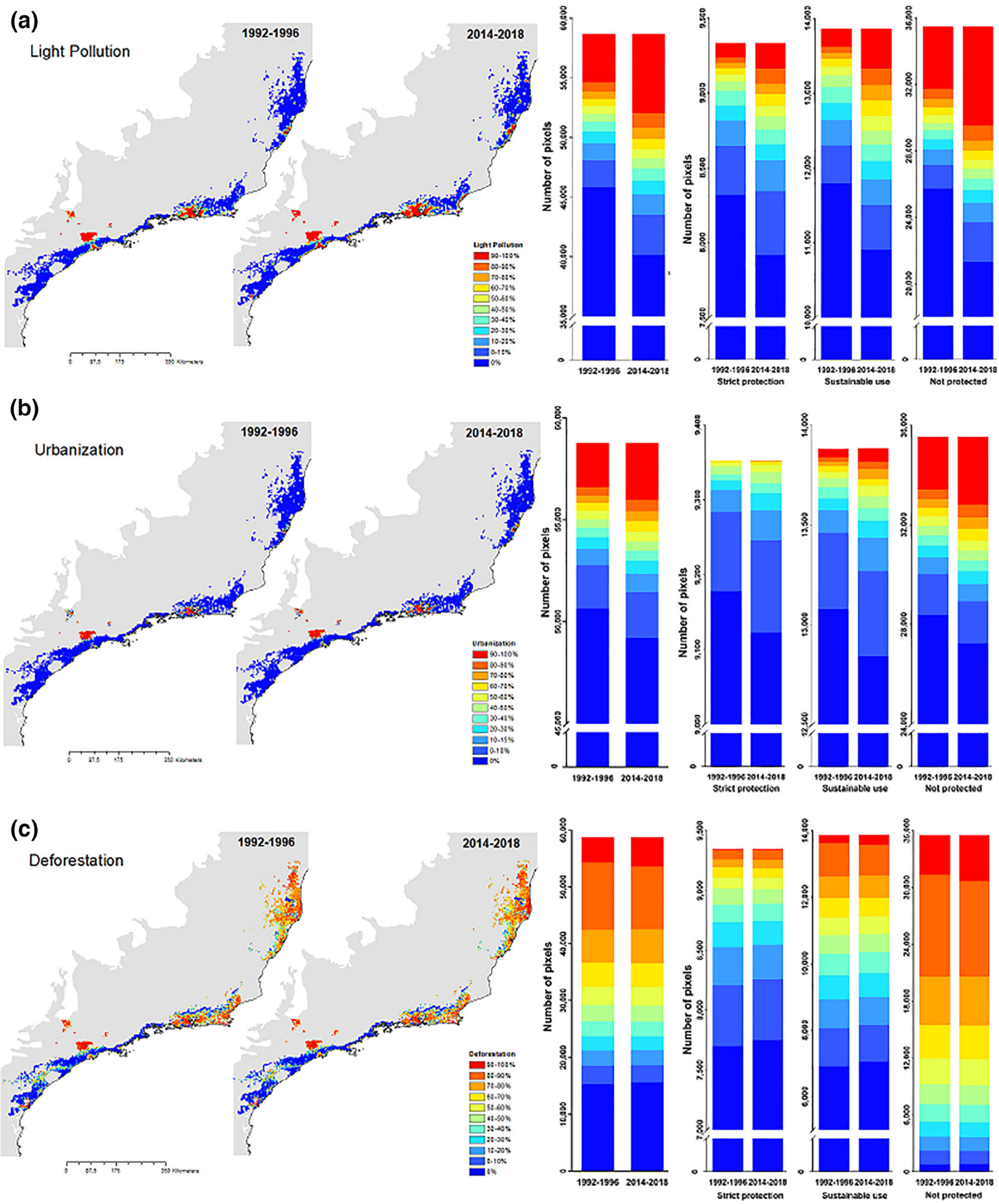

Fig. 3. Change in stressors over time over the total potential distribution of *A. fastigiata* and within PAs. Maps are mean values between two time periods (1992–1996 and 2014–2018), showing changing trends in the main stressors (a) light pollution, (b) urbanisation and (c) deforestation over the total distribution of the tracker ghost firefly. Graphs show the number of pixels in each category of stressor intensity (0–100%) between both time periods for the entire potential distribution and according to the degree of protection of conservation units. The effects are separated between areas with strict, sustainable use, or no protection (i.e. areas outside the limits of both strictly protection and sustainable use PAs). [Color figure can be viewed at wileyonlinelibrary.com]

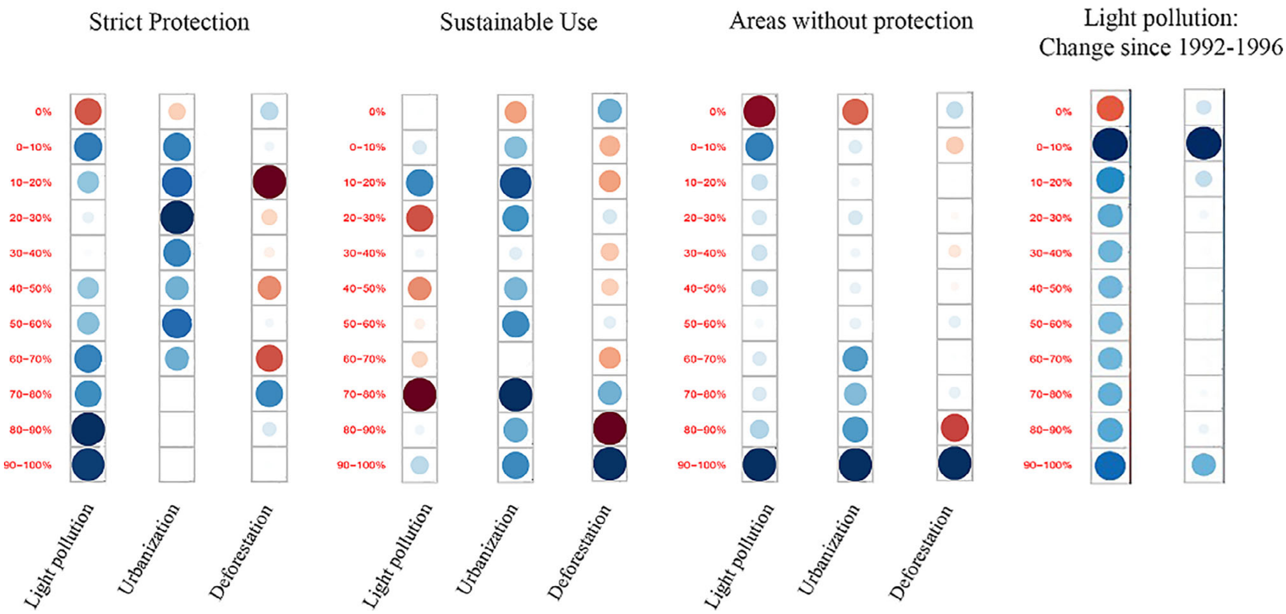

Fig. 4. Correlation of χ^2 residuals for the change in stressors over time in potential distribution of the *A. fastigiata* and within and outside PAs. Blue circles represent a positive correlation whereas red circles represent a negative correlation among each stressor over the time. Colour grading represents which percentages contributed more. Circle size represents how much it differed from the pattern. The changes correspond to the average of the last 5 years (2014–2018) compared to the average of the first 5 years (1992–1996) analysed in this study. [Color figure can be viewed at wileyonlinelibrary.com]

higher light pollution intensities. The largest increases over time lie within the transformation of darkness into slightly lit areas (0–10%) and increase in highest intensities (90–100%), both inside and outside PAs. The increase in light pollution over time displayed a low association (>0.1) both outside and inside PAs of sustainable use in the Cramér's V effect size of χ^2 test, while strictly PAs displayed little or no association (<0.1) over the time period assessed (Fig. 4; Supporting Information Table S2).

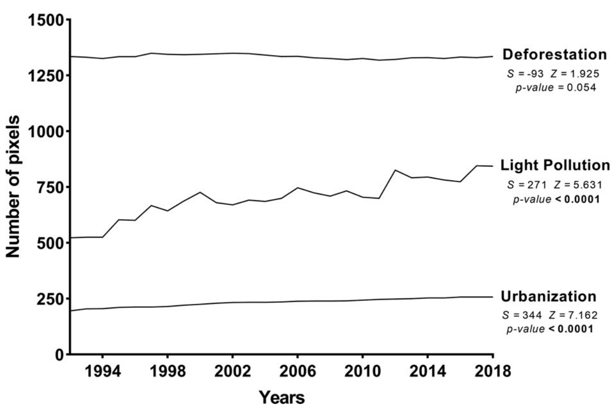

Fig. 5. Trends of increase in light pollution, urbanisation and deforestation over time. Lines represent a trend analysis of upward increase in number of pixels for three anthropogenic stressors (deforestation, urbanisation, light pollution) across the range of Amydetes fastigiata during the 27 years (1992–2018) analysed. Statistical results of Mann-Kendall trend test are displayed. Upward trends in light pollution and urbanisation are statistically significant ($P < 0.0001$).

Temporal trends in the exposure to the stressors

Different patterns of temporal trends in the exposure to the three anthropogenic stressors over the distribution of *Amydetes fastigiata* were detected. The exposure to light pollution over the geographic range of tracker ghost firefly during 1992–2018, calculated by considering the average number of lit pixels in each of the 27 years, showed a significant upward trend (S = 271, Z = 5.631, P-value < 0.0001; Fig. 5). The same pattern was detected to the exposure to urbanisation, with the average number of urban pixels in each year of the time series also showing a significant upward trend (S = 344, Z = 7.162, P-value < 0.0001; Fig. 5). Otherwise, there was no statistically significant temporal trend in the exposure to deforestation over the geographic range of *A. fastigiata* in the time series, in which the average number of deforested pixels in each of the 27 years showed a no significant downward trend (S = −93, Z = 1.925, P-value = 0.054; Fig. 5).

Discussion

Our methodological approach, combining species distribution modelling and threat mapping, yielded a framework to assess the spatial extent and trends of light pollution exposure, urbanisation and deforestation over the range of tracker ghost firefly, *Amydetes fastigiata*, a range data deficient species potentially vulnerable to light pollution. Our proposed approach can provide support to assessments of anthropogenic stressors' impact on biodiversity and influence decisions about conservation,

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particularly for species with no known range maps such as insects and fireflies.

Our results show that a great extension of *A. fastigiata*'s potential distribution is severely stressed by deforestation; however, it is also exposed to considerate urbanisation and light pollution. Although the amount of area exposed to urbanisation and light pollution is not as high as the area facing deforestation, they show faster rates of increase. Thus, light pollution emerges as a paramount concern that can become much more prominent in the future, especially because of its pervasiveness even within the boundaries of PAs.

Worldwide decline in firefly populations

During the past several years, decline in firefly populations has been linked to anthropogenic impact (Lewis *et al*., 2020), particularly habitat destruction (Gardiner & Didham, 2020) and pesticide use (Tabaru *et al*., 1970), whereas lights at night are usually regarded as a consequence of changes in land-use (Gaston *et al*., 2014). Land-use change, in the form of deforestation and/or urbanisation, has repercussions of loss of habitat that directly impact fireflies populations, and can lead to their extirpation (Gonçalves-Souza *et al*., 2020). Light pollution poses as an additional stressor, by-product of such changes in land, that do not directly extirpate populations. Instead, they are a more silent but constant threat in the individual-level affecting intra and inter-specific relations, which may lead to unforeseen consequences for the populations. Therefore, how the interplay between light pollution and changes in land-use affect firefly populations remained elusive. This is particularly important as it is currently unknown if PAs, especially in densely inhabited urban regions, effectively protect fireflies. We consistently showed that PAs are not enough, since light radiation sprawls inwards in their boundaries .

In the last decade, increased number of field experiments have reported the consequences of artificial light at night on firefly abundance, courtship activity, flash intensity and duration, and mating success in different firefly species (e.g. *Photinus pyralis*, *Photuris versicolor*, *Luciola italia*, *Aquatica ficta* and *Lampyris noctiluca*) – all of which in the northern hemisphere (Ineichen & Ruttimann, 2012; Bird & Parker, 2014; Costin & Boulton, 2016; Firebaugh & Haynes, 2016; Owens *et al*., 2018). Our study is the first to forecast evidence of a significant increase in light pollution and land-use change that can lead to a decline of firefly populations in the southern hemisphere.

We showed that light pollution is significantly increasing within the range of *Amydetes fastigiata* – the first Neotropical species assessed in this regard – which suggests that its habitat might be more affected as urbanisation spreads. The impact of light pollution on spotlighting fireflies like *A. fastigiata* is yet to be assessed, but given the use of light signals in their courtship, it is likely that they will be negatively impacted by light pollution. The protection of fireflies in different forest remnants inside PAs, especially close to urban centres, makes them well suited for conservation while disseminating social education by using them as a flagship species.

Light pollution as the fastest growing stressor to fireflies

Our results show that *A. fastigiata*'s distribution occurs in places that are under severe deforestation, urbanisation and with increasing light pollution intensity. The intensity of artificial light exposure in Brazil has been increasing over the last decades, extensively impacting different vegetation types, especially alongside its coast (Freitas *et al*., 2017), where most of *A. fastigiata* distribution lies within. Its distribution is limited to coastal forests – which largely overlap with the most urbanised areas of the country, especially its two biggest economic centres. Indeed, our results show that light pollution is increasing both in extent and in intensity over the range of distribution of *A. fastigiata*, casting concern about the future of the species. Below, we discuss actions that must be urgently taken in order to more effectively protect firefly populations in the Atlantic Forest to better conserve them.

The role of PAs

Conservation units in Brazil, especially at the Atlantic Forest, act as indispensable shelters for countless species and ecosystems. These PAs are known to buffer impacts from a wide range of anthropogenic threats such as deforestation, urbanisation and even climate change (Vale *et al*., 2018). Our results confirm that PAs successfully buffered deforestation trends over time and were able to reduce urbanisation to some extent within *A. fastigiata*'s distribution. However, the threat raised upon by light pollution is underestimated despite its profound consequences for biodiversity within PAs (Gaston, 2019).

Urban centres impose several threats to surrounding areas, most prominent within a 50 km radius from its boundaries. PAs are often close to urban areas, which already impacts the former (Mcdonald *et al*., 2009), but this distance is predicted to further shrink in the future due to urbanisation sprawl (Mcdonald *et al*., 2008). Our results reveal a large urban expansion that is already occurring in the last 20 years within the distribution of *A. fastigiata* and even within less strictly PAs. This is especially concerning in biodiversity hotspots in South America, including the Atlantic Forest, where future high urban growth is projected (Güneralp & Seto, 2013; Guetté *et al*., 2018).

Light pollution is deeply associated with urban city limits and population size (Operti *et al*., 2018), therefore, as cities expand, increased light pollution is also expected on the boundaries of PAs. Although areas both within and outside PAs have become brighter in the last decades, light intensity within PAs is still much lower than outside. PAs, therefore, still represent important darker havens for biodiversity within its boundaries. However, increasing artificial night light from neighbouring lit areas can exert continuous pressure and disrupt conservation efforts (Gaston *et al*., 2015a). Although inner PAs are darker, the high intensity of light in their surroundings weakens the darkscape's connectivity because light can be visible even at great distance (Guetté *et al*., 2018). Nocturnal landscapes far beyond lit urban areas are still affected (Kyba & Hölker 2013). Because light stemming from neighbouring areas can travel great distances, they can even escalate changes in species distributions (Kyba & Hölker 2013) (e.g. can even attract or repel biodiversity, Guetté *et al*., 2018). PAs are important shelters for biodiversity but they cannot stand alone: careful urban planning is imperative to mitigate effects of the ever-growing threat of light pollution in their surroundings.

Mitigation

Light pollution can interact with other by-products of urbanisation such as increasing temperature from urban heat islands (Miller *et al*., 2017) and noise pollution, thus affecting biodiversity and species interactions (McMahon *et al*., 2017). However, these effects are not homogeneous through urban landscapes (Cheon & Kim, 2020). Since light pollution effects are intertwined between physiological, ecologic and socioeconomic aspects, mitigating actions should be carefully designed (Hölker *et al*., 2010) in order to reduce the impacts over bioluminescent fireflies. Artificial lights worldwide are increasing in radiance and extent throughout the last decade, so mitigation of the effects of light pollution should take lamp design into consideration. The position of lighting can enhance light-trespass when positioned towards the horizon whereas towards the ground enhances shading (Gaston *et al*., 2012). Ultimately, efforts to reduce light pollution should aim at preventing enlightenment of dark areas, opting to reduce light duration and adjusting lamps to prevent high intensity lighting (Gaston *et al*., 2012, 2014). Maintenance of dark areas and protected dark areas is the most suitable target for conservation science, as they represent opportunities to preserve species in this threatened biome (Soanes & Lentini, 2019).

Conclusion

Here, we provided potential distribution maps and forecasted threat rates by combining taxonomic and ecological expertise towards filling in important gaps in South American firefly biology, which can help inform conservation policies. The prediction of occurrence of *A. fastigiata* in areas where it is not known (e.g. South of São Paulo and North of Paraná), or has seldom been collected (e.g. South of Bahia) underlines the need for further studies and fieldwork to inform the elaboration of effective conservation strategies and fieldwork to know species before they get extinct.

Our results suggest that the PAs (strictly protection and sustainable use) in the Atlantic Forest have been important to halt deforestation and are able to reduce urbanisation within its limits. However, they might be unable to shelter effectively species from light pollution, which calls for an evaluation of regional conservation policies. Although the areas predicted to be best suitable for *A. fastigiata* mostly fall within PAs, a great extent of its distribution is still unprotected – which highlights the need for designation of new areas to be prioritised.

Importantly, although deforestation still remains as the higher cumulative impact, light pollution has a tendency of advancing faster than the other stressors, raising serious concern about the pervasive impacts that this stressor may represent for fireflies in the future. Areas where we used to know as ‘darkness’ or with very low luminosity are the main areas that we should be drawing attention since their enlightenment might represent the loss of the last dark havens for biodiversity. We hope that the baselines and standards of our framework using *A. fastigiata* foster future applications with fireflies worldwide.

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Data availability statement

Data openly available in a public repository that issues data sets with DOIs.

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1: Statistical results from the distribution modelling of *A. fastigiata* on the Atlantic Forest.

Table S2: Cramér’s V effect size of Chi-square test.

Figure S1: Current distribution of *A. fastigiata* on the Atlantic Forest based on nine different modelling algorithms.

Figure S2: Total distribution of *A. fastigiata* over Atlantic Forest’s ecoregions.

Figure S3: Change in stressors over time over the three different categories suitability of distribution of *A. fastigiata*.

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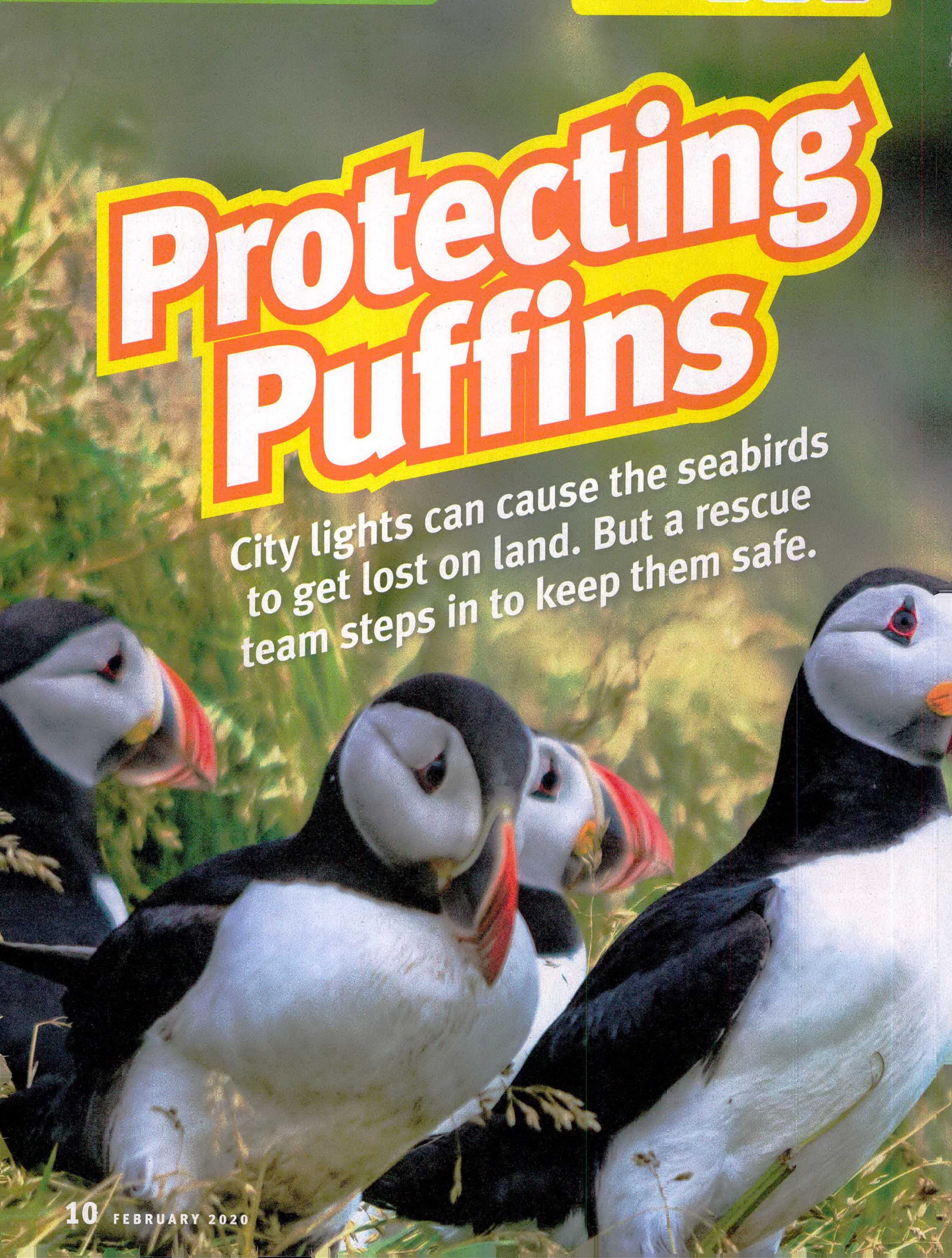
Protecting Puffins

City lights can cause the seabirds to get lost on land. But a rescue team steps in to keep them safe.



The night last August was cold and drizzly, but Addison Browne was excited to be out of bed. The 12-year-old was in a parking lot in Witless Bay, a town in Newfoundland, Canada. She pointed her flashlight under a parked car and found what she was looking for: a young puffin, looking lost and frightened.

Baby puffins look different from adults: Their beaks are dark and their faces are grayer.

Puffins nest in burrows they dig in steep sea cliffs.

Addison Browne holds a baby puffin she rescued with the Puffin Patrol.

Addison gently pulled the small bird out and set it down in a plastic crate. She breathed a sigh of relief. The baby puffin, called a puffling, was safe.

Addison is a member of the Puffin Patrol. Every summer, the group of volunteers saves pufflings that have become lost on their way to the sea. Since 2010, the Puffin Patrol has rescued more than 4,000 birds.

Birds of the Sea

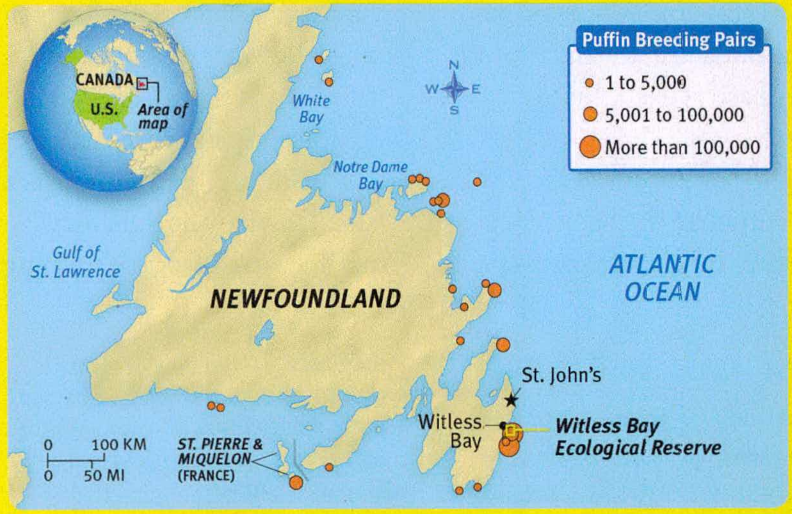
With their pudgy bodies and waddling walk, Atlantic puffins can appear clumsy on land. "But underwater they're so elegant," says Sabina Wilhelm. She's a biologist with the Canadian Wildlife Service. The pigeon-sized birds spend most of their lives at sea. They live all across the North Atlantic Ocean. Puffins can dive up to 60 meters (200 feet) to catch small fish.

In the spring, the birds come to land to breed. About 600,000 puffins nest in underground holes called burrows on four small islands in the Witless Bay Ecological Reserve *(see Puffin Homes, below)*. This protected area off the east coast of Newfoundland is home to North America's largest Atlantic puffin **colony**.

"When the pufflings hatch, they're like puffballs," says Suzanne Dooley. She's a director at the Canadian Parks and Wilderness Society, which runs the Puffin Patrol. The pufflings stay in the burrows for about 50 days. Then at night in August and early September, they use

Puffin Homes

Atlantic puffins breed in these areas of the Newfoundland coast in the spring. They spend the rest of the year at sea.



SOURCE: SABINA WILHELM, CANADIAN WILDLIFE SERVICE

Think: What do you notice about where puffins breed?

SHUTTERSTOCK.COM (PUFFINS); MARK COLOMBUS/ALAMY STOCK PHOTO (PUFFIN NEST); COURTESY OF STEPHEN BROWNE (ADDISON BROWNE); JIM MCMAHON (MAP)

Scientists weigh the pufflings to make sure they're healthy before releasing them.

Puffin Patrol volunteers release the birds the morning after they're rescued so they can fly safely to the ocean.

the light from the moon and stars to guide them to the ocean.

But some pufflings never make it to the sea. The problem is **light pollution**, light from nearby towns that brightens the night *(see What Is Light Pollution?, page 13)*. "The lights attract the pufflings," says Wilhelm. "It's their first time outside of the burrow, so they easily get confused."

Light's Dark Side

Humans have been using **electricity** to power lights for more than 100 years. Today, there are more bright lights from buildings, cars, street lamps, and billboards than ever. This light travels in all directions, brightening unintended areas. Big cities produce so much light that the stars can become hard to see! That happens when light **reflects** off particles in the **atmosphere**, causing the night sky to glow.

The coast near the Witless Bay colony is lined with several small towns. The light they produce can disorient pufflings on cloudy or foggy nights, when the moon and stars are hidden. Some birds fly into the towns and get stranded. Many are killed by cars or cats.

The Puffin Patrol brings the pufflings to scientists. The scientists weigh and measure the birds to see how healthy they are. Finally, volunteers help the scientists release the birds at sea.

Dimming the Lights

Light pollution affects other animals too, like turtles, frogs, and bats. There are many ways to help solve the problem *(see Light-Pollution Solutions, right)*. One way is to turn off the lights you're not using. "Every little action matters," Dooley says.

Addison started volunteering with the Puffin Patrol six years ago. In that time, she's

words to know

colony—a group of the same organisms living together

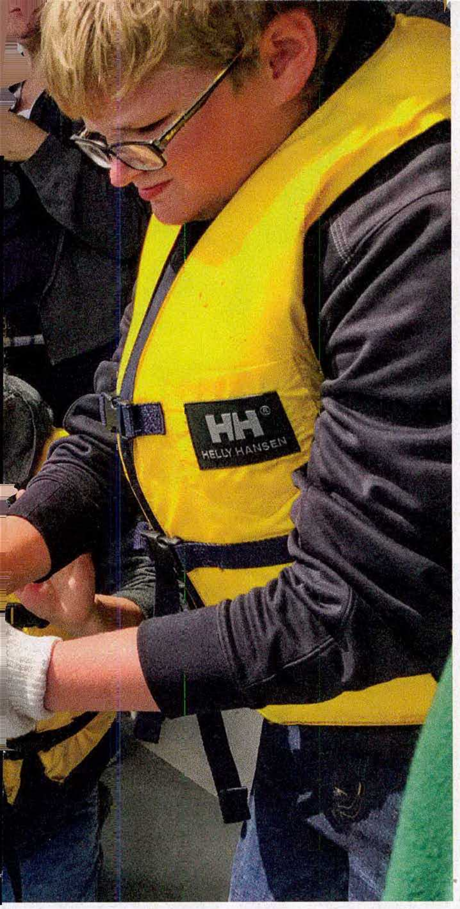
light pollution—artificial light that has negative consequences on people and the environment

electricity—the flow of electric charges that power light bulbs and other devices

reflect—to cause light or sound to bounce in a different direction

atmosphere—the protective layer of gases surrounding a planet

SANDER MEURS (WEIGHING PUFFLINGS); JENNIFER BAIN (PUFFIN PATROL)



saved more than 50 pufflings! She also tries to help by using less lighting at home.

The day after finding the puffling last summer, Addison helped Dooley release it on a beach. She felt happy as the bird took flight. "I feel better knowing it's safe now," she says.

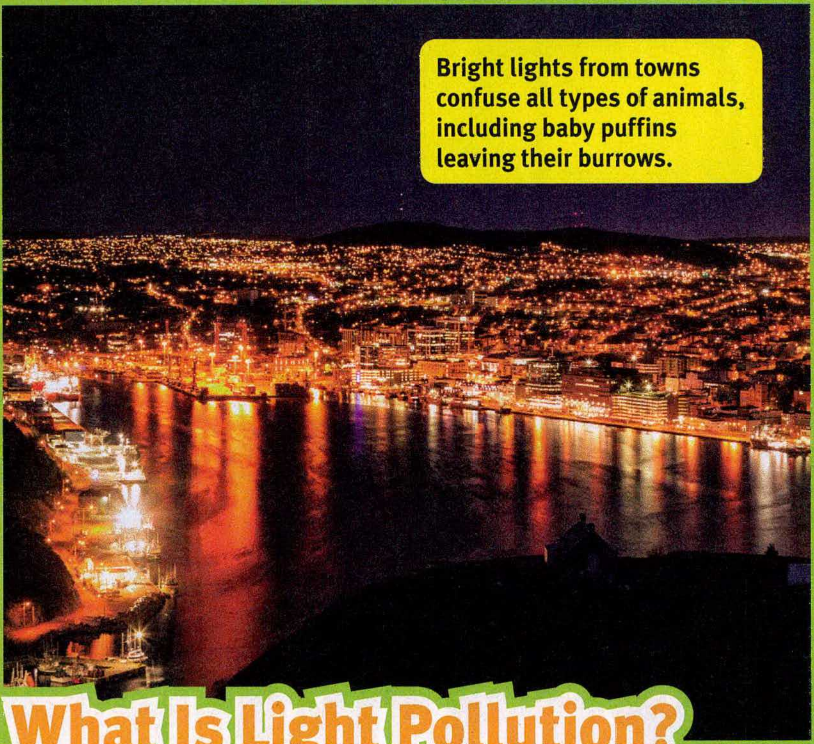
—Alessandra Potenza

SHUTTERSTOCK.COM (ALL PHOTOS); NICOLE HOCUTT FOR SCHOLASTIC (LIGHT-POLLUTION DIAGRAM)

Light-Pollution Solutions

Here's what you and your family can do to help reduce light pollution.

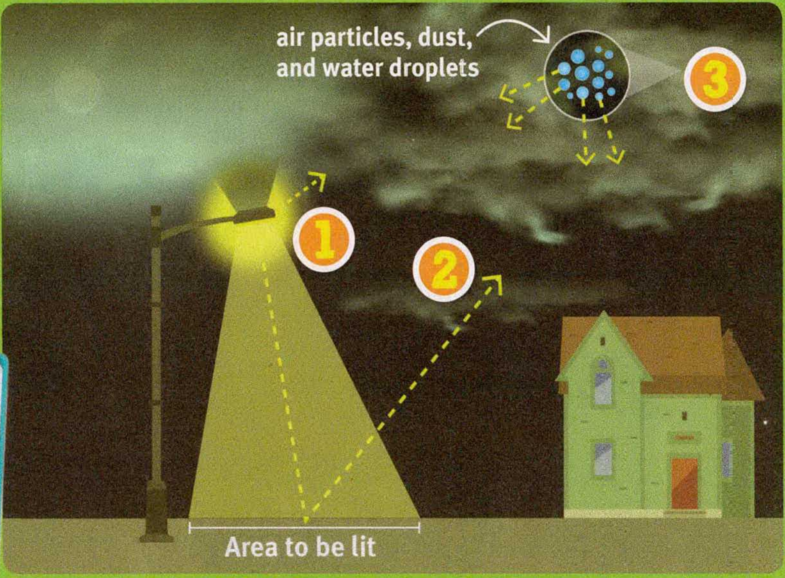
- ✓ Turn off unnecessary lighting outdoors and indoors.
- ✓ Keep outdoor lights low to the ground, and use light shields that keep light in the intended area.
- ✓ Use energy-efficient light bulbs that produce warm white or amber light. Blue light bothers animals more.



Bright lights from towns confuse all types of animals, including baby puffins leaving their burrows.

What Is Light Pollution?

Bright artificial light can spill into areas that are not supposed to be lit up. That can disrupt animal behavior. Here are three ways light pollution can cause a nighttime glow.



SOURCE: ALEXANDRE SIMONEAU, UNIVERSITÉ DE SHERBROOKE, CANADA

1 Light travels in straight lines in all directions, spilling into unintended areas. 2 When light reflects off surfaces like pavement, it travels upward. 3 Particles in the atmosphere reflect light, causing the night sky to glow.

Think: How does light pollution make the stars look dim?

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Science

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Light Pollution

Author(s): Kurt W. Riegel

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30 March 1973, Volume 179, Number 4080 SCIENCE

Light Pollution

Outdoor lighting is a growing threat to astronomy.

Kurt W. Riegel

It is my purpose in this article to delineate astronomical dark sky requirements for scientifically useful observing, to survey the influence on astronomical observing conditions of man-produced electromagnetic radiation, to examine what conditions will probably prevail for the next generation or two of observing astronomers, and to suggest changes in public policy that would alleviate some of the actual and projected damage to the astronomical observing environment. During this century, astronomers have had to contend with the phenomenon of light pollution, defined here as unwanted sky light produced by man, because of population growth and increased outdoor illumination per capita. Both of these causes of increased light pollution are important, the former having been more important early in the century and the latter being of most concern now.

Survey of the Problem

The last hundred years have been marked by two periods of very rapid growth in astronomical observing facilities in the United States. Both were initiated by the dual factors of improved techniques and favorable funding conditions. The early period, for example, saw the development of photography and spectroscopy when there was something of a fad for private philanthropy to observatories. Technological improvements made much more sensitive and accurate measurements possible at a time when appreciation for the scientific value of astronomical observations was growing. Wealthy benefactors provided the necessary funds to construct such observatories as Leander McCormick (Charlottesville, Virginia), Lick (San Jose, California), Yerkes (Williams Bay, Wisconsin), Mount Wilson (Pasadena, California), and McDonald (Fort Davis, Texas). These observatories were founded at a time when cities were small and dimly lit by today's standards.

During the second period, improvements in technology provided some impetus for the construction of new optical observatories in Hawaii, Arizona, Texas, and Chile. Again, a dramatic increase in available funds was a decisive factor, only now they were mainly public funds and related to the national space program. The latter period of expansion of astronomical facilities was accompanied by rapid expansion of our cities and populated suburban areas, and by technological improvements in outdoor lighting.

It is the goal of the astronomer to deduce as much as he can about the nature of various cosmic sources of electromagnetic radiation. He would like to extend his observations to include as much of the electromagnetic spectrum as possible, since the quantum mechanical correspondence between wavelength and energy implies that physical processes of radically different intrinsic energies produce radiation at widely differing wavelengths. The complete astronomical picture can come only from observations gathered at all wavelengths.

The transmission properties of the earth's atmosphere severely restrict the portions of the spectrum available for ground-based astronomical measurements. Figure 1 shows the atmospheric transmissivity as a function of wavelength. The electromagnetic spectrum is divided into a number of segments called windows, where the transmissivity is near unity. The optical window is the one which has received the most astronomical attention, for the natural reasons that our eyes respond at these visual wavelengths and that solar-type stars emit the bulk of their radiation at these wavelengths. The sun is a common sort of star in this respect, although there are many astronomical objects that emit most of their light at wavelengths outside the optical window.

Over much of the spectrum one must observe from above the earth's atmosphere because of its very high opacity; orbiting astronomical observatories contribute to our knowledge of astrophysics at infrared, ultraviolet, x-ray, and gamma-ray wavelengths. They have the advantage of immunity from scattered atmospheric light since they are in the near vacuum of space. The cost of doing astronomy from above the earth's atmosphere is high, although intelligently planned programs of this type are well worth the expense. Where one has the choice of making astronomical measurements from space or using ground-based facilities, one would always prefer the latter on economic grounds, all other things being equal. Thus, there is some economic justification for preserving our ability to continue to make useful astronomical measurements from the ground. Moreover, many types of observations, such as those involving untried experimental equipment and techniques, or particularly bulky apparatus, cannot be done

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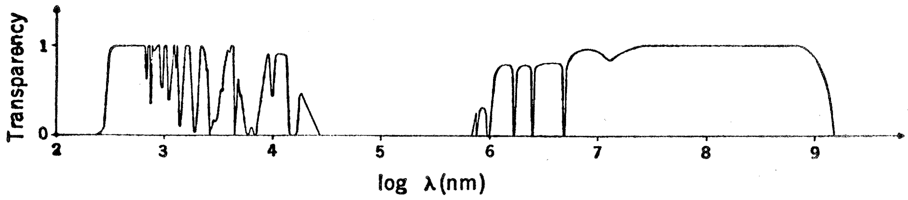

Fig. 1. Transparency of the earth's atmosphere as a function of wavelength (λ). The optical window lies at the extreme left and the radio window at the extreme right.

in orbit. Light pollution renders ground-based observations more and more difficult to perform.

Basically two types of measurements, narrow band and broad band, are made by astronomers. Examples are high-resolution spectroscopy of stars and photography of very distant objects like galaxies and quasars, respectively. The sources of interference are of the same two types. If the interference is narrow band, then most of the spectrum remains free from interference. On the other hand, within the narrow range of wavelengths affected by the interference, the problem will be very serious for a particular power level. If the interference is broad band or consists of a large number of spectral lines then the astronomer cannot escape it. However, for a particular interference power the intensity at a particular wavelength will be less, since the radiation is dispersed throughout a wide range of wavelengths. We may find that in spite of some broad-band (continuum) interference, narrow-band observations of bright cosmic sources are still possible. Moonlight is an example of a source of low-level continuum interference affecting optical measurements at certain times of the month—astronomers routinely do high-resolution spectroscopy of bright stars under such conditions. Narrow-band observations are still possible even with relatively intense interference, if that interference is confined to wavelengths outside the spectral region of interest. As an example, low-pressure mercury vapor lamps produce relatively few but intense spectral lines, with large gaps between them; as long as one is concerned only with details in the spectrum between the interfering lines, there is no serious problem. Unfortunately, this is often not the case; for example, the spectral line for triply ionized oxygen (O III) at 436.3 nanometers, which is critical in the plasma diagnostics of gaseous nebulas, is near the 435.8-nm mercury line.

Broad-band measurements such as astronomical photography and photoelectric photometry are seriously affected by interference, whether it is in spectral lines or spread over a continuum, as long as it falls within the passband being observed. Broad-band observations are extremely useful. Surveys of areas to faint limiting magnitude amount to what we might call "astronomical fishing trips," or observations which are intended to aid in the discovery of new and unsuspected phenomena. The list of fundamentally important constituents of the universe discovered in this way is impressively long.

Astronomical and Scientific Constraints

The astronomer must be able to detect the source of radiation he is interested in measuring. His detector will always indicate some response, even when it is not directed at the source of interest, because of natural causes including airglow, atmospheric scattered light, ground reflections, zodiacal light, and the light from background stars. In spite of interference from these causes, from noise generated within the detector, and from light pollution, it is still possible to do useful work, provided that the interference is not too strong. A high-resolution spectrum of the night sky at Kitt Peak National Observatory has been published (*1*). In the visible, for example, the zenith brightness is of the order 20×10^{-9} stilb (*2*), equivalent to about one star of magnitude 22 per square arc second. This value of the natural sky brightness provides us with a standard against which we can measure the consequences of contaminating the astronomical observing environment with man-made skylight. As long as the component of the local sky brightness which is generated by man is small compared to the natural level, then light pollution is not a serious matter.

It should be emphasized that the sky brightness sets very real limits for astronomers. Studies of the processes that produce the light of the night sky form an area of serious research, and they require dark-sky observing sites. Observations of the zodiacal light, the gegenschein, the airglow, and the aurora represent such studies. Observational cosmology is based on limiting magnitude results on the faintest quasars and galaxies, so an increase in sky brightness has the effect of shrinking the visible universe. For example, at Palomar Observatory on the 200-inch (5.08-meter) telescope, photographic exposures cannot be made for periods of time longer than that required to just record 24th magnitude stars on sensitive photographic emulsions under the best observing conditions. This is because of skylight, which fogs photographic plates when exposure times exceed a certain value. As a practical matter, increasing the telescope size is an expensive and relatively ineffective way to compensate for skylight, beyond the "seeing" limit, which corresponds to image blurring due to atmospheric turbulence and distortion. The limiting magnitude depends on the properties of the detector (*3*).

The natural sky brightness of about 22 magnitudes within a circle whose diameter is 1 arc second is 2 magnitudes brighter than the limiting magnitude given above. This is no coincidence, because 1 arc second is the size

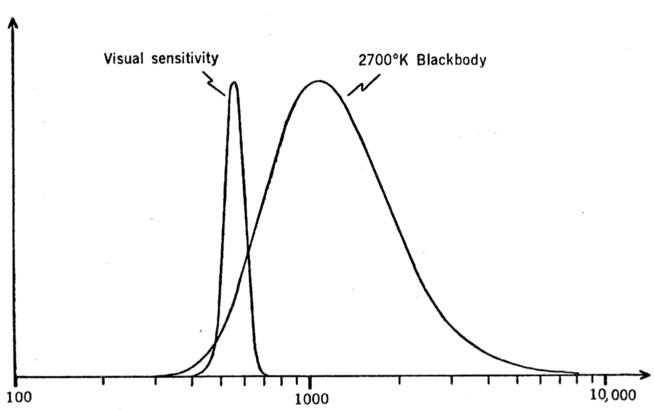

Fig. 2. Wavelength response of the human eye and spectrum of a blackbody at the temperature of a typical incandescent lamp. Most of the radiation produced by incandescent lamps evokes no visual response; hence, they have low luminous efficiency.

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of a stellar image under good observing conditions, and the photographic limit is reached when the star brightness drops below some fraction of the sky brightness. The relation between the sky brightness, *B*, and the apparent magnitude, *m*, of a star which contributes light equal to the skylight within the seeing circle diameter, *S*, is

$$B = 14.35S^{-2}10^{-0.4m} \approx 20 \times 10^{-9}$$

where the units of *B* are stilbs when *S* is in arc seconds. Thus, the limit set by skylight on the magnitude of the faintest object that can be photographed depends also on turbulence in the atmosphere, in the sense that bad seeing decreases the effective sensitivity. The corresponding limiting magnitudes are several magnitudes fainter, depending on the *f*-ratio of the telescope and on the detector system employed. It is possible to do even better, in principle, by using techniques of photoelectric photometry and multiple exposure photography to give longer integration times and improved signal-to-noise ratios. These techniques are only now coming of age in optical astronomy, but they are not likely to solve the basic problem of interference due to light pollution because they are applied with difficulty and at great expense.

Outdoor Lighting in the United States

Most outdoor lighting was of the incandescent type until very recently. The filaments of incandescent lights, which operate at only about 2700°K, radiate mostly longward of 550 nm, the peak of the visual response curve. Thus, incandescent lights have a very low luminous efficiency, only about 20 lumens per watt or less. Figure 2 shows the visual sensitivity curve for humans and the spectrum of a typical incandescent lamp. Most astronomical photographic emulsions and photoelectric detectors have their peak sensitivity toward the blue end of the spectrum. Thus, these lamps have two properties which make them desirable to astronomers: (i) they radiate with very low efficiency, producing relatively little light at visible wavelengths, and (ii) very little of the visible light that is produced interferes with blue-sensitive detectors. The first of these properties makes them undesirable to municipal lighting departments.

The high-intensity gas discharge lamp is succeeding the incandescent lamp for most outdoor lighting. The mercury vapor lamp is the most popular. Such lamps usually emit most of their light in a few spectral lines, which is good from the astronomer's point of view. The lighting engineer and the used car salesman consider this a disadvantage, however, since the appearance of objects tends to be more pleasing in light which has a smooth spectrum more closely approximating that of sunlight, perhaps somewhat reddened. In the newest vapor lamps the continuum portion is enhanced and the luminous efficiency is as high as 115 lumens per watt, a very significant change in connection with light pollution.

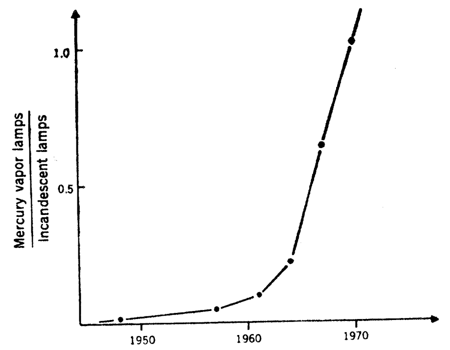

Fig. 3. Number ratio of in-service mercury vapor lamps to incandescent outdoor lamps in the United States for the past 22 years.

Most of the discussion on specific properties of light sources will refer to high-intensity vapor lamps and not the older incandescents. The relative importance of the incandescent lamp has been rapidly declining, as can be seen in Fig. 3, which shows the relative numbers of in-service vapor and incandescent lamps as a function of time (*4*). This conclusion is also supported by data from (*5*), which show that the rate of production of outdoor incandescent bulbs is now virtually constant, reflecting replacement use only; the rate of production of incandescent luminaires has declined drastically as that of high-intensity mercury luminaires has soared.

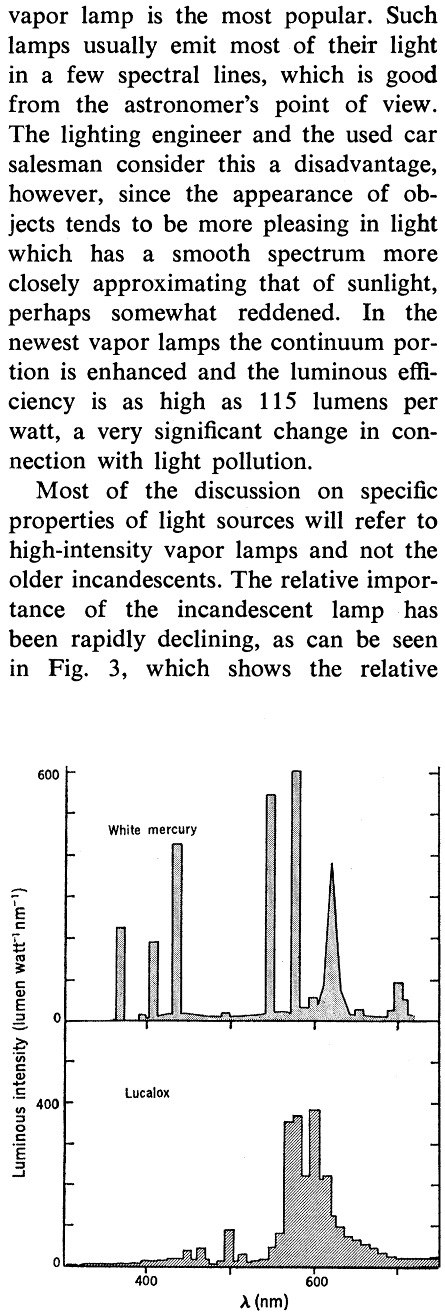

Fig. 4. Spectra of a commonly used mercury vapor lamp and the newer high-pressure sodium (Lucalox) type of lamp. These are low-resolution spectra, with data points only every 10 nm.

The growth curve in Fig. 3 can be used together with power consumption data from the same source (*4*) to derive the 1970 mix of lumens due to in-service vapor lamps and incandescent lamps, respectively. This ratio was about 6 in 1970, if it is assumed that the vapor/incandescent number ratio was 1.16 and the vapor/incandescent lumen ratio was 5 for typical street lamps. So, as early as 1970, the bulk of the total luminous radiation in the United States, about 85 percent, was produced by vapor lamps. However, most of the continuum was still produced by incandescents, since almost all of the mercury light occurs at wavelengths of 365.0, 404.7, 435.8, 546.1, and 578 nm. The 435.8-nm line has been most annoying to astronomers, since it is by far the strongest; it lies in the blue; and, most frustratingly, it is on the tail of the standard visual response curve (Fig. 2), where it contributes inefficiently to the lumen output of the lamp.

The spectrum of a commonly used mercury lamp is presented in Fig. 4. An increasingly popular new type of lamp is the General Electric Lucalox high-pressure sodium lamp, which has a very high luminous efficiency of 115 lumens per watt, or about six times that of ordinary incandescents. The Lucalox spectrum also appears in Fig. 4. Its most interesting characteristic is strong continuum radiation and a much richer line spectrum relative to the cleaner mercury vapor lamp spectrum. One has only to look at the light from these lamps through a hand-held spectroscope to see dozens of spectral lines. These high-pressure sodium lamps do not account for a very high percentage of outdoor lights in operation presently. However, municipalities and commercial light users are beginning to install them at a high rate, and the possibility that much of the skylight near urban areas will someday be from this type of lamp should be considered. Their large numbers of spectral lines would present a serious light pollution problem. A discussion of projected trends

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for the growth of outdoor lighting appears in the next section.

It is instructive to determine the present severity of the light pollution problem at observatories. Some of the principal research observatories in the United States listed previously are in reasonably good shape; others, such as Mount Wilson, where it is no longer possible to do broad-band work on the faintest stars, are experiencing more difficulty. According to Walker (*6*), Palomar suffered a zenith light pollution level in 1965 which was only about 0.1 magnitude, or roughly 10 percent of the natural light of the night sky. This was contributed to in almost equal parts by Los Angeles and San Diego at quite different distances. At a zenith angle of 45° toward either city, this figure rose to 20 percent. At Kitt Peak in 1972, the lights of Tucson are approaching the 1965 level at Palomar; this is far in excess of the most pessimistic predictions made before the construction of the major telescopes at Kitt Peak.

Unfortunately, accurate quantitive data on skylight levels have not been gathered in any systematic way at most observatories. There have been only a few programs—for example at Kitt Peak for the past 18 months and at Flagstaff for the past 10 years—to monitor sky brightness for urgently needed figures on the rate of increase of light pollution.

There is a dimension to the problem which should not be passed over, and which has to do with the phrase "major research facility." By definition, an observatory is a major research facility by virtue of the fact that competitive research is still possible at its location. For broad-band observations, this is no longer the case at many older observatories in or near major metropolitan areas. Part of the indirect cost of outdoor lighting has, for these cases, included the obsolescence of scientific research facilities, usually gradually over a number of years. Such costs are almost never considered by the agencies that authorize lighting projects.

Growth of Light Pollution

Accurate quantitative information on the total outdoor illumination in the United States as a function of time is not directly available; one can get rough information only from indirect sources. As with many other man-made environmental factors, no attention was given to the possible harmful effects of outdoor lighting. I am reminded of an all too recent statement by Meinel (*7*), of the University of Arizona, who remarked on observing conditions at Kitt Peak National Observatory: "Most of the city is hidden from view by the Tucson Mountains, west of the city. At present, the city's growth potential is limited by the availability of water and is directed eastward because of the Tucson Mountains. For the foreseeable future there appears to be no serious threat to the astronomical conditions at Kitt Peak." Virtually all would have agreed in 1960. Staff members at Kitt Peak no longer take such a sanguine view of the light pollution problem. In fact, they have mounted a vigorous and successful program in cooperation with the nearby Steward Observatory and the Smithsonian Observatory to persuade the city of Tucson to adopt lighting standards that will alleviate the problem.

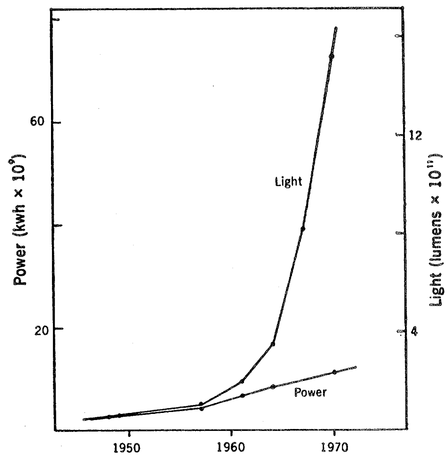

Fig. 5. The growth of power consumption devoted to outdoor public lighting (bottom curve), and the light (top curve) produced by that power, for the past 22 years.

The rapidly growing city of Los Angeles is an astronomical center and is typical of urban-suburban areas across the land. Most of the city streets are lit, and there are many interstate highways and freeways, parking lots, buildings, and outdoor sports arenas that are illuminated at night. On the cover are views of Los Angeles from Mount Wilson in 1911 and 1965. They show the dramatic growth of the city and the proliferation of streetlights, but they do not adequately convey the increase that has occurred in the level of light pollution of the sky. It is not only the number of lights that has increased but also the luminous output per lamp. Similar changing views of many cities could have been obtained, but are not readily available. Not even such a simple monitoring program as photographing the surrounding land area, say every 5 years, has been carried out systematically at most observatories.

Figure 5 is a plot of electrical power consumption devoted to street and highway lighting in the United States, as a function of time (*4*). Although power consumption for this purpose has been steadily rising, the growth has been approximately linear. For comparison, an estimate of the total light production as a function of time has also been plotted in Fig. 5. This was arrived at by using both the power consumption curve and the mix of incandescent and vapor lamps given in Fig. 3. The average incandescent lamp efficiency was assumed to be 20 lumens per watt, the vapor lamps were assumed to be five times as efficient, and all individual lamps were assumed to require the same power. This is a rough but adequate way of determining the shape of the luminosity curve. It should be mentioned also that the power survey figures are likely to be underestimates of the total power consumption for outdoor lighting, since the sample is presumably incomplete and since it does not include the very important component of outdoor lighting not used for public roads, for example, lighting in parking lots.

The lumen growth curve has the familiar exponential form associated with so many environmental factors which can result in stresses of some sort. In this case it is the scientist who plays the role of the highly sensitive system component feeling the stress first. It might also be interesting to attempt an assessment of the biological effects, if any, of outdoor lighting.

In 1970, outdoor vapor and incandescent lamps existed in roughly equal numbers. The present installation rate for new incandescents is essentially zero, and for new vapor lamps it is 6 to 10 percent per year nationwide, with a much higher rate for the Lucalox high-pressure sodium lamp. Figure 5 shows a rate of lumen growth which is exponential at an astonishing 23 percent per year between 1967 and 1970. An earlier examination of light pollution in California (*6*) was based on the assumption that light level and population would grow at approximately the same rate, but the true rate may be six to ten times as large.

If total outdoor lighting continues to grow at a rate of only 10 percent per year, by 1985 the national outdoor light level will have increased by a factor of 300 percent since 1973. A compounding factor is that the growth

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is likely to take place simultaneously with dispersal over larger suburban areas. These two factors taken together make it not unlikely that some observatories will experience more than a tenfold increase in the light level in the sky by 1985, which will render many observations impossible.

Light pollution has been concentrated for the most part in a few narrow spectral lines of mercury, which are avoidable under some conditions. The new high-pressure sodium lamps have a much richer spectrum, and will affect some kinds of astronomical research more. Thus, astronomy faces a potential hundredfold increase in sky brightness during the coming decade, for some kinds of programs. It is essential that astronomers begin to pay some attention to the spectral distribution of commonly used outdoor lamps, especially with regard to their continuum emission, and to the proportion of light emitted at the blue end of the spectrum. Currently available lamps differ tremendously with respect to these two qualities.

What really matters, of course, is not so much the nationwide pattern of outdoor lighting growth, but rather the proliferation of outdoor lighting in the immediate surroundings of the principal research observatories. Such observing facilities are not scattered uniformly across the country, and their distribution is likely to become even more nonuniform in the future. There are a number of factors which determine whether a location is suitable as a site for an astronomical observatory, aside from the darkness of the sky. These are (i) the quality of the seeing, which is determinated by the stability of the air above the site; (ii) whether there is significant air pollution, such as automotive smog and smoke from power plants (smog can increase light scattering during the daytime, adversely affecting solar observations, and dust is responsible for an increase in the atmospheric extinction of starlight); (iii) cloud cover; (iv) winds; (v) altitude; and (vi) whether the site is on jet routes, since contrails disturb observing.

When all the above factors are considered, there are remarkably few sites in the United States suitable for dark-sky observing. They are almost all in the Southwest. Walker (*6*) surveyed sites in California for a possible future major facility, and concluded that the factor of light pollution alone was enough to rule out more than half the land area of the southern part of that state. The other factors narrowed the

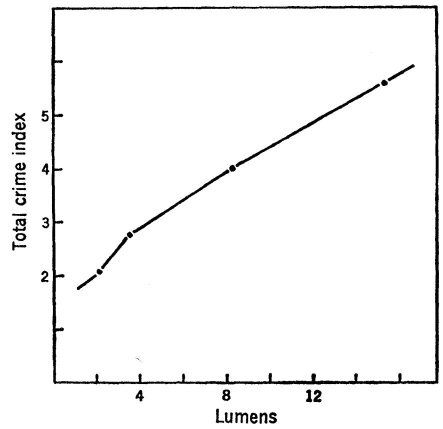

Fig. 6. Total crime index of the Federal Bureau of Investigation as a function of total outdoor illumination for the period 1960 to 1970. Powers of 10 have been dropped for both the ordinate and the abscissa.

possibilities further. One of the sites being given prime consideration for a new observatory in California is Mount Junipera Serra, which is already at the edge of Walker's circle of danger from light pollution projected to the year 1985. He assumed that skylight would grow at the same rate as population. We have seen that his estimate is unfortunately far too conservative. Furthermore, his light pollution estimates were based on measurements at very few locations and extrapolated to other locations mainly on the basis of population. It would be useful to make actual measurements of sky brightness from a great many locations around existing and potential observing sites.

Causes of Light Pollution Growth

There is a startling difference between the growth rates for population (about 1 percent per year) and outdoor lighting (about 23 percent). There are at least five reasons why outdoor lighting has grown faster:

1) The suburbanization of the United States, caused by conversion to the automobile as virtually the only mode of American surface transportation. Areas where the full range of government services such as education, police and fire protection, water, utilities, and sewer service are available have grown much faster than population. The public believes it needs more outdoor lighting, again principally for the automobile. The outdoor areas presently using the most outdoor illumination are streets, highways, and parking lots. Often such outdoor lighting is left to burn all night, even when there is no real need for it. It is common to see empty shopping center parking lots shining brightly and uselessly at 4 a.m.

2) Social factors such as fear of crimes of stealth and violence have contributed to the perceived need. Rising crime rates have been used effectively (see item 5 below) in promotional efforts for increased outdoor lighting. The argument used is that the crime rate will drop where illumination is increased, and there are some statistical studies which are put forward in support of this idea (*8*). Since such studies are usually financed and published by lighting equipment industries, they deserve to be looked at critically. I have two examples of how data supplied by such groups can be used to draw exactly the opposite conclusion from that intended about the desirability of increased outdoor illumination. (i) According to (*9*), only 2 percent of city streets are illuminated to minimum standards; 98 percent are underlit. Since (according to the same source) 80 percent of crimes occur on streets which fail to meet the standard, the conclusion is that we must buy more lights. However, the opposite conclusion results if one compares the crime rates per street for the two categories.

0.80 crimes per 0.98 dim streets =
0.82 crimes per dim street

0.20 crimes per 0.02 bright streets =
10.0 crimes per bright street

Or, crimes are 12 times as likely to occur on brightly lit streets. (ii) There are some studies (*8*) which connect light to reduced crime rates. Such studies have been confined to a few small areas. If one takes the larger view, considering not individual streets but entire cities or the nation at large, an inconsistency looms. One might expect to find that as the general level of outdoor illumination rises, crime rates would drop correspondingly. Figure 6 is a plot of the total crime rate determined by the Federal Bureau of Investigation (*10*) against outdoor lighting luminosity from 1960 to 1970. The sensationalist statistician with an ax to grind might try to use such a plot to conclude that lighting causes crime.

The point of these two examples is not that the unconventional conclusions are true, but that emotionally based or incomplete information can be used to persuade city councils and private businesses to undertake large outdoor lighting projects. The selling has obviously been very successful—most people now believe that outdoor lighting buys them security. I suggest that the deeper so-

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ciological roots of crime must be found and treated, and that outdoor lights will not only irritate the astronomer, they will deplete the public treasury possibly without affecting overall public security in any significant way.

It is possible that any demonstrated reduction of the crime rate in a brightly lit area may be negated as criminals simply move on to a softer target area. Evidence that outdoor lighting is largely irrelevant as a factor in residential burglary is given by the increase in daytime over nighttime crime rates (*10*). In the decade from 1960 to 1970 the daytime residential burglary rate rose 337 percent, and it now exceeds the nighttime rate. Factors such as changing life-styles which result in residences being vacant during the day would seem to be more important than illumination.

3) Technological improvements in lighting systems have resulted in luminous efficiencies up to six times higher than in the recent past.

4) An increase in nighttime business and recreational activity.

5) A vigorous, well-financed, and highly effective public relations and promotional campaign for increased outdoor illumination by manufacturers and suppliers of lighting equipment, their trade organizations, and related technical and professional societies. Foremost in this arena are such organizations as the Street and Highway Safety Lighting Bureau, the General Electric Corporation, and the Illuminating Engineering Society.

What Can Be Done

Factors that will influence the proliferation of outdoor lighting are (i) the rate of growth of the population, (ii) the evolution of zoning practices and the suburban sprawl rate, (iii) whether there is conversion from the automobile to public transportation systems, (iv) changes in lighting technology, and (v) esthetic and protective policies that governments might adopt which will have some bearing on light pollution. The last item on this list is the one that seems most likely to have the largest immediate effect. Most of the remarks in this section will therefore concern changes in public policy that reflect scientific needs.

Of course, outdoor illumination is intended for things like cars, streets, parking lots, and buildings, not the sky. All illuminated surfaces, however, have some reflectivity. Dark black asphalt has low reflectivity and light concrete has a much larger reflection coefficient. Encouraging the use of surface materials of low reflectivity, where possible, would help a little, but this approach is not likely to be very effective.

There is an additional factor of lamp design: how much light is directed downward where it will do some good, and how much goes uselessly up into the sky. The Tucson observatories have given much attention to this phase of the problem (*11*), and have persuaded the city to adopt an ordinance (*12*) setting regulations on the elevation distribution of luminaires—the amount of light that can be directed skyward. Lighting fixture standards of the kind proposed are attractive from a political point of view, since the objective of keeping the light on the ground happens to coincide with the objective of those who use the lights. There are some situations where this is not the case, for example, in outdoor sports stadiums.

The ordinance also requires that new luminaires be equipped with filters which are opaque to the far-blue and ultraviolet lines of mercury, such as the 435.8-nm line. This element of the Tucson ordinance should be considered for adoption in all regions where astronomical research might be affected. It embodies the concept of reserving for astronomy a portion of the spectrum toward the blue end, where visual efficiency is low anyway but where astronomical detectors tend to work very well. This specific ordinance requires that luminaires be equipped with filters which absorb at least 90 percent of radiation of shorter wavelength than 440 nm.

The Tucson example is a valuable precedent for protection of observational astronomical research. A useful model for regional or even federal protection is the situation for radio astronomy. The Federal Communications Commision and international bodies such as the World Administrative Radio Conference for Space Telecommunications have reserved bands at radio wavelengths for astronomical use. Unfortunately, the demand for space in the spectrum for communication and navigation is so intense that some of the frequencies used by radio astronomers are not reserved exclusively for astronomy. To give some additional measure of protection, a radio quiet zone centered on the National Radio Astronomy Observatory in Green Bank, West Virginia, has been established. Thus, the federal government already has a balanced scheme of radio wavelength emissions standards with control over both the spectral and geographical distribution of sources. It seems a ripe time for the astronomical community to seek extension of the same principles, perhaps in modified form, to other parts of the electromagnetic spectrum. An existing federal agency, such as the Environmental Protection Agency, might take the responsibility.

Street lighting is primarily for the benefit of the automobile driver. Since, apart from reasons of crime deterrence, there is no advantage to lighting the streets where and when automobiles are not present, most light might be considered to be wasted. It seems worthwhile then to consider completely new systems for lighting streets. Where only automobiles are involved, it might make sense to abolish streetlights and allow improved automobile headlight systems to do the same job. High-intensity vapor lamps could be developed for automotive use and used in conjunction with polarizers mounted on car lamps and windshields, tilted at 45° to the vertical. The headlights in use today are generally recognized to be inadequate for nighttime driving at high speeds, but if their luminosity were increased by a factor of 20 or so much of the need for perpetual nighttime lighting would disappear. The total amount of light produced would probably be much less than at present, although the fact that it would be horizontally directed is troublesome. A study of the effectiveness of any such system should include the light pollution aspect.

It is possible to make significant progress toward protecting the astronomical observing environment without compromising the legitimate lighting needs of the public. Minimum standards controlling the elevation distribution of light from individual lamps and the spectral and geographical distributions are feasible and should be sought while there is time to preserve useful observing sites.

The scientific community can make an immediate contribution. Every major optical observatory in the country should initiate a routine program to monitor the skylight as a function of position, wavelength, and time. It is essential that astronomers arm themselves with hard data on deteriorating observing conditions so that effective remedial action can be sought and won in the future. Some progress can be made by formulating the problem quantitatively, and by increasing communication on this subject in meetings such

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as the one organized by project ASTRA (*13*).

Finally, esthetic arguments against useless outdoor lights are beginning to be appreciated. The chairman of the Los Angeles City Planning Commission actually proposed in 1972 that the Santa Monica Mountains be outfitted with many searchlights to scan the skies every night, for their dramatic effect (*14*). Public outrage was instantaneous and nearly unanimous. But aside from this isolated and somewhat bizarre incident, there is some growing feeling that a dark night sky is a nice thing; millions of urban children have never seen the Milky Way. In 1971, the board of directors of the Sierra Club adopted a policy against unnecessary outdoor lighting because it wastes energy, is esthetically unpleasant, and interferes with astronomical research. This point of view should be encouraged.

Summary

There have been major qualitative and quantitative changes in outdoor lighting technology in the last decade. The level of skylight caused by outdoor lighting systems is growing at a very high rate, about 20 percent per year nationwide. In addition, the spectral distribution of man-made light pollution may change in the next decade from one containing a few mercury lines to one containing dozens of lines and a significantly increased continuum level. Light pollution is presently damaging to some astronomical programs, and it is likely to become a major factor limiting progress in the next decade. Suitable sites in the United States for new dark sky observing facilities are very difficult to find.

Some of the increase in outdoor illumination is due to the character of national growth and development. Some is due to promotional campaigns, in which questionable arguments involving public safety are presented. There are protective measures which might be adopted by the government; these would significantly aid observational astronomy, without compromising the legitimate outdoor lighting needs of society. Observatories should establish programs to routinely monitor sky brightness as a function of position, wavelength, and time. The astronomical community should establish a mechanism by which such programs can be supported and coordinated.

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The Genetics of Hereditary Disorders of Blood Coagulation

Functional and immunological studies provide evidence for the heterogeneity of many familial clotting disorders.

Oscar D. Ratnoff and Bruce Bennett

The dramatic nature of the symptoms of hereditary disorders of blood coagulation and the ease with which the affected tissue, circulating blood, can be studied contribute to the disproportionate interest in these rare conditions. Among the results of many published studies, a large volume of information has been generated which supplies support for principles of heredity adduced from other sources. The discovery that many of these diseases are heterogeneous in nature has overthrown our simplistic views and has raised, in the usual way, more questions than answers. The next few years should see a rapid expansion of our knowledge in this field, and the time seems appropriate for us to take stock and see just where we are.

Normal Blood Coagulation

In mammals, blood clotting results from the conversion of a soluble plasma protein, fibrinogen (factor I), into fibrin, an insoluble network of fibers. The jelly-like appearance of blood clots is due to the entrapment of cells and serum within the meshes of this network. The formation of fibrin is catalyzed physiologically by a hydrolytic plasma enzyme, thrombin, which cleaves two pairs of small polypeptides, fibrinopeptides A and B, from each fibrinogen molecule (Fig. 1). What remains, so-called fibrin monomer (*1*), then aggregates into an insoluble polymer, fibrin. The monomeric units of fibrin are further bound covalently through the action of another

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