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Citizen science to monitor light pollution – a useful tool for studying human impacts on the environment

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Highlights

- The alteration of light levels at night is a recent environmental change, which has become an increasing threat to nocturnal landscapes.
- Guidelines for illumination focus primarily on aesthetics, safety, security and energy efficiency. A policy shift towards considering the impact of light on ecosystems and health requires a sound transdisciplinary and supraregional approach.
- Citizen science projects could analyse changes in nighttime brightness worldwide, offer participation in various other scientific areas, and increase public awareness.
- Light pollution can be a unifying entry point for other environmental problems, connecting projects about the impact of human activities.

Introduction

In previous decades, the use of artificial light at night (ALAN) and the related brightening of the nightscape increased worldwide by more than 2 per cent per year (Kyba et al. 2017; Hölker et al. 'The Dark Side', 2010).

But compared to the global increase of temperature, the impact of alteration in ALAN has not yet been well studied. The research about ALAN is a showpiece example of how citizen science can assist collecting global data. To study the alteration of ALAN, measurements are needed from remote sensing, from the ground and about the impact of ALAN on the environment. Artificial light at night indicates hotspots of human activity and thus can be a unifying entry point for other environmental problems, potentially connecting citizen science for environmental monitoring (see also Owen & Parker; Peltola & Arpin; Danielsen et al.; Harlin et al., all in this volume).

As a result of increasing nighttime brightness, the measured range of night sky radiance is now often hundreds of times larger than it was before the existence of artificial light (Kyba et al., 'High-Resolution Imagery', 2015), depriving one-third of Earth's population of the possibility to enjoy a view of the Milky Way (Falchi et al. 2016). Light is the most important signal for circadian and seasonal rhythms, but ALAN can interfere with this signal, disturbing ecosystems (Hölker et al. 'The Dark Side', 2010; Schroer & Hölker 2016) and having adverse consequences on sleep performance and health (Reiter et al. 2011; Bonmati-Carrion et al. 2014). Furthermore, the transition to 'white' LED (light emitting diode) light sources increases the fraction of ALAN with short wavelength (blue) light. This is of concern for several reasons: Short wavelength light is more likely to scatter on clear dry nights (Aubé, Roby & Kocifaj 2013) and this part of the spectrum also has the greatest impact on the circadian system of higher vertebrates (Bailes & Lucas 2013; Brainard et al. 2015).

In the context of light pollution, citizen science is an indispensable tool for both data collection and knowledge dissemination, especially for collecting data on larger scales, such as at landscape or community levels (Kyba 2018; Kyba et al. 2013). Citizen science can mobilise people with various interests on a global level to measure the impact of ALAN (Schroer, Corcho & Hölker 2016). This chapter describes existing citizen science contributions to the highly interdisciplinary research field of light pollution. It discusses how raising awareness through citizen science may initiate changes in the use of illumination, and how citizens could become empowered to create a more social and sustainable environment. In contrast to other pollutants, reductions in light pollution could in principle be relatively easily achieved by increasing consumer awareness about the negative consequences and implementing guidelines for the use of ALAN: to use low light intensities, to shield lamps and to use lights with a low blue light content (Schroer & Hölker 2014).

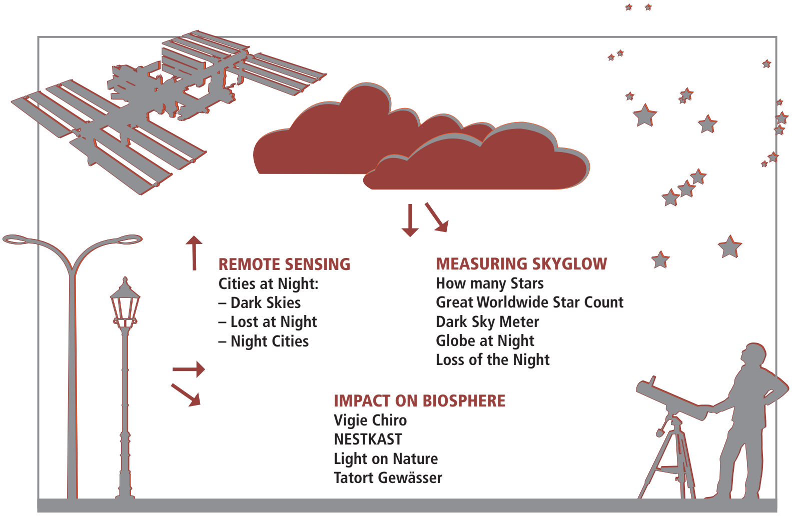

Fig. 24.1 Citizen science projects with focus on artificial light at night and changes of nightscapes. (Source: A. Rothmund)

Finally, this chapter shows how the ALAN research topic connects disciplines and interests, and how this issue can be used to network, for example, with social platforms focused on other pollutants such as air, water or noise pollution.

Citizen science projects on ALAN

Several citizen science projects focus on quantifying the effects of outdoor ALAN, which are summarised here to present both the broad ranges of used technologies (see also Mazumdar et al. this volume) and the diversity of disciplines engaged in ALAN research (figure 24.1).

Measuring ALAN with remote sensing tools

Members of the Group of Extragalactic Astrophysics and Astronomical Instrumentation from Universidad Complutense de Madrid use high-resolution images taken by astronauts from the International Space Station (ISS) to measure changes in ALAN. A lot of additional work is necessary to use the data scientifically. For this purpose, the project Cities at Night (http://citiesatnight.org/) involves citizens in creating a global map of satellite night views and artificial radiation (Sánchez de Miguel et al. 2014). Cities at Night uses three apps – Dark Skies, Lost at Night and Night Cities – to engage citizens to (a) identify images which qualify for mapping; (b) identify cities and communities; and (c) georeference the images.

The data obtained from remote sensing observes only radiation directed upward into the sky, but not the brightness that is experienced on the ground. Horizontal radiation and the degree of skyglow during overcast conditions are not recorded. Furthermore, satellite instruments show insufficient sensitivity to short wavelength light, such as for example to light emission by LEDs (Kyba et al. 'Worldwide Variations' 2015). Measurements from the ground are therefore needed.

Measuring ALAN and skyglow from the ground

Several citizen science projects assist in collecting data about the brightness of nightscapes from the ground:

- **How Many Stars** (http://hms.sternhell.at) encourages citizen scientists to classify how many stars they can see at their location in terms of the naked eye limiting magnitude (NELM), using a series of star charts on the Little Dipper and Orion constellations.
- **Great Worldwide Star Count** (http://www.windows2universe.org/citizen_science/starcount/) is part of Windows to the Universe and is designed to encourage learning in astronomy and identify changes in nighttime brightness, using star charts in a manner similar to How Many Stars.
- **Dark Sky Meter** (http://www.darkskymeter.com/) is an iPhone app that enables citizen scientists to measure night sky brightness by using the phone's camera as a photometer. The app also offers statistics about sunset, twilight and moon phases and provides weather forecasts based on satellite data.
- **Globe at Night** (http://www.globeatnight.org/) is a programme of the National Optical Astronomy Observatory, the national centre for ground-based nighttime astronomy in the United States. Citizen scientists are engaged in a similar way to How Many Stars but Globe at Night includes additional constellations for the Southern Hemisphere and invites participants to submit observations using a commercial sky quality metre (SQM).
- **Loss of the Night app** (http://lossofthenight.blogspot.de/) quantifies NELM, but instead of using star charts, participants are asked

to make decisions on whether individual stars are visible. Participants are interactively asked to make decisions on at least eight stars and the app checks participant data for self-consistency. The app also allows participants to submit SQM data.

Citizen science data measuring ALAN from the ground (e.g., from Globe at Night and the Loss of the Night app) have already proven to deliver fundamental contributions to academic publications and global maps about changes in ALAN (Falchi et al. 2016; Kyba et al., 'High-Resolution Imagery', 2015). This data can be valuable for projects about environmental monitoring. For example, light pollution data was shown to be a more useful predictor of bat activity than the proportion of impervious surface, a commonly used indicator for urbanisation (Azam et al. 2016). Comparing citizen science data of bat-monitoring with satellite data of light pollution showed that ALAN has a strong negative effect on bat activity.

Impacts on the biosphere

Wildlife responses to increasing ALAN and the loss of natural darkness in many nightscapes has far-reaching consequences for the environment, for ecosystems and their services, upon which human well-being relies (Hölker et al. 'Light Pollution', 2010; Gaston, Duffy & Bennie 2015). Various citizen science projects collect data on environmental conditions and put them into content of light pollution mapping. These projects do not always primarily focus on the effect of light pollution, but the data can still be used to analyse the impact of ALAN.

- **Vigie Chiro** (http://vigienature.mnhn.fr/page/vigie-chiro) is a French bat-monitoring programme and one example of how pre-existing citizen science data can be used to assess the impact of light pollution. In this programme, volunteer surveyors monitor bat activity along predefined transects. These results are compared with landscape characteristics such as the proportion impervious surface, intensive agriculture and radiance data from a polar-orbiting satellite.
- **NESTKAST** (https://www.vogelbescherming.nl/in-mijn-tuin/nestkasten) uses data from the project NEtwerk voor STudies aan nest-KASTbroeders, in which volunteers monitor songbirds breeding in nest boxes to analyse the impact of ALAN on the timing of breeding (de Jong 2016).

- **Light on Nature** (http://www.lichtopnatuur.org/) uses several experimentally illuminated semi-natural areas to monitor the responses of flora and fauna and analyse the impact of ALAN on the local species' community compositions (Spoelstra et al. 2015). Citizen scientists undertake the monitoring for some groups of animals, for example, moth populations are monitored by volunteers, co-ordinated by the Dutch Butterfly Conservation (De Vlinderstichting) and birds are caught and ringed by volunteers to measure bird populations, co-ordinated by the Dutch Centre for Avian Migration and Demography (Vogeltrekstation).
- **Crime scene freshwater [*Tatort Gewässer*]** (http://tatortgewässer.de/) is a German project developed to gain knowledge about the role of inland waters in the carbon-cycle and the effects of ALAN. The project is based on findings by Hölker et al. (2015), who observed changes in microbial community composition in freshwater sediments exposed to ALAN. Schroer et al. (2016) provided a questionnaire to the volunteers asking them to describe the local artificial light conditions. In just two weeks, more than 700 citizen scientists contributed to the project, providing an excellent data source for sediment and biodiversity pattern analysis in aquatic systems, far beyond the collecting capacity of scientist teams.

Many other citizen science projects about the occurrence of flora and fauna, such as monitoring wildlife, insects and plant species could in the future be examined in the context of light pollution (for wider examples see also Owen & Parker; Peltola & Arpin; Danielsen et al.; Harlin et al., all in this volume).

Collective Awareness Platforms for Sustainability and Social Innovation

The European Commission's initiative CAPSSI (Collective Awareness Platforms for Sustainability and Social Innovation) supports online platforms creating awareness of sustainability problems and offering digital networking between environmental and social platforms (funding framework of Horizon 2020). A platform like CAPSSI has the potential to link the multifaceted citizen science projects about light pollution and further to link existing projects monitoring environmental changes. Furthermore, CAPSSI has the prospective to recommend the principles as standard for future citizen science project development.

The CAPSSI project STARS4ALL provides a platform for citizen initiatives and activities to promote dark skies in Europe (http://www.stars4all.eu/). Light pollution initiatives are being developed to involve citizens, especially in cross-disciplinary areas such as energy saving, biodiversity and human health. The project expects to influence policy-making through the participation of citizens, by proposing specific measures for municipalities to protect dark skies in Europe.

Limits and opportunities for citizen science research on ALAN

This section presents efforts to increase the impact of citizen science involvement in scientific data collection about ALAN. It shows how data consistency and thus its impact can be improved and explains the benefit of enlarging networks and communities (see also Williams et al. in this volume).

Data reliability

Although citizen involvement in research about ALAN seems indispensable to allow data collection on a global scale, there are concerns about the reliability of the data for science. Citizens could in principle falsify data, or inappropriate handling of monitoring protocols could introduce errors that increase the uncertainty of the observations. Especially when using citizen science data for scientific studies, the measurements need to be approved and correlated with existing peer-reviewed scientific data. Kyba et al. (2013) and Schroer et al. (2016) have found a positive correlation of citizen science data with satellite measurements, demonstrating the usefulness of the data.

Another good example of how citizen science data can be evaluated and improved is the My Sky at Night project (http://www.myskyatnight.com). The web application was developed to allow participants of the Loss of the Night project to examine the observation data in detail, as well as measuring trends over time (including data collected by Globe at Night and the Dark Sky Meter app). The app visualises the self-consistency of the measurements and aims to motivate citizen scientists to improve their measurement technique (figure 24.2).

Georeferencing and the provision of automated apps may increase confidence in the data in the future. However, a lot of citizen science data has already been used without credit in academic publications, but its

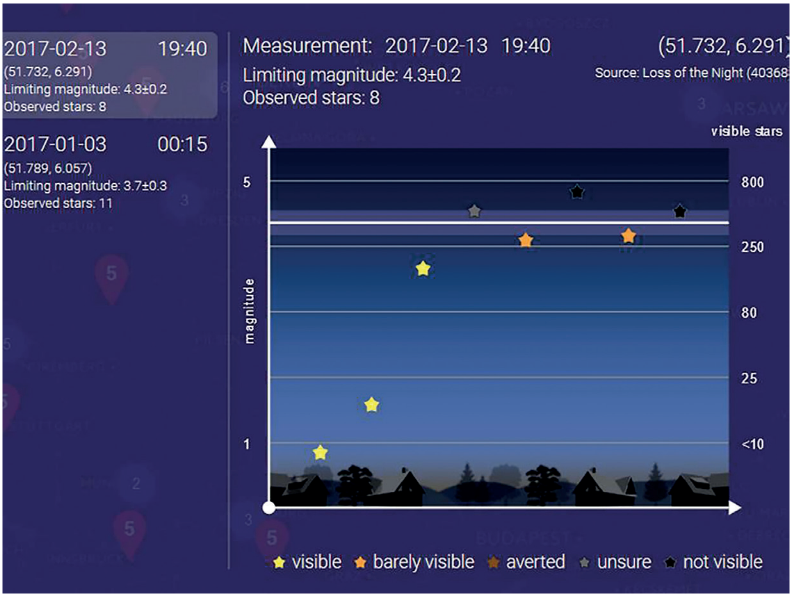

Fig. 24.2 Visualisation of citizen science observation data gives feedback to the user. (Source: www.myskyatnight.com)

acknowledgement may be the most important way to promote confidence in data from volunteers (Cooper, Shirk & Zuckerberg 2014).

Motivating citizen scientists

For the measurement of light pollution, it is critical to motivate people worldwide to measure sky brightness on a regular basis, especially in peripheral urban areas, where the most changes may occur. It is a challenge to engage new participants and raise awareness in young people (see also Harlin et al. in this volume). Motivation is needed for researchers and activists to step out of the circle of environmentalists and astronomers and to bring the relevance of light pollution to authorities, lighting planners, communities, the public and other stakeholders.

The STARS4ALL platform triggers the interest of citizens using a simple but powerful tool: broadcasting astronomy-related events such as solar and lunar eclipses, aurora borealis, meteor showers and so on, with the aim of involving citizens in experiencing a natural nighttime environment (http://www.sky-live.tv/). To encourage local engagement, the network uses participation portals in cities like Madrid (https://decide.madrid.es) and applications such as FarolApp4All (http://farolapp

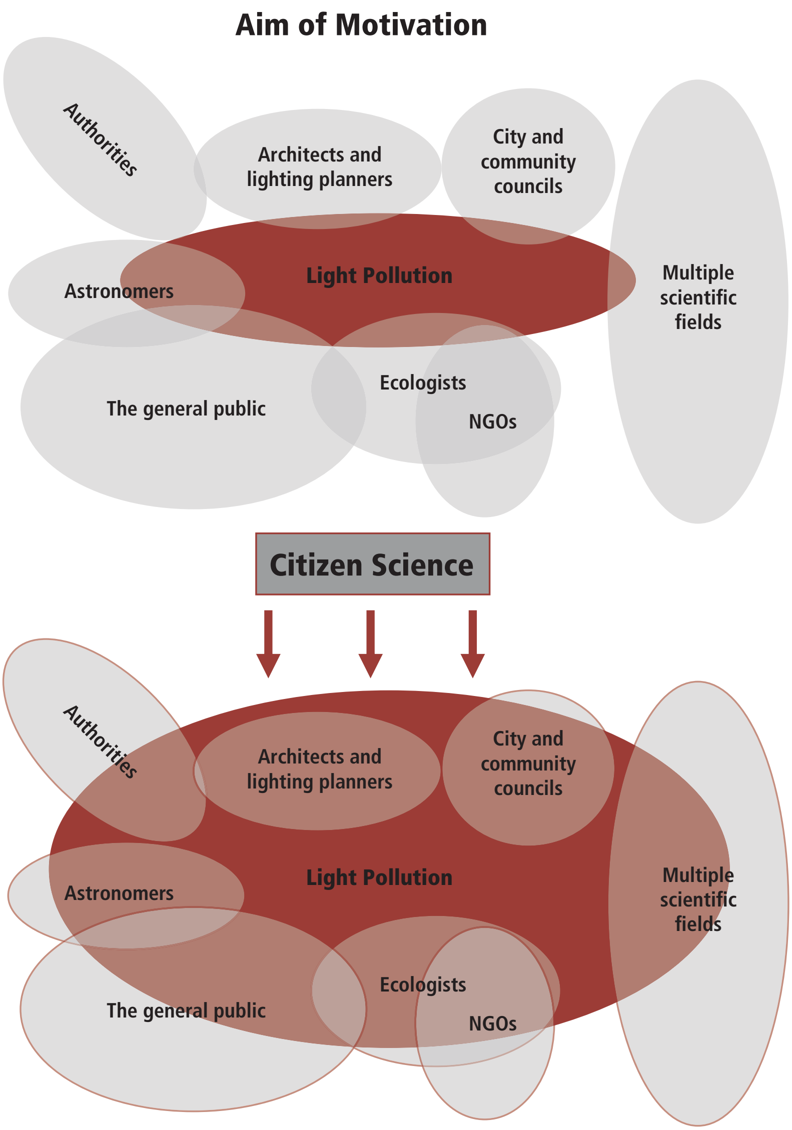

Fig. 24.3 Motivation aim to transfer the relevance of light pollution to a broader field of stakeholders

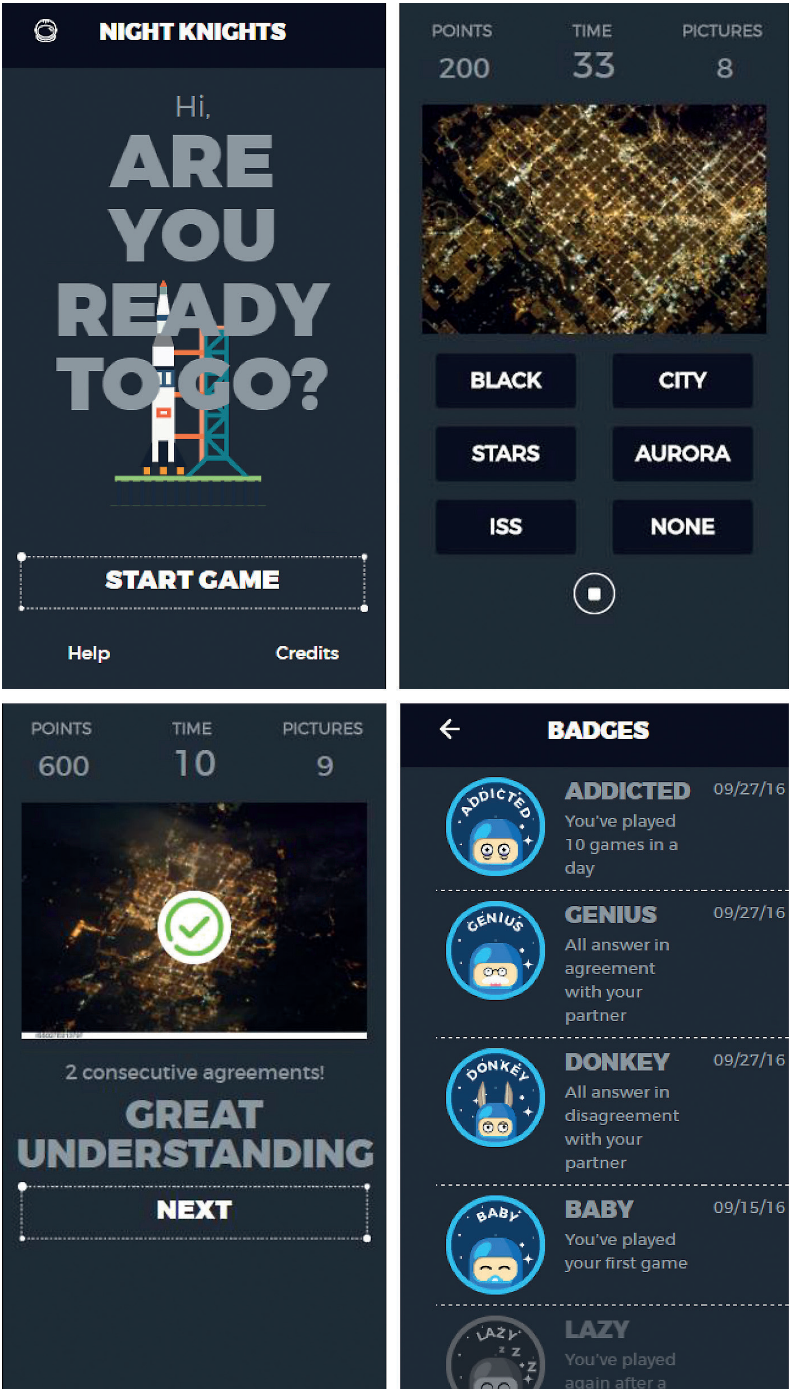

Fig. 24.4 Screenshot of the game *Night Knights*, which uses mechanics of output agreement, double player, contribution weighted by user reputation (measured against ground truth)

.linkeddata.es/) to allow citizens to detect and report cases where public lighting may not comply with guidelines for the sustainable use of ALAN.

Entertainment and gamification have increasingly been used to enlarge the number of participants in citizen science projects (Deterding 2012). For example, the Urbanopoly game involved players in validating and enriching OpenStreetMap data (Celino 2013). The STARS4ALL project has been experimenting with both the gamification of crowdsourcing initiatives, such as rewarding student crowdworkers with the prize of an international expedition to experience celestial phenomena, and pure entertainment apps to classify, for example, remote sensing images, implementing a 'game with a purpose' (von Ahn 2006). The game *Night Knights* (http://www.nightknights.eu) encourages volunteers to invest more time in categorising remote sensing photos. The game design follows recommendations for motivating sustained participation: The scoring mechanism provides personal milestone targets and feedback to maintain high-quality responses (Eveleigh et al. 2013).

Furthermore, interesting news and cartoons are disseminated by social media channels to revive attention within the light pollution community. The aim is to encourage the community to share personal experiences to foster a social aspect, and thus continued participation (Nov, Naaman & Ye 2009).

Establishing networks

The sheer range of environmental pollutants may discourage participants from becoming involved in monitoring a single environmental stressor. Networks could benefit each other, allowing citizen science data to be used for multiple purposes. Volunteers may be increasingly motivated by contributing to broader project about more than one environmental issue (Rotman et al. 2012).

Most pollutants are associated and mutually dependent, so sensors collecting data on pollutants can be combined. For example, air pollution sensors could be fused with photometers (for more on sensors see Volten et al. in this volume). Remote sensing data of ALAN may visualise human activity and locate high-priority areas for nature protection measures (Aubrecht et al. 2010). It is a matter of communication between project developers to make multiple sensor systems available and expand their networks. Platforms such as Pinterest can be useful tools to connect different environmental projects, share interesting content about various environmental actions and initiatives and distribute knowledge (Hansen, Nowlan & Winter 2012).

Integrating citizen science in policy

Guidelines for illumination currently focus primarily on aesthetics, safety, security and energy efficiency (Kyba, Hänel & Hölker 2014). This section discusses if citizen science has the transformative potential to reduce the negative impacts of light pollution through policy development (see also Nascimento et al.; Shirk & Bonney, both in this volume).

Light emission is mainly regulated on a regional or national level (Kyba, Hänel & Hölker 2014) and a common European policy, for example, for the reduction of light pollution is missing. The European Ecodesign Directive (Directive 2009/125/EC) aims to improve the energy efficiency of lighting products, but it does not address the adverse effects of ALAN on biodiversity or nightscapes. European Union regulations for infrastructure and outdoor activities recommend minimum lighting requirements but do not provide limits to brightness levels. For example, the European standard 'Road lighting' (EN 13201: 2015) is a non-binding recommendation for member states to implement minimum lighting requirements. Sound scientific justification for these minimum illumination levels, however, is missing. Many communities do not meet the recommended requirements on brightness and uniformity, and yet still appear to offer safe conditions. A recent study in the UK found no evidence of harmful effects on traffic casualties or crime when street lighting was reduced or switched off late at night in rural contexts (Steinbach et al. 2015). If more authorities felt compelled to implement EN 13201, this would result in higher energy consumption and a wider loss of natural nightscapes (www.cost-lonne.eu). The same applies to standards elsewhere, for example the ANSI/IES RP-8 in the United States.

A rising number of municipalities use planning instruments like lighting strategies or master plans to address the complexity of modern lighting technologies and the different dimensions for sustainability. These concepts require consultation with broadly trained lighting experts, experienced in the social, cultural and economic as well as the ecological impact of light. Currently, most municipalities avoid this investment and are often influenced by consultation with unbalanced expertise or industrial interests (Köhler 2015).

A policy shift will require a sound transdisciplinary approach to understanding the significance of the night and its loss for humans and the natural systems (Hölker et al., 'The Dark Side', 2010). Citizen science data from multiple disciplines may be able to support the process of scientifically determining requirements for sustainable lighting concepts.

With the help of citizen science comparison of lighting levels in various cities, exceedingly high light levels – and thus sites where lighting needs regulation – could be detected. Furthermore, engagement could lead to more participative democracy in empowering citizens to demand measures to improve the quality and level of public lighting. For example, the STARS4ALL project will empower citizens by aiming at the generation and presentation of a European Citizen Initiative to the European Commission in order to reconsider legislation for lighting in Europe (see Shirk & Bonney and Nascimento et al., both in this volume).

Conclusion

As nighttime brightness increases globally, well-distributed data collection is required to analyse its impact and determine the thresholds between beneficial to negative impacts of lighting. This data cannot be provided by single institutions or small groups of scientists working in isolation. Collective awareness of, and readiness for, volunteering is urgently required because changes in light at night is an experiment with unpredictable outcomes (Hölker et al., 'The Dark Side', 2010). Citizen science can help to understand the complexity of investment in public lighting technology and may increase willingness to invest in sustainable lighting. Collective awareness platforms can be useful for motivating and empowering citizens and offering collaborative solutions to change consumption trends. Social platforms can connect and build even larger communities. Light pollution can be a unifying entry point for other environmental problems and has the potential to create a global citizen science network increasing knowledge and awareness about the impact of human activities.

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