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BAND 4

Annette Krop-Benesch, Christopher Kyba, Franz Hölker

**ALAN 2013**  
**First International Conference**  
**on Artificial Light at Night**  
Berlin, 28. – 30. October 2013  
Abstracts

**VERLUST**  
der   
**NACHT**

Annette Krop-Benesch,  
Christopher Kyba, Franz Hölker

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# PROGRAMMIE

## SUNDAY

### 16:00-0:00 EXKURSION WESTHAVELLAND

- 16:00      Departure from SeminarisCampus Hotel, Berlin  
                  Visit of the Information Centre of the Nature Park and Reserve Westhavelland  
                  Evening meal in Milow  
                  Stargazing and Night Sky Watching
- ca. 00:00      Return to SeminarisCampus Hotel, Berlin

## Monday

### 9:30-11:00 PLENARY SESSION I

*Chair: Franz Hölker, IGB*

- Welcome to Berlin\_*Senatsverwaltung Berlin*  
 Welcome\_German Federal Ministry of Education and Research  
 Introduction\_*Gunnar Nützmann, IGB*  
 The Toxicity of Light at Night and its Human Health Consequences\_*Abraham Haim*  
 Light pollution as a hidden driver of biodiversity loss – are we missing a trick?\_*E. Stone*

COFFEE BREAK

### 11:30-12:30 PLENARY SESSION II

*Chair: Dietrich Henckel, TU Berlin*

- Pleiades and Prairie Chickens: Dark Sky Preservation in the Central U.S.\_*Terrel Gallaway*  
 Examples of Urban Lighting Design\_*Volker von Kardorff*

LUNCH

### 13:40-15:00 SESSIONS I

Chronobiology

Society I

Ecology I

COFFEE BREAK

### 15:30-16:40 SESSIONS II

Dark Sky Parks I

Society II

Ecology II

### 17:00 POSTER SESSION

**Tuesday****9:00-10:20 PLENARY SESSION III***Chair: Stephan Völker, TU Berlin*Street lighting systems: state-of-art and future trends\_*Georges Zissis*The value of less Light – Sustainable architectural lighting design\_*K. Zielinska-Dabkowska*Regulation of light pollution in France\_*Lory Waks*

COFFEE BREAK

**11:00-12:30 PLENARY SESSION IV***Chair: Barbara Griefahn, IfADo*Improving sleep with natural light and circadian darkness\_*Thomas Kantermann*Electric light at night can compromise human health\_*Richard Stevens*Artificial light and stream ecosystems: what we know and where we're headed\_*Elizabeth Perkin*

LUNCH

**13:40-15:20 SESSIONS III**

Ecology III

Measurements &amp; Models I

Regulations

COFFEE BREAK

**15:50-17:10 SESSIONS IV**

Health

Measurements &amp; Models II

Technology &amp; Design

**19:00 CONFERENCE DINNER****Wednesday****9:00-10:30 PLENARY SESSION V***Chair: Axel Schwoppe, AIP*Measurement of human exposure to LAN\_*Mariana Figueiro*Advances in Nighttime Lights Satellite Imagery\_*Kimberly Baugh*The urgent need for transdisciplinary research on light pollution – from "Verlust der Nacht" to "LoNNe"\_*Franz Hölker*

Address by the organizers

COFFEE BREAK

**11:00-12:00 SESSIONS V**

Ecology IV

Measurements &amp; Models III

Dark Sky Parks II

LUNCH

**13:30-17:00 LONNE/ALAN STAKEHOLDER WORKSHOP****18:00 ESR (COST EARLY STAGE RESEARCHER) MEETING**

# PLENARY TALKS

# PLENARY TALK

## THE URGENT NEED FOR TRANSDISCIPLINARY RESEARCH ON LIGHT POLLUTION – FROM “VERLUST DER NACHT” TO “LONNE”

---

FRANZ HÖLKER,

*Leibniz Institute of Freshwater Ecology and Inland Fisheries, D*

Technology rarely fulfils only its intended function, but instead often shows unexpected impacts on natural and social systems. Although the invention and widespread use of artificial light is one of the most important human technological advances, the transformation of nightscapes is increasingly recognised as having adverse effects on humans and nature. Humans often illuminate their environment uncritically, with no regard for the manifold impacts of artificial light. As a result, the rapid increase in artificial light has fundamentally transformed our nightscapes in the past few decades.

Most organisms, including humans, have evolved molecular circadian clocks controlled by natural day–night cycles. These clocks play key roles in metabolism, growth, and behaviour. A substantial proportion of global biodiversity is nocturnal (30% of all vertebrates and > 60% of all invertebrates), and for these organisms their temporally differentiated niche has been promoted by highly developed senses, often including specially adapted eyesight. Light pollution threatens biodiversity through changed night habits and is changing the rhythm of

human life. Furthermore, light pollution is considered an important driver behind the erosion of provisioning, regulating, and cultural ecosystem services. Thus, the illumination of our nightscapes may have serious physiological, ecological, and evolutionary consequences for animals, plants, and humans, and may reshape entire social-natural systems.

Our understanding of the adverse effects of light pollution is still vague. Whilst air and water pollution have been investigated experimentally for decades, light pollution remains scientifically, culturally, and institutionally in the dark. Thus, there is an urgent need for transdisciplinary research on the significance of the loss of the night that addresses how illumination can be improved, both technically and institutionally, to have fewer adverse effects. This new research requires enrolling multiple disciplines, including ecology, physiology, chronobiology, sociology, economics, landscape architecture, remote sensing, astronomy, and light engineering, which will enable us to better understand the consequences, to develop improved technologies, and to adapt policies better.

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Astronomers were the first to recognise that sky-glow hampers the detection of faint celestial objects, obliging them to conduct their observations from darker areas or from orbit. Founded in 1988, the International Dark Sky Association is one of the first organisations to call attention to the hazards of light pollution. However, it is only very recently that the multiple negative effects of artificial lighting on ecology, human health, and social well-being have gained broader scientific recognition. In 2009, six institutes of the Leibniz Association have joined forces with three institutes of the Technische Universität Berlin, the Freie Universität Berlin, and the Helmholtz Centre for Environmental Research to found the transdisciplinary research platform “Verlust der Nacht”. Member institutes encapsulate a wide range of expertise in biological, social, and technological disciplines and aim to address the significance of artificial lighting with a holistic approach. The research platform is funded by the Federal Ministry of Education and Research (Germany) and the Berlin Senate Department for Economics, Technology and Research (Germany).

However, existing research associated with the impact of artificial lighting on various aspects of our environment and lives is often fragmented, and generally at best at a regional or national level. The current potential for networking to enhance mobility between different actors from science, health care, public authorities, and industry is limited. While *Verlust der Nacht* marks an important milestone in transdisciplinary research, a broader, European-scale activity was the logical next step. In 2012, the European COST Action “LoNNe” (Loss of the Night Network) was formed. LoNNe aims to facilitate the transfer of existing knowledge between fragmented national research projects, to stimulate transdisciplinary research, and to initiate dialogue regarding light pollution with concerned and involved stakeholders, in particular the general public. This will help to identify potential corrective measures, and to stimulate innovations in technology. LoNNe is open to any field of research, with the explicit goals of influencing the development path of modern lighting technology, and creating guidelines for lighting concepts that are ecologically, socially, and economically sustainable.

# PLENARY TALK

## THE TOXICITY OF LIGHT AT NIGHT AND ITS HUMAN HEALTH CONSEQUENCES

*ABRAHAM HAIM,  
University of Haifa*

*The Israeli Center for Interdisciplinary Research in Chronobiology, IL*

Background: Light at night (LAN) is considered today as toxic for humans. Over one year ago AMA (American Medical Association) passed a resolution where LAN is considered a source of pollution, as among others it suppresses Melatonin (MLT) production, disrupts circadian rhythms and interferes with sleep. As LAN suppresses MLT production it can be considered a source of toxicity due to the fact it interferes with the production and secretion of pineal melatonin (MLT) hormone at the dark period of the 24h. MLT is known as a “jack of all traits”. In regards to temporal organization of our daily rhythms and seasonality MLT plays a crucial role, in which high MLT levels are a signal to cells, tissues and organs that its night where high levels for a long duration are a signal for winter characterized by long nights. MLT secretion may be affected by LAN depending on wave length and intensity. Short wave length (SWL) illumination is considered as “environmentally friendly” while it is most efficient in suppressing MLT production. Our knowledge from the recent years, in regards to the avenues used for transferring environmental illumination

from photoreceptors in our retina to the brain, revealed the importance of the Non Image Forming Photoreceptors (NIPF) for regulating the circadian rhythms. The discovery of the protein melanopsin in the bipolar cells of the retina and its high sensitivity to SWL illumination, could explain the relations between exposure to SWL illumination and suppression of pineal MLT production. So, what can be the health consequences of MLT suppression? In The Israeli Center for Interdisciplinary Research in Chronobiology we have been studying this topic in the last years.

Objectives: To measure suppression of MLT production by exposing animal models to different wavelength illumination and to assess the effects of MLT suppression on breast and prostate cancers, immune activity as well as in modulating stress effects caused by exposure to LAN mainly that of SWL.

Methods: For breast and prostate cancers we inoculated short day (SD) acclimated BALB mice (4T1 for breast cancer given to females and TRAMP for prostate cancer given to males) and exposed them to SWL illumination for

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30min between seven and eight hours after lights went off using fluorescent illumination of almost 470nm at an intensity of 450lux. For mole rats we used three different wave length illuminations, short (479nm) medium (586nm) and long (697) and they were exposed to LAN for 30min from 24:00h. Golden spiny mice for immune responses were interfered every four hours for 15min while, for measuring stress response we used a protocol similar to that of the mice and mole rats. In different experiments different variables were measured. For assessing MLT production we used its urine metabolite 6-SMT.

Results: Exposure to LAN of mice inoculated with 4T1 or TRAMP resulted in an increase of rate growth relatively to SD-control not expose to LAN. However, MLT treatment to LAN exposed mice moderated the rate growth of the tumors and their volumes were lower than those of the control group. Exposure of mole rats to LAN using different wave length illumination revealed that only under 586nm no suppression of MLT is noted with time. This wave length has also a minimal stress effect regarding cortico-adrenal secretion. Assessing LAN response on immune system as a response to KLH, revealed that such mice showed a similar pattern of atypical lymphocytes in long day acclimated mice and mice exposed to LAN, while MLT treatment resulted in a constant pattern with low

levels of atypical lymphocytes similar to SD-acclimated. LAN was noted as a stressor also at the cellular level where HSP70 levels increased in brain and liver tissues, 48h after exposure however, these values decreased after seven and 21 days of exposure in these tissues but increased in cardiac cells.

Conclusions: Our results suggest that SWL has a negative impact on our health among others because of suppressing pineal MLT secretion which among other functions, is known as a strong anti oxidant and as an anti oncogenic agent. Bearing in mind that SWL illumination is dominant at the late hours of the morning and early hours of the afternoon, such an exposure close to midnight “confuses” the biological clock and disrupts the function of our biological clock in the Suprachiasmatic nuclei (SCN) which contain MLT receptors. Furthermore, the melanopsin in the bipolar cells of the retina that controls our circadian rhythms responds to SWL, by suppressing pineal MLT production and secretion. Apart of suppressing MLT production LAN is also a stressor and mainly SWL illumination. As we do not think to go back and live in the dark, we should adopt the AMA resolution also calling upon finding new technologies for illumination. At this stage, we can call upon decision maker to dim LAN resources and control illumination in a more rational way.

# PLENARY TALK

## LIGHT POLLUTION AS A HIDDEN DRIVER OF BIODIVERSITY LOSS – ARE WE MISSING A TRICK?

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*EMMA LOUISE STONE,  
University of Bristol  
School of Biological Sciences, GB*

### ECOLOGY

Global biodiversity is threatened and decreasing at an alarming rate. This has significant consequences for ecosystem services that sustain humanity. Artificial light is one of the most widely distributed forms of anthropogenic pollution globally but has received little attention and has only recently become a focus of research. There has been a recent interest in assessing the biodiversity impacts of light pollution and artificial light is now recognised as a key threat to terrestrial biodiversity. We are beginning to identify complex and diverse impacts which are often species specific and can occur at

different spatial and temporal scales, from the community to the taxonomic level. The diversity of lighting regimes, changes in trends and fast moving developments in lighting technology makes predicting impacts more challenging. I discuss our current understanding of the impacts of artificial lighting on terrestrial biodiversity, drawing on examples from my own research demonstrating the complexities of predicting effects. I discuss the potential challenges and the future directions in understanding and mitigating the biodiversity impacts of light pollution.

---

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# PLENARY TALK

## ARTIFICIAL LIGHT AND STREAM ECOSYSTEMS: WHAT WE KNOW AND WHERE WE'RE HEADED

*ELISABETH PERKIN,  
University of British Columbia  
Department of Forest & Conservation Sciences, CDN*

Artificial light is becoming increasingly recognized as a potential disrupter of ecosystem function, but few studies have looked at the effects of light on stream ecosystems. Studying how artificial lights affect stream ecosystems is an important topic, as recent research in Berlin has shown that flowing waters are disproportionately more likely to experience increased levels of nighttime illumination. In this talk, I will review the results from several studies that examined the ways in which artificial light affect

stream organisms, with an emphasis on aquatic insects. I will also talk about the need for future experiments to examine how artificial light might interact with other urban stressors and the potential role seasonality plays in influencing organismal response to artificial light. Future research in the field will need to incorporate not only ecological, but also sociological aspects to best determine how and where changes in artificial light can take place.

# PLENARY TALK

## PLEIADES AND PRAIRIE CHICKENS: DARK SKY PRESERVATION IN THE CENTRAL UNITED STATES

*TERREL A. GALLAWAY*  
*COLORADO STATE UNIVERSITY, USA*

This paper explores the potential for preserving dark skies in eleven states in the central part of the United States.\* When considering dark skies in the United States, one often thinks of the American West with its vast stretches of public lands and scarcely populated deserts. By contrast, the eastern United States is ablaze with lights from its major metropolitan areas and numerous smaller cities. The central part of US, both in terms of geography and artificial light at night, lies somewhere in between. These states, falling roughly between the Rocky Mountains in the west and the Mississippi River in the east, contain much of the Great Plains and the Central Plains. This region is generally rural and agricultural, with the low population density one might expect in such areas. Accordingly, these states contain rather large expanses where nighttime skies are relatively dark. In some areas, the night sky is nearly pristine.

The states we are studying make up a very large area, covering over 2.4 million square kilometers. Accordingly, generalizations are necessarily imperfect. Nevertheless, while proceeding cautiously, we

can offer a rough overview. In addition to being rural and agrarian, much of this area also enjoys sunnier weather (fewer cloudy days) compared to the Pacific Northwest and the eastern part of the US. Its central location makes it accessible to those living in other parts of the country. In particular, the dark skies of these central states are much closer to the population centers of the Eastern Seaboard than are the National Parks and deserts in the western US. All of these factors lend themselves to the usefulness and viability of preserving dark skies in special areas within the central states. At the same time, much of the area tends to be somewhat politically conservative and might be suspicious of federal efforts to protect what might be considered a somewhat esoteric environmental amenity. Additionally, these states have fewer and smaller public lands than what are found in the western US. Given that such lands are generally protected from development, their absence makes night sky preservation a different challenge in the central US than it is in the American West. Nevertheless, people in these states often share a deep sense of place,

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as well as an interest in historic preservation and wildlife conservation. These attitudes are an excellent fit with dark sky preservation.

The goal of the paper is to help identify areas where it might be most fruitful to pursue dark-sky conservation efforts. Such efforts might include setting aside areas primarily designated for dark-sky preservation, adding dark skies to the list of conservation goals of pre-existing public or private conservation lands, or establishing cooperative agreements among citizens and other stakeholders in a broader area. The focus is not limited to pristine areas, but instead we hope to identify numerous areas where people can visit to enjoy access to very good views of the heavens. More generally, it is hoped that such research can help raise awareness in areas where significantly dark skies are a distinctive local amenity.

Perhaps the biggest challenge to creating dark sky preserves is that many people in the region do not consider light pollution to be a pressing issue. Therefore, a reasonable strategy is to look at complementary conservation goals. There are a number of conservation goals that favor remote, rural locations. Often these same goals require relatively large tracks of land. For example, efforts to restore or protect native prairie, and native deserts, generally, or to protect specific species such as the prairie chicken or the American bison, are often located in rural locations requiring large, un-fragmented

tracts of land. By way of illustration, it is believed that a minimum of 4,000 to 5,00 acres of open grassland is required to support a stable population of prairie chickens. Significantly, a tract of land that is remote, rural, and relatively large will also be isolated from artificial light at night, thereby ensuring dark skies above this land.

In order to achieve the above goals, this paper will utilize GIS techniques to identify areas, within the central United States, suitable for potential night sky conservation. The project will rely on artificial-light-at-night satellite data from the National Oceanic and Atmospheric Administration's National Geophysical Data Center. In addition, it will rely on demographic and economic projections from the Census Bureau, as well as geographic data including local weather, land coverage, and land use—such as existing public lands or private conservation lands. The hope is to develop a forward-looking model that can help identify areas that are good conservation candidates, not just now, but for the years to come. These data will be examined from a variety of standpoints, including analyzing the dark-sky potential of existing conservation areas, and identifying areas of high potential where no current conservation efforts exist.

\* The subject states include: North Dakota, South Dakota, Minnesota, Nebraska, Iowa, Kansas, Missouri, Oklahoma, Arkansas, Texas and Louisiana.

# PLENARY TALK

## EXAMPLES OF URBAN LIGHTING DESIGN

*VOLKER VON KARDORFF,  
Kardorff Ingenieure Lichtplanung GmbH, D*

The density of cities places and the needs of people places highly complex demands on lighting. The expectations concerning light in public spaces are shaped by different interest groups, which are quite contrary.

Aspects such as energy consumption, tourism, safety, atmosphere, and last but not least, luminaire maintenance and operation play a role in virtually all situations.

In addition, the desire for better usability of cities at night stands in direct opposition to the equally important aspect of energy savings and reduction of light pollution.

A city does not consist of isolated spaces. An interplay exists between the public lighting, for which the city is responsible, and private lighting, which mingles with, adds to or diametrically opposes the lighting in these public spaces. Without a dialogue and balance of interests, sustainable solutions will not be found. And if such a balance of interests is reached for one city, the particular solution will in no way be applicable to others.

Regional differences within a country already require individual solutions. If one begins to think beyond national borders or even continents, then it becomes clear how strongly cultural identity and mentality affect the perception of and need for light. Only after these regional differences and country-specific needs have been understood, is it then possible to comprehend the status quo.

Additionally, the lighting for a city and its inhabitants has a strong influence on the development, well-being and health of people, animals and plants. Therefore it is imperative that, alongside the struggle to find a solution, to introduce limits and guidelines for the protection of all involved.

### Examples in Germany

1. Energy consumption – Altes Stadthaus, Berlin: The illumination of the Altes Stadthaus in Berlin is distinguished by its very low energy use. For the first time in Germany, Kardorff Ingenieure Lichtplanung applied a patented lighting system from Switzerland. This system uses Gobos (Gobo =Graphical optical blackout) to project

the light precisely on the facade, leaving out the windows. Using this technology, it is possible to illuminate facades directly and have the lowest level of energy use per square meter of facade.

2. Tourism – Brandenburg Gate, Berlin:

Although low energy consumption was not the overriding goal for the Brandenburg Gate, the lighting design by Kardorff Ingenieure Lichtplanung made it possible to reduce the electrical wattage by 60%.

The Brandenburg Gate without its night-time illumination would simply be inconceivable. This is true for many buildings that play an important role for tourism.

3. Identity – Marktplatz, Neubrandenburg:

Identity formation is not only a topic for large cities, but also in particular for smaller ones, whose competitive profile will become increasingly important in the future. The Marktplatz in Neubrandenburg is an example of the new interpretation of a city's main square.

Kardorff Ingenieure proposed eight large poles that spectacularly surround the square as special lights and through their direct-indirect illumination have become a new emblem for the city.

4. Safety – Alexanderplatz, Berlin:

The sheer size of Berlin's Alexanderplatz posed a challenge in terms of lighting design. While placing only a few

lighting fixtures on the square, the desire was to still achieve a high level of illumination in order to do justice to the major safety aspects.

For this project Kardorff Ingenieure designed a special type of lighting fixture. The reflector technology applied here combines the light from three lamps, placed one above the other, to achieve a high level of luminous power in the middle of the square.

5. Atmosphere – Marktplatz, Stralsund:

Safety issues did not stand in the foreground for the market place in Stralsund, rather the creation of a pleasant light atmosphere for this square lined by a town hall and church, whose medieval characteristics have special significance.

6. Maintenance and operation – Products:

Only a small part of public lighting consists of illuminating facades and squares as outlined in the examples above. The much larger part of public lighting is the responsibility for lighting streets.

In the past, street lights were already very long-term products that were not allowed to reflect short-lived trends in their appearance, but rather were required to adapt respectfully and self-evidently to diverse urban landscapes. The very durable LED strengthens this requirement even more. In the future, we will experience a complete switch from conventional luminaires in street lighting to LED technology.

# PLENARY TALK

## STATE-OF-ART ON LIGHTING SYSTEMS FOR CITIES

*GEORGES ZISSIS,  
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Artificial light sources play an indispensable role to daily life of any Human being. Electrical light sources are responsible for an energy consumption of around 1/6 to 1/5 of worldwide electricity production. On the one hand, street lighting represents 8% of the above stated quantity. On the other hand, street lighting should guarantee security (traffic and pedestrians), guarantees user's well being and beautify the city and sets a mood.

Although classic lighting technologies are now mature, the luminous efficiency of the light sources together with their quality of light have not quite reached their limits: there is still room for innovation. Today, there are many opportunities for enhancing not only the efficiency and reliability of lighting systems but also improving the quality of light as seen by the end user. However, despite many scientific and technical progresses in the field of the electrical discharge light sources, the maximum efficiency of these systems has reached its limits, since the seventies, to about 125-130 lm/W. Today, thanks to intense technological developments, the latest ceramic metal halide lamps

show an efficacy as high as 150 lm/W for high quality white light. Overcoming this barrier is possible through intelligent use of new technologies, a deep scientific understanding of the operating principles of light sources and a good knowledge of the varied human needs for different types of lighting in different settings. For example, NumeLiTe project shown, few years ago, that new light sources exploring the mesopic vision conditions could be used for achieving energy savings and offering the right quantity of light to the end user.

Furthermore, currently the next revolution in lighting is taking place: Solid State Lighting (SSL). In the long term SSL, inorganic and organic light emitting diodes, could become the next generation light sources. In fact, LEDs, with a continuous growth of their luminous efficiencies, establish themselves as breakthrough solutions. Street lighting is considered as an important issue for this technology. This paper give some examples of projects and their outcomes in this domain, based on the features of the European LITES project, to prove in real life experimentation that intelligent

street lighting using solid-state lights LED drastically reduces energy consumption. The paper presents strategies for increasing the electric energy savings, by implementing the Best Available Techniques and Sustainable Development Strategy, which focus on two factors: the use of the best state of the art technology available and the environment protection, while the human needs are met. Today, technical criteria must be considered in the context of a broader technico-financial analysis that also takes into account the economic performance, the maintenance constraints, the environmental impact and the competitiveness of the commercial proposal – which can be used to judge the suitability of the

choice of given technology in comparison with conventional solutions.

All in all, in order to achieve considerable savings from lighting, a coherent strategy is required to transform the lighting market in both International and National levels. The paper emphasises the importance of taking a holistic view in the development of lighting systems in order to obtain high quality lighting that is need for ensuring quality of life, health and security of end-users.

What are the challenges and also the limitations of new technologies? What is the impact on the environment, health and security? All these will be discussed during the presentation.

# PLENARY TALK

## THE VALUE OF LESS LIGHT – SUSTAINABLE ARCHITECTURAL LIGHTING DESIGN

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Since its beginning, the art of external illumination has substantially influenced the creation and the perception of architecture and the night-time urban environment. In her lecture, the author examines and defines the significant interdisciplinary conditions related to architectural lighting design that have evolved over the years, starting from the first simple exterior lighting projects to the more modern, complex concepts of illumination. The first artistic experiments with the effects of lighting on architecture date back to the ancient times. However, the more mature intentions of lighting building facades for usability as well as aesthetic and artistic purposes appeared on a larger scale in the late nineteenth and early twentieth centuries. This went hand-in-hand with the invention of the electric light bulb. The significant role in the search for new directions on how to illuminate buildings played a central role at various world exhibitions, the experiences of building form using light performed by architects of modernism era as well as experiments inspired from theatre, primarily driven by Stanley McCandless, Abe Feder and Richard Kelly.

These experiments conducted mainly in the 1950s and 60s led to the birth of a new discipline called architectural lighting design. Since then many creative visions of architectural lighting started to appear in urban environments at night.

When this concept of “painting with light” seemed to be reaching its peak, a number of limitations associated with architectural lighting design emerged. The energy crisis of the 1970s forced the need to reduce the costs of lighting and led to the abandonment of costly and unnecessary elements such as exterior lighting.

Later research in seemingly distant and unrelated disciplines to architectural lighting design such as biology, medicine, ecology and environmental protection has highlighted a number of conditions and restrictions which exterior lighting projects should take into consideration. Inappropriately designed exterior lighting in cities has been identified as one of the reasons for climate change and disorders in the integrity of ecosystems. Attempts to address these interdisciplinary conditions in today’s projects of external illumination are not an easy task. However, it should be noted that the

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rapid development of innovative lighting technologies has helped in resolving these issues to a certain extent. At the same time, this development comes with its own limitations, as the necessary technical knowledge is highly complex and beyond the scope of most architects. The above issues related to interdisciplinary conditions translate directly into new research questions on whether the necessary technical expertise and complex requirements arising from the need to save energy, to protect the environment or even to fulfill political demands have a negative impact on the quality of proposed lighting design solutions. In the era of new and numerous constraints and requirements, is it still possible to not only unfold a building's forms after dark, but also to creatively complement architectural concepts? It is also important to define how to integrate specialist knowledge from the field of illumination in the process of developing the concept of an architectural building.

### Conclusion

This research reveals that despite the current new requirements of the twenty-first century that need to be fulfilled, it is still possible to complement architectural concepts and urban environments with quality projects of illumination. Despite the limitations resulting from studies on the effects of artificial illumination of building such as light pollution, human

health and ecosystem integrity, electric lighting highlights the basic elements of a three-dimensional architectural composition in a night-time environment.

Sustainable architectural lighting design does not have to be unimaginative. Lighting designers should see light as a "24-hour system" in which natural light plays the key role and which is supplemented and sometimes replaced by artificial means.

It doesn't mean that lighting design has no future due to the issues presented – quite the opposite. Skilled professionals in this field are needed more than ever; their experience and knowledge can lead to innovations, cost and energy savings and a positive environmental impact. By designing lighting with balance, intelligent thinking and awareness of environmental and civil implications, professional lighting designers actively play a role in the quality of life for generations to come.

The research study also examines the importance and extent of coordinating and integrating lighting design within an architectural project. The author provides evidence that collaboration between architects and lighting designers established adequately at the early stages of concept design is necessary in order to achieve better creative results in "painting with light" as well as to help generate original lighting solutions for external concepts of architecture and urban masterplans.

# PLENARY TALK

## REGULATION OF LIGHT POLLUTION IN FRANCE

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In France, the light pollution issue first came out in 2007, becoming a public and political topic.

In 2009, a first law defined 4 objectives: biodiversity, energy consumption, discomfort (glare, intrusive light...) and preservation of the starry sky.

In 2010, a second law set up a strategy to reach these objectives. The scope is wide: road lighting, urban lighting, shop signs and illuminated adverts, buildings, illumination for enhancing the cultural and natural heritage...The Minister of the Environment may impose technical requirements to the operator or user of these light installations after consultation with all stakeholders.

If appropriate, these requirements may be adjusted for the operating zone of the installation: inside or outside urban areas, protected natural areas, some astronomical sites.

The main technical regulatory requirements envisaged concern direction of light, energy efficiency, operating time of some installations, amount of light (useful) output.

The Minister has also the power to ban or restrict the use of lighting,

temporarily or permanently, of some light sources depending on their nature (eg: powerful skytracers) or local characteristics (eg: protected natural areas...).

The first regulatory initiatives was to frame the operating time of shop signs, illuminated adverts, shop windows, non residential buildings... in order to save energy and reduce the print of artificial lighting on the nocturnal environment.

A decree has been taken in January 2012 concerning shop signs and illuminated adverts. On the outlines, these facilities have to be turned off from 1.00 to 6.00.

This rule which is intended to save the energy consumption of 370,000 households (1TWh per year) and avoid the emission of 120,000 tons of CO2.

A decree was issued in January 2013, which entered into force on 1st July.

The outlines of this decree are: the interior lights of nonresidential buildings will have to be turned off an hour after the last worker leaves, and lights on building facades and in shop windows will have to be extinguished by 1 a.m.

This decree will cut carbon dioxide emissions by 250,000 tons a year and

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save the equivalent of the annual consumption of 750,000 households (2 TWh per year).

The Ministry also aim at raising citizen and local authorities's awareness about light pollution (Earth Hour, Jour de la nuit, Villes et villages étoilés...).

Key figures: on average, public lighting represents around half of municipalities' consumption of electricity. The 9 millions light points feature over 1300 MW or the equivalent of a nuclear unit and consume 6TWh per year. Shop signs amount to 750 MW.

# PLENARY TALK

## IMPROVING SLEEP WITH NATURAL LIGHT AND CIRCADIAN DARKNESS

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Sleep is a basic human need and essential for good health, quality of life and performing well during the day. Humans must sleep to function optimally as otherwise the consequences are disastrous and costly to both the individual and society. Good sleep requires our biological clock to be synchronised to the natural alternations of light and darkness. The biological clock is synchronised (entrained) to the 24-hour light-dark cycle by its primary zeitgeber light. The relationship between external (social) and internal (biological) time is called phase of entrainment. People that differ in this trait are different chronotypes (e.g. 'early larks' and 'late owls'). Whereas for most of human history, light was solely available during the day, it is now an on-demand commodity. Artificial light penetrates our days and pollutes our natural dark hours, with worrisome consequences on sleep and health that concern us all. But, why is this a problem? The human biological clock is only sensitive to the effects of light at specific times of day. Light is only able to advance the clock in the morning. Light in the evenings delays our clock. If we are not

exposed to sufficient morning light and/or to too much evening light, delayed sleep phase and circadian misalignment results. Because we still need to get up in the morning, this results in sleep loss, typically on workdays. Alarmingly, about 80% of the general population rely on their alarm bells on workdays, which includes all later chronotypes. Consequently, sleep quality and quantity decrease, leading to chronic sleep deprivation, mal-recuperation and long-term ill health. Epidemiological research shows that average sleep duration is decreasing worldwide, meaning that an increasing number of people do not fulfil their biological sleep needs on a regular basis. From controlled laboratory studies there is ample evidence on the detrimental effects of sleep deprivation on health and performance, with consequences that would be catastrophic in real life – especially in shift-work occupations. In addition, field studies have shown that sleep loss accumulated over the work-week is compensated by longer sleep on free days, mostly in later chronotypes. This phenomenon is termed social jetlag and is positively correlated with smoking,

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obesity, depression and cardiovascular risk.

In a nutshell, through widespread and uncontrolled use of artificial light, we create un-natural light/dark cycles that interfere with entrainment of our biological clock leading to chronic sleep deprivation, circadian misalignment and adverse lifestyle habits with severe longer-term health risks. One could even conclude that today both light and sleep have become commodities on-demand, which are more subject to social lifestyles than to biological needs. To develop countermeasures we have to identify ways to control the key players in this network of biology, environment and behaviour that impact our biological clock, sleep and health. Currently, our knowledge about all potential biological side effects of light pollution is too limited to design final remedies, but it is sufficient to initiate first actions. An analogy shall help to explain the situation: carbon footprints are profiles of energy consumption and introduced to quantify the balance between needed and wasted energy in our everyday lives. Enforcing the use of more regenerative energy sources to prevent the waste of energy and to protect our environment

from potential side effects of exploiting natural resources has become central to climate politics almost worldwide. Hence, similar to acknowledging a wrong use of our planet's energy supplies, we must re-consider our daily use of light. Chronobiology and circadian entrainment theory tell that light will change circadian entrainment and the consequence of changes in circadian entrainment is altered timing of sleep. Hence, light pollution must be taken very seriously, because it impacts our biological clock that governs our sleep and everything else with a daily up and down. In addition, solutions that promote thorough and more careful application of artificial light will help to decrease our carbon footprints alike. To understand how light-styles impact sleep and health under real life conditions is central to my work, which aims to better understand natural entrainment and to quantify biological effects of light pollution. The results will help to promote the re-introduction of natural dawn and dusk into participants' bedrooms, and to develop non-invasive, easy accomplishable solutions for both private homes and workplaces that help to decrease chronic sleep deprivation and that increase sleep quality, well-being and health.

# PLENARY TALK

## ELECTRIC LIGHT AT NIGHT CAN COMPROMISE HUMAN HEALTH

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The vast bulk of human evolution on Earth was under conditions of lighting that depended on the Sun for a daily cycle of day and night. Domestication of fire, and the later invention of candles, began to provide some anthropogenic lighting but this light was dim, red-yellow spectrum, and sporadic. A dramatic change came with the development of the electric light bulb, so that now light at night is bright and pervasive, and extending to a rapidly expanding proportion of the world's population.

Adaptation to the solar signal of about 12 hours of bright, broad-spectrum light and 12 hours of dark, dawn and dusk permitting, has taken several billion years, and as a result, an endogenous circadian rhythmicity is now integral to human physiology, and to that of nearly all life on the planet. This rhythmicity is pervasive in our biology affecting almost all cells, tissues, and organs. It includes ~24-hour rhythms in hormone production (notably melatonin), sleep, metabolism, DNA damage response, and expression of the core clock genes, each of which has pleiotropic effects in addition to its role in the generation of the

endogenous rhythm. This endogenous rhythm is kept at precisely 24 hours by the light-dark cycle of Sun exposure.

Electric lighting of night disrupts circadian rhythmicity, and the health consequences are only recently becoming recognized as potentially severe. Light at night suppresses melatonin production and alters clock gene expression. Sleep is disrupted as well. Experimental studies in humans have demonstrated that short-term sleep disruption and/or nighttime light exposure can change physiological markers relevant to diabetes, obesity, and cancer.

A recent theory to explain the evolving breast cancer pandemic proposes that increasing use of electricity to light the night, explains a portion of the breast cancer burden worldwide, perhaps a large portion. It is based primarily on a suppression of melatonin, a molecule that has been shown to have strong anti-cancer capabilities in cellular and animal models. Epidemiological studies of predictions of the idea have so far generally supported it: for example, shift working women appear to have higher risk and blind women lower risk.

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If electric light at night does increase risk of some of the dreaded diseases of modern life by disrupting circadian rhythms, then there are practical innovations in lighting technology and applica-

tion that could mitigate electric light's impact on circadian rhythmicity, and create lighting that is more conducive to good circadian health.

# PLENARY TALK

## MEASUREMENT OF HUMAN EXPOSURE TO LIGHT AT NIGHT

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Light at night (LAN) has been implicated in recent literature as a risk factor for breast cancer. There are two competing, but possibly interrelated hypotheses put forward to interpret these epidemiological results: 1) nocturnal melatonin suppression, caused by exposure to light at night, or 2) circadian disruption, caused by irregular light exposures over 24 hours.

Animal studies have demonstrated that melatonin limits the proliferation of cancer tumors. Epidemiologists have shown an association between the presence of outdoor lighting observed in satellite images and an increased incidence of breast cancer in Israel<sup>1</sup>, attributing this finding to nocturnal melatonin suppression by outdoor lighting. Indeed, previous literature<sup>ii</sup> has shown that there is more outdoor light at night in urban environments compared to rural ones. Obviously however, light level measurements from satellite images do not provide the important information about the quantities, spectra, duration and timing of light exposure actually received at the eye, particularly inside residences at night. Thus, the causal link between

outdoor light measurements and indoor light exposure at night as it might affect cancer proliferation has not been forged.

Circadian disruption is caused by exposure to light-dark patterns that do not occur regularly every 24 hours. Circadian disruption has been linked to cancer<sup>iii,iv</sup>. An urban lifestyle may be associated with a wide range of features that cause circadian disruption. Limited exposure to daylight in the built environment can, in principle, cause circadian disruption. Sleep is another important consideration and an urban environment has many more stress related factors that can affect sleep efficiency and duration. One study showed that sleep duration was shorter in urban environments than rural environments<sup>v</sup>. Sleep duration has also been shown to be reduced as commute time increases<sup>vi</sup>. It has also been demonstrated that sleep curtailment can negatively impact the immune system<sup>vii</sup>. To test both the light-induced nocturnal melatonin suppression and circadian disruption hypotheses, one requires precise quantification of the light stimulus in terms of amount timing, duration and spectrum of light. To that

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end, Lighting Research Center (LRC) has developed a simple measurement device called the Daysimeter that should help test these hypotheses<sup>viii</sup>. The LRC has also developed a mathematical technique to determine, from the Daysimeter light and activity data, levels of circadian entrainment and disruption<sup>ix</sup>. Therefore, the Daysimeter can, not only measure absolute light levels as they might affect melatonin synthesis, but also the impact of light-dark patterns as they might affect circadian entrainment and disruption experienced by those who wear the device.

The presentation will discuss field measurements of circadian light exposures for various populations, focusing on evening light exposures. It will also discuss how data from the Daysimeter can be used to characterize circadian disruption in the field and used in parametric studies using animal models <sup>x,xi</sup>.

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## ADVANCES IN NIGHTTIME LIGHTS SATELLITE IMAGERY

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Until recently, the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) data has been the only global low light imaging data available. For the past 40 years, a series of twenty-four DMSP satellites have collected low light imaging data using the OLS. However, the design of the OLS has not changed significantly since the late 1970's. Because the design has not been updated, the OLS data have a relatively coarse spatial resolution, a limited dynamic range, and lack in-flight

calibration. NASA and NOAA launched the Suomi National Polar Partnership (SNPP) satellite in 2011. The SNPP carries the first Visible Infrared Imaging Radiometer Suite (VIIRS) instrument, which has a Day-Night Band (DNB). At night, the DNB records low light imaging data globally. The DNB data is calibrated and has vastly improved spatial resolution and dynamic range as compared to the OLS data. The nighttime low light imaging capabilities of these two systems and their global data products will be compared.

# CHRONOBIOLOGY

## LIGHT AT NIGHT: EXTEND OF ANNOYANCE AND SLEEP DISTURBANCE IN THE NETHERLANDS

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Environmental light at night (eLAN) is outdoor man-made light, as opposed to indoor LAN. Although LAN is associated with severe health effects, less detrimental effects like annoyance and sleep disturbance may be more common with respect to the number of people affected.

To assess the prevalence of annoyance and sleep disturbance due to eLAN among residents in the Netherlands we performed a survey.

The survey was an inventory of nuisance due to a variety of ambient stressors in the living environment (e.g. noise, malodour, vibrations) among which light at night was considered as well. 1250 residents participated in the survey, which was performed by means of a face-to-face, structured interview. The sample appeared to be representative with respect to the distribution of age, gender and socio economic status in the Netherlands.

Altogether, residents evaluated 9 different sources (spot lights on buildings, street lights, head lights, outdoor light, assimilation light, light by enterprises, lighting of sports fields, illuminated advertising and reflection of glazed facades). Annoyance and sleep disturbance were assessed by means of an 11-point scale (0: not at all annoyed or disturbed;

10: extremely annoyed or disturbed). People with a score of 5 or higher are considered 'annoyed' or 'disturbed', people with a score of 8 or higher are considered 'severely annoyed' or 'severely sleep disturbed'. The proportion (in %) of residents '(severely) annoyed or (severely) disturbed are presented.

Most annoying light sources at night studied were 'street lights', 'head lights' and 'outdoor lights'. 'Street lights' was the most annoying source: 5% of the residents were annoyed, 2% were severely annoyed. These sources appeared to be also the most sleep disturbing light sources studied, although the proportion of residents whose sleep was disturbed was lower than the proportion of residents annoyed. Again 'street lights' was the most sleep disturbing light source with 3% of the residents indicating to be disturbed at night and 1% being severely disturbed.

Although noise is the most important source of nuisance in the living environment, eLAN leads to a considerable proportion of people annoyed or whose sleep is disturbed. Considering that one percent point represents 135.000 adult Dutch residents, some 675.000 people are annoyed and about 400.000 are sleep disturbed by eLAN.

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## PERCHES IN SPOTLIGHT – DOES LIGHT POLLUTION IMPAIR FISH'S BIOLOGICAL RHYTHM?

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Light pollution can have serious consequences, not only on terrestrial organisms like humans, birds, insects and plants, but also on aquatic ones. The shores of rivers, lakes and seas are often urbanized and thus marked by plenty of artificial light sources. Illuminated water-side promenades, bridges and harbours and the urban skyglow itself can alter the light-regime in the water during the night. Hence, the natural day-night-distinction can become blurred. However, behavioural and physiological processes in plenty of aquatic organisms are controlled by the rhythm of day and night. This biological rhythm in turn is regulated by the light dependent production of melatonin. If the production of melatonin is affected by light pollution, it is most likely that processes that underlie circadian and circannual rhythms will also be impaired.

This study deals with the influence of light at night on European perch, *Perca fluviatilis*, a common and widely distributed freshwater predator. The aim was to examine the effect of different light quantities (0 lux, 1 lux, 10 lux, 100 lux) and qualities (light spectra) during the night on the levels of melatonin and the stress marker cortisol. Melatonin and cortisol are secreted into blood circula-

tion and are also released into the water via the gills. For non-invasive measurements of melatonin and cortisol, water samples were taken every 3 hours during a 24 h-period and the hormones were extracted and analysed. The 0 lux-treatment re-vealed that melatonin levels displayed a typical pattern, i.e. increased during the night and decreased during the day. However, even at the very low light level of 1 lux there were almost no amplitudes measurable for melatonin concentrations, barely rising in the night, and in the 10 and 100 lux treatments no rises were detectable anymore.

These results strongly suggest that even at low light conditions an impairment of circadian rhythmicity can occur. These lighting conditions are in fact physiologically relevant, since similar lux values have been measured in urban waters. Thus it seems to be highly probable that light pollution is able to disturb circadian patterns like physical regeneration and circannual processes like reproduction. With increasing light pollution in the future it is conceivable that perch and particularly more susceptible fish species will have serious problems in maintaining their natural rhythmicities, which might implicate even impacts on population levels.

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## CIRCADIAN DISRUPTION AS A MODULATOR OF RESILIENCE TO STRESSORS

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Circadian (daily) rhythms in physiology and behavior are phylogenetically ancient and are present in almost all plants and animals. In mammals, these rhythms are generated by a master circadian clock in the suprachiasmatic nucleus (SCN) of the hypothalamus, which in turn synchronizes “peripheral oscillators” throughout the brain and body in almost all cell types and organ systems. While circadian rhythms are phylogenetically ancient, modern industrialized society and the ubiquity of electric lighting has resulted in a fundamental alteration in the relationship between an individual’s endogenous circadian rhythmicity and the external environment. The ramifications of this desynchronization for mental and physical health are not fully understood, though numerous lines of evidence are emerging that link defects in circadian timing with negative

health outcomes. Our group has begun to explore animal models of circadian disruption to understand how disrupted brain and body clocks contribute to physiological and neurobehavioral changes that bear similarity to chronic stress, or how such states can alter the response to additional stressors. I will show that a mouse model of circadian disruption by light leads to loss of neural complexity in the prefrontal cortex, changes in prefrontal mediated behaviors, metabolic dysregulation, and altered immune responses. The role of circadian clocks in maintaining optimal behavioral and physiologic function, and the consequences of circadian disruption for brain, behaviour and physiology will be discussed in the context of what we know about how stress can affect the brain and body.

## LIGHT POLLUTION AT NIGHT MODIFIES THE EXPRESSION OF BIOLOGICAL RHYTHMS AND BEHAVIOURS IN A NOCTURNAL PRIMATE.

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Light pollution altering light/dark cycles constitutes a new threat for biodiversity. However, despite many observations on the effects of artificial lighting on fauna, few experimental studies have documented its consequences on nocturnal mammals. The impact of light pollution was studied on a nocturnal primate, the grey mouse lemur (*Microcebus murinus*), of which all behavioural, physiological and chronobiological parameters are strongly driven by photoperiodic changes both in the wild and in captivity. Captive males ( $n=8$ ) maintained in short-photoperiod were first exposed during 14 nights to near darkness then exposed to light pollution treatment during 14 nights to a streetlight (high pressure sodium lamp). Daily rhythms of locomotor activity and core temperature were recorded continuously by telemetry. Nocturnal and feeding behaviours were recorded by video recording during the 14th night. Light pollution significantly modified the daily rhythms of locomotor activity and core temperature by phase delays associated with increases in core temperature. Changes in nocturnal and feeding behaviours patterns were also observed in males exposed to light pollution. In adult females, which remain in an

inactive sexual state during short-photoperiod and enter oestrus at the beginning of long-photoperiod, a preliminary study was conducted to determine the impacts of light pollution on reproductive function. During 5 weeks at the transition between short-photoperiod (SD: 10/14) and long-photoperiod (LD: 14/10) 6 females were exposed to light pollution at night (yellow LED) and compared to 6 females non-exposed to light pollution. Likely to males, light pollution led to changes in daily rhythms of locomotor activity and core temperature in females. More, using morphological changes in the vulva and urinary 17- $\beta$ -estradiol levels, it was demonstrated that oestrus occurrences and peaks of urinary estradiol were significantly advanced (by 10 days) in females exposed to light pollution compared to control females. These studies strongly suggest that light pollution leads to modifications of daily rhythms and behaviours in mouse lemurs with potential consequences in terms of maladaptive responses to seasonal environmental changes. Further studies on light pollution have to be done to test its effects on seasonal reproductive synchronization between sexes and to determine its impact on reproductive fitness.

# DARK SKY PARKS

## IDENTIFICATION AND QUALIFICATION OF DARK SKY PARKS

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We present methods how still dark places can be identified in Central Europe by using satellite data. These places can be used for observing by people enthusiastic in astronomy and for creating dark sky reserves. We controlled potential places using observations with fisheye lens pictures and sky brightness measurements. Calibrations between the fisheye pictures and the SQM measurements were made. The factors influencing the sky bright-

ness during the nights like reduction of artificial lighting, influence of vegetation or astronomical influences like Milky Way, airglow were analysed to determine characteristic values for dark places.

Within these regions lighting inventories have been made and recommendations for future lighting installations have been formulated to reduce light pollution in these regions.

## LIGHT URBAN DESIGN TACTICS – A SENSE OF DARKNESS

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This paper wishes to present an approximation between Lighting Design and Urban Design through tactical manoeuvres with the intention of proposing qualitative Design principles which may help mitigate Light Pollution.

This paper's ambition is to establish a constructive dialogue between designers and those involved with urbanity such as astronomers, biologists, and other organized dark-sky defenders, and possibly with the lighting industry and general public, regarding the city by night.

A qualitative approach to public space lighting detects that no form of lighting pollution has a simple explanation. Pollution as a consequence of human activity seems to result from the fragile intersection between many driving forces, mostly human, rooted strongly on the economic and ecological side of urban life.

The human being is progressively becoming an urban-being and the future of the species seems to increasingly depend on potentials of sustainable cities, their extension, flexibility and mutability, where inner city per capita levels show better results on energy use, waste management and CO<sub>2</sub> emissions (EC, 2009).

An introduction to a qualitative approach to lighting where tactical manoeuvres are proposed as the case-studies:

a) LED technology in test installation: Analysis international cooperation, b) Lighting Design meets Urban Design: International Competition, c) Starlight

Foundation: Light Pollution mitigation through design criteria

### Discussion: Light Pollution

From the Design perspective lighting pollution definition (proposal):

"That amount of lighting that, by waste or bad design, does not contribute in any way positively to human nighttime activities."

### Cases of study

1. LED Project art installation "Amber Drops" - Gdansk, Poland  
LED Light in Public Space (2009-2012)  
Component 3 coordinator.
2. Nordic Urban Lighting Design Competition - Stavanger, Norway  
"Light Urban Senses" criteria developed during this on-going research.
3. Alqueva Dark-Sky Reserve, Portugal - The Mediator Design  
The "Alqueva Dark-Sky Reserve" is the first ever "Starlight Tourist Destination".

### Conclusions (Preliminary)

Outdoor lighting for public places in the urbanity is a transdisciplinary issue.

Cooperation highlights the role of the designer defining the criteria as a mediator role.

European Commission. (2009). Sustainable and responsible business. Available: [http://ec.europa.eu/enterprise/policies/sustainable-business/documents/eco-design/legislation/framework-directive/index\\_en.htm](http://ec.europa.eu/enterprise/policies/sustainable-business/documents/eco-design/legislation/framework-directive/index_en.htm). Last accessed 18th February 2013.

## APPROACHES FOR ESTABLISHING DARK SKY RESERVES

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*CHAD MOORE, US National Park Service, Night Skies Program Manager, USA*

Dark sky parks, starlight reserves, and similar initiatives are increasingly being used to protect the nighttime environment. Such reserves attempt to define a boundary on the landscape within which there is common benefit from and responsibility for dark skies. Identifying such charismatic geography can educate the public, bolster public support, and

may be part of a regulatory structure to limit anthropogenic light. This paper explores different societal approaches, examines the impact of potential management actions, and devises scenarios for improvements in night sky quality. Efforts to create a large voluntary reserve in the Colorado Plateau of the USA and other areas are discussed.

## THE SKY QUALITY INDEX

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*CHAD MOORE, US National Park Service, Night Skies Program Manager, USA  
DAN DURISCOE, US National Park Service, USA*

The protection of starry night skies has been hampered by the lack of an objective index that can be communicated easily to interested members of the public and decision makers. In response, the US National Park Service has developed a Sky Quality Index (SQI) that captures the aesthetic quality of the night sky on a 0-100 scale. Derived from all-sky photometry, the index is designed to numerate units of equal aesthetic

change and capture the visual impression one gets from stargazing. The index uses four components, each evenly weighted, to derive the final value. The SQI has been cross-referenced to existing measures such as zenith sky luminance, all-sky average luminance, and the Bortle Dark Sky Scale. This aids in providing a functional impact assessment of various degrees of anthropogenic light.

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## QUALITY NIGHT RECREATION AND OUTDOOR LIGHTING IN U.S. NATIONAL PARKS: INDICATORS, STANDARDS, AND RELATED VISITOR

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Outdoor nighttime recreation experiences are of value to national park visitors. A 2011 system-wide National Park Service (NPS) unit management study found that over 15 such activities exist and that visitors participate in these “light-sensitive” experiences (Smith & Hallo, 2013). The novel sensory conditions (e.g., decreased viewshed; diverse sounds) offered during nighttime as compared to day is known to be a factor in why one may seek to engage in night recreation (Beeco, Hallo, Baldwin, & McGuire, 2012; Smith, 2007). Moreover, research suggests that outdoor lighting characteristics play a role in how one uses the nighttime environment and how enjoyable those experiences are—as a function of both visual perception (Rea, Radestsky, & Bullough, 2011; Stamps III, 2005) and innate tendencies (Nasar & Fischer, 1992; Ruddell & Hammitt, 1987). Despite NPS managements’ perceived high rate of visitor participation in nighttime recreation, little is known about visitor attitudes regarding night recreation or night resources, or what constitutes a high quality night recreation experience. Likewise, outdoor recreationists’ attitudes toward, and perceptions of, lighting in regard to nighttime recreation have not been empirically addressed.

To investigate, a visitor survey was conducted in 2012 at Yosemite, Grand Canyon, and Acadia National Parks, and Golden Gate National Recreation Area. This survey used attitudinal questions, photo simulations and normative approaches to 1) refine and validate indicators for night recreation experiences, 2) gather data to help formulate standards for night sky viewing quality, using the Bortle Scale as a reference, and 3) understand visitors’ perceptions of night recreation and night resources, including outdoor lighting. A related outdoor lighting preference experiment was then conducted with visitors at Acadia National Park to produce a set of good light characteristics (e.g., brightness, color) that constitute quality outdoor lighting in relation to outdoor recreation.

Findings suggest confirmation of night recreation popularity among park visitors. However, there is indication that visitors do not make the connection between their stated standards for indicators of quality nighttime recreation and the lighting characteristics that would render those conditions. These data may help parks and protected areas manage nighttime environments to provide high quality night recreation experiences.

## IMPACT OF LIGHT POLLUTION ON THE FIRST INTERNATIONAL DARK SKY RESERVE

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Light pollution shall be defined as any artificial light source in our environment. It causes bright haloes, harmful for night sky observation. Night sky has been altered by the presence of light ever since humans invented outdoor lighting. In addition to harming the starry sky, light pollution affects fauna, flora and human health.

In 2007, the establishment of the International Dark Sky Reserve at the Mt Megantic Observatory (MMO, located in Quebec, Canada) allowed to take a significant step forward in reducing light pollution by replacing all the street Cobrahead light fixtures (~6% uplight) by Helios fixtures (~1% uplight) within a 25 km radius of the observatory, and reducing, at the same time, their luminosity by almost half.

In this paper, we will show how this change in the lamp inventory impacts on light pollution levels. To do such analysis, we used the ILLUMINA model, which is a 3D radiative transfer model designed to compute the sky brightness at any viewing angle and wavelength while accounting for heterogeneity of the environment (reflectance, topography, light geographical distribution, atmospheric profile etc). We will provide some guidelines to help authorities to manage and preserve the sky brightness reduction obtained with the light fixture conversion project. We will also show that the same kind of analysis can be used for any other dark sky place on Earth. As another possible application, the model results can be used for studies aiming to link sky brightness with human, flora or wildlife perturbation.

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## PROTECTING DARK SKIES IN COLOMBIA

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The growing development and industrialization of major cities around the world such as in the case of Bogotá and the Tatacoa desert generate different sources of pollution affecting ecosystems and living beings. One such source is not so common object of study and generate some discomfort in the quality of life of people has to do with the pollution caused by the lighting systems both public and private, also known as light pollution.

We focus on determining the impact of light pollution in certain areas of Bogota and Tatacoa desert due to the unwillingness of different light sources and lighting ornamental street lighting from various establishments. This developed the following specific objectives:

- Identify major emission sources contributing to light pollution.
- Locate by measurements and surveys with citizens of the sites that have excessive emission of luminous flux.
- Identify the main changes and disturbances that affect the quality of life of people because of light pollution.

Therefore it is important to clarify that the protection of the night sky in my country is evolving. The agency responsible for public lighting systems is the ministry of mines and energy and makes it through resolutions and technical regulations. The most important technical regulation is lighting technical regulations and public lighting RETILAP (for its

acronym in Spanish) It sets the general rules instilling the rational and efficient use of energy, and identifies the requirements and minimum specifications for lighting installations ensuring the safety and comfort based on their good design and operational performance. The main purpose of this rule is to establish requirements and measures to be met by lighting systems and street lighting to ensure standards and quality of the light energy required in visual activity, energy supply security, consumer protection and environmental protection. The installation of a street lighting system in addition to complying with the technical requirements for optimal performance, has to examine the environmental conditions of the place in which will be installed. It is mandatory in the entire country and applies to lighting systems, products used in them and the people who are involved.

Despite legislative progress is not enough, the Colombian night sky is still unprotected since light pollution is treated as a residual problem and not as main object of a rule allowing punishes offenders and protects the right to see the stars. We need a change in regulations that defines the roles of each state agency, including the prevention and reduction of light pollution as a function of the environment ministry, thus generating greater control and perhaps changing lighting systems for not pollute the night sky.

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## STARLIGHT AND WORLD HERITAGE – THE IAU/UNESCO INITIATIVE, THE “OUTSTANDING UNIVERSAL VALUE” OF STARLIGHT AND TOOLS TO QUANTIFY AND MANAGE THE “PERFECT SKIES” FOR PARKS

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The IAU UNESCO initiative on astronomy and world heritage continues towards the first “starlight” world heritage sites. Five “extended case studies” of starlight sites have been prepared by the IAU and were adopted by the 2012 general assembly of the International Astronomical Union. These scientific preparation and documentation for official world heritage proposals, so called “dossiers” is available via the new IAU/UNESCO portal <http://www2.astronomicalheritage.net/>. It will help the nations to prepare their world heritage nominations. The “outstanding universal value” that is necessary for world heritage sites is explained and concepts are presented of how to include astronomical sites (starlight reserves, dark sky parks, starlight tourist destination, etc.) into the framework of

the UNESCO world heritage convention. The following concepts are introduced and described:

- quantification of the “perfect sky” for a starlight world heritage site
- sky-landscape-systems
- regional skies
- cultural skies
- epoch skies
- the night sky as fact basis for science-epochs.

These concepts are then applied to the “extended case studies” for three “windows to the universe” (Mauna Kea, Canary Islands Observatories, Cerro Tololo), the New-Zealand Aoraki-Mout Cook Starlight Reserve and the Eastern Alpine Starlight Reserve with the Grossmugl starlight Oasis.



# ECOLOGY

## THE IMPACT OF LIGHT POLLUTION ON MICROCYSTIS AERUGINOSA

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Light pollution affects a wide variety of living organisms such as mammals, insects, birds and plants. But what about photosynthetic microorganisms? For the first time, we studied the potential impact of light pollution on cyanobacteria. For that purpose, *Microcystis aeruginosa* was grown in turbidostats with and without realistic levels of light pollution. Chlorophyll a content, variable fluorescence, photosynthetic protein concentrations, photosynthesis versus irradiance curves and cell counts were followed in order to detect changes in photophysiological variables. While several of the measured

variables did not show any changes, some showed significant responses to light pollution including, among others, the maximum quantum yield of charge separation measured by variable fluorescence (Fv/Fm), the intracellular chlorophyll a concentration, the functional absorption cross-section of photosystem II and the number of Rubisco per cell. All together, those results suggest that light pollution may increase the expression of chlorophyll-binding proteins influencing the photophysiological response of *M. aeruginosa*.

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## ECO-LIGHTING SHOW CAVES: USING LED LIGHT TECHNOLOGY TO OVERCOME CONFLICT BETWEEN ENVIRONMENTAL AND VISITOR REQUIREMENTS

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Artificial light at night poses an ecological problem as well as a human health risk. New LED lighting technologies, although energy efficient and thus considered “environmentally friendly”, have raised concerns due to the strong physiological effects of short wavelength output of white LED lights.

Underground caves are unique environments that are inherently totally dark by nature. Yet many “show caves” exhibiting spectacular geological phenomena are open for public display, and thus require lighting. The light that is necessary for the visitors supplies enough energy for phototrophic organisms such as cyanobacteria, algae, and bryophytes (collectively termed “lampenflora”) to colonize rocky surfaces, sediments and artificial materials around lamps within the cave. These may grow to the point of defacing and damaging seriously the cave itself.

Caves frequented by visitors may thus serve as natural laboratories for investigating different ecological effects of artificial light in a relatively simple environment, as well as for testing the efficacy of newer lighting technologies.

The Soreq Cave in the Avshalom Nature Reserve in Israel is a 5,000 m<sup>2</sup> cave, unique for its dense concentration of stalactites. The cave was discovered in 1968 and opened to the public in 1975. In 2012 the Israel Nature & Parks Authority decided to replace the old energetically inefficient lighting system with a new LED-based lighting system. The requirements for the new lighting system included energy efficiency, esthetic viewing and visitor safety considerations while maintaining a minimal ecological impact. The latter was achieved by designing a lighting system which will not influence lampenflora growth, this by eliminating specific wavelengths (both short and long wavelength) utilized by cave phototrophs for photosynthesis. Monitoring plots located throughout the cave serve as sensors for examining the biological effectiveness of the new lighting system.

In the lecture we will discuss the technological challenges of designing such an optimal lighting system, the initial results for the outcome, and visitor response to the project.

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## ARTIFICIAL LIGHT AT NIGHT DETERS FRUGIVOROUS BATS FROM DISPERSING SEEDS

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The entire world population growth of the forthcoming decades will concentrate in urban areas, particularly in less developed countries [1]. Urban areas will sprawl and introduce artificial light at night (LAN) into formerly dark rural habitats. Consequently, light pollution is spreading fast at an annual rate of about 6% all across the world [2], which might be deleterious for light sensitive wildlife. Obligate nocturnal animals such as bats can be expected to be particularly affected, since LAN is present in urban as well as in many rural habitats during their nocturnal activity period.

Among bats, a large diversity of feeding habits evolved. In the tropics many bat species are specialized on nectar and fruits. Those frugivorous bats are particularly important for forest regeneration in the Neotropics, since they are among the most effective seed dispersers during early succession. Short-tailed fruit bats (genus *Carollia*), for example, constitute the main disperser of many *Piper* species - pioneer plants in the Neotropics that grow at forest edges or gaps and thus are key to reforestation. However, due to this habitat preference, *Piper* plants are predisposed to become affected by LAN, for example if street lights become installed along roads. If bats avoid illuminated areas, human encroachment into natural habitats may compromise bat-mediated

seed dispersal due to an increase in light pollution. However, the effect of LAN on frugivorous bats has not yet been studied experimentally.

We asked whether LAN is reducing the visitation rate, and thus the dispersal of seeds by *Carollia* bats. In a dual choice experiment with captive bats, *C. sowelli* explored a dimly illuminated compartment less often than a dark compartment, and were less likely to harvest fruits in the illuminated than in the dark compartment. Also in free-ranging bats, we observed that *Piper* infructescences were less likely to be harvested when plants were illuminated by a street lamp than under natural darkness.

We conclude that succession and forest regeneration may suffer heavily from urban sprawl when nocturnal seed-dispersers, such as bats, reduce their activity in areas illuminated by street lamps. This might be particularly relevant in the tropics, where ecosystem services of bats are ecologically important for ecosystem functioning, and where at the same time the potential for light pollution to increase is very high.

[1] World Urbanization Prospects: The 2011 Revision. United Nations publication (ST/ESA/SER.A/322). <http://esa.un.org/unpd/wup/Documentation/final-report.htm>

[2] Hölker, F., Moss, T., et. al. (2010) The dark side of light: a trans-disciplinary research agenda for light pollution policy. *Ecology and Society* 15: 13.

## ARTIFICIAL LIGHT INTENSITY AFFECTS HATCHLING BEHAVIOUR AND GHOST CRAB PREDATION RISK IN NESTING BEACHES

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Most of sea turtles nest at night even in artificially illuminated beaches. Hatchlings that emerge on beaches with artificial lighting become disoriented, thus increasing their risk of death. Ghost crabs are the main hatchling predators and artificial illumination could influence such predator-prey interaction. We have evaluated the effect of three types of artificial lights on hatchling and ghost crab behavior, as well as the predator-prey interaction.

The study was conducted in the loggerhead nesting population of Cape Verde in the high density nesting beaches of Boa Vista where ghost crabs intensively predate on loggerhead hatchlings on the beach. Hatchlings and ghost crabs were studied under three type of artificial light: yellow, orange and red with mean luminance at 4 m in front the lights of 25.6, 7.8 and 7.3 lux respectively. The orientation and behaviour of 1194 loggerhead hatchlings from 34 different nests was individually studied on the beach into a 4m diameter circle that was at 20 m from the high tide line and at 15 m of the light source at the opposite side of the circle. 400 hatchlings were individually tested in a choice experiment in order to test which type of light was more attractive to the turtles.

Finally, 360 hatchlings were individually released on the beach in order to test the rate of crab predation under the three light treatments and the control. Hidden observers recorded at the different light treatments hatchling speed, orientation, direction, time to first interaction with a crab and number, type and intensity of the hatchling-crab interaction. No people or other animals were visible during any of the experiments.

Around 80 % of hatchlings exposed to the experimental lights moves toward the lights. 94.4 % of control hatchlings moves toward the sea. However, only 20.1, 17.0 and 2.0 of hatchlings from lights red, orange and yellow went toward the sea. The type of light had a highly significant influence on hatchling behavior. The reflection of the moon on the sea was very attractive to hatchlings and clearly reduced the influence of the red and orange lights on hatchlings though had no influence on the impact of the yellow light. In the choice tests, the yellow light was always selected by hatchlings. The orange light was much more attractive to hatchlings than the red light. The yellow light caused more predation than orange and red lights. Further studies are needed to clarify these ecological interactions.

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## EFFECTS OF ARTIFICIAL NIGHT LIGHTING ON THE TIMING OF DAWN AND DUSK SINGING IN COMMON SONGBIRDS

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It is well established that artificial night lighting can influence animal movements, but there is less information about its effects on reproductive behaviour. Previous work suggested that light pollution can affect both seasonal and daily patterns of behaviour. The aim of our study was to investigate the effects of artificial night lighting and other confounding factors such as noise on the timing of the dawn and dusk song in six common songbirds. In 2012, we recorded singing behaviour in 11 forested plots: 2 plots with light, but no noise, 3 with light and traffic noise, 3 with noise, but no light and 3 undisturbed forests. Our results show that artificial night lighting, but not noise, leads to an earlier start of dawn singing

in 5 out of 6 songbirds. This effect is strongest during the egg laying period. We further show that dusk song is much less affected: only in two species (the European robin and the blackbird) dusk song continues for longer in artificially lighted areas. We also investigated the effects of natural variation in the light environment, and show that this has minimal effects in comparison to artificial night lighting. Furthermore, the effect of the artificial night lighting is directly related to the strength of the light source. We discuss the implications of our findings in the context of sexual selection, i.e. in relation to the function of dusk and dawn signaling.

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## CLOCKS FOR THE CITY: CIRCADIAN DIFFERENCES BETWEEN FOREST AND CITY SONGBIRDS AND THE INFLUENCE OF LIGHT AT NIGHT

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To keep pace with progressing urbanization organisms must cope with extensive habitat change, including nocturnal illumination. Urbanized species, like birds, are known to advance their activity to early morning and night hours. We hypothesized that such modified activity patterns are reflected by properties of the endogenous circadian clock. Using automatic radio-telemetry we tested this idea by comparing activity patterns of free-living forest and city European blackbirds (*Turdus merula*). We then recaptured the same individuals and recorded their activity under constant conditions. City birds started their activity earlier and had faster but less robust circadian clocks than forest conspecifics. Circadian period length predicted start of activity in the field and this relationship was mainly explained by fast-paced and early-rising city birds. In a second exper-

iment, we tested whether the circadian differences between forest and city blackbirds are caused by light at night. We first recorded the circadian rhythm of blackbirds kept under light/dark cycles (LD). We then exposed half of the individuals to LLdim with 0.3 lux at night, while the other half remained under LD. After two months we again recorded their circadian rhythm again. Birds that were exposed to light at night had significantly shorter period length under constant conditions than birds exposed to dark nights. Our findings point to a link between city-life, chronotype and circadian phenotype in songbirds, and suggest light at night as a potential driver of such link. We urgently call for an understanding of the fitness consequences of altered circadian rhythmicity in species that colonized urban areas.

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## EXPERIMENTAL ILLUMINATION OF THE FOREST – A LONG-TERM ECOSYSTEM WIDE STUDY ON THE EFFECT OF ARTIFICIAL LIGHT

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That artificial light influences plants and animals has been known for a long time. However almost all current knowledge is on short term, direct effects. Long term effects and effects on population or ecosystem level have hardly been addressed while from a conservation perspective these are most important. Therefore the current knowledge is insufficient to address the potentially negative conservation aspects of artificial illumination. Potentially, these effects are mitigated by adaptation of the light spectrum. In order to study long-term effects of artificial light of different spectral composition on many species and species groups, we have started the Light On Nature project. The main component of this project is a large long-term monitoring study for which we have established 8 field sites where we experimentally illuminate forest edges with rows of streetlights. These result in three illuminated treatments, with white, green and reddish light and

a dark control. The setup has a generic nature in order to enable a comprehensive study of many species and species groups: we monitor a.o. breeding birds, bats, mice, moths, ground dwelling arthropods and vegetation. We follow presence and abundance of these groups but also assess differences in behaviour and possible changes in daily and seasonal timing. All field sites are studied since early 2011, and are illuminated in the years 2012, 13 and 14. The comprehensive approach will enable us to gain insight in effects of artificial light on populations and possible cascading effects.

To maximally utilize the setup, and to gain as much information as possible on ecological changes in response to illumination, we explicitly invite other researchers to use our facilities. In this talk I do present the setup, and include the first results on litter-dwelling arthropods.

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## BEHAVIOUR OF MAMMALS IN EXPERIMENTALLY ILLUMINATED NATURAL HABITAT – SHY AWAY OR TAKE ADVANTAGE?

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Many mammal species have a clear modulation in their daily activity as they are strictly nocturnal and hence may be sensitive to artificial light at night. For example, some bat species are deterred by artificial light. In contrast, other bat species are known to utilize the accumulation of insects around street lights. Most mice species shy away from light, as they may become more visible to predators. Indeed, this response to light is well known from the laboratory and from a few studies in (semi) natural habitat. Effects of artificial light on behaviour of large mammals in natural habitat are largely unknown yet. With the global increase in artificial illumination, it is important to better understand the response of mammals to artificial light exposure. We have measured mammal activity at eight study sites specifically set up to study long-term ecosystem-wide effects of artificial light. On these sites, we experimentally illuminate forest edge

habitat with white, red or green light. The presence and activity of all mammal species is measured with different techniques. Roosting activity of bats is assessed using bat boxes placed in close proximity of the experimental lights. Bat foraging activity is measured close to the light and in the area surrounding the light posts with the use of bat detectors which automatically store echolocation sound. Activity of all other mammals is monitored with camera traps; for mice we used a unique camera trap setup capable of continuous assessment of mouse activity. The response of mice to different colours of light at night is very clear, but the response of bats has so far been found to be very species specific and highly dependent on the type of behaviour. Our data do not yet show a clear response of large mammals. We discuss the consequences our results have for the application of spectrally altered artificial night lighting.

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## INFLUENCE OF NATURAL AND ARTIFICIAL NOCTURNAL LIGHTING ON FLYING INSECTS IN THE STRAIT OF GIBRALTAR

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It is assumed that artificial lighting negatively affects many animals and there is a large amount of documented examples about changes in behavior due to artificial lights. Some previous studies have already assessed the relative impact of different lighting systems mainly focusing on moths. However, to our knowledge, the potential effects on nocturnal insects of new energy-efficient lighting systems like Light-Emitting Diode (LED) remain still unknown.

In a study still ongoing, we are assessing differences in abundance and richness of insects attracted to four different types of lamps that represent the present and future of outdoor-lighting: High Pressure Mercury Vapor Lamps (HPMV), High Pressure Sodium Vapor Lamps (HPSV), Metal Halide Lamps (MH) and Light-Emitting Diode Lamps (LED). We assessed the obtained results in relation to moonlight and nightly patterns. We sampled insects using two light traps per night, with only one type of lamp each night (a total of 36 nights) during September 2012-February 2013. The samplings were carried out in a natural area near Tarifa, in the Strait of Gibraltar.

Until the date, we have collected more than 15,500 specimens belonging to ten different orders. The most common

insect groups found in the samples were: Coleoptera, Diptera, Hymenoptera and Lepidoptera. Regarding the nocturnal activity patterns, our preliminary data showed a greater insect activity in the four hours immediately after sunset. Non-parametric analysis (Mann-Whitney U-test) based on our preliminary data showed significant differences in the abundance of the captures according to the type of the lamp used. HPMV lamp captured the largest amount of insects whereas LED lamps captured the lowest abundances. However, we did not find significant differences in the richness of families (U-test), although LED lamps captured the lowest richness compared with the other types of lamps. Moon phase affected both the abundance and family richness of the captures. We detected significantly higher abundances and family richness on new moon nights compared with full moon nights (Kruskal-Wallis test).

These preliminary results show that LED lamps are not only the most energy-efficient of the four tested type of lamps but they also seem to be the less harmful for insects. Additional sampling in the next months allow for more conclusive data.

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## INSECT ATTRACTION BY MODERN ARTIFICIAL LIGHTING

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Many nocturnal animals are affected by light at night. The attraction at night of night-active flying insects to outdoor lighting is one of the most visible examples of this. Therefore, both researchers and practitioners have been paying attention to this phenomenon for quite some time. This resulted in the publication of a number of action spectra to describe the dependence of insect attraction on the spectral composition of the emitted light. These action spectra were derived from the eye sensitivity curves of bees and other insects which were a hot topic in animal research at the time.

During that period, public lighting was dominated by a limited number of lamp types. The lighting market was dominated by low and high pressure sodium lamps and high pressure mercury lamps, with short wavelength and UV radiation increasing in that order. Insects are known to be attracted most by short wavelengths, hence the use of UV-A, black light and actinic lamps in insect traps. The predictive power of the available action spectra seems to be based on their high sensitivity in the UV-A.

With the rapid introduction of LED lighting technology in outdoor lighting,

and legislation banning relatively energy inefficient lamp technologies, like high pressure mercury, the number of UV emitting outdoor lights is declining rapidly. Instead, a whole variety of more or less white, UV-free light sources are entering the market. Now the question is whether the available action spectra are able to predict the attractiveness of these sources.

We performed a series of field experiments using a range of representative commercial as well as experimental light sources in insect traps. A large number of insects were caught and determined, which results in a database of insect catches as a function of light spectrum, intensity and ecological and meteorological data.

It turned out that the actual insect attraction by UV free light sources did not correlate with the predictions of the available action spectra. Therefore, based on our data, a new action spectrum was determined and tested in a large validation experiment.

Here we will present our experimental work and the resulting new action spectrum. Also, the practical implications for outdoor lighting design are discussed.

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## ARTIFICIAL LIGHT AT NIGHT AFFECTING AVIAN BEHAVIOUR

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Light pollution has increased dramatically over the past decades. Correlative evidence for short term effects of anthropogenic illumination on several species groups exists, but experimental studies are few. For birds, photoperiod is the main cue for timing of daily and seasonal activity. Night lighting has been shown to affect laying dates, timing of dawn song, reproductive physiology, chick feeding rates and disturb nocturnal migration. The current, worldwide change to LED outdoor lighting may allow for a possible reduction in these effects by using different light spectra. Thus, knowledge on the effects of nocturnal illumination with different colour composition on avian behaviour is urgently needed. To experimentally assess such effects we exposed a wild great tit (*Parus major*) population to either white, green or red low intensity LED lights outside their nest boxes and we recorded daily activity patterns during the chick provisioning period. We found an effect of the light treatments on chick feeding rates which we aim to link to diet and begging behaviour of

the chicks. We have studied the effects of night light on parental and nestling condition and fitness in both the same and following year. Complementary to this specific experimental approach, we used a long term experimental set-up to investigate the effects of white, green and red artificial light at night on breeding birds at a forest edge habitat. This set-up includes eight experimentally illuminated sites throughout the Netherlands. Each site contains three transects illuminated with white, green or red LED light, respectively and one dark control transect. For several nest box breeding bird species we recorded egg laying dates, extra pair paternity rates, chick feeding activity patterns and chick and adult condition. Also, for all forest song birds we recorded onset of dawn chorus throughout the season. The interaction between these ecological parameters will be studied and the results of both studies will be linked in order to provide essential insights in the way different colours of artificial night light affects avian behaviour.

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## EFFECTS OF ARTIFICIAL LIGHT ON ECOSYSTEMS AT THE POPULATION AND COMMUNITY LEVEL

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While substantial effects of artificial light at night on the behaviour of many species of wildlife have been well documented, we have a limited understanding of the nature and ubiquity of impacts of artificial light on species populations and community composition. Roadside invertebrate communities have been shown to be altered under street lighting; such impacts may be widespread. We describe

ongoing work within the ERC-funded ECOLIGHT project to understand population and community-level impacts of ALAN across spatial scales. Given the current lack of detailed knowledge of the ecological effects of light at night at the population and community level, we discuss ways in which such impacts might be minimised.

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## GREEN ENERGY – GREEN LIGHT? NIGHT-TIME OBSTRUCTION LIGHTING FOR OFFSHORE WIND FARMS AND BIRDS. WHICH COMPROMISES ARE POSSIBLE?

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International and national regulations regarding ship and air safety require that wind mills have to be marked with obstruction lights during night-time. High numbers of migrating birds are known to cross large waterbodies - e.g. the North Sea - during night-time; orientation of these migrating birds relies on a number of mechanisms from magnetic compass over polarized light to night cues such as sunset and stars. The disturbances of night-migrating birds by artificial lights range from des-orientation to exhaustion and/or collisions.

Approvals / permissions for offshore wind farms in German waters including the Exclusive Economic Zone (EEZ) are only given under the condition, that bird migration must not be at risk; furthermore, the ensuing permissions include the collateral clause, that bird monitoring is mandatory, and if results suggest that migrating birds are at risk, mitigation actions must be taken.

In a cooperation project - including representatives from ship and air

safety, legislation, energy providers and nature conservation - the requirements for night-time obstruction lighting have been presented and discussed; a final scenario has been decided, assessed and discussed.

Results suggest some facts: as little light as possible, light color may play a role, i.e. green light may be better than white or red lights.

Search for compromise is difficult, as obstruction lighting rules are hard to be changed, and conclusive results on the effects of lights offshore are hard to get at. There may be options for a "light-on-demand" solution.

An overview on the state of knowledge about lights and birds will be given, followed by an ecological assessment of different obstruction lighting options with regard to night-time migrating birds. Results from recent projects in German offshore waters are put into perspective. Finally, mitigation options will be suggested.

## ONLY SEX WITH THE LIGHTS OFF? ARTIFICIAL LIGHT EFFECTS ON MOTH REPRODUCTION

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The rapid increase in artificial night lighting exposes nocturnal fauna to major alterations of their habitat and may be a serious threat to insect biodiversity and ecosystem services such as pollination. Nevertheless, artificial light effects on ecosystems and species population sizes remain poorly studied to date. Moths (Lepidoptera) are an functionally important and species rich group of nocturnal fauna of which populations have shown dramatic declines over the past decades. Because moths are strongly attracted to artificial light at night, these population declines are often believed to be, at least partly, caused by rising levels of artificial night lighting. However, the effects of artificial light at night on moths have in the past mainly been sought in phototaxis (attraction to light). In our studies, we move beyond phototaxis and focus on artificial light induced changes in moth behaviour and development that potentially underlie a causal relationship between

artificial light and moth declines. We demonstrate for the first time that moth reproduction can be severely affected by artificial night lighting in several ways. For example, female moths that were subjected to artificial light at night produced less sex pheromone than females that were kept in darkness. Furthermore, the composition of the pheromone blend of artificial light subjected females was significantly altered, with strongest reductions in those compounds that are responsible for the attraction of males. These negative effects on reproduction were observed under green, white and red lamps, indicating that presently proposed spectral alterations suggested for moth conservation need reassessment. Our results provide mechanistic evidence for artificial light inhibition of moth reproduction, and thus provide a possible explanation for the decline of moth populations and call for the conservation of darkness.

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## STREET LIGHTS GENERATE A FRAGMENTED LANDSCAPE WITH HIGH COSTS FOR SHORT DISTANCE DISPERSAL

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Many insects actively congregate around light sources during the night until they die of exhaustion. Many predators such as spiders and bats take advantage of this situation.

Recent studies show for moths that the attraction radius of mercury vapor lamps is relatively small, for 15W lamps often even below 10 meters. Due to the fact that light attracts moth but the radius of attraction is small it is an open question if street lights are a serious dispersal barrier with landscape fragmentation as a consequence.

To determine the extent to which street lighting increases local migration costs of insects we carried out a community wide experiment in Westhavelland. We installed combi-traps beneath each

lamp of a 3 X 4 street light matrix field with 20m meter distance of each lamp.

Altogether 283 moths consisting of 54 macrolepidoptera species were caught. We found that the position of the lamp in the matrix is important for the average number of catches sampled by a combi-trap. Overall the average number of catches was highest for corner lamps, intermediate for edge lamps and lowest for center lamps.

We used a Markov model to predict how high the mortality rate for a moth is when it tries to pass a lamp. Depending on the family we found mortality rates between 0.3-0.4 up to 0.7-0.8.

We conclude that crossing illuminated streets is costly for moth because the illuminance levels of our experimental design are not atypical for road lighting.

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## MONITORING HATCHLING ORIENTATION AND LIGHT POLLUTION

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The Gorgon Liquid Natural Gas (LNG) project currently under construction on Barrow Island, on the North West Shelf of Western Australia, is located adjacent to six flatback turtle nesting beaches on the east coast of the island. Strict regulatory agency environmental conditions covering every aspect of the project include the female and hatchling flatback turtles that use these nesting sites. Light associated with night time construction activities is being monitored using a novel technique developed for the Gorgon project marine turtle monitoring program. A standard digital camera modified for use in remote locations (Sky 42 imaging system) is used to collect images of project related light spill from turtle nesting beaches. Post-processing of the images provides empirical data for low light levels, e.g. glow, that otherwise cannot be quantified in a field setting. The numerical results can be used to assess the success of pro-

ject light management activities and to compare between different light sources.

The camera images are also utilized in the interpretation of hatchling behaviour as they leave the nest and crawl to the ocean. A separate hatchling monitoring program collects data on the orientation of fanned out tracks that are left in the sand by hatchlings as they engage in sea finding. Data collected from the fanned out tracks include the angle of the fan spread and the angle of fan offset from the most direct line to the ocean. These data are used to derive an average orientation value for each beach and when combined with the Sky42 images, provide a pictorial representation of light and hatchling behaviour in a single figure. These results are used by project Environmental Practitioners to assess the impact of night time construction activities on hatchling orientation.

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## SLEEPLESS IN THE CITY – ARTIFICIAL NIGHT LIGHT AND TRAFFIC NOISE IMPACT EUROPEAN BLACKBIRDS

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Urban living organisms are exposed to completely different environmental conditions compared to their rural conspecifics. Two main factors, anthropogenic noise and artificial night light, are equally linked to urbanization and pose new challenges to urban species. Particularly songbirds are prone to these factors because they rely on the spread of acoustic information and adjust their behaviour to the rhythm of night and day. Regarding anthropogenic noise, many studies investigated the effects on birds and adjustments are well documented, while on the other side, the impact of artificial night light on behaviour, phenology and physiology was often neglected. Only recently, ecologists showed that artificial night light can alter the activity patterns

and even the timing of reproduction in birds.

In our study, we investigated the behaviour, reproduction and physiology of a wild population of European Blackbirds along a steep urban gradient in terms of anthropogenic noise and artificial night light, ranging from an urban forest to the city centre of Leipzig, Germany. City birds began their daily activity significantly earlier than those in the urban forest, e.g. started to sing up to five hours earlier, due to the impact of noise and ambient night light. Preliminary results indicate fitness consequences of this change in daily activity pattern and suggest that urban hazards as ambient noise and light pollution interfere manifold with naturally evolved cycles of urban blackbirds.



# HEALTH

## URBAN LIGHT INTENSITIES – EFFECTS ON THE SYNTHESIS OF MELATONIN AND OF CORTISOL

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**Background.** Light at night is supposed to contribute to the genesis of several multifactorial chronic diseases. A plausible mechanism is the suppression of melatonin synthesis.

**Hypothesis.** This study tested the hypothesis that urban light intensities suppress melatonin production, that this suppression is greater with variable than with constant light intensity and stronger in the dark than in the light season.

**Methods.** Sixteen persons each (8 female, 8 male) were with weekly intervals observed five times over 24 hours in summer and in winter. During the day they spent 7.5 hours outdoors. During the night light intensities were adjusted to 0.1 lx (reference), to 30 lx constant

and variable and to 50 lx constant and variable light. Melatonin and cortisol profiles were ascertained with hourly saliva samples.

**Results.** As compared to the reference condition the duration of melatonin production was consistently (though not significantly) shorter in each experimental illumination, the increase of melatonin concentration and of melatonin production during the night was reduced in summer, cortisol concentration increased steeper in winter.

**Conclusion.** The results suggest that light at night affects the synthesis of melatonin and of cortisol and might contribute to the genesis and premature manifestation of several chronic diseases.

## TOWARD CONSENSUS-BASED THRESHOLD EXPOSURE LEVELS FOR LIGHT AT NIGHT

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Public concerns have been expressed regarding the possible negative impact of nighttime lighting on melatonin suppression and circadian disruption in people. In particular, questions have been raised about the consequences of exposure to phosphor-converted white light emitting diodes (LEDs) because they have relatively high emission at short-wavelengths where the circadian system is most sensitive. To meaningfully address these concerns it is first necessary to model both the spectral and the absolute sensitivities of the human circadian system. Once the expected system operating characteristics have been specified, it is then possible to empirically test predictions of circadian system response to light as might occur from lighting systems used at night. In two experiments, nocturnal melatonin suppression was measured in response to different amounts of “warm white” light from commercially available LEDs. The lighting conditions selected were near modeled threshold and, importantly, like those people might actually experience in their living environments. In addition to dark, control nights, subjects were exposed to

8, 22, and 60 (photopic) lux at the cornea (study 1, n=14) and to 60, 200, and 720 lux (study 2, n=14) of the “warm white” light source (CCT = 2670 K). The spectral power irradiances at the cornea translate to modeled melatonin suppression levels of 1%, 2%, 6%, 19%, and 42%. In both studies, participants came to the laboratory for four nights, separated by one week. Using an orthodox statistical criterion for a Type I error of  $\alpha < 0.05$ , only the 200 lux and the 720 lux exposures produced significant suppression levels, 19% and 37%, respectively. The statistically significant suppression levels were very close to those predicted by the model. Using a much more conservative criterion for a Type II error of  $\beta < 0.05$  and a modeled suppression level of 5%, a corneal light exposure of 30 lux for 30 minutes from “white” light sources is proposed as a working threshold for nocturnal melatonin suppression. The computational model of the spectral and absolute sensitivities of the human circadian system, validated by the present data, may help form a foundation for establishing consensus-based threshold levels for nighttime outdoor light exposures.

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## DARK SKY AREAS AND CLIMATIC HEALTH RESORTS IN GERMANY – HOW DOES IT MATCH?

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The illumination of nocturnal skies by artificial light has a societal background. Effects of this environmental change of atmospheric conditions can be found in ecology and society, likewise. Remains of untouched natural areas have the chance to be labelled as touristic attractions.

On global level two touristic brands with foci on atmospheric aspects can be specified:

- On international level the label of ‘Dark-Sky-Park’ was established recently. Atmospheric parameters related to nocturnal light intensity have to be met in order to enable the experience of a clear view to the starry sky.

- In Germany, ‘Climatic Health Resorts’ assure quality standards of climatic remedies for prevention and rehabilitation. Customers can expect certain standards concerning atmospheric conditions as well as on medical supply.

Aim of this study is to compare these two labels according to their regulations and impact on environmental conservation. Furthermore, it will be investigated to which extend a spatial congruency of (potentially) labelled places in Germany is given.

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## ARTEFICIAL LIGHT AT NIGHT, HEALTH, HUNGARY, 2013

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Increased attention has been paid even to health aspects of arteficial light at night (ALAN) worldwide. Melatonin, which production is blocked by ALAN, has been proved to be a strong scavenger, immune stimulant, moreover, a definitely oncostatic hormone. Breast, colon, liver and prostate cancer stem cells have suppressive melatonin receptors. However, International Agency for Research on Cancer (IARC) declared shiftwork involving night work as group 2A, potential carcinogenic.

In Hungary, thematic conferences were organised since 2004. Since 2006, when National Institute of Environmental Health (NIEH) had been involved in the issue, journals and internet articles, radio and tv broadcasts gave official medical information about the subject. Moreover, Zselic Starry Sky Park (SSP) was the first one in Europe in 2009 (with Galloway Park along), followed by Hortobágy SSP in 2011. As a governmental ordinance, the new and ALAN-regulating National Settlement and Building Requirements came into force in 2012.

By the 2<sup>nd</sup> National Children's Respiratory Survey, 2010/2011, NIEH sent out about hundred thousands of standardised anonym questionnaires countrywide to be completed by parents of 8-9 year old pupils. Albeit two of three NUTS-1 regions' data will be finalised

soon, here the yet completed county's results (Borsod-Abaúj-Heves county) shall be showed (n=4294): the childrens' sleep was slightly disturbed by outside light effect in 16.7% and heavily disturbed in 1.9%. Odds ratios (adjusted [aOR] for sex, age, during-pregnancy/passive smoking, early chest infection, traffic/other polluting establishments nearby and crowdedness/mould in the flat) were calculated by clustered multiple logistic regression by STATA SE v10.0 for Windows for chronic bronchitic symptoms (slight and heavy disturb, respectively): aOR=2.26\*\*\* and 2.62\*\*, for recent asthmatic symptoms: aOR=1.96\*\*\* and 1.84\*, for diagnosed airway allergy: aOR=1.50\*\*\* and 1.51, for injuries, at home: aOR=1.94\*\*\* and 4.95\*\*\*, on the street: aOR=2.38\*\*\* and 5.10\*\*\* and at school: aOR=1.94\*\*\* and 3.51\*\*\*.

Albeit simple cross-sectional study can not prove effects, results are coherent with underlying mechanisms, moreover, with medical literature.

Further steps are completing data entry and analysis, performing new investigations as well, establishing new SSPs, keeping on disseminate results countrywide and concentrate efforts on breakthrough of the 2<sup>nd</sup> stage law.

\*\*\*p<0.001

\*\*p<0.01

\*p<0.05

# MEASUREMENTS & MODELS

## USING A 3D HETEROGENEOUS RADIATIVE TRANSFER MODEL TO ASSESS THE ORIGIN OF THE LOCAL HEMISPHERIC SPECTRAL SKY ARTIFICIAL RADIANCES FROM DIFFERENT PARTS OF A TERRITORY

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In this paper, we suggest to use an artificial sky radiance numerical model that consider the heterogeneous distribution of light fixtures, their photometry, the satellite based ground reflectance, topography along with atmospheric optical properties and the 2nd order scattering for inferring the gridded contribution of a given territory to the artificial sky radiance at specified observer position and viewing angles. During the past few years, the model has been validated with many In-situ hyperspectral sky radiance measurements experiments (e.g. Canary Islands European Northern Observatories, Spain in 2010, Micoua, Québec Canada in 2007 and US Naval Observatory, AZ USA in 2006). Such model helps to understand the non-linear behavior of light pollution propagation in the atmosphere. But among the most striking benefit of that modeling approach, we can identify and characterize zones for which any lighting level increase or de-

crease may have a larger impact on light pollution and then help to control and/or reduce light pollution. This innovative methodology, can be seen as a high level decision tool to help local authorities to restrict or reduce light pollution impacts. Among possible applications it can be used 1- to protect research class astronomical sites, 2- to constrain potential impact on human/animals health and more specifically on potential circadian cycle disruption, 3- to reduce night-time photosynthesis of the vegetation canopy, and 4- restrict power waste related to over-illumination and light trespass and associated impact on climate changes. We recently released an online portal allowing access, exploitation, and analysis of the model outputs, for the benefit of end users. This portal is an interactive georeferenced system that displays model results on OpenStreetMap maps or satellite/aerial images.

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## ARTIFICIAL LIGHT AT NIGHT IN PUBLIC PORTAL 'ATLASLEEFOMGEVING'

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AtlasLeefomgeving is a public portal where the public as well as professionals can find all kinds of information about the living environment. Core of the Atlas are maps for many different issues concerning the living environment, completed with background information on various themes. Themes vary from air quality, via soil and noise, to asbestos. Recently, the theme 'Artificial Light At Night' was added. In this theme, the visitor can find light emission maps from DMSP-OLS,

VIIRS and the ISS, as well as night sky brightness maps. Maps can be compared within one theme, but also outside their own theme. For example, light emission can be compared with air quality indicators, or night sky brightness can be compared with noise. This presentation will focus on how the public and professionals use the information within the theme 'Artificial Light At Night'. Knowledge on the uptake of this information will help us define user products.

## PROTECTION OF THE NIGHT SKY IN ANDALUSIA: MEASUREMENT, COMMUNICATION, OUTREACH AND LAW

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The Andalusian regional government is driving outstanding efforts pursuing an integral approach to the protection of the night sky in the southernmost extreme of Europe. The Andalusian approach covers all possible action fields: advanced legal regulation, education, public outreach, information programs for technicians and for the general public, etc. The scope is not only astronomical (protecting the forefront astronomical facilities in the area), but much wider, taking into account the protection of the ecosystems, the natural landscape, the population and

energy savings as well. In this general frame, measurement and modelling play a central role, and considerable efforts are being devoted to this aspect. A general program to produce a region-wide map of light sky brightness is being developed. Also, several outstanding and innovative instruments have been built in our region, to produce all-sky multi-band scientific-grade photometric measurements, what will be followed by instruments with all-sky spectroscopic capabilities very soon.

## NIGHTPOD: NIGHT-TIME IMAGING FROM WITHIN THE INTERNATIONAL SPACE STATION

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In support of ISS Andre Kuipers' long term PromISse mission, ESA uploaded a system supporting the Astronaut in taking pictures of the Earth at Night from inside the ISS Cupola. In particular, the NightPod has been used for observation of human settlements (e.g. cities, roads, sea establishments), wild fires, volcano activities, and is expected to provide an unprecedented resolution of <15m/pixel.

The NightPod is a state-of-the-art electro-mechanical system which accommodates commercial optical cameras and compensates for the orbital motion and attitude of the ISS. The compensation is achieved by a non-linear motorized rotation of the camera with arcsecond accuracy. The NightPod computer directly controls the camera and synchronizes the non-linear rotation of the pointing axis and the integration time of the camera. The NightPod allows rotation in 4 axes. Two axes are used to align the NightPod to the ISS local nadir direction. The third motorized axis rotates during operation keeping the desired target steady in the camera's field of view for the several seconds integration period. The fourth axis is used to manually point at off-track targets.

The NightPod is stowed disassembled and can be easily mounted in Cupola

before operation. When assembled, the NightPod interfaces to the Cupola via custom-made, easy to use locking mechanisms.

The NightPod is the first payload installed by ESA in the Cupola. The lessons learned from this project will be beneficial to the development of future payloads for Earth Observation from ISS. The challenging flight hardware design and development process, together with a full Proto-Flight testing campaign, was successfully concluded in only five months in order to be on time for the launch of the Soyuz 29S to the ISS, on the 21th of December 2011.

Commissioning has been successfully completed on the 24th of February 2012. The NightPod is part of the Crew standard training and will be operated by all Crew Members flying to the ISS in the coming years. The NightPod is the result of an efficient collaboration between cosine (NL) as prime contractor, Astro-und Feinwerktechnik (DE) as sub-contractor, and the directorate of Human Space Flight and Operations (ESA)- HSO. The project is funded by ESA under the GSTP programme, with the support of the Dutch and German delegates.

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## A COMPARISON OF CITY LIGHTSCAPES USING NIGHTTIME AERIAL PHOTOGRAPHY

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*JON SADLER, The University of Birmingham, School of Geography, GB*

Artificial lighting is changing at a global scale, with numerous social, economic and environmental implications. For example, street lighting can improve people's perception of safety and security, but can also disrupt sleep patterns and alter key ecological processes. Many of these effects are strongest in urban areas, where an increasing majority of people live. Exploring these effects and balancing the benefits with the impacts requires a basic understanding of how lighting varies within cities; yet the relationships between lighting, urban form and urban function are poorly understood. There is therefore a need to secure baseline mapping of artificial lighting in order to describe these relationships and to explore the similarity of models between cities. Here we present an approach to mapping artificial lighting within cities that uses aerial nighttime photography and we compare spatial analyses of lighting in London and Birmingham, UK. Colour photography was collected by plane at a height of 800m and at a resolution of 10cm, then orthorectified and mosaiced into a single image. Ground photometry

and radiometry surveys were undertaken, permitting the reclassification of the images to represent incident lux and the identification and classification of individual lamps. Lighting indicators were extracted using a Geographic Information System, and compared with measures of built density and land use at a range of sample extents. Total illuminated area and lamp density both correlated positively with percentage built surface cover, although the strength of these relationships differed slightly between cities. Roads and car parks within residential and industrial areas were responsible for much of the bright lighting within both cities, yet for many land uses there was considerable variation both within and between urban areas. This suggests that changes to the form and function of large UK cities should have broadly predictable implications for urban lighting, although additional unidentified factors are responsible for variation at a local scale. Night-time aerial photography would appear to be a practical and effective tool for monitoring key aspects of urban form, function and performance.

## CROWD SOURCED LIGHT POLLUTION MONITORING WITH THE DARK SKY METER APP

*NORBERT SCHMIDT, DDQ: Apps, Webservices & Project Management, NL*

The Dark Sky Meter app for iPhone enables users worldwide to measure night sky brightness and submit the results to a central server. The app is available for iPhone (and maybe later for specific Android devices). The 'lite' version will be free. We expect a lot of downloads. When promoted by the IDA and other websites the number of downloads can be tens of thousands. So the distribution of the app is much higher compared to a commercial Sky Quality Meter, which is really a quite expensive niche product. The app measures the sky brightness using the built in camera. So no external hardware is needed. Until now, the iPhone4S and the iPhone5 have sensors that can detect subtle changes in brightness and have a reproductive readout.

The big benefit of a smartphone, aside from central distribution (an app store) is the availability of sensors (GPS, inclinometer, Gyroscope) and the internet connection of the smartphone.

So, when the user measures the sky, the data is submitted along with other useful information: device orientation (is it pointing towards the Zenit?), date/time, GPS location, moon phase, cloudyness indicator.

The data is being collected on the internet in a central database. From there, information can be shown on a map (visible within the app or on a website) or it can be used for scientific research.

The 'lite' version will be for free, aiming for a broad audience. It gives an indication of the night sky brightness to the user. Note that the data submitted to the servers will output in SQM value = Mag/square seconds of Arc.

The 'pro' version of the Dark Sky Meter app will aim at (amateur) astronomers and environmentalists.

The app will be available in April 2013 for iPhone4S and iPhone5. (We will continue our research to support other devices as well)

The app is developed and engineered by Norbert Schmidt / DDQ.nl, an app developing company in the Netherlands. DDQ creates crowd science apps and is known for the Venus Transit app (worldwide experiment with more than 130.000 downloads measuring the distance between Earth and the Sun). We are currently developing iSpex: aerosol measurement using spectrometry for Leiden University.

## A QUANTITATIVE FOUNDATION FOR EASILY AND SIGNIFICANTLY REDUCING LIGHT POLLUTION

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Although light pollution can have many negative social and environmental consequences, the wasted light contributing to light pollution can be objectively defined and readily quantified in terms of three aspects: sky glow, light trespass and glare. A comprehensive method for quantifying these aspects of lighting pollution has been developed for use with commercially available, photometrically-accurate software. Despite the relative ease with which light pollution can be measured and calculated using this comprehensive methodology, little has been done to systematically reduce it. A purpose of the present paper is to provide quantitative comparisons among the following contributions to light pollution: Illuminance level, luminaire intensity distribution, light source spectral power distribution, and shielding. With very few exceptions, reducing illuminance level is the most effective and the least expensive option for reducing light pollution. Reducing illuminance levels may evoke concerns among specifiers sensitive to current prescriptive regulations based upon photopic illuminance. Most lighting specifiers would agree, however, that good lighting design for roadways and car parking lots should be based upon human safety and security as can be

provided by outdoor lighting, not simply upon the readings of an illuminance meter. Logically then, if reduced photopic illuminance levels do not compromise the important design goals, then light levels should be reduced to minimize light pollution. Current prescriptive lighting regulations are based upon the photopic luminous efficiency function  $V(\lambda)$ , which was derived from human perception experiments in the 1920s. Research has shown that  $V(\lambda)$  is not the appropriate design criterion for parking lots and roadways because it is not predictive of driving safety (off-axis hazard detection) and perceived sense of security in parking lots (overall brightness perception). Photometric metrics based upon off-axis detection and brightness perception are better than  $V(\lambda)$  for characterizing the benefits of outdoor lighting for human safety and security. Because these benefit metrics better meet the stated design goals for outdoor lighting than  $V(\lambda)$ , they provide a rational, quantitative foundation for reducing current light levels and, thereby, light pollution. A second purpose of the present paper is to introduce two new photometric metrics that could be used for specifying outdoor lighting levels.

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## VERLUST DER NACHT: A SMARTPHONE APP FACILITATING CITIZEN

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The last four years have seen a major increase in the amount of information available on the levels of external light at night. The radiance of the sky is now continuously monitored at many tens of locations worldwide, the new VIIRS instrument on the Suomi NPP satellite has greatly enhanced spatial and radiance resolution over DMSP, and imagery from the ISS and nighttime flights have allowed high resolution analyses. It is likely that many or all of these devices will be replaced within the next decades by advanced instruments with different sensitivities, and this is problematic from the perspective of developing time series.

The slow evolution of the human eye makes it an ideal instrument for developing time series over a period of decades. We have developed a smartphone app that allows citizen scientists to quantify the naked eye limiting magnitude (i.e. the faintest visible star). This parameter is very highly correlated with skyglow, is

easy to understand, and should be very stable with time. The ubiquity of smartphones means that skyglow luminance data could be acquired worldwide, and in particular in areas undergoing rapid development. We present the methodology of the app, and preliminary results based on data taken in spring and summer, 2013.

In addition to providing valuable data, the app has educational and cultural value. Its use requires no prior observational experience, and users can very quickly become familiar with the names of the brightest stars and some constellations, bringing urban dwellers into closer contact with the cosmos.

Finally, the app also provides an instrument for students to assess skyglow luminance without purchasing a lightmeter. Students can thus conduct their own projects, while at the same time participating in a worldwide citizen science project.

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## ONE FULL YEAR OF NIGHT SKY BRIGHTNESS MEASUREMENTS: A RURAL MOUNTAINTOP AND CITY SKIES IN COMPARISON

THOMAS POSCH, *University of Vienna, Institute for Astronomy, A*  
JOHANNES PUSCHNIG, *University of Vienna, Institute for Astronomy, A*

Since more than a year, the authors have been using two Sky Quality Meters (SQM-LE) and a sophisticated software to systematically collect and evaluate night sky brightness data at two sites:

1. Vienna University Observatory, located about 3km to the west of the Vienna City centre, and
2. Leopold-Figl-Observatorium fuer Astrophysik (LFOA), located 35km to the westsouthwest of Vienna at an altitude of 880m.

Location (1) is representative of the night sky under which many inhabitants of large cities live today. Location (2), in contrast, suffers from little light pollution and represents an almost natural night sky.

We will compare our rich data sets in order to answer questions such as:

- Is there anything left of the circalunar change in night sky brightness in a metropolitan region like Vienna? - Is the main source of variation of the night sky brightness in a city like Vienna the degree of cloudiness?

- How about the circalunar and cloud-related night sky brightness variation at a rural place like LFOA?

In addition, we present the effect of the 11 p.m. and 12 p.m. curfew on the night sky brightness in Vienna. At 11 p.m., a part of the public illumination is reduced in the Austrian capital (step 1), while at 12 p.m., many facade illuminations are switched off (step 2). We show that on average, step 1 results in a night sky brightness decrease by  $0.18 \text{ mag/arcsec}^2$  while step 2 leads to a decrease by  $0.09 \text{ mag/arcsec}^2$ .

Further aspects of our presentation include night sky spectra taken with an 80cm telescope at location (1) and the assignment of the main detected spectral lines to known emission lines of frequently used types of street lighting.

Finally, the implications of our data for astronomical observing conditions and for chronobiological issues will be discussed.

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## MEASURING AND CHARACTERIZING NIGHTTIME SKY BRIGHTNESS IN AND AROUND TUCSON AND ON SURROUNDING OBSERVATORY

*CONSTANCE WALKER, National Optical Astronomy Observatory (NOAO), USA*

Two NSF Research Experiences for Undergraduate students, Linsey Jensen (summer 2012) and Rachel Nydegger (2013), and NASA Space Grant student, Michelle Walker (Fall 2012) (with mentors, Drs. Connie Walker of NOAO and Don Davis of the Planetary Science Institute) have used 5 Sky Quality Meters around Tucson and 3 more on nearby observatory mountaintops to measure and characterize the night sky brightness. The SQM-LU-DL+H devices were bought from Unihedron. The “LU” stands for lens with USB connection; the “DL” stands for data logging; the “H” stands for housing. The sky brightness meters automatically log data and have housing to protect them from extreme weather. The students downloaded the data onto a computer every few weeks. 5 devices are in Tucson. There was an SQM at NOAO as the central location and the others are 8 miles N, E, S and W of NOAO. The other 3 devices are on Mount Lemmon, Mount Hopkins, and Kitt Peak. Initially, there were a pair of devices at NOAO and Kitt Peak; one was in the housing unit and the other was exposed to the night sky to track the loss within the glass of the housing unit. In placing the SQM on the observatory mountaintops,

we want the SQM in proximity to “Night Sky Brightness Monitor” (NSBM) on Mount Lemmon, Mount Hopkins, and Kitt Peak. There is already an NSBM on Mt. Hopkins. With the help of Scott Kardel, managing director from the International Dark-Sky Association, an NSBM is to be installed Spring 2013 on Kitt Peak. The SQM-LU-DL+H is compared to the NSBM data on the mountaintops, weather data (temperature and humidity), the all-sky camera on Kitt Peak and the SQM results from Tucson. Weather stations already exist very close to all of the locations (usually within a mile or a few feet). Data is extracted when there is a moon, the Milky Way galaxy going through the SQM’s FOV at zenith and bad weather. The resulting differences in nighttime “profile” are examined between all locations and, in particular, among the three different types of locations (city center; city outskirts, and mountaintop). The primary focus of the effort is measure and compare the sky brightness at these locations over time (over hours, nights, weeks, months, and seasonally). Finally, Rachel Nydegger will model the natural sky brightness using Dan Duriscoe’s software to extract the natural sky brightness.

## MONITORING THE NIGHT SKY BRIGHTNESS IN HONG KONG

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WAI YAN RYAN LEUNG, University of Hong Kong, Department of Physics, HK  
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Outdoor lighting is an integral and indispensable part of modern societies. The accompanying issue of light pollution has just begun to arouse the attention of a wide spectrum of the general public, including ecologists, medical professionals, astronomers, and energy conservationists. Since 2010, we established the Hong Kong Night Sky Brightness Monitoring Network (NSN) for long-term monitoring of the zenith night sky brightness in 18 distinct locations in the city using the Sky Quality Meters – Lens Ethernet (SQM-LE). Until August 2012, a total of 2.9 million individual night sky brightness (NSB) readings were collected. As expected, the night sky of Hong Kong was severely affected by the usage of lightings from public, commercial and residential sources. The brightest location in the urban centre averages 510 times brighter than the moonless pristine zenith night sky background as defined by the International Astronomical Union, while the darkest site sampled still averages 15 times the standard.

Furthermore, by studying the average NSB observed in each station, we revealed the strong effects of outdoor lightings in urban / suburban areas. It was found that significant darkening could be observed at 23:00, 00:00, and 01:00, which closely resemble the pattern of light usage of manmade public and commercial lightings. Moreover, the

drop of NSB in urban locations is greater than the rural ones, possibly suggesting that a higher fraction of decorative or commercial lightings (as reflected in our measurements between 20:30 and 23:00) versus the essential lightings (as indicated in our late-night readings after 01:00) in these places.

The survey also indicates that the actual NSB measured in a particular night could be influenced by many factors, including variations in meteorological factors such as humidity, atmospheric conditions such as cloud amount and visibility, or astronomical factors such as moon phase and location. For example, from the simultaneous observations of cloud amount and NSB in one urban and one rural location, it is found that the variation of NSB can be highly affected by changes in the cloud amount. A higher cloud amount would generally imply a brighter night sky, with identical cloud amount variation leading to a larger change in the observed NSB in the urban location compared to that for the rural site. The observed correlation between the cloud amount and the NSB can be explained by the back-scattering effects of upward-directing light back down to Earth. Therefore the net effect is that clouds can make the light pollution effects more severe. Finally, attempts to model the effects of moonlight on the observed NSB will be discussed.

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## LOUDS AND NIGHT SKY BRIGHTNESS

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Clouds may enhance or diminish the night sky brightness depending on the configuration and locations of light sources that are already present in the nearby area. Using data of the Dutch monitoring network on the night sky brightness and from dedicated measurement campaigns, we established an empirical relationship between the effect of cloudiness on the night sky brightness and the site-characterising parameters.

The Dutch monitoring network comprises nine sites; locations are in industrial, urban, rural and pristine nature areas. Each site was characterised by means of GIS calculations yielding a distant dependent average land use with co-existing light sources for each site. Taking into account this distance dependency, the impact of clouds on the night sky brightness is derived. A comparison with independent cloud data is made.

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# REGULATIONS

## THE LEGAL REGULATION OF LIGHT POLLUTION

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Research continues to highlight the risks that light pollution poses to human health, safety, ecology, the environment and the loss of the night sky. These issues raise important regulatory questions, namely as to how light pollution is defined in law, without which there can be no effective regulation; the reasons for and against regulation and why and how we should regulate.

Certainly, in the past decade, there has been a surge in regulatory initiatives across the globe. In Europe, there has been regulation in a number of Member States, including the Czech Republic, Slovenia, the UK, a number of Italian regions, France, Germany and Spain. Some aspects of light pollution may be addressed under European Union Directives, and a recent Council of Europe Resolution has expressed a need to regulate. Elsewhere in the world, the United States

has examples of regulation in the form of local ordinances and the Model Lighting Ordinance.

These regulatory mechanisms use a variety of different legal approaches, varying from laws dedicated to light pollution itself (such as in Slovenia); pre-existing laws within which light pollution might be incorporated (such as in the UK); to “soft law” or guidance provided by industry and advisory bodies, (such as the Model Lighting Ordinance in the USA).

This paper will discuss a legal definition for light pollution, weigh the arguments for and against legal regulation (such as safety and security), compare and contrast the relative strengths and weaknesses of some of these different national approaches. It will also highlight what is considered to be best practice for the effective regulation of light pollution.

## ECOLOGICALLY RESPONSIBLE OUTDOOR LIGHTING GUIDELINES

*BOB PARKS, International Dark-Sky Association, USA*

The IDA has spent the last two years working with the United States National Park Service to analyze current outdoor lighting practices in national parks and to develop best practice standards that can be used in environmentally sensitive areas. During the project we also worked with the Royal Astronomical Society of Canada to produce the RASC/IDA Guidelines for Outdoor Lighting in Dark Sky Parks.

We are now condensing the knowledge gained during this process into a report to the CIE that will become the basis of the TC 5-27: "Artificial Lighting and its Impact on the Natural Environment" committee recommendations.

The work has focused on determining the appropriate illumination levels and spectrum of light that allows human activity with minimum impact to other species.

The level of illumination required to navigate dark locations has traditionally been poorly understood. By maintaining average illumination levels of 5 - 10% the recommended practices of traditional lighting standards, it is possible to transition between the lighted and

unlighted environment without forcing humans into photopic vision. By carefully maintaining scotopic or mesopic adaptation, humans can safely traverse terrain in unlighted areas. In addition, avoiding the use of white light significantly decreases the time necessary to become dark-adapted after being exposed to higher illumination levels.

We reviewed available research regarding the visual spectral sensitivity for nocturnal species. The results confirmed that there is no "one size fits all" approach. Ecologically sensitive lighting design requires a survey of the native nocturnal species population and use of spectrally tuned lamps. In many instances, bi-modal fixtures should be employed to match optimum spectrum to the appropriate time of the night and/or season. We have worked closely with several LED lighting manufacturers to develop narrow-band monochromatic LED lamps that minimize impact on the nocturnal environment.

This presentation will provide an overview of the available options for designing outdoor lighting that does the least harm to the nocturnal environment.

## A COMPARATIVE STUDY OF THE LIGHT POLLUTION CONTROL LAWS OF THE US AND THE UK

*PEDITHEP YOUYUENYONG, De Montfort University, Leicester De Montfort Law School, GB*

Artificial light at night are used in public and private applications where there is either no naturally occurring light at night, or where supplemental light is required at nighttime or the period of time between the sunset and the sunrise, for example, domestic security lights, commercial advertising lights and industrial and commercial security lights. Although artificial light is essential in national and local modern society, however lighting at night in the wrong place and the wrong time can be environmental pollution. Artificial light from public and private premises is able to have many negative impacts on the environmental and national resource quality. Therefore, incorrect outdoor light fixtures and design can produce light pollution and energy waste. In order to reduce the negative effects of light pollution, many countries establish

specific legislative controls on light pollution, for example, the US 's State level legislation.

Even though the Clean Neighbourhoods and Environment Act 2005 amended the Environmental Protection Act 1990 to bring artificial light from premises under a specific statutory nuisance regime as of 6 April 2006 and under section 79 of the Environmental Protection Act 1990, local authorities have a duty to take reasonably practicable steps to investigate complaints of statutory nuisance, including: 'Artificial light emitted from premises so as to be prejudicial to health or a nuisance', but It seems that the UK have not considered adding other specific legal frameworks associated with light pollution control to the common law statutory as written law.

## RESPONDING TO LIGHT POLLUTION: PROTECTING THE DARK AND SHAPING THE LIGHT

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*KATHARINA KRAUSE, Leibniz Institute for Regional Development and Structural Planning, D*  
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The fast-paced increase in artificial outdoor lighting has resulted in growing awareness of the negative impacts of what is often referred to as “light pollution”. As a result, discussions on effective policy responses are currently (re)emerging.

While these debates have intensified in the past two decades, they are not a new phenomenon. Especially in times of transition when new technologies and infrastructure were tested and implemented, the choice of light sources, their extent and distribution were often highly controversial. Advocates of nature and cultural heritage protection, for example, criticized the nightly illumination of buildings and technical artifacts from the 1910s (especially flood-lighting and luminous advertising), resulting in the development of regulations to reduce light pollution.

In current debates, two different and complimentary approaches can be identified. On the one hand, efforts are being made to regulate outdoor lighting in light-polluted urbanized areas, either by rewriting and adapting existing regulations or by developing new sets of laws. These regulations aim at a variety of lighting sources, while embracing the societal, spatial or economic functions of lighting practices. These endeavors

are usually connected with questions of energy efficiency or the aesthetic quality of cityscapes. On the other hand, policy responses also focus on the designation of dark sky areas in regions still largely unaffected by light pollution. These are often nature reserves which receive an additional layer of protection to preserve the visibility of starry skies as well as naturally dark nights for flora and fauna. This approach is relatively new: The International Dark-Sky Association was founded in 1988 and the Royal Astronomical Society of Canada’s Light-Pollution Abatement Program was launched in 1991, designating the first Dark-Sky Preserve in 1999.

In this contribution, we will discuss the difficulties and potentials of both approaches to mitigating light pollution. Drawing on case study research on the governance of darkness in dark sky areas in Germany and North America, on the governance of lighting in urban and suburban areas in Berlin and Brandenburg, and on the history of lighting conflicts, we will analyze past and existing institutional arrangements, stakeholders involved and interests at play in related policy-making processes. Finally, we will formulate recommendations for the development of further policy.

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## IT'S ALL ABOUT MONEY?! COSTS AND BENEFITS OF ARTIFICIAL OUTDOOR LIGHTING

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*BENJAMIN KÖNECKE, TU Berlin, Department for Urban and Regional Planning, D*

Artificial lighting is one of the most significant technologies of the past century. It contributes to a sense of increased security, is a prerequisite for the temporal expansion of economic and leisure activities, and opens up new possibilities for the design and staging of buildings and public spaces at night. However, outdoor artificial lighting also has a dark side. The increasing overuse of outdoor lighting – referred to as “light pollution” – has considerable negative impacts on human beings and the environment.

Our project is involved in the joint research project *Verlust der Nacht*. Its goal is to systematically document and analyse the direct and indirect costs and benefits of artificial lighting by summarising the conclusions of a wide spectrum of international literature, interviews and workshops, and classifying them to establish a taxonomy of possible costs and benefits, exploring their interrelations and getting a rough idea of dimensions.

What is known today is that artificial light at night provides value for humans

but also some kind of disadvantages for ecosystems and human health. The first step of our research was to name and define these positive and negative effects of artificial night-light. Subsequently, we investigated how to assess them from an economics perspective. The complexity of this task lies in the recognition and combination of a scattered research field with different states of knowledge. Light pollution is until now almost disregarded in environmental- and welfare-economic studies.

The aim of this submission is to present and discuss the main findings of our research. For planning and implementing new lighting concepts, it is essential to know, first, the direct and indirect effects of light on its environment and, second, how to assess them. Our research will provide a basis for the relatively new instrument of urban lighting plans as it helps to rank the different functions and utility values of light and lighting.



**SOCIETY**

## THE EFFECTS OF CHANGES IN STREET LIGHTING

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There are claims that ‘improved’ (brighter) lighting is highly beneficial in reducing undesirable events such as road traffic accidents and the occurrence of crimes. Claims of this nature have been made using research synthesis of some lighting experiments. However, we know from other areas of study, such as pharmaceutical research, that there can be large problems, for example resulting from publication bias and it has been the case that initially claimed benefits have not been seen when subsequent, more abundant information is obtained.

This presentation will state what might be wrong with such lighting claims and what is needed to get reliable estimates of true effect. Work will be presented which goes some way towards getting proper estimates of the effect, using extensive data on lighting changes and concomitant changing event rates in a large number of small areas. The UK has areas where lighting has been bright-

ened and whitened as well as others where it has been reduced.

Ultimately costs (of all sorts) of lighting need to be traded against any benefits. Reliable information is clearly needed before this can be done satisfactorily.

This paper will contain updated elements of two previous presentations, given at:

1. The 12<sup>th</sup> European Symposium for the Protection of the Night Sky, 13-15 September 2012, Bielsko-Biala, Poland. (The presentation slides are not available on-line on the Symposium website).
2. The joint meeting of the Royal Statistical Society Social Statistics Section with the Leeds and Bradford Royal Statistical Society Local Group, 27 March 2012. See: [https://sites.google.com/site/rssleedsbradford/home/meetingarchive/2011\\_2012](https://sites.google.com/site/rssleedsbradford/home/meetingarchive/2011_2012) for abstract and presentation slides.

## FROM HME TO LED: NEW LIGHTING LAYOUTS AND RESIDENTS' PERCEPTION OF ARTIFICIAL LIGHT

*ROBERT HÄNSCH, TU Berlin, Department for Urban and Regional Planning, D*

*SEBASTIAN SCHNEIDER, TU Berlin, Department for Light Technology, D*

*ANJA BESECKE, TU Berlin, Department for Urban and Regional Planning, D*

Light pollution is a problem that came to the focus of scientific research only in relatively recent times. Old and unscientifically conceived street lighting and the advent of LED lighting raise questions on their influence on human and animal health and its economic efficiency. Up to the present day, light is mostly associated with positive feelings. However, the increase of "light pollution" shows lighting's dark sides as well, and critical voices are becoming more and more heard.

"Verlust der Nacht" (VdN, "loss of night"), a research program funded by German Federal Ministry of Education and Research, tries to approach the issue on a holistic basis, bringing together a diverse range of researchers from all relevant fields. For this paper, two research partners of VdN joined to analyze the results and outcomes of three urban and suburban street lighting modernization measures. In urban Berlin, a major traffic road was retrofitted from HME to

LED street lighting. In suburban Berlin, residential streets were either retrofitted from HME to LED or provided with a completely new LED lighting solution.

The task of the Department of Lighting Technology was to measure the installed lamps and luminaires both prior and after the modernization, and both on location and under laboratory conditions. Measurements included horizontal and vertical illuminance, luminance distribution on the street, total luminous flux, spectrum, and intensity distribution of the luminaires. The task of the Department of Urban and Regional Planning was to conduct opinion polls of the residents' view on lighting situations and darkness, both prior and after the modernization, as well as the view on the process itself. On the conference ALAN we will present the results of both the objective measurements and the subjective survey and draw conclusions on the feasibility of the modernization measures.

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## LIGHTSCAPES, NIGHTSCAPES AND DAYSCAPES – ANALYSIS, CONFLICTS AND GOVERNANCE

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*DIETRICH HENCKEL, TU Berlin, Department for Urban and Regional Planning, D*

What are the differences between dayscapes and nightscapes in urban morphology? High quality photos from the ISS of night time cities – which have only become available recently – and photos from google earth allow new analytical approaches to the comparison of the nighttime and daytime structures of cities and of cities' nightscapes. The poster provides first tentative attempts toward such analytical comparisons, which already show the great potential and the vast amount of questions raised. One question which arises relates to the

time when the photos of the nightscapes are taken. All available photos give the impression that the cities are extremely lit up. However, a time lapse study of Alexanderplatz, a "light hotspot" in Berlin, during an entire night in June 2013 shows that the light intensity at this place varies considerably. These new methods could also provide a more substantial empirical base for relevant aspects for light master plans, which are being established for ever more (at least European) cities.

## LIGHTING THE CITIES OF THE FUTURE

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*BOB PARKS, International Dark-Sky Association, USA*

The world is poised to make a once in a millennia conversion in outdoor lighting technology. Solid State Lighting (SSL) and LED in particular will offer significant energy savings over the High Intensity Discharge (HID) technology of the past century. The ability to dim SSL now allows society to fundamentally rethink how and when we use outdoor lighting and other passive illumination options.

In order to embrace real energy conservation goals, society must confront its basic fear of the dark and scientifically analyze the real and measurable impact of lighting on safety. Most current public outdoor lighting policy today is based on an assumption that lighting reduces crime and more lighting will provide more safety. Review of the limited

available research does not support this assumption. In a society that spends vast sums of money on the installation of outdoor lighting and the energy to operate it, now is the time to spend whatever is necessary to provide cities with accurate information to guide their lighting policy.

This talk will outline the available research related to the effect of outdoor lighting on crime and safety and what additional research is needed. It will also detail the best available and emerging lighting technologies, including adaptive controls that will allow SSL to radically reduce energy consumption and its impact on the environment. Additionally it will explore innovative new lighting designs that improve visibility by reducing glare and improving contrast.

## LIGHTING THE KINGDOM OF FRANCE: THE INTRODUCTION OF STREET-LIGHTING IN 1697

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Public lighting during the Early Modern Era is still a subject largely unpublished in french historiography. If the parisian example is known in outline, the establishment process of the first public lanterns on a national scale has been little studied. Existing works on the issue most often go back to the nineteenth and the early twentieth century (Herlaut, *Street Lighting in Paris at the end of the 17th and eighteenth century*, 1916). Since the 1970s, some urban monographs occasionally deal with the topic (Perrot, *Genesis of a modern city, Caen in the eighteenth century*, 1974). Yet, the subject is at the intersection of political, economical and cultural history of urban societies during the Ancien Regime. In addition, public lighting archives are especially abundant, even if they mainly come from public administrations (State Council, intendant's correspondence, municipal archives).

This paper suggests to follow the process of street-lighting from its introduction in 1697 by Louis XIV in the main cities of the kingdom, until the early years of its implementation. We aim to investigate the reasons of the establishment, thirty years after its installation in Paris (1667). Did the king require a «public illumination» (the term then used) to increase his control over cities, or only

with financial intentions in a war context, because of the establishment of a public lighting tax?

Then, this communication proposes to study the reception of the edict. Indeed, most often, municipal authorities showed reluctant to establish public lighting they deemed unnecessary. Any pretext was good enough to criticize the new measure. Sending the complaints to the king, the intendant at the head of the province, appeared as an intermediary with the central power.

However, it is more difficult to study users' reactions, because their speech is the most often reported by urban authorities: in the complaints sent to the king, or in the police reports on attacks against the lanterns or against public lamplighters. Testimonies of inhabitants on the introduction of the first public lanterns randomly appear in private writings.

The consequences of the edict differ according to the cities or the provinces. While some of them managed to be exempted from the establishment, others were forced by the intendant to apply it. The installation of public lighting, despite initial reluctance, gradually changed the city dwellers' habits and urban landscape. It created new activities, new professions, and in the longer term, new sensibilities and new needs emerged.

## PEOPLE, PLACES, OR THINGS? DETERMINANTS OF LIGHT POLLUTION IN THE WESTERN UNITED STATES

*DAVID M. MITCHELL, Missouri State University, USA*

The problem of Light Pollution is one that has been studied in the natural sciences for many years but has been neglected in the social sciences until recently. Until just a few years ago, it was believed that population was the biggest determinant and contributor to light pollution and that there was a mathematical relationship between population and levels of light pollution, i.e. Walker's Law. However, recent research by Gallaway, Olsen, and Mitchell in the field of economics has shown that, although population is important, there are other factors that also contribute significantly to light pollution. Some of these factors include Gross Domestic Product per capita and energy extraction as a percent of GDP for a country. Not surprisingly, as GDP and energy extraction increases, light pollution increases. However, this previous research has been very broad in its metrics and has focused on light pollution, GDP, and energy at the country level. Although this might be an appropriate

scale of measurement for countries with a very small area in size, it is not appropriate for countries with a large or even medium sized area. Furthermore, it is unknown as of yet if the mix of industries has an impact on levels of light pollution. This paper seeks to fill in these gaps and give policy makers a sharper focus on which industries contribute to light pollution. This paper compares changes in light pollution from 2000 to 2012 in the Western United States with changes in population, industry mix, and other factors that might, or have been shown, to contribute to light pollution. This allows us to determine not just if economic growth contributes to light pollution but what types of economic growth contribute to light pollution. Policy makers can then use this research to help guide and develop industries which will contribute to economic growth while at the same time minimizing the negative effects of light pollution.

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## TOWARD A NIGHTTIME LANGUAGE OF LIGHT

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We as a society are becoming more used to living our daytime lives at night. As steadily more people move into cities, the nighttime economy also increases; hospitals, transit stations and airports with 24-hour service, police stations, construction areas, hotels, etc. all operate during the night. The general premise has been to provide lighting for these functions that attempts to re-create daylight in terms of color and perception, and technological progress in lighting has been focused in developing electric sources that seek to mimic daylight. However, as concerns with energy use, light pollution, and health and well-being grow, it is important to reconsider the attitude toward lighting at night. This presentation provides a starting point for this discussion. I will use three different topics that lighting professionals come across every day to question the ideas we generally hold about nighttime lighting.

### 01. Light levels in general

As a lighting professional one often finds oneself in the paradox of having a set of codes to follow (though they are not legally binding, many clients will treat them as though they are), while there places in every city that we all live in that do not comply with these standards, that are perfectly safe and comfortable to inhabit at night. This will be demonstrated during the presentation with light measurements taken by myself and my colleagues in several places (for example, the Magere Brug in Amsterdam,

1 lux average). When are light level recommendations something to be followed and when are they abstract numbers?

### 02. The feeling of safety

This is historically linked to the idea of surveillance and being surveyed. Before public street lighting, people in Western Europe needed to carry lanterns not only to see but to be identified. We carry that history with us by adopting light level codes that are based on how much light is needed to recognize a stranger from a distance. A more extreme example is the lighting needed for CCTV cameras to record a discernable face – depending on the camera, this requires a much higher lighting level than what is normally recommended. Do we need to be able to see others to feel safe? Or do we need to have the feeling that we ourselves are not seen?

### 03. City identity

It is quite pertinent that this conference is taking place in Berlin, a city which certainly played a part in using light integrated into architecture as a symbol of its World City status (Berlin Im Licht festival, 1928). In this case nighttime lighting functions as a symbol, it changes the way that space is understood and perceived. Careful consideration of what should be lit and what should not be illuminated can save a great deal of energy by simply allowing large areas to be left dark. Can we also use temporary lighting installations as a means of expression?

## VERLUST DER NACHT – A PUBLIC RELATION CAMPAIGN AGAINST LIGHT POLLUTION

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Although the interest in environmental topics is high in western societies, the awareness and knowledge about light pollution is rather low. Most people have not heard the term light pollution and even if, they might not be aware of the consequences of nocturnal illumination. Since light is general considered as a sign of beauty, modernity and safety, the dark sides of light are not easily seen.

As part as the Science Year 2012 “Project Earth, Our Future”, which was founded by the Federal Ministry of Education and Research, the research network “Verlust der Nacht” has conducted a public relation campaign on light pollution. The parts of the campaign were:

- Participation in established events like science nights and the children party of the German public television (ARD)
- Own events in planetariums and zoos including talks and experiences of darkness
- Visits to schools
- An interactive exhibit with a computer game; the task is to fly an owl through a park at night and reduce light pollution by answering questions on light and night. This exhibit was presented on the MS Wissenschaft science ship touring Germany and was very popular with the students.
- A poster exhibition, which, based on the research done in the network, gives information about sources, history and

consequences of artificial lights, but also the importance of the night sky for human culture.

- Open access publications of scientific texts and lay information material
- A citizen science mobile app for android smart phones, with which the user can evaluate the sky brightness by stating the visibility of certain stars. These data are collected in the GLOBE at Night open access data base for research projects on skyglow (see Kyba et al. in this issue).

For many people, our campaign was the first contact with the topic light pollution. The general reaction was surprise, interest, and concern about the possible consequences. Many shared their own experiences with light pollution or voiced the wish to help to reduce it.

Initial concerns about a possible decrease in safety and life quality were mostly relieved by information about innovative light concepts. People appreciated solutions that take more into account than CO<sub>2</sub>-reduction, but also impacts on biodiversity and human health. There was also positive feedback from politicians about the campaign, stating that light pollution is an important topic and has to be reduced. We therefore believe that such campaigns are worth the money and effort to raise awareness in the broad public.

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# TECHNOLOGY & DESIGN

## OUTDOOR LIGHTING, BUT PLEASE TIMELY

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The impact on nocturnal ecosystems by outdoor lighting gets growing attention.

The current use of outdoor lighting is based on standards which are based on findings on perception of the human eye. They are developed without consideration of environmental protection. Limiting the effect of light nuisance for people was added later by the CIE150.

Several requirements in the standards are based on findings with old lamp technology and those possibilities. With the advancement of the discharge lamps and especially with the LED technology, much has been changed:

1. Not all functions of street lighting are being taken into account.
2. The glare evaluation, a TI assessment allows no reliable conclusion to the perception of glare anymore.
3. With LED's it's possible to optimize light distributions further. Therefore the standards must allow this.

At this point do the requirements for visual perception, energy efficiency and environmental sustainability meet.

Fortunately, they all point in the same direction:

1. Well shielded luminaires.
2. Uniform Lighting
3. Optimized Assessment of Energy-Efficiency with „E min instead of E ave

Changes in the application of outdoor lighting are necessary. If sustainability is not only related to energy consumption, but also to habitat protection for animals, many manners must be questioned. Who needs illuminated trees? Nice illuminated high rise buildings impose on long distance, also for migratory birds, which clash by thousands on them and die. Biologists report more and more new knowledge of the negative effects of outdoor lighting on wildlife.

This shows that for the use of outdoor lighting not only the purpose for the users, but also all the “side effects” must be considered. Solutions cannot only be found in abandonment or temporal limitation. Also the adaption of quality criteria can induce a lot.

## EXTRA LOW COLOUR TEMPERATURE SOLID-STATE SOURCES FOR ARTIFICIAL NIGHT LIGHTING

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Due to energy efficiency, longevity, improved mesopic efficacy and colour rendering, reduced maintenance, and the ease of integration into intelligent control networks, light-emitting diodes (LEDs) are an attractive replacement of discharge lamps in outdoor lighting. However, common white LEDs emit light that is rich in blue wavelengths and should be avoided at night because of the nonvisual photobiological effect (pineal melatonin suppression), which poses a health hazard. Also, such LEDs cause aesthetic inconvenience at low luminance due to the Kruithof effect.

In this work we introduce LED-based sources for artificial night lighting with the minimized circadian action factor, which is the ratio of nonvisual photobiological circadian efficacy to the mesopic luminous efficacy of radiation. Such sources have very low correlated colour temperatures (ca. 2000 K) and their spectral power distributions are composed of an intense orange compo-

nent and a weak blue component. The circadian action factor of these “firelight” solid-state sources is similar to that of HPS lamp; however they have chromaticity that is similar to that of a black body (fire).

A prototype “firelight” solid-state source was developed by assembling commercial direct-emission blue and phosphor-converted amber LEDs into a cluster. The laboratory investigation of the psychophysical performance of the source against a HPS lamp showed a reduced time of reaction to achromatic stimulus and a reduced error score in the Farnsworth-Munsell 100-hue test. The “firelight” source showed improved colour rendering characteristics that were appropriate for mesopic conditions, when the colour discrimination ability of human vision is reduced. Also, a pilot experiment on semantic-differential scaling showed that the “firelight” LED cluster better meets aesthetic and safety needs of subjects.

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## CONTRAST ORIENTATED LIGHTING DESIGN & DARKNESS MINDED CONCEPTS

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Artificial light in contemporary urban nightscapes shouldn't be applied in a manner that deprives citizens of a natural night experience. Darkness should be deemed an auspicious ingredient of intense simultaneous contrasts, which make observers perceive the luminance of visual stimuli brighter. A darkness minded Lighting Design Concept aims at creative handling of visual perception and light potential of materials by minimizing the need for light energy and maximizing energy efficiency. According to the Ricco & Piper Law a fragmentation of light into 10' stimuli can double perceived brightness of the same luminance value.

According to the Helmholtz Kohlrausch Effect, saturated red monochromatic light appears twice brighter than white light of equal luminance, and according to Steven's Law and the logarithmic relation between luminance & brightness, light energy saving becomes exponential, when brightness perception rests on saturated colors. Thus, adjusting the spectral distribution of radiation of multicolor led sources to the spectral reflectance of lit objects increases the key parameter for enhanced brightness perception, namely saturation in an energy efficient way, by dispensing with the unnecessary part of the spectrum and not by filtering it while relevant energy is being consumed. Aside from the above visual perception principles, there is also

another natural and energy efficient way of illuminating without light by means of invisible ultraviolet radiation, which makes materials with intrinsic photoluminescence properties glow when exposed to uv radiation of appropriate excitation wavelength. Such a lighting technique doesn't only prevent the sky glow effect, it helps preserve the precious background of natural darkness in favor of enhanced brightness contrasts, as light can be radiated only from materials containing the fluorescent particles or donated with such particles and not by the source of invisible radiation.

As light color of photoluminescent materials appears mostly saturated, the impression of relevant visual stimuli brightness is further enhanced according to the Helmholtz Kohlrausch effect. For instance manganocalcite exposed to 320 nm appears reddish with a dominant wavelength between 610 and 630 nm and can be embedded into concrete tiles used in façade cladding. On the other hand the phenomenon of photoluminescence can't be called artificial and is as natural as night. The way we treat our night environment shouldn't be artificial. Modern Lighting Designers should care about the formation of natural urban nightscapes and reject any form of lighting artificialism by creatively applying available lighting technology with their mind on the importance of darkness.

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# POSTER

## POSTER

## TWO-YEAR NIGHT SKY BRIGHTNESS MEASUREMENTS IN THE NETHERLANDS.

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Since begin 2011 continuous sky brightness measurements are being performed at nine locations in the Netherlands using so-called 'Sky Quality Meters' (SQMs). The monitoring locations involve industry, urban, rural and nature reserve sites. Meanwhile, two measurement campaigns were held at the advanced remote sensing site at Cabauw, The Netherlands; one of the nine monitoring locations. The latter campaign comprises fifteen SQMs of six institutes from four different countries. Intercalibration factors for the

SQMs were derived in both campaigns and give insight in the mutual comparability of the SQMs and long-term stability of these devices. These results are incorporated in the preliminary climatology for the nine locations inferred from the two-year monitoring period. Figures and graphs are presented characterising the four different types of monitoring locations in terms of median, average, minimum and maximum luminances for various time slots.

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**POSTER**  
**CREATION OF A MULTISPECTRAL MOSAIC AND SPATIAL ANALYSIS OF  
 A NOCTURNAL AERIAL SURVEY OF BERLIN**

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Artificial light is steadily increasing for years. So far the effects on humans, animals and plants have been barely researched. Therefore the objective was to create a multispectral mosaic of Berlin. As foundation, digital images were used, previously acquired by a nocturnal aerial survey of Berlin, on September 11, 2010. The digital images were available as raw data, without further adjustments taken. One challenge of the recordings was that images of each channel (red, green & blue) were successively and separately taken. It follows that moving objects on each channel are on a different location and therefore are displayed separately as red, green and blue elements on the multispectral mosaic later on. The raw images were converted into the GeoTiff format and afterwards geographically rectified based on control and reference points, with an average distortion of 0.4 meters. Furthermore each image stack, this includes an image for each channel of the same area, was superimposed and adjusted to create a single multispectral image out of the channels. Now the individual multispectral images were combined into a single multispectral mosaic. In order to further improve the result, the image histograms were adjusted und harmonized.

The result is a multispectral mosaic with a resolution set to one meter.

A map of this high resolution provides an ideal basis for a spatial analysis of the distribution of artificial light at night in Berlin and its possible connection with the issue of environmental justice. Referring to a general tendency of poorer people living in areas with higher amounts of environmental stressors (e.g., noise or fumes) while richer people reside in less polluted areas, the concept of environmental justice tries to reduce these stressors. For there is prove that artificial light might have a negative effect on human health and natural biotopes a method for measuring artificial light within a defined area was established using the concept of "living environment areas" (lebensweltlich orientierte Räume, LOR). Each area is defined by social economic and traffic data thus giving a reliable overview of a population's living conditions. To situate the lightest areas the map was intersected with the LOR and later a newly developed brightness factor (Kuechly) was applied in order to estimate the influence of night at light within a LOR. In the future these maps can provide a solid foundation for manifold studies in sociological and ecological disciplines.

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**POSTER**  
**SPATIAL ANALYSIS OF URBAN NIGHT TIME BRIGHTNESS**

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Nighttime light now exceeds natural twilight intensity in many urban areas, increasing the likelihood of potentially negative effects on municipally integrated natural environments. However, little information exists concerning the impact of artificial night lighting on ecosystems.

The goals of our research are to understand both what the sources of upwards directed light are, and to identify patterns in the distribution of the lights. Therefore first-time information about the existing conditions of artificial lighting using Geographic Information System (GIS) and Remote Sensing (RS) technology is compiled, to analyze the illumination impact of various land use and on different administrative levels. While it can be generally assumed that all areas are affected by artificial night lighting (e.g. indirectly through sky glow), this analysis is restricted to aerial data of the direct and reflected illumination.

A high resolution mosaic image of the city of Berlin, Germany at night is spatially analyzed to identify the major sources of light pollution in the city based on urban land use data. An area-independent "brightness factor" is introduced that allows direct comparison of the light emission from differently sized land use classes.

Using this methodology, lighting associated with streets has been found to be the dominant source of zenith directed light pollution, although other land use classes, like airports are up to ten times brighter than the average pixel. These results are compared with other urban light pollution quantification studies.

This study offers fundamentally new observations and underlines the need to include light pollution into urban and landscape planning

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POSTER  
OUTREACH ACTIVITIES ON PRESERVING A DARK SKY IN HONG KONG

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Hong Kong's light pollution problem had recently been described as the "worst in the world" in the public media\*. Light pollution brings adverse effects on ecology, energy consumption, human health, and is unscrupulously destroying the few remaining star-gazing locations in Hong Kong. Our team has studied the light pollution conditions in Hong Kong for 10 years and established a huge data archive of night sky brightness measurements. Armed with these scientific data, we also have dedicated efforts to spread the message of dark sky conservation to the public through running a series of outreach projects, raising awareness on preserving the dark sky via a public website, and a series of talks to concerned professionals such as real-estate developers, building surveyors, engineers, and housing

managers. Furthermore, we established an engagement project which involves not only educating school students to appreciate the beauty of the night sky and the importance of light pollution reduction, but also allowing them to experience first-hand the extent of light pollution by designing a few simple-to-follow research projects through the use of the portable Sky Quality Meters (SQM). Finally, we just conducted a large-scale science roadshow event during the Earth Hour 2013 to highlight and demonstrate the impact of outdoor lightings to light pollution (Over 2000 buildings switched off their exterior lighting for one hour on March 23, 2013 in Hong Kong). Activities related to advocating restriction of external lighting usage to the government will also be discussed.

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POSTER  
EUROPEAN STREET LIGHTING POWER CONSUMPTION ESTIMATION  
USING DMSP/OLS IMAGES

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In this work we study the emission detected by the DSMP satellites and we related it with power consumption in street lighting in Europe. It have been used a empirical calibration of the calibrated and non-calibrated DMSP/OLS images using the official statistics of the Spanish government about power consumption in street lighting. In this work we have taken in account the projection effect without movement of information,

so without reprojection. We have used GIS techniques to measure the flux of the regional divisions of the first order with the aim of new statistical data available in the future. It have been observed a clear differences in the relative evolution in the different regions. There is a very large relative increase in countries like Spain, Ireland or Portugal, off the slight decrease in others like Germany or the Czech Republic.

POSTER  
LIGHT ON NATURE: A VIEW FROM WITHIN THE LIGHTING INDUSTRY

*MAURICE DONNERS, Philips Research, NL*

The design of a good lighting installation is often based on a compromise. A compromise between initial investment and running costs, between available budget and a desire for esthetics; between energy use and a welcoming, comfortable atmosphere, between installation costs and perceived safety, or between road safety and hindrance by lighting.

The last decade has seen an increased interest in some negative effects associated with public lighting. Nuisance to people living close to the lighting installation, hindrance to astronomers and difficulties in seeing the starry sky and possible negative effects of nocturnal lighting on our natural environment.

The same decade has seen a host of innovations in the lighting industry. The coming of age of LED technology is disrupting the whole lighting world. Meanwhile, developments in electronics and information technology enable the widespread use of control systems. As with any technological development, its' introduction has many blessings, but everyone – from researcher to buyer – should also be aware of possible drawbacks and think about possible solutions.

The challenge now is to work together to use all these new technological options to reconcile the human need for lighting with the need to limit the possible disadvantages. When there are no people present, there is no need for lighting. When people are present, their lighting

need depends on their activities. After all, different visual tasks require lighting differing in light level, distribution or spectrum.

This is exactly what modern lighting technology enables. With modern optical systems, spill light can be accurately controlled. Sensors can be employed to dim lighting depending on the presence of people or traffic. Electronic systems can be used to remotely control road lighting, giving flexibility in switching time schedules, in dimming levels and specific seasonal settings. Compared to conventional lamp technology, LEDS simplify switching, dimming and changing light colour or distribution.

Here we will illustrate this, using a number of examples of real lighting installations from all over the world, designed with the purpose to meet human lighting needs with the smallest possible negative effects on ecology. Good fixture design, the judicious application of light spectra, the use of sensor and control technologies will be shown to be able to benefit a range of animals, as diverse as sea turtles, badgers, bats and migrating birds.

In the end, the lighting industry serves itself best, if it serves the needs of its' customers best. Only if its' experience and innovative power are combined with the knowledge of external experts, really meaningful and sustainable lighting solutions can be introduced in the market.

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POSTER  
DARK SKY PROTECTED AREAS:  
WHERE ASTRONOMERS, ECOLOGISTS AND PUBLIC COME TOGETHER

---

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There are many reasons to reduce light pollution, from environmental and human health protection, through energy efficiency and public safety, to preserving the right of people to enjoy the sight of an unpolluted night sky. At its World Conservation Congress In 2012, the IUCN endorsed the importance of controlling light pollution for ecological reasons, since ecosystems function day and night. The IUCN recommendation includes several elements, for example that dark sky protection should become part of the management regime of all protected natural areas, and that clear night skies also add a valuable visitor experience. The concept of dark sky places dates to the 1993 establishment of Michigan's Lake

Hudson Dark Sky Preserve. In 1999, Ontario's Torrance Barrens Conservation Reserve was recognized as Canada's first dark sky preserve by the Royal Astronomical Society of Canada (RASC). Beginning in 2007 the International Dark-Sky Association (IDA) established a programme to recognize dark sky parks, reserves and communities. Several other countries also have dark sky places recognized by various institutions such as national astronomy societies, local government and universities. As of March 2013, the RASC, IDA and other national astronomical organizations recognize forty-seven dark sky protected places worldwide. Several examples are included.

## POSTER

## ARTIFICIAL LIGHT AND PREDATOR PREY DYNAMICS IN FRESHWATER ECOSYSTEMS

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Light pollution is among the fastest growing anthropogenic influences on the natural environment, but there are major gaps in knowledge about effects on most animals. This is particularly true in freshwater ecosystems of which many have close proximity to sources of artificial light.

This presentation will outline the potential behavioural and ecological impacts of artificial night lighting on the predator-prey dynamics of wild freshwater fishes of high economic or conservation value (Atlantic salmon, *Salmo salar*,

and Bullhead, *Cottus gobio*) and their invertebrate prey.

The project combines experimental field and laboratory studies examining behavioural and physiological responses to broader spectrum street lighting including; shifts in diel rhythms, cortisol stress response, and predator-prey interactions. Likely outcomes will be discussed in relation to the conservation and management of threatened fish populations to provide an evidence base for policy decisions and management of night light regimes affecting UK rivers.

## POSTER

**HAS ARTIFICIAL ILLUMINATION AN IMPACT ON SEASONAL METAMORPHOSIS OF MOTHS? – AN OBSERVATION ON DIAPAUSE INDUCTION**

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Light pollution due to artificial illumination of the environment, such as street lightening or illuminated advertisements, increases annually worldwide with unknown consequences for human health and nature. The intension of this study was to investigate the impact of street lightening on the circadian rhythm and seasonal metamorphosis of moths. *Cameraria ohridella*, the horse chestnut leafminer was used as test organism because of its high abundance in urban greens. In October, the development of the leafminer at illuminated versus non-illuminated sites in the city of Berlin and the rural area of Brandenburg was compared. Extended larval activity was recorded in the city and at illuminated rural trees. Illuminated leaves seemed to be larger than those grown in natural darkness, but the mine density did not differ. In the greenhouse, infested seedlings were exposed to two light regimes; both had short day-light conditions (natural light with additional grow-light for 8hrs) and one had additionally 24hrs

illumination (~100lux) from 18W warm-white compact fluorescent lamps. After only one week, the mine size was significantly lower on the 24hrs-illuminated seedlings. Leaf senescence was notably delayed by the additional illumination. The leafminer developed a significantly lower proportion of diapausing pupae and accordingly a higher proportion of free pupae, when illuminated for 24hrs, compared to short-day conditions. These effects decreased, when greenhouse temperature dropped below 12°C. The greenhouse results confirmed the outdoor examinations that larval activity was extended due to street lightening. The effects seemed to be food related. For moths less adapted to environmental changes than the invasive leafminer, the consequences of street lightening in conjunction with warmer temperature, due to global warming, might be fatal. Further research is urgently required to create sustainable street lightening guidelines and protect natural darkness, where it is needed.

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POSTER  
ILLUMINATING FOR SAFETY

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Current street lighting implementations are designed to serve various utilitarian functions, such as the deterrence of crime or providing people with a sense of safety. However, in an era where excessive and redundant street lighting is increasingly viewed as a waste of energy and a major cause of light pollution, there is a growing need for innovative street lighting developments. The introduction of intelligent dynamic LED street lighting systems, which continually adapt lighting levels to the current needs of street users, offers a promising solution to reduce energy usage and diminish light pollution. Yet the implementation of such intelligent street lighting systems may also adversely affect a core function such as providing people with a sense of safety. Thus, important questions are raised with respect to how these systems should react when a street user is detected.

Consequently, there seems to be pressing need for predicting system behavior based on our knowledge of the dynamic relationship between street lighting and perceived personal safety. In our project we focus on these important questions in designing intelligent street lighting systems. For example, where do people need light in order to feel safe? How does (street) lighting affect people's perceived personal safety? We address these questions from an environmental psychologist perspective and we combine both laboratory and field studies in which we try to understand the theoretical (e.g., how do people form safety perceptions?; how does lighting affect these safety perceptions?) as well as the more practical (e.g., under which lighting conditions will people feel most safe?) issues concerning innovations in street lighting.

## POSTER

## ARTIFICIAL LIGHT AND DISORIENTATION IN NESTING SEA TURTLES

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We already know that artificial lights influence hatchling survival disrupting their normally accurate seaward orientation. Hatchlings show a nocturnal emerge and use simple visual cue, avoiding dark objects and crawling toward the uniformly flatter beach-facing horizon which typically reflects and emits more light from the stars or moon. There are also some studies that found a correlation between relative darkness and nesting density, but the information about how artificial light influences nesting behavior is scarce.

We have studied the nesting behavior of loggerhead sea turtle (*Caretta caretta*) in a high density nesting beach of Boavista (Cape Verde) during 36 entire nights (July and August 2012) under three types of lights provided by Philips lighting and a control with no light. Each treatment was replicated 9 nights. Every night two lights of the same type were turned on, illuminating 180 meters of the beach from dusk to dawn. All nesting stages (rise from the water, nest digging, egg laying, nest covering, nest camouflage and return to the sea) were studied and measured. At control nights a nocturnal visor was used. Every day, and immediately after dawn, we recorded the number, length

of the way up and down and location of all crawls, discriminating whether it had nest or not. Using non-parametric analysis (Kruskal-Wallis and U-test) we assessed whether different types of artificial lighting affected nesting success and orientation in the way up and down. Our results confirmed that females nested in illuminated areas, though nesting success was higher in the dark areas. We also detected significant differences in nesting success according to the type of the light used. Although artificial lighting does not significantly affected the way up, disorientation in the way back to sea was significantly different among light treatments at the 0.05 level. Disorientation increases risks for turtles and may even prevent turtles from coming back to sea causing the death because of exhaustion and dehydration.

We suggest that visual cues for the seaward orientation are the same in adult nesting females than in hatchlings; therefore it would be an innate trait maintaining all their lifelong. Consequently, artificial lighting is not only harmful for hatchling as it had been thought until now, and adult female turtles are also affected. These results should be considered in future sea turtles management projects.

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tba

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