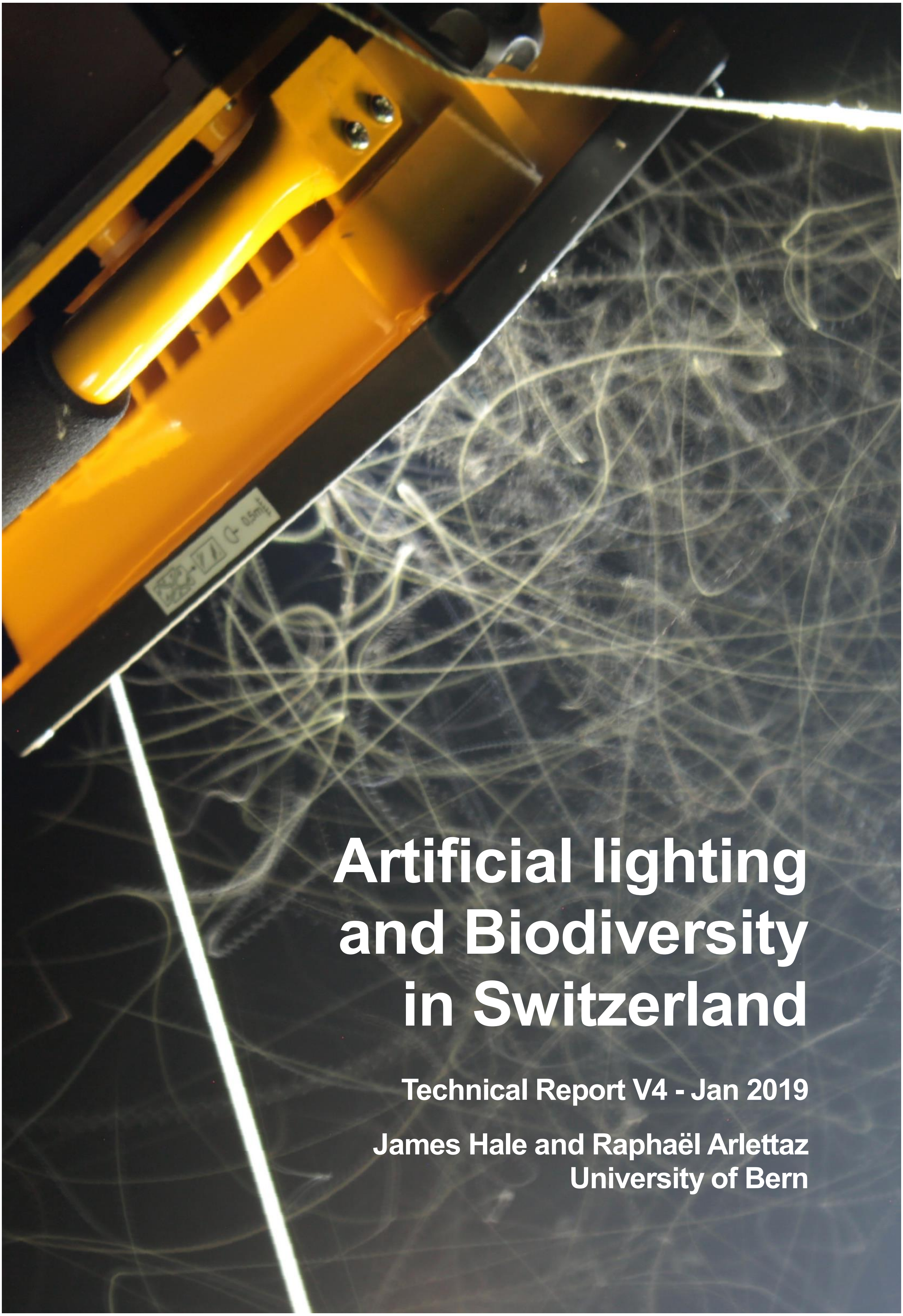


Artificial lighting and Biodiversity in Switzerland

Technical Report V4 - Jan 2019

James Hale and Raphaël Arlettaz
University of Bern

Table of Contents

1 Introduction 4
1.1 Background to this report 4
1.2 Key findings from this study:..4
1.3 Key recommendations:..5
1.4 Ecological actions overview...7
2 Data availability on Swiss artificial lighting 9
2.1 Summary..9
2.2 Introduction and background 10
2.3 Review and analysis of Swiss lighting data...10
2.3.1 VIIRS DNB (satellite mounted sensor)..10
2.3.2 ISS images..12
2.3.3 Street lamp inventories..18
2.3.4 Aerial plane night photography 22
2.3.5 Sky quality measurements and mapping 23
2.3.6 Defense Meteorological Satellite Program (DMSP) Operational linescan system (OLS) 25
2.3.7 Other data sources..26
2.4 Spatial and temporal lighting analysis...26
2.4.1 Spatial Analysis...26
2.4.2 Temporal Analysis..37
2.5 Emission indicator development 43
2.5.1 Existing lighting indicators 43
2.5.2 Future Swiss lighting indicators 44
3 Literature review on the impacts of artificial lighting on Swiss species and habitats.......46
3.1 Summary..46
3.2 Introduction 47
3.2.1 Recent research progress 48
3.2.2 Scope...49
3.2.3 Aims of this review 49
3.3 Methodology...49
3.3.1 Identify species and habitats of conservation concern in Switzerland 50
3.3.2 Identifying lighting search terms 50
3.3.3 Undertake literature searches 50
3.3.4 Paper coding...51
3.4 Results..52
3.4.1 Mammals (excluding bats)..52
3.4.2 Bats..53
3.4.3 Birds...55
3.4.4 Amphibians 57

3.4.5 Reptiles 58
3.4.6 Fish 58
3.4.7 Coleoptera 58
3.4.8 Lepidoptera 59
3.4.9 Odonata 59
3.4.10 Orthoptera 59
3.4.11 Ephemeroptera, Plecoptera and Trichoptera (EPT) 59
3.4.12 Gastropods and Bivalves 60
3.4.13 Decapoda 60
3.4.14 Fungi and Lichens 60
3.4.15 Plants 61
3.5 Discussion 61
4 Ecological impact mapping 62
4.1 Summary 62
4.2 GIS analysis of Swiss lighting vs sensitive habitats 64
4.2.1 Local lamp databases and fine-scale ecological impacts 64
4.2.2 VIIRS data and locations of potential conflict 66
4.2.3 3 VIIRS-based indicators of potential ecological impacts 68
4.3 Exploration of the impact of future lighting scenarios 98
4.3.1 Predicting locations of change in artificial lighting emissions 98
4.3.2 Exploring other future changes in lighting emissions 99
4.4 Mitigation options 100
5 Report recommendations 102
6 References 104
7 Appendices 110
7.1 Appendix 1 - Accompanying group for the project 110
7.2 Appendix 2 – search terms used for WoS (Web of Science) search 111

1 Introduction

1.1 Background to this report

This report provides an overview of the findings from the project - Artificial Lighting and Biodiversity in Switzerland, funded by the Bundesamt für Umwelt (BAFU) and undertaken by Dr. James Hale and Prof. Raphaël Arlettaz at the University of Bern. The project began on the 1st October 2015 and was completed at the end of 2017. Its goal was to build solid foundations for sound assessments of lighting emissions in Switzerland, to support emerging research on the ecological impacts of artificial light emissions. The research project had three distinct phases, which are presented as the three main chapters of this report.

1 Review, secure and explore a range of spatial and temporal datasets for lighting infrastructure and emissions in Switzerland.
2 Undertake a review of the priority species, habitats and ecological groups in Switzerland that are sensitive to artificial lighting.
3 Ecological impact mapping to identify locations where impacts are expected now, and under future plausible lighting scenarios.

1.2 Key findings from this study:

Because of the interest in artificial lighting from energy, nuisance, astronomy and ecology perspectives, it is important to try and understand how the quality and quantity of lighting emissions and lighting infrastructure varies within Switzerland and over time. Fortunately there are many valuable types of lighting data that already exist, and the monthly VIIRS satellite data appears to have good potential for both emission and ecological-impact indicators. Seasonal winter peaks are evident for Switzerland as a whole, and are particularly clear for medium-high altitude settlements, but apparently absent in cities. Summer VIIRS data appears to be more stable and may therefore be a good indicator of actual changes to lighting infrastructure (e.g. greater installed flux or improved shielding). Annual summaries of VIIRS data are the best option currently available for tracking changes in vertical emissions over time. However, trends should be interpreted with care – an increase in the VIIRS emissions indicator may simply be due to greater winter snowfall (increasing surface reflectance) in a given year. Unfortunately, the VIIRS data does not give any indication of changes in emissions of lighting within the blue part of the spectrum, so the impact of new LED lighting may remain undetected. International space station photography and aerial plane/drone photography provide good opportunities for estimating the mix of lamp types in use, and for identifying the precise locations of high lighting emissions. However, image calibration is challenging and there are currently few images available. An analysis of existing images shows that lighting emissions are often dominated by large contributions from a few point sources in or adjacent to urban areas (e.g. sports stadiums). Lamp inventories are the main tool by which existing research on ecological impacts could be implemented in practice, and these inventories are the most precise and practical option for tracking the increase in public LED street lights over time.

The ecological impacts of artificial lighting on Swiss priority species are poorly researched, despite all groups being sensitive to natural sources and rhythms of nocturnal lighting. Bats and birds were the most extensively researched groups, but many gaps remain, including impacts on migration and predation, and identifying roost illuminance thresholds. No research papers were found for other priority mammal species, which is surprising given that nocturnality is common in this group – this is a major research gap. Aquatic habitats are disproportionately exposed and particularly vulnerable to impacts; many priority species of amphibians, fish and aquatic insects demonstrate sensitivity to both artificial and natural light sources at night. In general, the results of existing studies are difficult to use by practitioners, often because lamp inventories are difficult to access.

According to three new VIIRS-based indicators of ecological light pollution, urban green infrastructure, orchards, vineyards, surface waters and amphibian spawning areas are disproportionately exposed. Because of their abundance in Switzerland, agricultural and wooded land-cover are highly exposed (by area). Cantons Zurich, Vaud, Bern and Valais have the highest number of priority biotopes exposed to these lighting indicators, and along with Aargau and Fribourg, these are the cantons where most increases in lighting might be expected in the future. Amphibian spawning areas are particularly vulnerable to greater exposure to light pollution; 29% of these habitats are located in areas vulnerable to urban expansion. Numerous ecological mitigation options are proposed, but few have been tested.

1.3 Key recommendations:

Data and indicators

- VIIRS data should be used as the replacement LABES annual indicator for total vertical lighting emissions. Consideration should be given to a second lighting metric using data from August each year as an indicator of stable installed luminous flux, avoiding signal variation due to changes in snow cover, festive lighting and winter sports activities.
- Greater collection and calibration of ISS and aerial night photography is needed.
- The quality, consistency and public availability of street lamp inventories must be improved, and be supplemented by inventories for other outdoor lighting types.
- ISS-derived data and self-reported commune street lighting surveys should be made available every 5-10 years to provide an indication of national changes in lamp type.

Biodiversity

- Broad mitigation efforts should be targeted at the few locations that are responsible for a large proportion of Swiss lighting emissions, notably outdoor sports centres.
- A precautionary approach to retain dark habitats is advised, given known sensitivities of many priority species to lighting cues.
- Restrictions on/removal of lighting near to core bat habitats should be strengthened.
- Rapid action is also needed at a policy and practice level to reduce the exposure of aquatic habitats to artificial lighting.
- Develop national lamp and light-exposure databases for sensitive priority habitats.
- In cantons where urban expansion is most likely, a proactive approach is needed to ensure awareness about light pollution, with tools to ID potential ecological impacts.
- Any future national lighting strategy needs to engage with difficult questions about tensions, trade-offs, priorities and unintended outcomes. These include how to balance the carbon savings of LED lamps with their ecological impacts, and deciding whether protecting existing dark habitats is more important than darkening ones that are currently lit.

Research

- Ecological light pollution research should focus on LED studies, designed so results are easily used by practitioners to mitigate impacts on priority species and habitats.
- Research on ecological impacts for priority mammal species (other than bats) is urgently needed.
- More research on distance and illumination thresholds for aquatic habitats, and related mitigation effectiveness.
- Additional research is needed to address knowledge gaps on lighting impacts for other priority species and habitats, and on highly exposed land-uses.

- More research is needed on impacts on bird migration and dispersal.
- Research should broaden its focus on lamps to include species impacts of skyglow.
- There is an urgency to understand the effectiveness of ecological mitigation techniques such as amber LED lights or reactive lighting, before they are promoted.
- Structured interviews are needed with experts in social and technological futures, in order to better identify new sources of light pollution (e.g. commercial drones).
- Broader impacts of lighting on ecological communities, processes or ecosystem services are outside the scope of this report, but deserve serious attention.

1.4 Ecological actions overview

	Urban habitats	**Surface Waters**	**Agricultural**	**Wooded Areas**	**Low Productivity Habitats**
Birds	More research is needed on attraction of migrating priority species to heavily lit locations, and associated predation. Research also needed on impacts of nest exposure.	Consider a citizen science approach; aquatic habitats are highly exposed - is the behaviour of priority bird species impacted?	More research needed on impacts for nesting and night-active birds in orchards and vineyards, and on *Tyto alba* more generally.	More research needed on impacts for nesting and night-active birds. Also consider impacts of isolated lights in light-naïve woodland.	Research needed on impacts of lighting on migration bottlenecks and winter-active species in alpine areas.
Bats	Remove lighting in/adjacent to building roosts of *Rhinolophus ferrumequinum, Plecotus auritus* and *Myotis emarginatus*. Research needed on roost/feeding illumination thresholds for all species.	Minimise direct exposure of important feeding locations. More research needed on lighting exposure thresholds.	Minimise lighting within commuting routes of all species, particularly *Rhinolophus hipposideros.*	Minimise lighting within commuting routes of all species, particularly *R. hipposideros.* Remove lighting near all roosts particularly, *P. auritus*. Research needed on *Myotis myotis*.	Remove lighting in/adjacent to all cave roosts particularly for *R. ferrumequinum* and *M. emarginatus*
Other Mammals	A precautionary approach is needed - prevent lighting of key habitat features. More research needed for priority sp.	More research needed for priority sp.	More research needed for priority sp.	Precautionary approach. More research needed.	
Amphibians	High levels of pond exposure according to several lighting indicators. More research needed on phenology, phenotype and genotype impacts.	High exposure of known amphibian spawning areas and fens for some indicators. Lighting surveys, a precautionary approach and more research is needed.			

	Urban habitats	Surface Waters	Agricultural	Wooded Areas	Low Productivity Habitats
Fish	High exposure of urban streams and lake edges. Precautionary approach needed - remove or reduce lighting of fish passes, bridges and riparian areas. More research needed to identify sensitivity thresholds.	Include darkening measures as part of future efforts to restore *Salmo salar* and *Anguilla anguilla* populations. More research needed on *Lampetra fluviatilis* and *Salmo trutta*.			
Insects and invertebrates	Given the high exposure of green infrastructure to lighting, more research is needed on priority species impacts. Broad process and ecosystem service impacts also need checking.	Given the diverse impacts on Ephemeroptera and Trichoptera communities, a precautionary approach is needed. More research should be targeted on priority species and impact thresholds.	Known impacts on moths communities, but more research needed on priority species. Focus research on orchards, vineyards, dry meadows and pasture. Broad process and ecosystem service impacts need checking.	Research needed on priority species. Broad process and ecosystem service impacts need checking.	Precautionary approach - protect remaining light-naïve habitats. Research is needed on priority species impacts - are light naïve populations particularly sensitive?
Plants	Given the high exposure of green infrastructure to lighting, more research is needed on priority species impacts. Broad process and ecosystem service impacts need checking.	More research is needed on priority species. A precautionary approach makes sense as aquatic habitats are already highly exposed.	Research is needed on priority species. Focus research on orchards, vineyards, dry meadows and pasture. Broad process and ecosystem service impacts need checking.	Research needed on priority species. Broad process and ecosystem service impacts need checking.	Precautionary approach - protect light naïve habitats such as raised bogs. Research is needed on priority species impacts - are light naïve populations particularly sensitive?

2 Data availability on Swiss artificial lighting

2.1 Summary

- Artificial lighting is a pollutant with a broad range of known impacts on human and ecological systems.
- Phase 1 of this project aimed to establish a strong baseline measurement of outdoor artificial lighting in Switzerland, which is essential for supporting work to reduce its unwanted impacts at a national and local level.
- Four classes of lighting data currently have sufficient spatial coverage, or the spatial and temporal resolution to make them of use for research and practice in Switzerland:
    - VIIRS monthly satellite data
    - Calibrated images from the International Space Station (ISS)
    - Aerial night photography
    - Street lighting inventories
- It was possible to gain full access to the first two of these data classes (VIIRS and ISS images), which have only become available in the last two years.
- Of the two remaining data classes, some street lamp inventories proved difficult to access and their quality appears to vary by canton.
- A variety of aerial night photography exists for Swiss cities, but these are not yet fully corrected or calibrated – this is a significant consideration for any future photography.
- However, both lamp databases and aerial photography still have potential value for supporting the processing and interpretation of the ISS photography based products, and may also be highly useful as stand-alone data in the future.
- The development of a national lamp inventory would be very useful as a way to track lighting change, as well as to inform mitigation efforts.
- GIS analyses of the VIIRS and ISS data highlight that there is a strong correlation between lighting and built surface cover, but that there also appears to be a positive association with altitude and snow cover.
- As might be expected, typical emission values for settlement areas are higher than for agricultural, wooded or unproductive land.
- However, each of these land classes has outliers that are up to 400 times brighter than the typical class values.
- An exploratory analysis of one ISS image covering 42% of the total Swiss land area revealed that for the *settlement* land class, the brightest 5% of sample locations are responsible for 33% of all emissions; the top 10 brightest locations in canton Zurich are all some form of outdoor sports centre.
- Any strategy to reduce overall lighting emissions in Switzerland should include initiatives to address this small number of extremely bright locations.
- These outliers require more investigation, although a limited exploration suggests that sports centres on urban fringes may be particularly strong sources of winter emissions.
- Strong evidence of seasonality in lighting emissions has also been found for Switzerland as a whole and for medium-high altitude settlements, which appear to be strongest during the winter. Increased surface reflection of lighting due to winter snow cover is partially responsible for this, but the effect of additional winter lighting cannot be discounted.
- As a broad indicator of emissions (e.g. for astronomy purposes) annual VIIRS summaries may be a useful indicator to adopt (replacing the existing LABES indicator)
- However, due to the impact of snow cover (i.e. albedo change) on the VIIRS indicator, a second indicator restricted to data from August each year may be a better proxy for installed flux.
- A revision of ISS derived data and self-reported commune street lighting surveys every 5-10 years may be sufficient to provide an indication of changes in lamp/spectrum type.

2.2 Introduction and background

Phase 1 of this project aimed to review, secure and explore a range of spatial and temporal datasets for lighting infrastructure and emissions in Switzerland.

Artificial lighting is a recognized pollutant that has a range of negative impacts, both on humans and biodiversity (Falchi et al. 2011). These impacts often alter the behaviour of individuals, which may result in impacts that accumulate at the scale of populations and communities and ecosystem processes. Despite this, lighting is one of the few pollutants that is steadily increasing in the western world, boosted by developments in lighting technology, urbanisation and economic growth. With the introduction of LED technology, the spectral quality of outdoor artificial lighting is also changing, moving towards whiter light with a lower UV component. Relatively little is known about how outdoor lighting varies between and within countries, between land-covers and land-uses. However, new mapping technologies are allowing the main *causes* of emissions to be identified. In addition, little is known about where ecological impacts are most likely, although a considerable increase in research effort over the last 5 years has identified impact thresholds for several particularly sensitive species. The results of Phase 1 should therefore be of broad interest to researchers and practitioners working on themes as diverse as nature conservation, landscape character, strategic planning, environmental impact assessment, human health and wellbeing and energy efficiency. This is reflected in the composition of the accompanying group for this project (Appendix 1).

Phase 1 is further broken down into three elements:

1) A review of the availability of data on lighting in Switzerland.
3) A spatial-temporal analysis of Swiss lighting emissions and infrastructure.
2) The potential development of new lighting indicators.

2.3 Review and analysis of Swiss lighting data

Data on Swiss lighting infrastructure and emissions is available in a variety of formats. The following datasets were identified via three approaches. First, a literature search was undertaken on the Web of Science (https://apps.webofknowledge.com), using the following search terms: TI=((lighting* OR light OR lamp OR nighttime OR night-time) AND (mapping OR Satellite OR inventor*))

Next, a web-search was undertaken using the same search terms, in both English, French and German. Finally, additional information was gathered from the accompanying group of experts, from Swiss overviews of the topic e.g. www.bafu.admin.ch/elektrosmog/13893/15176/index.html?lang=de, and from information distributed by the EU COST Loss of the Night Network (www.cost-lonne.eu/). As a result, a series of potential sources of information on Swiss lighting infrastructure and emissions were identified, which are described below. These range from data that is freely available and has high spatial and temporal coverage, to data that has been collected in other locations and has the potential to be collected in Switzerland, but at present is not available, or not yet realistic to collect. The sections below have been ordered so that the most comprehensive and accessible datasets are described first. For each class of lighting data we recorded:

1) Key data characteristics (spectral information, spatial extent and resolution, temporal frequency and limitations)
2) Whether it is accessible for research.
3) Case studies for its use.

2.3.1 VIIRS DNB (satellite mounted sensor)

Visible Infrared Imaging Radiometer Suite (VIIRS) instrument is a group of sensors that are mounted on the Suomi National Polar Partnership (SNPP) satellite. Its low-light channel (the day-night band or DNB) and has been collecting data on lighting emissions from the earth's surface since 2011. It is considered superior to the Defence Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) satellite light emission series data in terms of spatial resolution, dynamic range and calibration (Elvidge et al. 2013).

Like the DMSP data, VIIRS night time data is panchromatic, representing emissions between 0.5 and 0.9 um (Miller 2013). In effect, it is blind to blue parts of the visible light spectrum, but its on-board radiance calibration means that the reported pixel values are a reliable indication of emissions in the green and red wavelengths. Its low-light sensitivity is reported as ~2E-11 Watts/cm^2/sr (Elvidge et al. 2013), and unlike the DMSP data it does not saturate in heavily lit areas such as urban cores. Data collection is at ~01:30, so unfortunately this misses the expected evening peak in urban emissions, but likely captures lights that are present throughout the night. The coverage is global and data is collected nightly, although until recently, processed data were only available only as monthly averages. As with many other forms of satellite data, the spatial resolution that it is captured at is not the same as the resolution which is available to the public. Data is collected at an almost constant ground footprint of 742m x 742m, but then resampled to a 15 arc-second WGS 1984 geographic projection (Baugh et al. 2013). As a result, pixel sizes vary within the raster image, requiring further re-sampling for some GIS analyses.

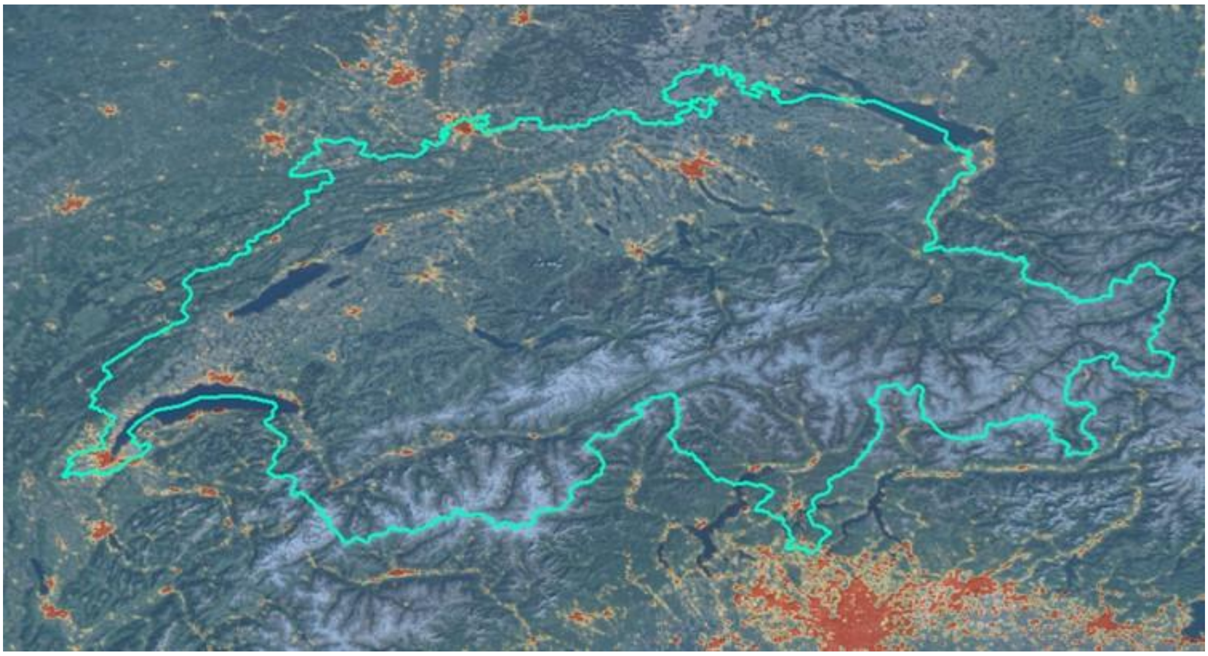


Fig.1 An example of a monthly VIIRS composite, clipped for the approximate extent of Switzerland. Source for this and subsequent figures - World Imagery basemap supplied by Swisstopo, 1st December 2017 (http://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9).

Monthly averaged mosaics have been available for download at no cost since Jan 2014 from here https://ngdc.noaa.gov/eog/viirs/download_dnb_composites.html and include correction for stray light, lightning, lunar illumination, and cloud-cover (V1 format). Lights from aurora, fires, boats, and other temporal (non-fixed) sources are not yet excluded. Earlier monthly summaries for April 2012, Oct 2012 and Jan 2013 are not yet available as V1 products.

Daily mosaics have been available since November 2017 at http://www.ngdc.noaa.gov/eog/viirs/download_ut_mos.html. To support this research project, all monthly mosaics from Jan 2014 were downloaded, selecting tile 2 (that covers most of Europe). The vcmslcfg file type was selected, which includes the stray light correction. Each monthly data folder contains 2 GeoTIFF files, whose filenames end in *rade9* and *cvg*. *Rade9* is the raster containing the monthly averaged radiance emissions as floating point radiance values with units in nanoWatts/cm2/sr. The cvg file is a raster where the integer counts represent the number of cloud-free coverages. First, all files were re-named to start with the month and date, using http://www.bulkrenameutility.co.uk/. They were then clipped in ArcGIS 10.3, using a polygon derived from the boundaries of Switzerland, buffered by 1 degree. Each image was then re-projected to the Swiss Grid CH1903 and resampled to a consistent pixel size of 500m (Fig.1). A model was created to allow batch processing of the clipping and resampling steps for each image, to facilitate the easy inclusion of new time series data in the future (e.g. for monitoring emission change over time). Finally, each *cvg* file was visually inspected to ensure that all parts of the monthly composite had at least 1 evening that was cloud free, i.e. that any zero values in the *rade* file were not simply the result of no data.

The VIIRS data has started to be used for a range of research purposes, some of which have the potential for being applied to monitoring light pollution and reducing its impacts. These include the use of VIIRS lighting data in the spatial modelling of ecological impacts (Escobar, et al. 2015; Rodriguez et al. 2015) and artificial night sky brightness (Falchi et al. 2016).

2.3.2 ISS images

ISS images are colour photographs taken by astronauts through a window on the International Space Station (ISS) using commercial reflex cameras. They provide higher spatial and spectral resolution than the VIIRS or DMSP OLS satellite data. However, there is little consistency regarding the date and time the image is captured, or the camera settings and lenses used. In addition, each of the Red, Green and Blue channels need to be calibrated and corrected for a range of fixed effects. ISS images therefore provide the opportunity to estimate the proportion of lamp types within a region at a particular point in time, and can also be used to identify the precise sources of emissions in areas where lamp density is relatively high. For example, in the image of Bern in Fig.2 B, several of the brightest lights can be attributed to sports centres with ice hockey fields.

The use of ISS images to study lighting emissions has only become possible very recently. This is largely due to the work of Dr Alejandro Sanchez de Miguel, who submitted his thesis in 2015 and has assisted us with the processing of ISS data for Switzerland. These images were processed as outlined below, and made available for analysis on 11th July 2016.

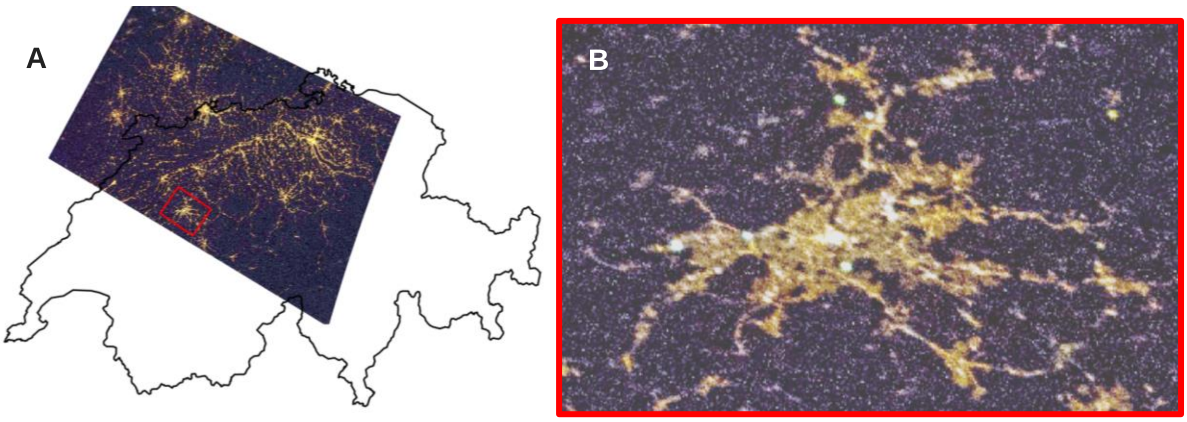


Fig.2 A) An example of an ISS image that corresponds to part of Switzerland (Bern indicated by small red box), and B) a clipped section of the image that corresponds to the city of Bern.

2.3.2.1 Finding the images

The *Gateway to Astronaut Photography* is an online database that is used to store (and make freely available) photographs taken by astronauts from the International Space Station - http://eol.jsc.nasa.gov/SearchPhotos/. Due to the large number of photographs collected, and the fact that photographs are not always taken of locations directly below the space station, the images within the database are generally not labelled with their location. For this reason, we first made use of the citizen science project http://www.citiesatnight.org/, led by Dr Alejandro Sanchez de Miguel. This project aims to identify the sub-set of images that are taken of the earth at night, and then to geo-locate them. In December 2015 the following map was used to identify images; it shows the approximate location of the ISS when each night photograph was taken https://pmisson.cartodb.com/viz/281a7eb6-fa7a-11e4-8522-0e853d047bba/public_map. By navigating to the area of the map containing Switzerland, it was possible to visually check images to see if they were actually taken of a Swiss city or region. This was done by clicking each image (which opened a preview in http://eol.jsc.nasa.gov) and then visually comparing it to maps of Swiss cities (aerial daytime photography, VIIRS DNB layers and the 2006 EEA Revised Soil Sealing raster). The area screened included a buffer of approx. 100km around the Swiss border. The most useful diagnostic features were urban rivers (Fig.2 B) and large water bodies such as Lake Geneva, as these were often dark, fringed by lights and therefore easily recognizable in night photographs. Clearly the success of this approach is dependent on familiarity of the user with Swiss geography. For each confirmed image of Switzerland, the preceding and following 5 images on the camera roll were inspected (http://eol.jsc.nasa.gov), as astronauts often collect multiple images of the same location using different exposure settings. In addition, astronauts may choose to photograph several locations within a country in succession, so additional photographs were identified by this method. This was a relatively time consuming process, but the result was a list of 12 candidate images, from which 7 were selected for processing (see Table 1 and Fig.3). This selection was made based upon the following goals: 1) Generate maximum geographic coverage for Switzerland, 2) Select images that are comparable in terms of spatial resolution and 3) Allow temporal variation to be explored.

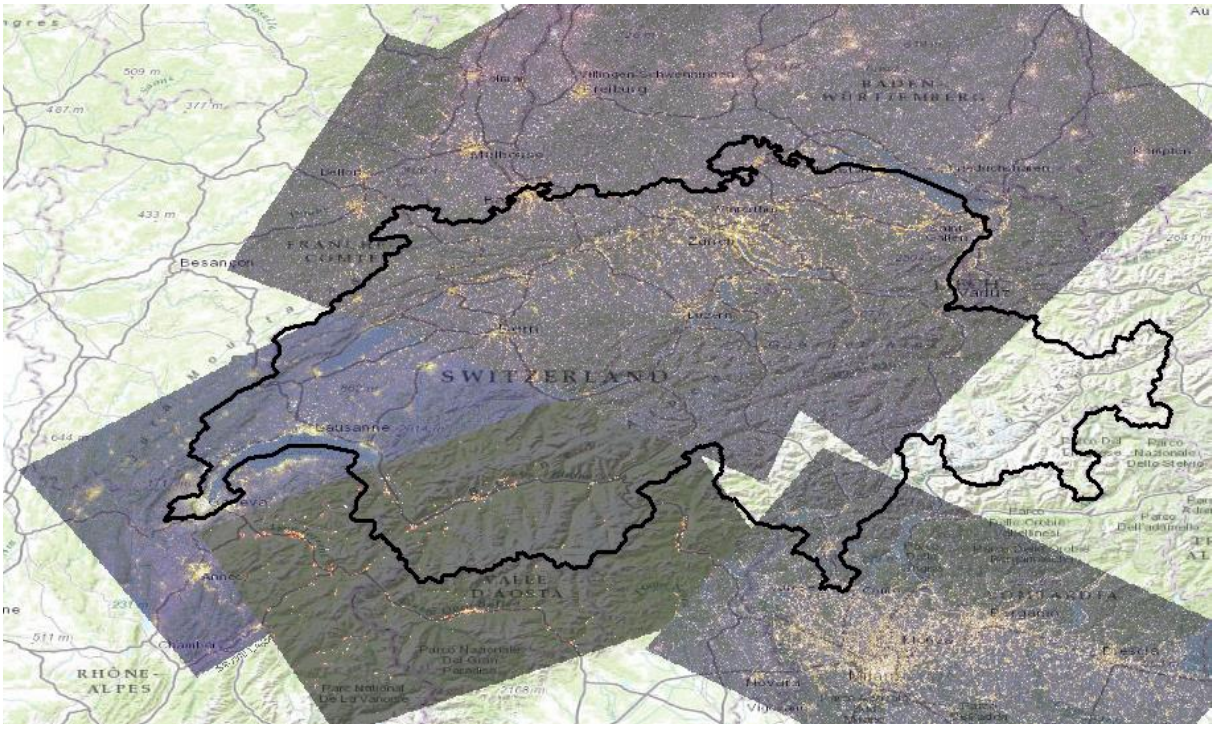


Fig.3 Geographic coverage of the selected ISS images after georectification. World Topographic Map (basemap) for this and subsequent figures supplied by Esri, 1st December 2017 (http://www.arcgis.com/home/item.html?id=30e5fe3149c34df1ba922e6f5bbf808f).

Table 1. ISS images covering parts of Switzerland. The first 7 images highlighted in red were chosen for correction, calibration and spatial analysis.

CITIES/ REGIONS	LENS	CAMERA	DATE AND TIME	NOTES	SOURCE
BERN, ZURICH, BASEL, LUCERNE	85mm	Nikon D3S	2013.12.07 20:32:14 GMT (22:32:14 Swiss Time)	Sharp and excellent coverage. 88m res	http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS038&roll=E&frame=16196
ZURICH AND NE SWITZ	85mm	Nikon D3S	2013.12.07 20:33:07 GMT	Overlaps with 16196 93m res	http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS038&roll=E&frame=16198
TESSIN AND MILAN	85mm	Nikon D3S	2013.12.05 20:33:46 GM	74m res	http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=iss038&roll=e&frame=14947
VALAIS INC SION	85mm	Nikon D3S	2012.03.28 02:01:13 GMT	92m res	http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS030&roll=E&frame=188218
LAKE GENEVA	180mm	Nikon D3S	2010.12.18 02:40:09 GMT	Some areas of cloud. 42m res	http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=iss026&roll=e&frame=10948
LAKE GENEVA + SION AREA	80mm	Nikon D3S	2011.02.22 23:17:49 GMT	Partial cloud. 90mres	http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=iss026&roll=e&frame=28806
BERN + ZURICH	80mm	Nikon D3S	2011.02.22 23:17:54 GMT	Partial cloud. 94m res	http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=iss026&roll=e&frame=28808
LAKE GENEVA	80mm	Nikon D3S	2011.02.11 23:13:39 GMT	Slightly poor focus	http://eol.jsc.nasa.gov/scripts/sseop/photo.pl?mission=ISS026&roll=E&frame=26507
ZURICH	400mm	Nikon D3S	2012.04.18 21:21:21 GMT	High spatial resolution	http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS030&roll=E&frame=237338
GENEVA	400mm	Nikon D3S	2012.04.02 00:26:55 GMT	High spatial resolution. Slightly out of focus.	http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS030&roll=E&frame=258963
VALAIS AND ITALY	180mm	Nikon D3S	2013.10.17 20:51:22 GMT	Snow cover	http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS037&roll=E&frame=15303
TESSIN AND MILAN	50mm	NIKON D4	2014.12.11 21:57:13 GMT	Calibration for this model not yet available	http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=iss042&roll=e&frame=34977

At the time this project was started, not all of the cameras and lenses used by astronaut photographers had been characterized in the laboratory. As a result, we selected images only from the Nikon DS3 camera, using the 80, 85 and 180mm lenses. The 80 and 85mm lenses produce images that are very similar in terms of ground sample resolution (approx. 75-95m once re-projected) (Table 1), and together these 6 images cover ~80% of the surface area of Switzerland (Fig.3). Image ISS026-E-10948 was taken with a 180mm lens and provides a higher resolution image of Geneva (approx. 40m once re-projected), potentially allowing us to explore questions about the benefits of higher resolution data, and the fine-scale variation in urban lighting. It was not possible to calibrate images ISS030-E-258963 and ISS030-E-237338 (Geneva and Zurich respectively), but this is likely to be possible in the future, providing very high resolution data for these cities. Temporal comparisons of between 1 and 3 years are possible for the areas surrounding Sion, Zurich and Bern.

2.3.2.2 Processing the images

The key processing steps are outlined below. This should be a useful guide if more ISS images of Switzerland are identified in the future, but the majority of steps are also relevant to the correction and calibration of other night photography products e.g. plane-based photography.

2.3.2.2.1 RAW format images and noise

The RAW files (as opposed to Jpegs) were downloaded from http://eol.jsc.nasa.gov , which is important as this retains the linearity of the sensor (counts for each pixel are proportional to light exposure). The Nikon DS3 camera automatically corrects these RAW images for fixed noise. Otherwise, dark frame subtraction would be necessary.

2.3.2.2.2 Linearity correction

The Nikon DS3 has an anti-blooming system which extends the dynamic range of the sensors. Whilst in principle the RAW format means that counts for each pixel follow a linear relationship with light exposure, the anti-blooming system alters this relationship at high counts. This was therefore characterized in the lab and each image was processed to correct for this.

2.3.2.2.3 Flat field correction

Optical vignetting was corrected for by capturing flat field images in an integrating sphere. Without this step, the edges of the images can be up to 70% less bright than in the centre (Fig.4).

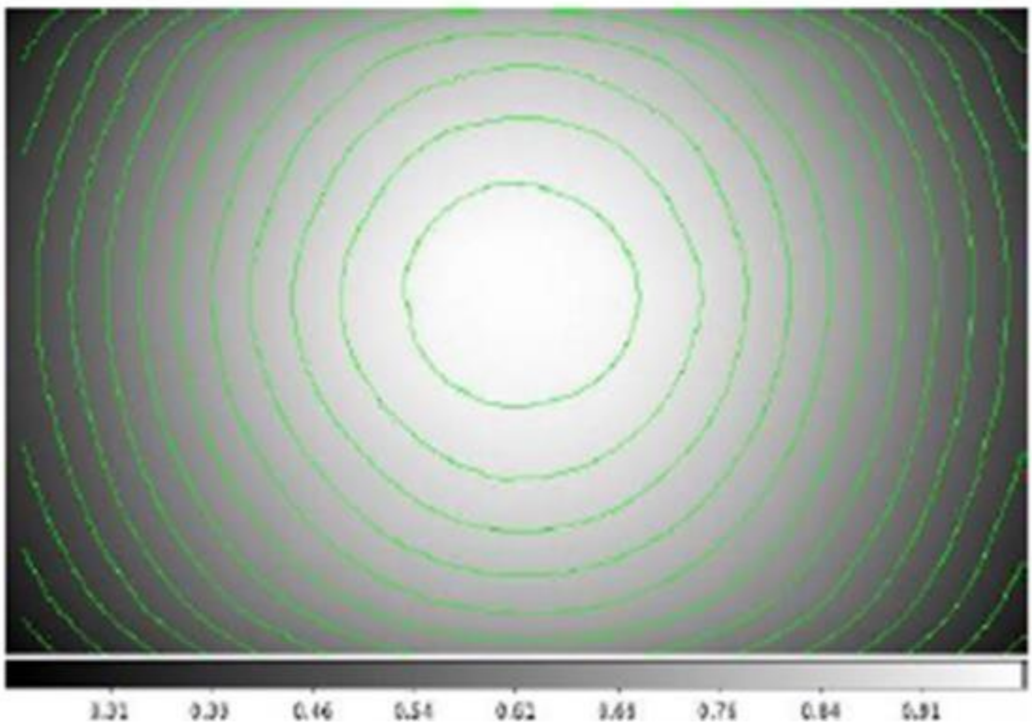


Fig.4 An example of vignette correction using a flat field. Image: Sánchez de Miguel (2015)

2.3.2.2.4 Camera settings correction

The cell counts within the RAW image depend upon camera settings such as exposure time, aperture and ISO setting. The signal is a linear function of these variables, so standard corrections were applied.

2.3.2.2.5 Photometric radiance calibration

Until this point, the pixel values in each image are still in arbitrary units and each channel therefore needs to be radiance calibrated. Spectral characterization of the camera was then undertaken in a laboratory, to clarify the spectral response of the R, G and B channels i.e. their sensitivity to different wavelengths of light (Fig.5). This was performed using an integrating sphere, a tungsten lamp of known response and a monochromator. Next, photometric calibration of the images was undertaken based upon star fields. Many ISS photographs include star fields, and a selection of ISS images containing photometric-standard stars (whose radiant emissions within specific bands is known) were used to derive magnitude values. Combined with the colour correction of the images to match the astronomical filters, this allowed the radiance calibration of the R, G and B bands in nW/cm^2/sr.

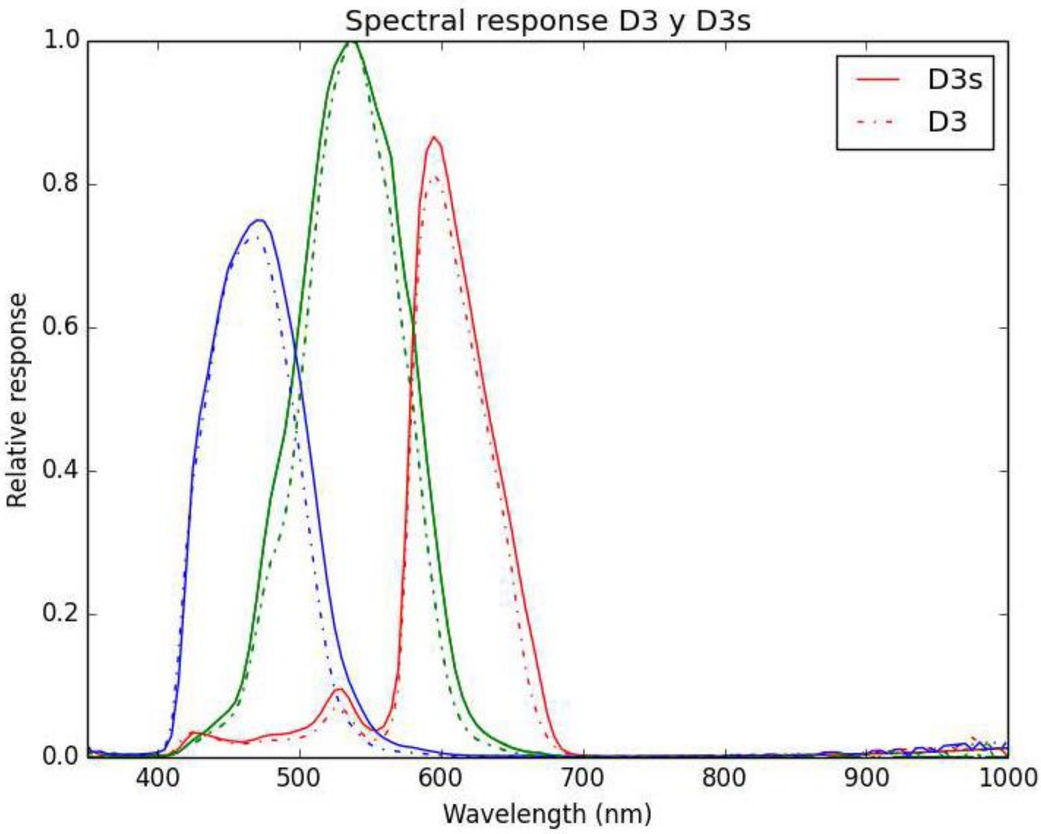


Fig.5 The spectral response of the Nikon DS3. Image: (Sánchez de Miguel 2015)

2.3.2.2.6 Georeferencing

Images were georeferenced in ArcGIS, using approximately 100 pairs of ground control points (GCPs) for each image, stratified using a 10km grid. Again, aerial daytime photography, VIIRS DNB layers and the 2006 EEA Revised Soil Sealing raster were used as backgrounds to identify the location of point sources of emissions e.g. a lit road intersection in a rural area, or a brightly lit church. Such a large number of control points are not normally required, but the extra points were collected to help account for the distortions in the image due to topography – some images related to areas of Switzerland where height above sea level varied by over 3000m. A third order polynomial transformation was applied which helped to correct for much of this distortion. However, to improve the accuracy of the alignment in mountainous areas the GCPs for each image were used to generate a Rational Polynomial Coefficient, which together with a digital surface model for Switzerland were used to further correct for topographic effects.

2.3.2.2.7 Radiance correction using a synthetic VIIRS image

The extensive processing of the images is expected to have made the relative differences within an image, and between the R, G and B bands reliable. However, there may still be errors in the absolute radiance calibration due to atmospheric effects. To correct for this, each raster that resulted from the photometric calibration was used to generate a synthetic VIIRS layer i.e. the calibrated G and R bands were weighted and combined to generate an estimate of the signal that would be expected in the VIIRS sensor data. This was resampled and compared to actual VIIRS data from May 2014. Differences between these two rasters were then used to generate a correction to the photometric calibration that could be applied to each of the R/G/B images. It is suggested that all spatial analyses should be undertaken with the photometrically calibrated data, then repeated with the VIIRS corrected data and compared.

2.3.2.2.8 Spectral classification

Based upon earlier research (Sanchez 2015), the photometrically calibrated RGB images were classified, according to the ratios of emissions between the three colour bands. This classification was derived from a previous analysis of the ISS pictures for areas of known lamp type (but not in Switzerland). This classification will need to be formally verified, but initial checks suggest this is a reasonable classification. For example, the file Corr_iss038e016196Composite.tiff.LV95.tiff is the lamp classification for image iss038e016196. It includes an area of classified lamp emissions for Delémont, the capital of the Swiss canton of Jura (Fig. 6).

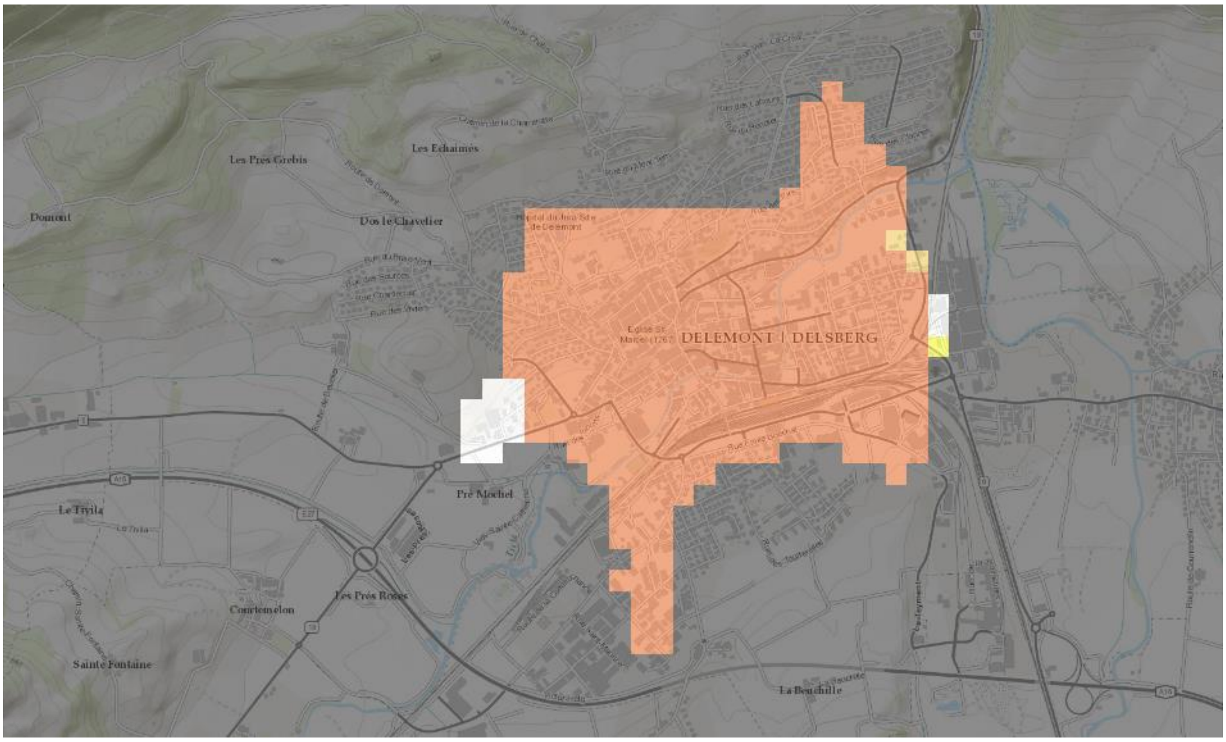


Fig.6 Lamp classification for Delémont, Jura, Switzerland in December 2013.

As an example, according to the classification, the lamps in Delémont in December 2013 were dominated by sodium, with cold white lamps in the South West corner. This appears to agree with the street lamp types visible in google streetview (April 2016). Full checking of this classification is difficult, as street lamps may be changed over time, as canton and commune (Geminde) street lamp inventories may not be available, and because some of this lighting is from private land where the lamp type cannot be checked by ground measurements. The lamp classes provided are as follows:

1) Cold White lights (Metal halide, Cold LED (CCT>3500 k), Mercury vapor, etc.)
2) Transition 2 (greenish) Mercury vapor, or low signal to noise Cold White.
3) Transition 1(white warm) Special type of High Pressure Sodium (HPS) or Warm LED (CCT<3500 k), Incandescent or Warm Metal halide
4) HPS – yellow/orange
5) Low Pressure Sodium (LPS) dark orange

2.3.2.2.9 Data products

The calibrated ISS images were supplied in three formats:

4 rasters for each ISS image, with radiance values ((nW/cm^2)/sr) for each channel, based upon the photometric calibration. Note that there are 2 green rasters, as the RAW data from camera is actually captured as RGGB. e.g. for image iss038e016198 the rasters are:

- Corr_iss038e016198R1Fo2_rect.cal2NW.tiff
- Corr_iss038e016198G2Fo2_rect.cal2NW.tiff
- Corr_iss038e016198G3Fo2_rect.cal2NW.tiff
- Corr_iss038e016198B4Fo2_rect.cal2NW.tiff

Another 4 rasters for each ISS image were supplied, this time with photometric radiance calibration + the VIIRS correction e.g. for image iss038e016198 the rasters are:

- Corr_iss038e016198R1Fo2_rect.cal2NWcoor.tiff
- Corr_iss038e016198G2Fo2_rect.cal2NWcoor.tiff
- Corr_iss038e016198G3Fo2_rect.cal2NWcoor.tiff
- Corr_iss038e016198B4Fo2_rect.cal2NWcoor.tiff

1 raster for each ISS image, classified to represent dominant lamp types. e.g.

- Corr_iss038e016198Composite.tiff

Additional processing is required to generate a single raster for green emissions, simply by averaging the two green bands. In addition, a total radiant emission raster can be created by simply summing the RGB layers in raster calculator. The final images will be made accessible for researchers at no cost, potentially via an online gateway for processed ISS images. The final supply of these products has been delayed slightly, due to the additional work required to correct for topography. This is to be considered a version 1 supply. More and improved versions will be supplied at no cost in the future, as associated research progresses.

2.3.2.2.10 Resampling, reprojecting, thresholding and mosaicing

The above datasets were supplied with a WGS 1984 geographic projection. To facilitate spatial analyses, the 6 processed images taken with 80mm and 85mm lenses were re-projected to the Swiss Grid projection (CH1903) and resampled to a 100m pixel size. In contrast, iss026e10948 (taken with a 180mm lens) was resampled to a 50m pixel size. All images were snapped to the 100m grid used to generate the Swiss land cover and land use statistics. To remove noise, known dark areas of the image will be sampled and used to determine radiance thresholds, below which data will be masked from analysis. This is still an outstanding action.

Due to seasonal differences, and differences in the dynamic range between images, it does not make sense to mosaic them into a single image. However, images ISS038e16196 and ISS038e16198 could be resampled to 100m pixel size and mosaicked, as they were taken a few seconds apart. Similarly, iss026e28806 and iss026e28808 could be resampled and mosaicked. The exception is for the lamp classification, which may be less likely to vary seasonally – all 6 lamp classification rasters derived from images collected using 80 and 85mm lenses could be mosaicked to get an overview of Swiss lamp composition.

2.3.3 Street lamp inventories

Whilst many other sources of outdoor artificial lighting exist, street lighting is likely to be a major component in terms of numbers of lighting sources and total flux. Reliable estimates of the number of street lamps, their location, age and lighting type and lamp design are therefore potentially very useful for generating baseline data on lighting emissions and infrastructure (see Fig.7). Two main types of street lighting inventory data exist in Switzerland: 1) databases maintained by managers of street lighting at the Commune or sub-canton scale, and 2) data generated by national surveys.

2.3.3.1 Local databases

Databases held by street lighting managers are the primary tool used for the management of street lighting. However, it is common for these databases (or *inventories)* to be incomplete. In some cases, the owner of a particular street lamp may be unknown. In some cases records only exist for the lamps that have been installed during the past 15-20 years, due to the costs of comprehensive surveys. Best practice is for the exact geographic location of each street lamp to be recorded, along with the lamp type, shielding design, manufacturer, installation date and operation procedure (e.g. part night vs. full night). At the start of this project, several commune street lighting managers were contacted to request copies of their inventory. Most failed to reply, but one confirmed that whilst they did have an inventory, it was incomplete and only held data at the resolution of individual streets. Since then, lamp location databases have been secured for Geneva and Zurich. In addition, as part of a collaboration with the Naturpark Gantrisch, a full street-lamp inventory was secured, which demonstrates that the development of a large-scale lamp inventory is realistic.

Whilst the reasons for some lighting managers refusing us access to lamp inventories are unclear, we suspect that this is due to a combination of professional pride and suspicion about how the data would be used, which is complicated by the operation and management of some street lamps by the private sector. We also suspect this is a systematic/industry-wide problem and therefore we did not make further attempts to secure lamp data for all cantons in Switzerland. However, we consider that implementing common and high-quality standards for lighting inventories should be a priority for future initiatives seeking to reduce light pollution.

Fig.7 An illustration of why comprehensive data on outdoor lighting is needed. In this case, simply recording the bulb type (energy efficient compact fluorescent) gives no indication that it is fitted into a highly inefficient lamp design (lacking any shielding to restrict up-lighting).

2.3.3.2 National surveys

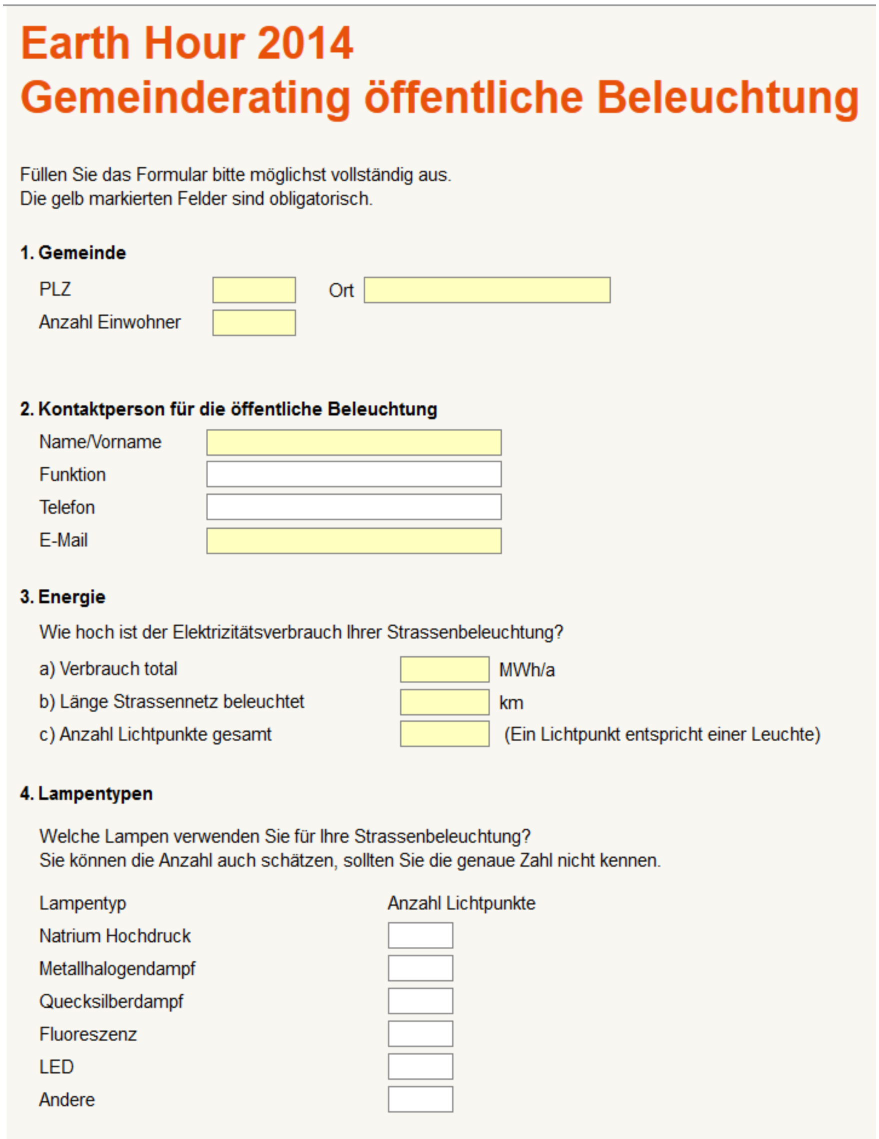
Data generated by national surveys are seen as a more reliable/realistic source of baseline data on street lighting, and we explored two potential suppliers. The first is a time-series held by the Schweizerische Agentur für Energieeffizienz (S.A.F.E). Since 2006, S.A.F.E has undertaken annual surveys of street lighting throughout Switzerland. The project leader is Giuse Togni. The project aims to support municipalities, power providers and lighting managers to transition to more efficient forms of street lighting. S.A.F.E invites lighting managers to use an online tool, which collects information on lighting and energy use. Each commune can then compare the energy efficiency of their street lighting in terms of energy/Km lit road with other communes. Currently (June 2016) S.A.F.E ask for the total lighting energy consumption and total lit road length. However in previous years, information on lamp type and operation was also collected. Unfortunately, no data on LED lamps has been recorded. Participation is voluntary and it is not possible to verify the information provided. However, this provides a potentially useful model for collecting national data on street lighting over time. The challenge is to ensure that data on lighting type and operation is collected without excluding participation (e.g. by alienating users who do not have comprehensive inventories).

One route to collecting more comprehensive data would be to periodically repeat the work of WWF, who collaborated with S.A.F.E in 2013/14 to collect more data on lamp type as part of Earth Hour 2014. The project leader was Mirjam Gasser. The goal was to see which gemeinde had the most or least efficient street lighting. Again, commune lighting managers were given the opportunity to complete an online form (Fig.8) which included the total number of street lamps, the numbers of different lamp types, the total lit road length and the total energy consumption of street lighting (calculated using www.topstreetlight.ch/rating). More than 10% of Swiss communes participated, and importantly, they recorded the total number of lamps, including LEDs. WWF has made the data available for us to use in this project, although because it was collected for energy efficiency purposes there are some restrictions. The data have to be used in a way which retains the anonymity of the commune that supplied it. However, it is still useful as a baseline for understanding the lighting mix for a range of communes, to explore how lighting mix varies with economic or social statistic variables. These lamp data could be useful for checking the classification of ISS images, with the caveat that the data supplied by a commune cannot be checked, and it does not include industrial lighting and lamps on private land. Clearly, there may also be a bias towards communes that have good lamp inventories, or those who wish to demonstrate the efficiency of their recent lamp replacement program. However, it may still provide a useful baseline, especially if these communes could be re-visited at 5-yearly intervals to provide an indicator of lamp change over time. According to the 2013/4 survey, the majority of communes had less than 10% street lights as LED, implying that modernisation of street lighting in Switzerland was not particularly widespread (Fig. 9)

This digital infrastructure and the contacts developed by S.A.F.E and WWF also offer a potential route for disseminating best practice information on lighting, tools such as inventory templates, and light pollution maps that may derive from this project.

2.3.3.3 Other sources of street lighting data

There is also some potential for street lighting inventories to be generated automatically via the analysis of high-resolution night photography, as has been attempted for the Geneva photography (c.f. Hale 2013). Alternatively, a citizen science approach could be used to crowd-source this data, with large numbers of volunteers mapping outdoor lighting. These approaches have the benefit that they could include other sources of lighting (e.g. security lights). However, both approaches still require a sample of locations where the lamp types are known, to inform the classification process and to validate its accuracy.



Earth Hour 2014
Gemeinderating öffentliche Beleuchtung

Füllen Sie das Formular bitte möglichst vollständig aus.
Die gelb markierten Felder sind obligatorisch.

1. Gemeinde

PLZ ____ Ort ____
Anzahl Einwohner ____

2. Kontaktperson für die öffentliche Beleuchtung

Name/Vorname ____
Funktion ____
Telefon ____
E-Mail ____

3. Energie

Wie hoch ist der Elektrizitätsverbrauch Ihrer Strassenbeleuchtung?

a) Verbrauch total ____ MWh/a
b) Länge Strassennetz beleuchtet ____ km
c) Anzahl Lichtpunkte gesamt ____ (Ein Lichtpunkt entspricht einer Leuchte)

4. Lampentypen

Welche Lampen verwenden Sie für Ihre Strassenbeleuchtung?
Sie können die Anzahl auch schätzen, sollten Sie die genaue Zahl nicht kennen.

Lampentyp	Anzahl Lichtpunkte
Natrium Hochdruck	
Metallhalogendampf	
Quecksilberdampf	
Fluoreszenz	
LED	
Andere	

Fig.8 A screenshot of the online form used by WWF to collect data on street lighting at the commune level in 2013/14.

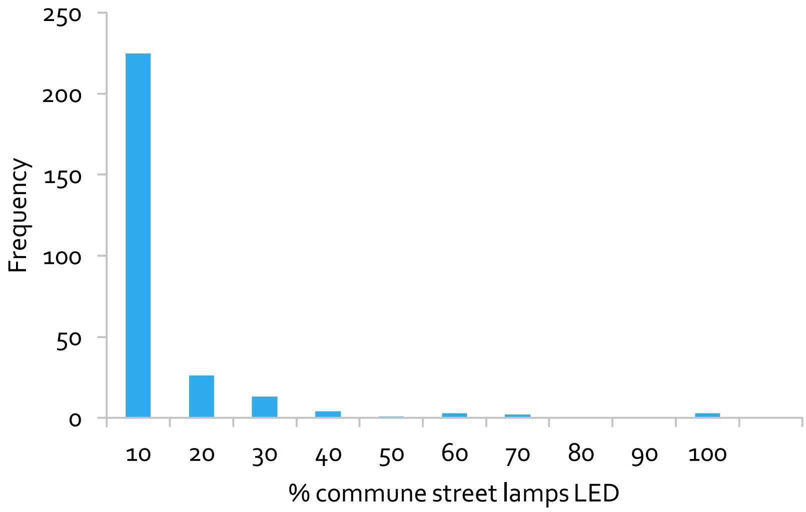


Fig.9 % composition of LED street lamps reported by 277 communes in 2013/4.

2.3.4 *Aerial plane night photography*

Aerial photography from airplanes and helicopters at night offers exceptionally high resolution images and has been utilized by several researchers to explore spatial variation in artificial lighting (Hale et al. 2013; Kuechly et al. 2012). The technique involves flying a plane back and forth across the area of interest (e.g. a city) and taking large numbers of digital photographs, which are later mosiaced together to form a single image. Whilst the high spatial resolution and colour information potentially allow the sources of light pollution to be more easily identified, there are several drawbacks regarding cost, temporal variation within the image and the correction and calibration of the images. In comparison to the ISS photography, aerial photography is superior in terms of resolution – individual lamps are easily identified. This has been exploited by some researchers to identify individual lamp locations (Hale et al. 2013). However, unlike the ISS images, aerial night photography requires many images to be taken to generate coverage for a single city. As the collection of these images can span several hours, the final image does not represent a snapshot of a moment in time, but rather a temporal transect or gradient covering the area of interest. Like the ISS images, aerial photographs contain errors that need to be corrected for.

2.3.4.1 Geneva

Aerial colour night photography for the canton of Geneva was collected on the 14th and 15th April 2013, in order to support the development of *dark corridors* for nature conservation and to support broader spatial planning objectives. Almost 1000 images were captured between 11:00pm and 3:30am, and mosaicked into a single image covering 700 km^2 at a resolution of 40cm^2. This was captured as part of a joint project between the Geneva Directorate of Cadastral Surveying (BMD), and the French National Institute for Geographic Information (IGN), using a bespoke system developed by the IGN. We have access to the full details of this image capture and processing, but due to commercial confidentiality concerns, some details have been omitted from this draft report. We can confirm that many of the processing steps that were undertaken for the ISS data (e.g. flat field correction) were undertaken on these aerial photographs, but it is clear that the RGB bands have not yet been radiance calibrated. Some processing has also taken place to derive classifications for broad lamp types. More details can be found at http://ge.ch/mensuration-officielle/node/268 and the aerial photography can be downloaded from http://ge.ch/sitg/ .

The aerial photography is freely accessible for use, although it is not clear whether the lamp classification will be accessible for researchers. So far the data have been used semi-quantitatively for planning dark corridors, making use of pixel values as an indicator of radiant emissions. This is of course reasonable, although absolute calibration would be preferable, making future photographic surveys more easy to compare. In phase 1 of this project we have made use of the Geneva photography as a background for adding control points for the high-resolution ISS image of Geneva iss026E10948 (Fig. 10).

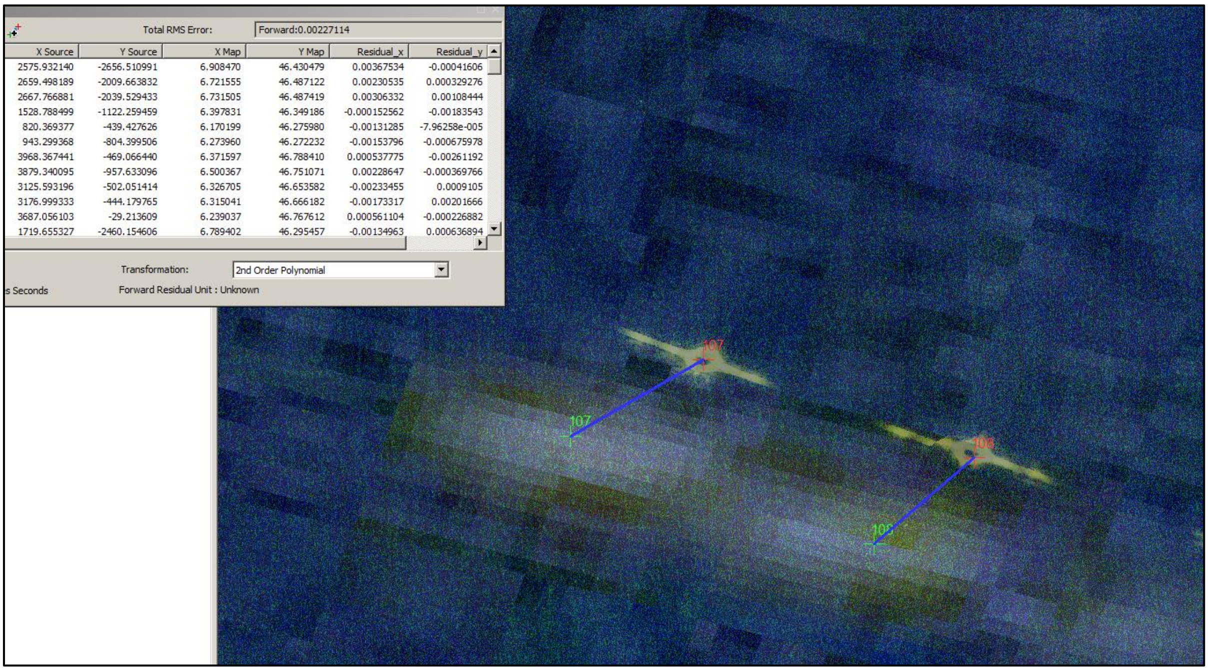


Fig.10 An ArcGIS screenshot depicting the creation of control points for the georectification of ISS image iss026E10948, using the Geneva aerial night photography as a baseline.

2.3.4.2 Le Locle, Neuchâtel and La Chaux de Fonds

Aerial night photography was also captured in 2012 for the settlements of La Chaux-de-Fonds, Le Locle and Neuchâtel. A remote surveying company called Altilum captured this data for Viteos, a large energy and water supplier operating within the canton of Neuchâtel. It was collected by helicopter and ground truthing measurements were undertaken during collection. The key contact is M. Claude Duriaux – (responsable service éclairage public, Viteos). To date, it has not been possible to gain access to this photography. Metadata for these images has proved difficult to secure, as the company that collected these images (Altilum) no longer exists (M. Claude Duriaux – personal communication). A video in French summarizing this data can be found at https://www.youtube.com/watch?v=Vgf2zBJr1O8

2.3.4.3 Basel

Some data has also been collected by a Swiss company called *Flotron* for part of Basel. There is limited data available online, although through personal contact with a member of staff, it is clear that there is still interest in developing capacity to undertake such surveys. www.flotron.ch/de/Angebote/Fotogrammetrie/Orthofoto

In general, the collection of aerial night photography has huge potential for clarifying the contribution of different land uses to lighting emissions and for the identification of individual lamps, especially for cities which tend to have a high spatial variability in lighting. It is feasible for each of the major cities within Switzerland to be surveyed. However, if this were to be developed into a project, high standards would have to be met for the radiance calibration and ground truthing of the images, to ensure quality and consistency between photographic products.

2.3.5 Sky quality measurements and mapping

The measurement of sky quality/brightness is common in areas where amateur and professional astronomy is practiced, typically as a way to find locations with low levels of light pollution. Sky Quality Meters (SQMs) are the most common method for measuring sky brightness (measured in magnitudes per square arcsecond), with some locations having nightly data covering several years. This potentially provides a mechanism for monitoring sky quality in a way that *could* be used as an official indicator for Switzerland. However, it would require several observatories to participate, with locations covering the major biogeographic regions. http://www.sqm-network.com/index.php/en/interactive-map?jjj=1468928191066 Perhaps using the Tessin network as a template http://www.oasi.ti.ch/web/dati/inquinamento-luminoso.html. The key drawback is the poor spatial resolution, despite the relatively low spatial variability of skyglow in comparison to the artificial lights that cause it. However, efforts to crowd source similar data using mobile phone apps to allow non-specialists to map star visibility may provide better spatial data coverage in the near future http://lossofthenight.blogspot.ch/2015/01/brief-introduction-to-loss-of-night-app.html. There are however concerns that SQM measurements are difficult to compare between regions that have different lighting mixes, or when the lighting mix of a location changes over time (Sánchez de Miguel et al. 2017).

The question of spatial resolution has been addressed by recent advanced in the global modelling of skyglow, using VIIRS emission data and assumptions about the spectral composition of light sources. The New World Atlas of Artificial Sky Brightness http://cires.colorado.edu/Artificial-light is a raster model that has only recently been released (Falchi et al. 2016a). Details are provided in (Falchi et al. 2016b)but essentially this is a model of sky brightness (skyglow) due to artificial light. It was generated using light pollution propagation software, applied to VIIRS data from 2014 and ground based measurements. The resulting prediction of zenith sky brightness at each pixel (Fig. 11) accounts for VIIRS emissions arriving from sources up to 195 km away. Incidentally, this reflects a key challenge for mitigation, as some of the sky brightness in Tessin for example, will originate in Milan! Whilst this model is likely to have a range of valuable applications (e.g. for identifying candidate dark-sky parks, and reserves for species which make sure of star fields for navigation), there are some important caveats to be aware of. Because of the large computing power required to create this atlas, the screening effect of mountains was not included. This means that the sky brightness of some parts of Switzerland may have been overestimated, especially when they are separated from a large lowland settlement by a mountain. In addition, the VIIRS raster used was a composite (average) from May, June, September, October, November, and December in 2014. As we have demonstrated, VIIRS emissions can have strong seasonality, at least in part due to snow cover. This means that seasonal changes in sky brightness will not have been captured in the model. Similarly, the impacts of cloud cover are not reflected in the model. Therefore, whilst this can be seen as a useful indicator of sky brightness, local measurements may be more useful for some applications. Another note of caution is that the VIIRS data are not sensitive to blue wavelengths of light, so models will underestimate sky brightness.

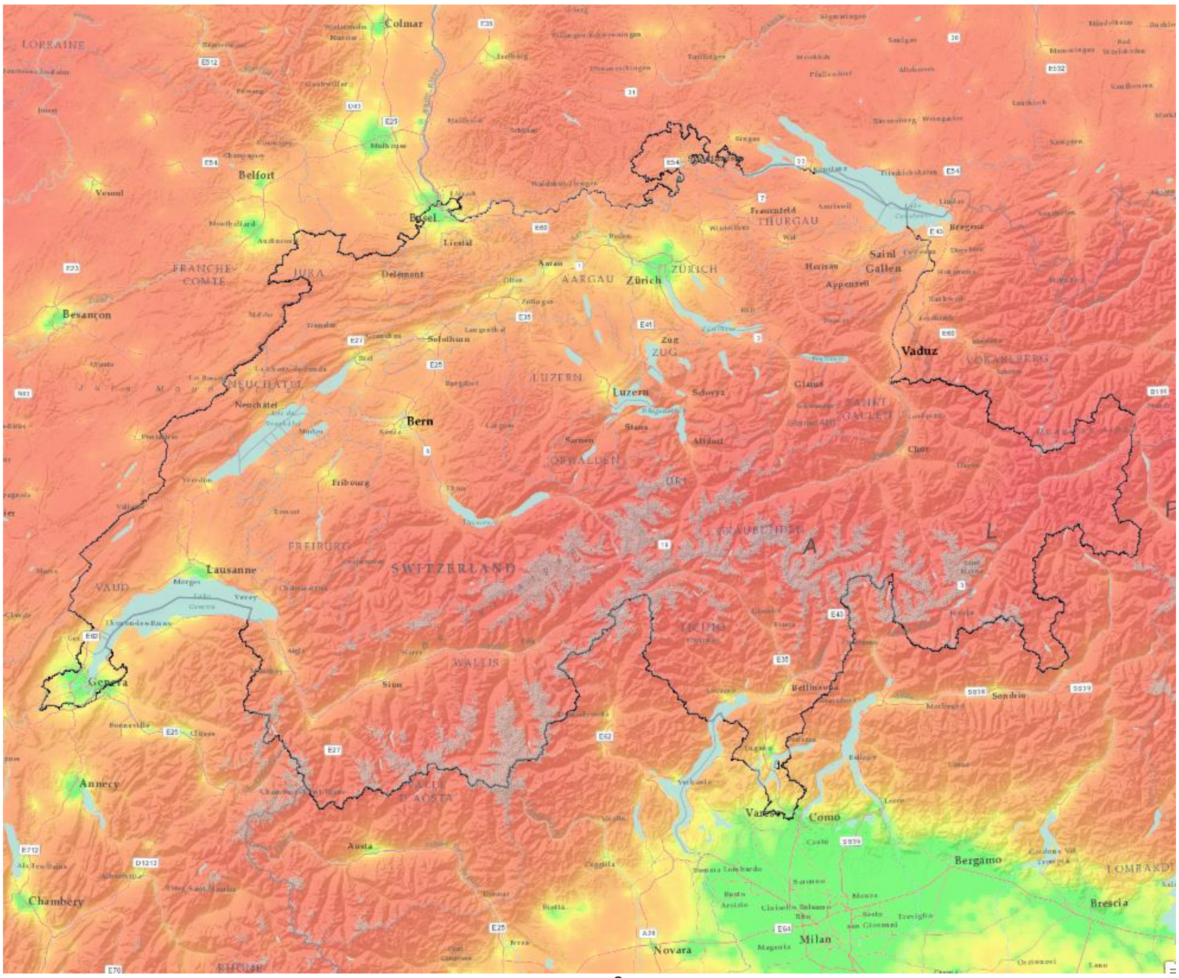


Fig. 11 Simulated zenith radiance data (mcd/m^2) by Falchi et al 2016. Radiance values in this image range from 0.02 (red) to 9.91 (green).

2.3.6 *Defense Meteorological Satellite Program (DMSP) Operational linescan system (OLS)*

Until recently, this was the only satellite system collecting low-light imaging data at a global scale http://ngdc.noaa.gov/eog/dmsp.html. DMSP derived data has been used by a wide range of researchers and national governments (including Switzerland) to provide a broad indicator of lighting emissions and human activity, and to monitor change over time. Like the VIIRS data, DMSP data is panchromatic, representing emissions between 0.5 and 0.9 um (Miller et al. 2013). Unfortunately, there is no internal radiance calibration of the sensors, which are periodically replaced, and alter in sensitivity over time. Some researchers have attempted to correct for this using parts of the globe whose lighting is thought to have been stable, but this is still a relatively controversial subject. In addition, the resulting data is captured at a relatively coarse resolution (5 km x 5 km at nadir), making the sources (i.e. particular land uses) of the emissions difficult to identify. The also sensor saturates in bright urban areas, so it cannot be used to monitor the brightening of many locations. For these reasons the VIIRS data is considered superior (Elvidge et al. 2013) and we have therefore not undertaken any analysis using the DMSP data. Yearly products can be downloaded from here http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html, but the last product made available is for 2013 and it is clear that this will be the last in the time series. In principle, the VIIRS data could be resampled to match the DMSP data in order to extend the time series for monitoring purposes. However, the differences in the spectral sensitivity and dynamic range of the sensors would still need to be corrected for, and we are yet to find a satisfactory attempt at this in the literature.

2.3.7 Other data sources

A range of other techniques have been employed to map lighting and associated infrastructure, but these are not considered well enough developed or practical enough to be useful at present over large areas. These include other satellite data (Levin et al. 2014) and visual surveys of lamps (Luginbuhl et al. 2009). Balloons and UAVs/drones mounted with light meters have been successfully tested (Bay et al. 2014; Sánchez de Miguel 2015) but are limited in the spatial extent that they can cover. Drone-mounted light meters or cameras have strong potential for mapping sparsely populated areas (e.g. national parks), but their flight tends to be severely restricted near settlements. However, there is the potential for drones to capture images from multiple fixed and safe locations, which could then be mosaicked together (see https://www.youtube.com/watch?v=aNSVyyJ0FmA)

In addition to SQM measurements, some astronomers use spectroradiometers (Massey and Foltz 2000) to measure the spectrum of the light polluted sky. This provides an opportunity for developing an important temporal dataset, but its spatial coverage is likely to be limited. Similarly, all-sky cameras can be used to get a view (and in some cases a measurement) of sky quality in all directions down to the horizon e.g. http://www.allskycam.com/u.php?u=471

2.4 Spatial and temporal lighting analysis

Now that we have established a baseline for what lighting data exists for Switzerland, the focus can be switched to understanding variability in space and time. We can ask basic questions such as whether emissions and spectral profile vary depending upon land-use or region, whether emissions are increasing over time and whether there are any consistent seasonal patterns. To do this, we aim to focus upon 4 classes of lighting data which provide temporal and spatial coverage at different scales.

- VIIRS satellite imagery - full Swiss coverage at monthly intervals for the past 2 years.
- ISS photography (processed) – 80% coverage, but mosaic of different dates
- Lamp inventories*
- Night photography*

*Note, we are still waiting for access/permission to use various lamp inventories and night photography (Dec 2018).

2.4.1 Spatial Analysis

The goals of this spatial analysis are to:

1) Identify LCLU types where emissions are highest (in both absolute and relative terms).
2) Identify locations where emissions are highest
3) Identify correlations between lighting and landscape variables, to inform future predictive modelling.

2.4.1.1 GIS land-cover land-use data

For the spatial analysis, the aim is to use land-cover and land-use (LCLU) data for Switzerland that are used as standard by Swiss researchers and practitioners. We also aim to select LCLU data that facilitates international comparisons. This should make the results of this analysis as broadly useful as possible. We therefore used the following data:

2.4.1.1.1 Land cover and land use (LCLU) statistics (Arealstatistik) Switzerland 2004/9

The data file *AREA_NOAS04_17_131004.csv* was downloaded at no cost from:

http://www.bfs.admin.ch/bfs/portal/de/index/dienstleistungen/geostat/datenbeschreibung/arealstatistik_noas04.html. LCLU data is provided at 100m intervals, with each of the 4,128,498 points classified into 4 high-level categories and 17 sub-categories (as below). We selected the most recent data (2004/9). There is also the option to further break down analyses into 72 categories, although this data would require a subscription/payment to gain access. This might be beneficial for the sub-category Erholungs- und Grünanlagen (Recreational areas and green spaces), which could be further broken down into parks, sports facilities, golf courses, camping, allotments and cemeteries. It is likely that much of the emissions within this broader category are due to sports facilities, but this needs to be tested. Similarly, the sub-category Besondere Siedlungsflächen (special urban areas) breaks down into energy plants, water plants, waste treatment plants, dumps, quarries, construction sites and brownfields. One would expect considerable variation between these land uses, reflecting security level and night working.

4 basic LCLU categories

1 Siedlungsflächen (settlement areas)
2 Landwirtschaftsflächen (agricultural land)
3 Bestockte Flächen (wooded land)
4 Unproduktive Flächen (unproductive land)

17 sub-categories

1 Industrie- und Gewerbeareal (Industrial and commercial areas)
2 Gebäudeareal (Building areas)
3 Verkehrsflächen (Traffic areas)
4 Besondere Siedlungsflächen (Special urban areas)
5 Erholungs- und Grünanlagen (Recreational areas and green spaces)
6 Obst-, Reb- und Gartenbauflächen (Fruit, Wine and Horticulture surfaces)
7 Ackerland (Farmland)
8 Naturwiesen, Heimweiden (Natural meadows, pastures)
9 Alpwirtschaftsflächen (Alpine farmland)
10 Wald (ohne Gebüschwald) (Forest (except brush forest))
11 Gebüschwald (Scrub forest)
12 Gehölze (Shrubs)
13 Stehende Gewässer (Standing water)
14 Fliessgewässer (Watercourses)
15 Unproduktive Vegetation (Unproductive vegetation)
16 Vegetationslose Flächen (Unvegetated surfaces)
17 Gletscher, Firn (Glaciers, hard-packed snow)

2.4.1.1.2 Soil sealing

In a recent analysis of a UK city, the levels of lighting emissions were found to correlate with % built surface cover at a variety of spatial scales (Hale et al. 2013). It is therefore reasonable to explore whether this relationship holds for the Swiss landscape. One source of data is the European soil sealing map – Degree of Soil Sealing (2006) available from http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing#tab-european-. This provides a raster of sealed surfaces at a resolution of 20m. This dataset has been used for initial analyses, but will be replaced with the Imperviousness 2012 dataset from the Copernicus programme, again at 20m resolution. http://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/view

2.4.1.1.3 Altitude data

Lighting has been found to vary with LCLU in other studies (e.g.(Hale et al. 2013; Kuechly et al. 2012)), and LCLU in Switzerland is known to vary considerably with altitude. It is therefore reasonable to explore the use of altitude as an explanatory variable. Two similar datasets were used to generate estimates of altitude:

- The Digital Elevation Model over Europe (EU-DEM) - *eudem_dem_5deg_n45e005 and eudem_dem_5deg_n45e010 was downloaded from http://www.eea.europa.eu/data-and-maps/data/eu-dem#tab-european-data.* It is a DSM model, covering the whole of Europe at a resolution of 1 arc second, but with limited validation. This data is therefore particularly useful when generating international comparisons. It was clipped using the Swiss boundary, re-projected to the Swiss Grid and resampled to a resolution of 26m.

- The Digital Height Model of Switzerland is an alternative that could be used for future analyses, where greater accuracy is required. It is supplied at 25m resolution and is a validated digital elevation model – it excludes buildings and trees. https://shop.swisstopo.admin.ch/en/products/height_models/dhm25

2.4.1.2 GIS analysis

2.4.1.2.1 ISS vs. Swiss LCLU statistics 2004/9

The aims to this analysis were to:

1) Describe how emissions vary between LCLU types
2) Identify locations where emissions are highest

The boundaries of each ISS image were used to extract 7 subsets of the Swiss LCLU statistics point layer (one for each ISS image). For each image, these points were intersected with the radiance calibrated ISS rasters within the GME tool V 7.4.0 (Beyer, 2015). This allowed a breakdown of emissions by LCLU type. As an example, we present the results of this intersection for the total visible radiance emissions for the area covered by iss038e016196, which covers 1730071 landscape survey points (17,300km^2). Clearly not all LCLU classes are represented equally within image iss038e016196, although this image still covers 42% of the total Swiss land area.

The boxplot in Fig.12 demonstrates that for each broad type of LCLU, most sample areas are relatively dark, although a few locations are much brighter, extending well beyond 3x the IQ range. These extreme outliers might be expected for settlement areas (where we might find occasional airports or sports stadiums) and for unproductive land such as lakes (where we might expect a few brightly lit marinas), but it is surprising that locations within agricultural and forest areas are also very brightly lit. Potential causes include particular farming or forestry activities that require light, or that these areas are immediately adjacent to another land-use with a strong source of light. Similarly, it may be that the ISS image is not perfectly aligned, so that the signal we detect is not coming from the forest, but from an adjacent settlement.

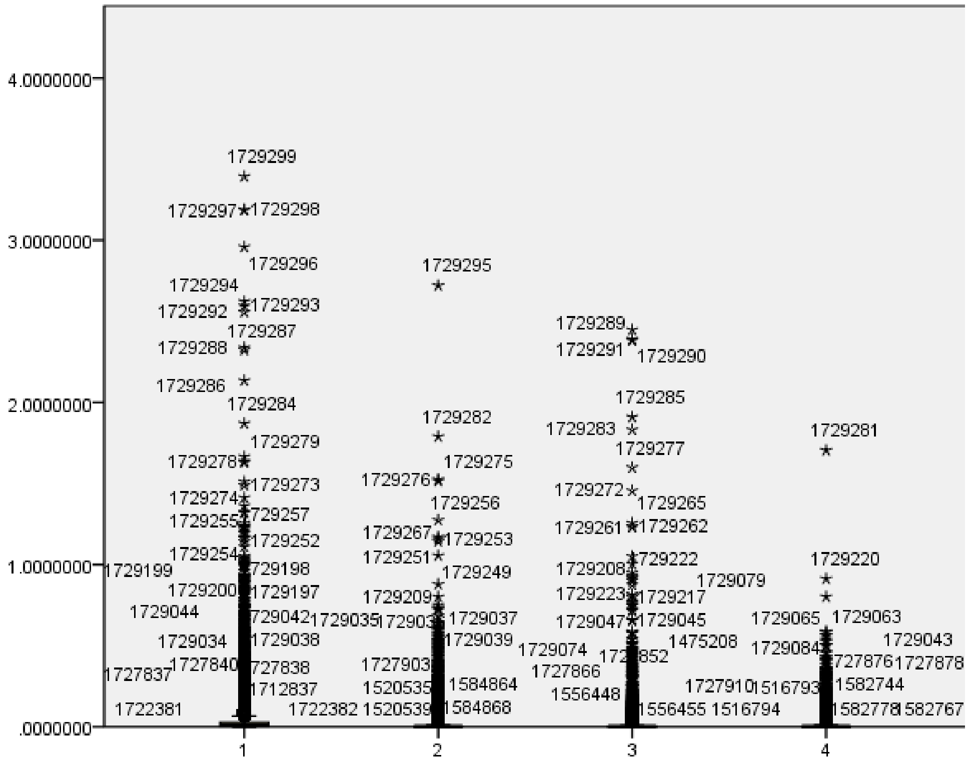


Fig.12 A box plot of total visible radiant emissions for the area covered by iss038e016196 (Y axis in nW/cm^2/sr), for 1) settlement areas, 2 agricultural land, 3 wooded land and 4) unproductive land.

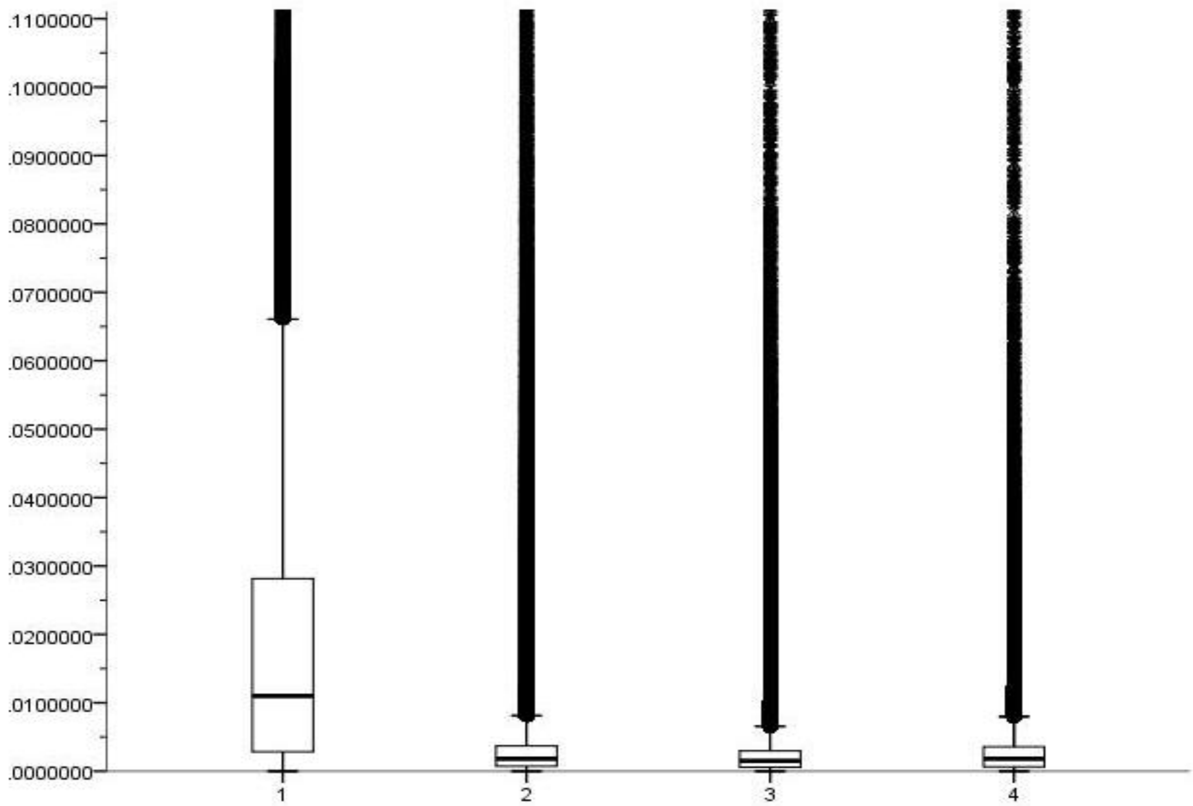


Fig.13 A box plot of total visible radiant emissions for the area covered by iss038e016196 (Y axis - nW/cm^2/sr), with restricted Y axis, for 1) settlement areas, 2 agricultural land, 3 wooded land and 4) unproductive land.

By limiting the Y axis to 0.11 nW/cm^2/sr, the typical emission values for each LCLU class are clearer (Fig.13). Unsurprisingly, the typical values for settlement areas are higher than for the other broad LCLU categories. Of the 179,735 LCLU sample locations classified as settlements, the brightest 10% account for 47% of total emissions, with the brightest 5% of locations accounting for 33% of emissions (Fig.14)

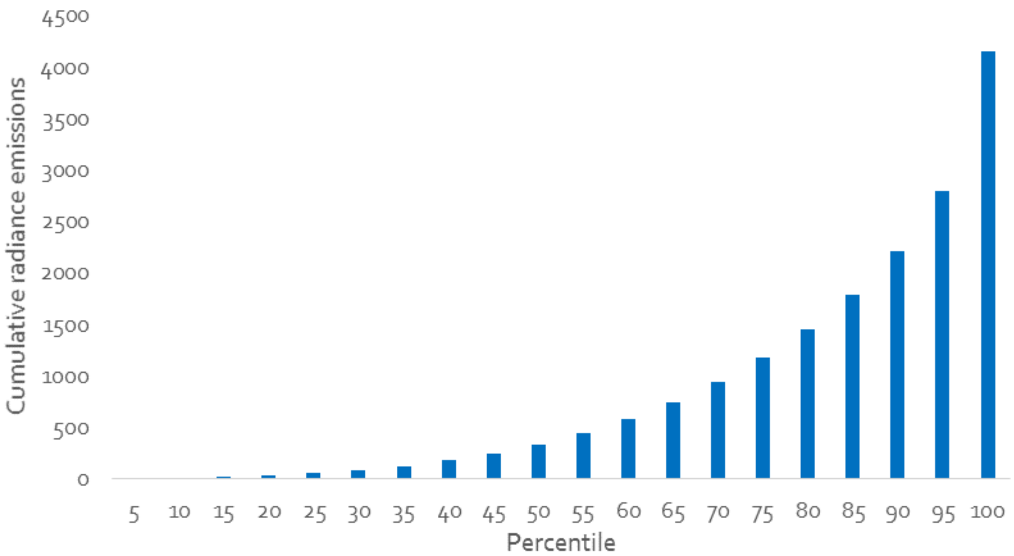


Fig.14 Cumulative radiance (nW/cm^2/sr) vs. percentile for parts of iss038e016196 classified as *settlement.*

Breaking the settlement category down into its sub-categories reveals that industrial and commercial areas appear to have typically higher lighting emissions (Fig.15), but again each sub-category has extreme outliers (Figs 15 and 16) that are more than three times the IQ range. In addition, it is surprising that recreational areas and green spaces seem to have similar typical values to industrial/commercial areas and areas of buildings. This may perhaps be related to sports centres, but this category would benefit from further breakdown and analysis.

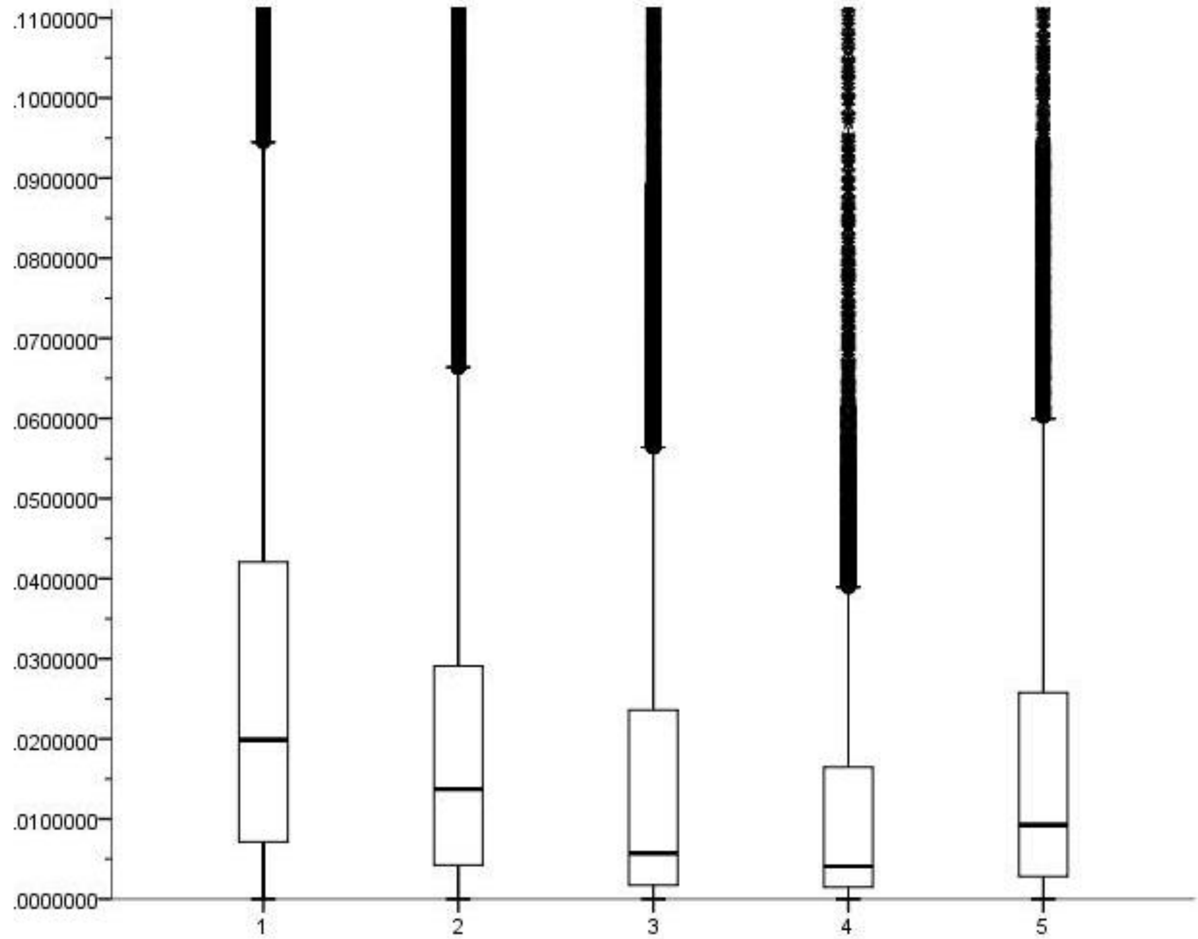


Fig.15 A box plot of total visible radiant emissions for the area covered by iss038e016196 (Y axis in nW/cm^2/sr), with restricted Y axis, for the following settlement sub-categories 1) Industrial and commercial areas, 2) Building area, 3) Traffic areas, 4) Special urban areas and 5) Recreational areas and green spaces.

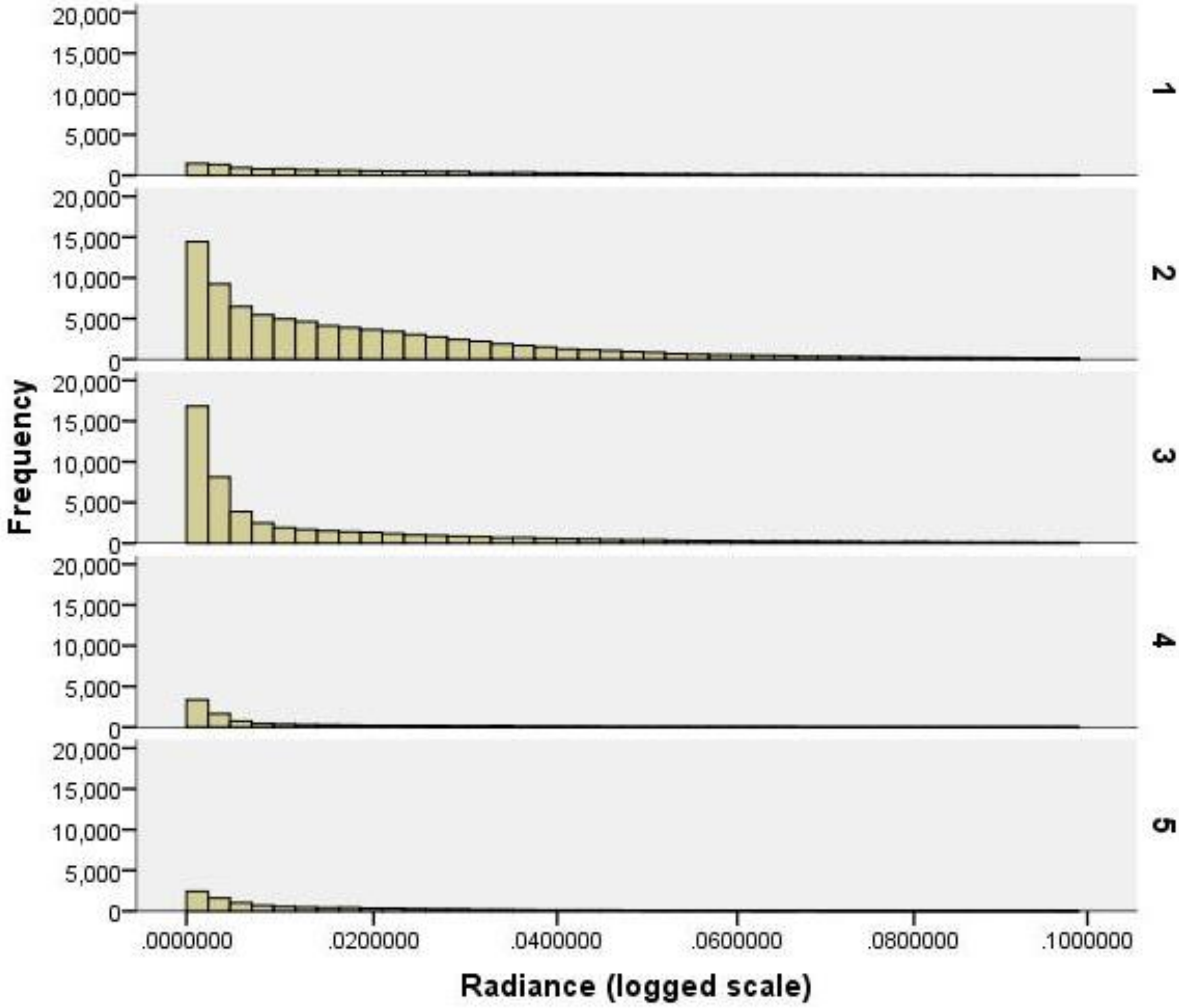


Fig.16 Histograms for total visible radiant emissions for the area covered by iss038e016196 (X axis in nW/cm^2/sr), with restricted X axis, for the following settlement sub-categories 1) Industrial and commercial areas, 2) Building area, 3) Traffic areas, 4) Special urban areas) and 5) Recreational areas and green spaces.

For practical emission reduction or impact mitigation purposes, it may be useful to identify the locations and precise land uses with particularly high emissions. In the absence of any threshold radiance value, we illustrate this process by identifying the 10 brightest locations within canton of Zurich (Table 2). In the future, it may be worth undertaking this process for all extreme outliers within each image.

Table 2. The 10 brightest locations within canton of Zurich, based upon the visible radiant emissions for the area covered by iss038e016196.

FID	*X*	*Y*	*AS09_4*	*AS09_17*	*Radiance*	*Notes*
0	680500	248500	1	5	3.1897	Letzigrund Stadium
1	680500	248600	1	4	3.3938	Letzigrund Stadium
2	686000	247800	1	5	1.63635	Dolder sports (ice)
8	695300	252800	1	5	1.48901	Sportzentrum Effretikon (ice)
5	686100	247800	2	8	1.7887	Dolder sports (ice)
3	686100	247600	3	10	1.83237	Dolder sports (ice)
4	686100	247700	3	10	1.91034	Dolder sports (ice)
6	686500	255100	3	10	2.44843	Swiss Arena (ice)
7	686600	255100	3	10	2.38287	Swiss Arena (ice)
9	695400	252700	3	10	1.4563	Sportzentrum Effretikon (ice)

The 10 most brightly lit locations were associated with just 4 areas of Zurich (Fig.17), all of which had sport-related land uses (1 sports stadium and three sports centres with ice hockey rinks) (Fig.18). Of the four urban locations (AS09_4, category 1), two were associated with the Letzigrund Stadium, with the remaining two associated with large outdoor icehockey rinks. Only 1 of the 10 brightly lit sites was on agricultural land (AS09_4, category 2), but this was adjacent to Dolder sports centre. Two brightly lit wooded areas were also adjacent to Dolder sports centre. Another two brightly lit wooded areas were also adjacent to the Swiss Arena ice hockey centre. The potential implications for predictive modelling are that distance to settlement area and distance to sports facilities might be useful explanatory variables.

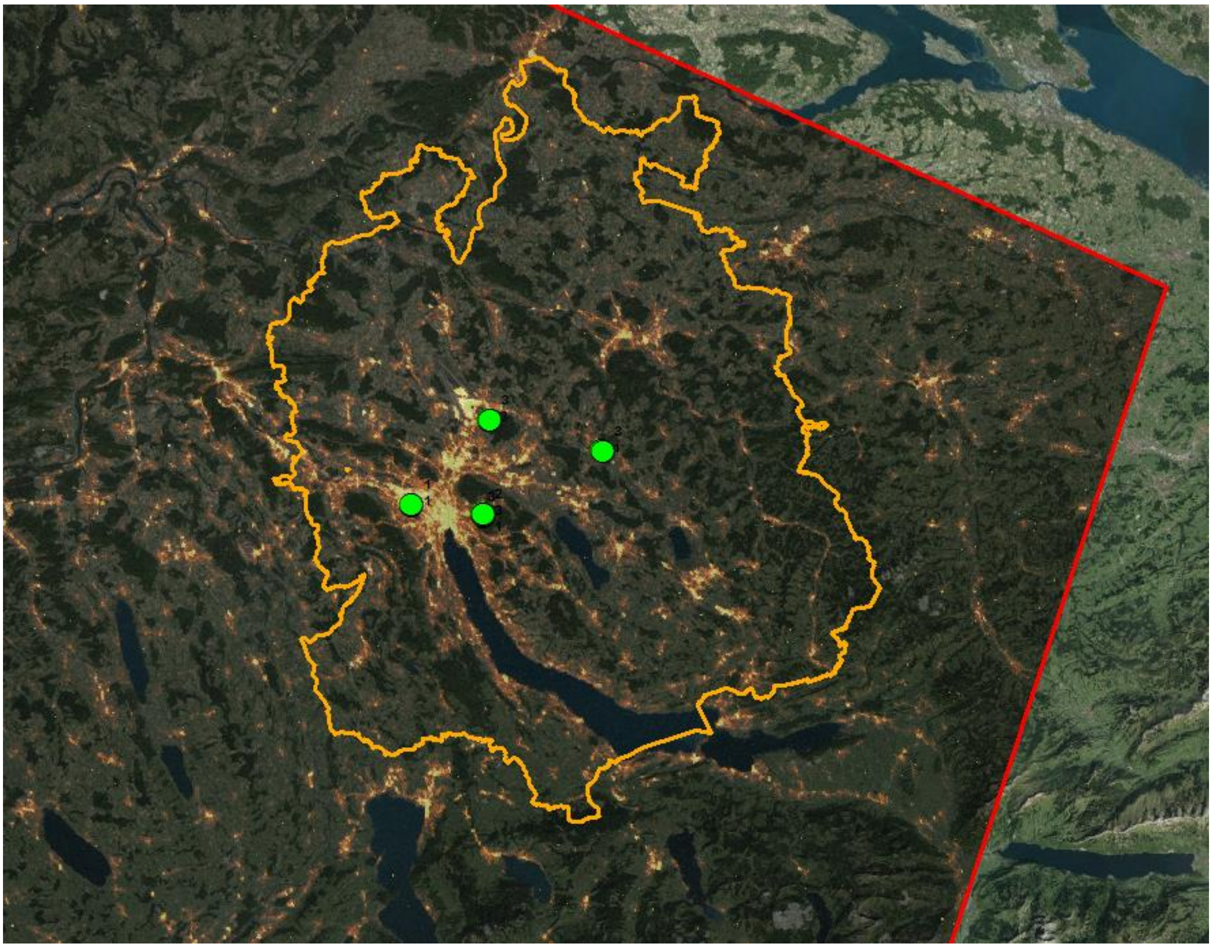
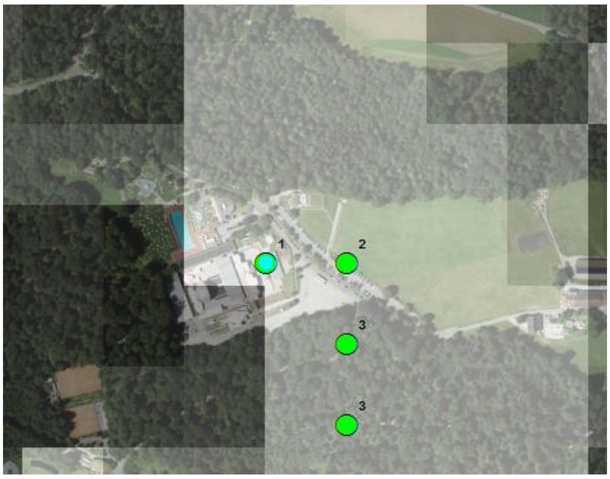


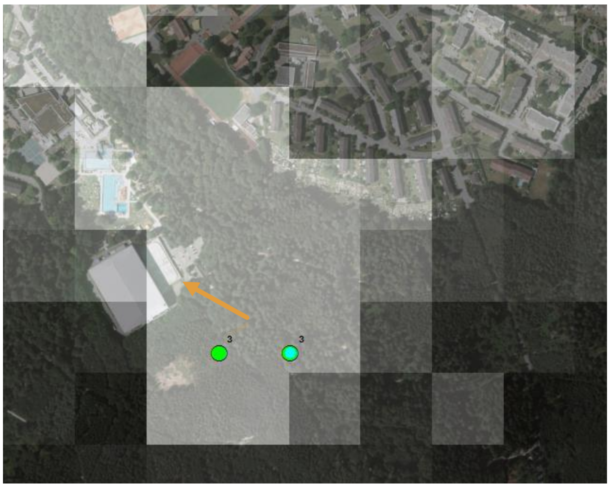
Fig.17 The 10 brightest locations within canton of Zurich, based upon the visible radiant emissions for the area covered by iss038e016196.

Letzigrund Stadium



Dolder Sports

Sportzentrum Effretikon



Swiss Arena

Fig.18 A zoomed in view of the 10 brightest locations within canton of Zurich, based upon the visible radiant emissions for the area covered by iss038e016196. Pixels are 100m.

2.4.1.2.2 VIIRS vs built surface cover vs altitude

To explore any broad relationships between lighting emissions, built land cover and altitude, we restricted our analysis used the monthly VIIRS data from Jan 2014 to Dec 2015. Despite its coarse spatial and spectral resolution, the VIIRS data has the advantage that it offers complete coverage of Switzerland, and allows comparison with other regions. At a resolution of 400m, this is coarser than the gridded Swiss LCLU classification (100m resolution) and much coarser than the European DEM (26m) or European Soil sealing data (20m). To avoid undertaking an analysis at a false level of accuracy, we created a 5km sample grid covering the entire extent of Switzerland (snapped to the nearest 5000m Swiss grid coordinate), selecting grid cells whose centroid was contained by the Swiss boundary (Fig.19). This was used to create summaries for total monthly VIIRS emissions, median altitude and % built surface cover for each 5km^2 grid cell. To avoid noise generated by any seasonal effects, we restricted our analysis to data for the early winter months, averaging the emission totals for January, February and December 2014 and 2015, and plotted these against median altitude and % built surface cover respectively (Fig.20 A and B). Although emissions appear to increase with built land cover and to decrease with altitude, this is complicated by the fact that built land cover and altitude appear to co-vary (Fig.20 C), or at least that heavily built areas are rare at higher altitudes. To account for this we divided the average emission values of each 5km^2 cell by the % of built cover. This reveals that emissions/unit of built area increase with altitude, suggesting that lighting of built surfaces is stronger at higher altitudes, or that lighting in the alps is more strongly linked to other land uses or behaviours. Similar patterns were observed when this analysis was repeated using averaged data for June, July and August 2014 and 2015.

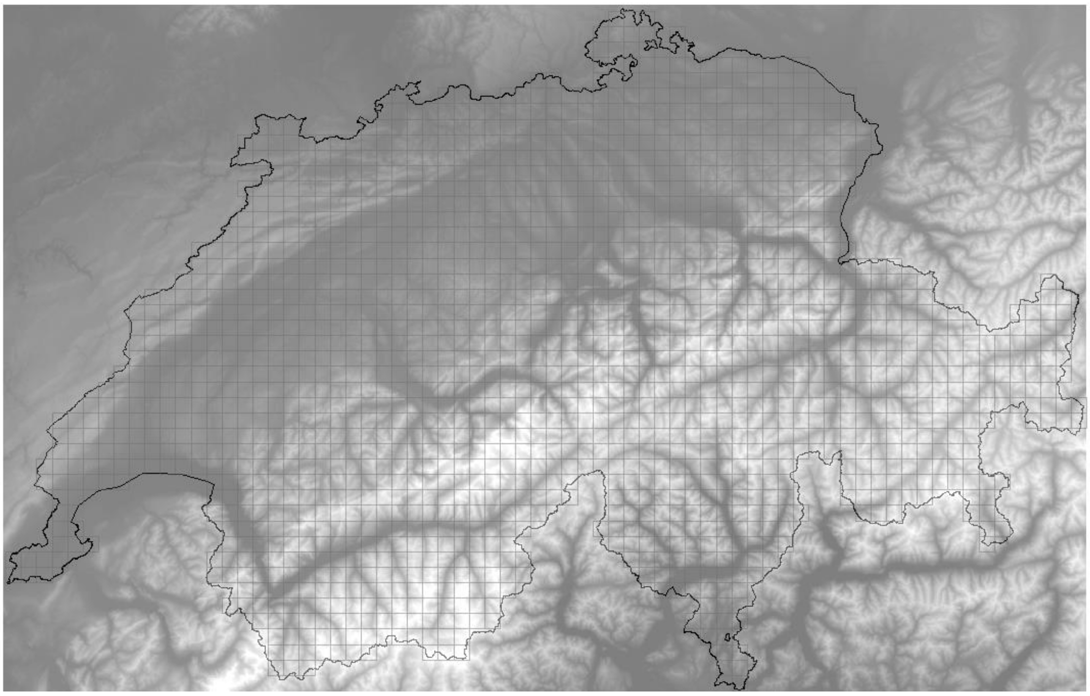


Fig.19 A 5km sample grid covering the Swiss extent (with a DEM as background).

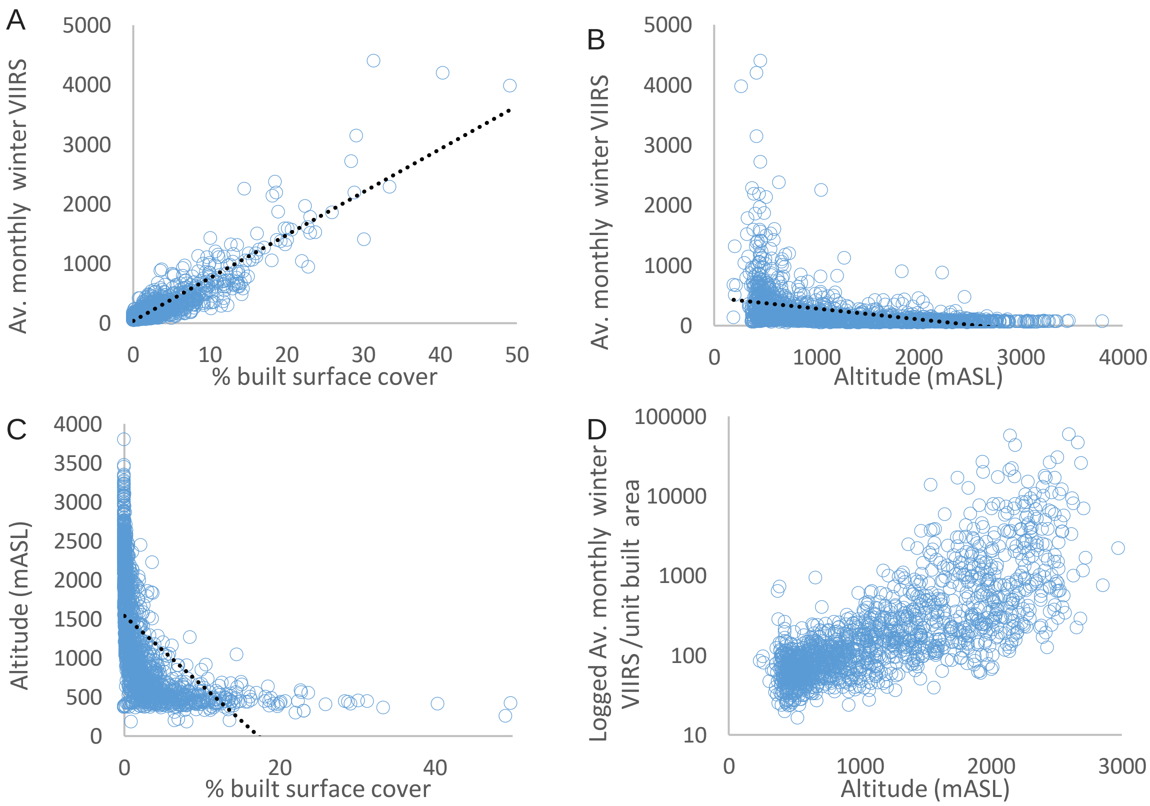


Fig.20 Monthly average winter VIIRS emissions at a 5km^2 sample scale, plotted against A) built surface cover and B) altitude. C) Illustrates that built surface cover and altitude co-vary. D) Winter VIIRS emissions per unit of built surface cover area vs. altitude.

Additional analyses might be undertaken using summaries of Swiss LCLU statistics data, possibly using a smaller sample grid (e.g. 500m, to approximately match the resolution of the VIIRS data). In a similar way to the ISS analysis presented earlier, it would be possible to explore how emissions vary with land use, and to examine the causes of these outliers to inform future modelling. To illustrate this we present a summary of the highest emission 5km^2 grid cells for winters 2014 and 2015. This process draws attention to the dominant role of city centres (Table 3, Fig.21), but the exact land-uses responsible still need to be revealed.

Table 3. The 10 brightest locations within Switzerland for averaged winter months in 2014 and 2015, based upon the VIIRS detected radiant emissions, at a 5Km sample resolution.

Id	*X*	*Y*	*Av. Winter Radiance*	*Notes*
1458	2682500	1247500	5715	Zurich city centre
442	2537500	1152500	4401	Lausanne city centre
132	2497500	1117500	4201	Geneva city centre
1583	2612500	1267500	3979	Basel city centre
133	2502500	1117500	3146	Geneva city centre
1499	2682500	1252500	2719	Zurich North
818	2577500	1182500	2375	Freiburg
51	2717500	1097500	2281	Lugano centre
1197	2552500	1217500	2254	La Chaux de Fonds
441	2532500	1152500	2189	Lausanne West

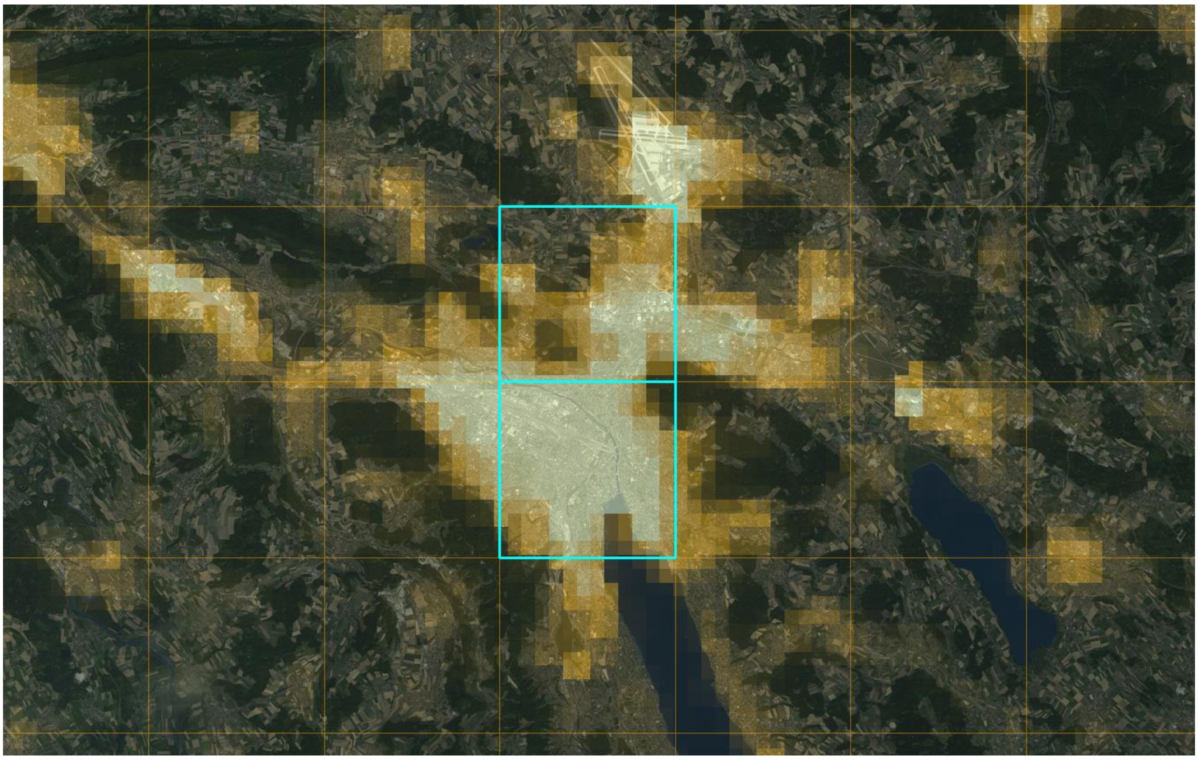


Fig.21 Zurich city centre – the highest source of winter emissions according to VIIRS data for 2014 and 2015, at a 5km sample resolution.

The potential implications for predictive modelling are that % built surface cover should be included as a candidate explanatory variable, and that either altitude be included, or that separate models are created for each of the 4-5 bioregions (see Price et al. 2015).

2.4.2 Temporal Analysis

Almost nothing is known about temporal variation in artificial lighting emissions, with research on seasonality only published very recently (Levin 2017). In addition to changes in surface albedo, we suspect some variations occur due to festivals, seasonal activities (icehockey and other winter sports) and other events which might be difficult to predict.

2.4.2.1 VIIRS seasonality

To explore for evidence of seasonality, we analysed 24 rasters derived from the VIIRS data described in section 2.1, spanning January 2014 to December 2015. First we explored whether there was any evidence of seasonality for total Swiss emissions. This was done by creating a model in ArcGIS that calculated zonal statistics as a table for each VIIRS raster, collected all 24 tables and merged them. In this case, the zonal statistics were based upon a single polygon representing the boarder of Switzerland. Values were standardised to show changes in relation to Jan 2014 (Fig. 22). There appears to be a winter peak in emissions, which is supported when the exercise is expanded to cover almost 3 years (Fig. 23) and repeated for individual cantons (Fig. 24).

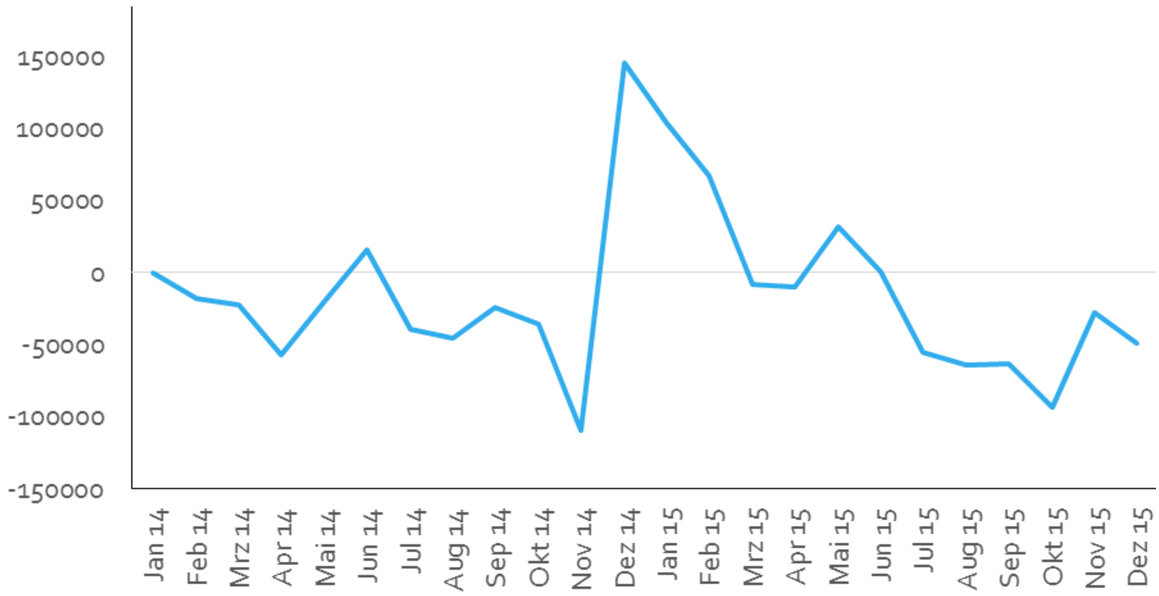


Fig.22 Monthly VIIRS emissions for Switzerland over 2 years, relative to Jan 2014.

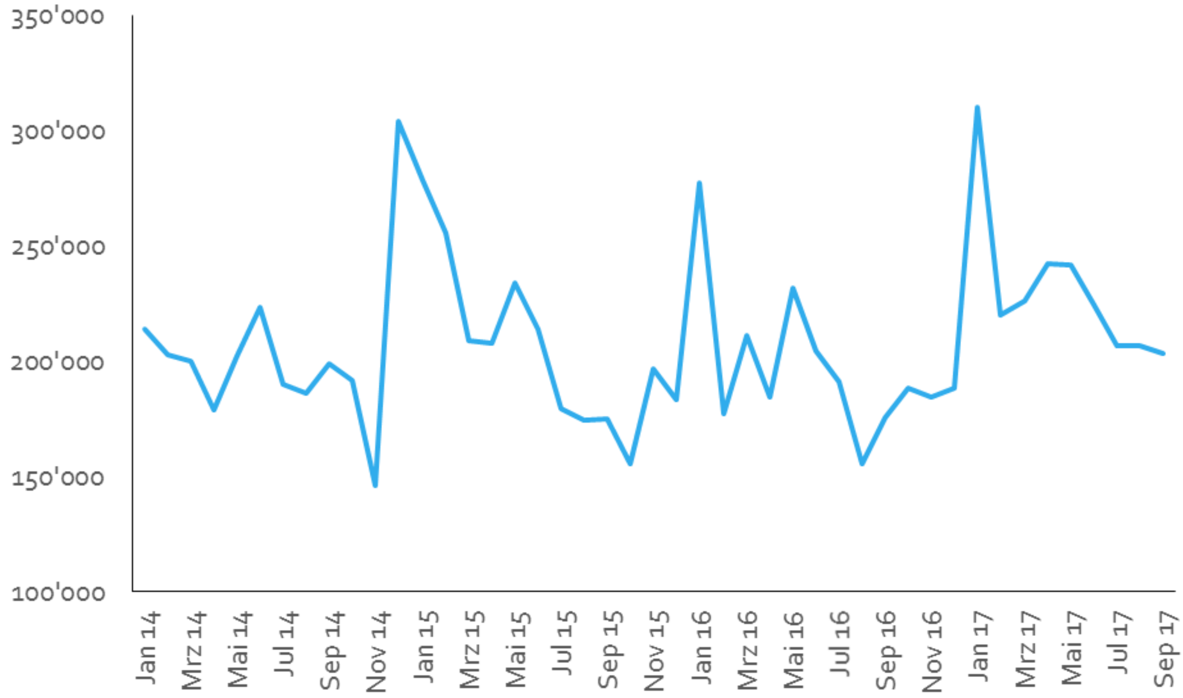


Fig.23 Total monthly VIIRS emissions for Switzerland, Jan 2014 to September 2017

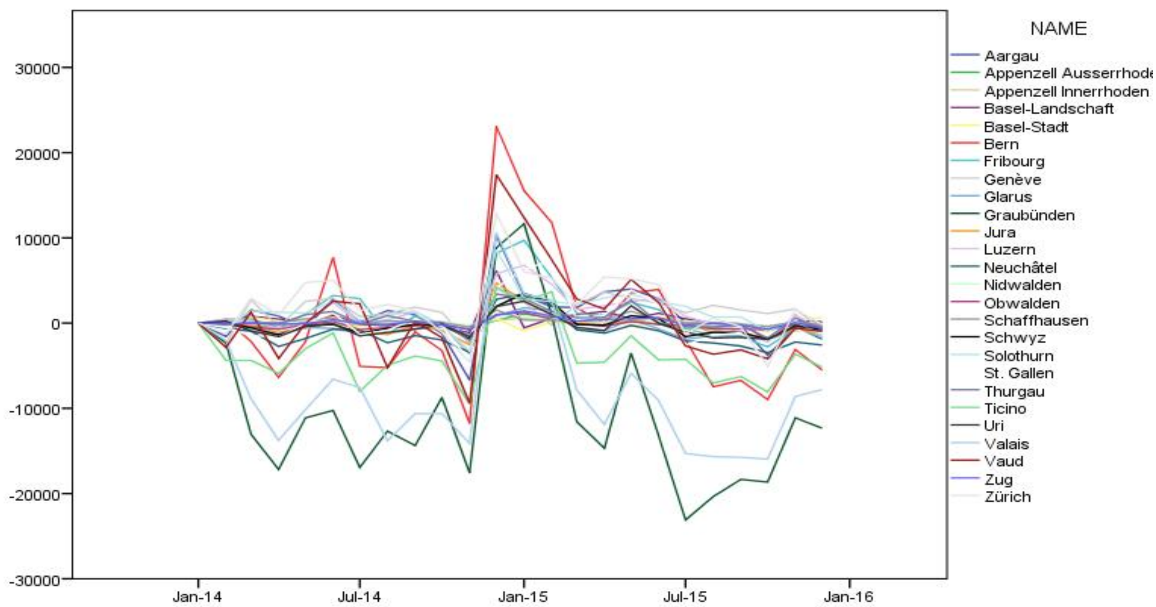


Fig.24 Total monthly VIIRS emissions, relative to Jan 2014, broken down by canton.

However, a canton is not a consistent sampling unit; it is still not clear whether this seasonal signal is evident in all parts of Switzerland and for all LCLU types. To explore this further, we used the 5km^2 grid described earlier to generate contrasting seasonal samples. These were a *winter* sample that resulted from averaging the emission totals for January, February and December in 2014 and 2015, and a *summer* sample using averaged data for June, July and August in 2014 and 2015. By calculating both relative (winter/summer) and absolute (winter-summer) differences, it was possible to map two coarse indicators of seasonality within the GIS (Fig. 25 A&B).

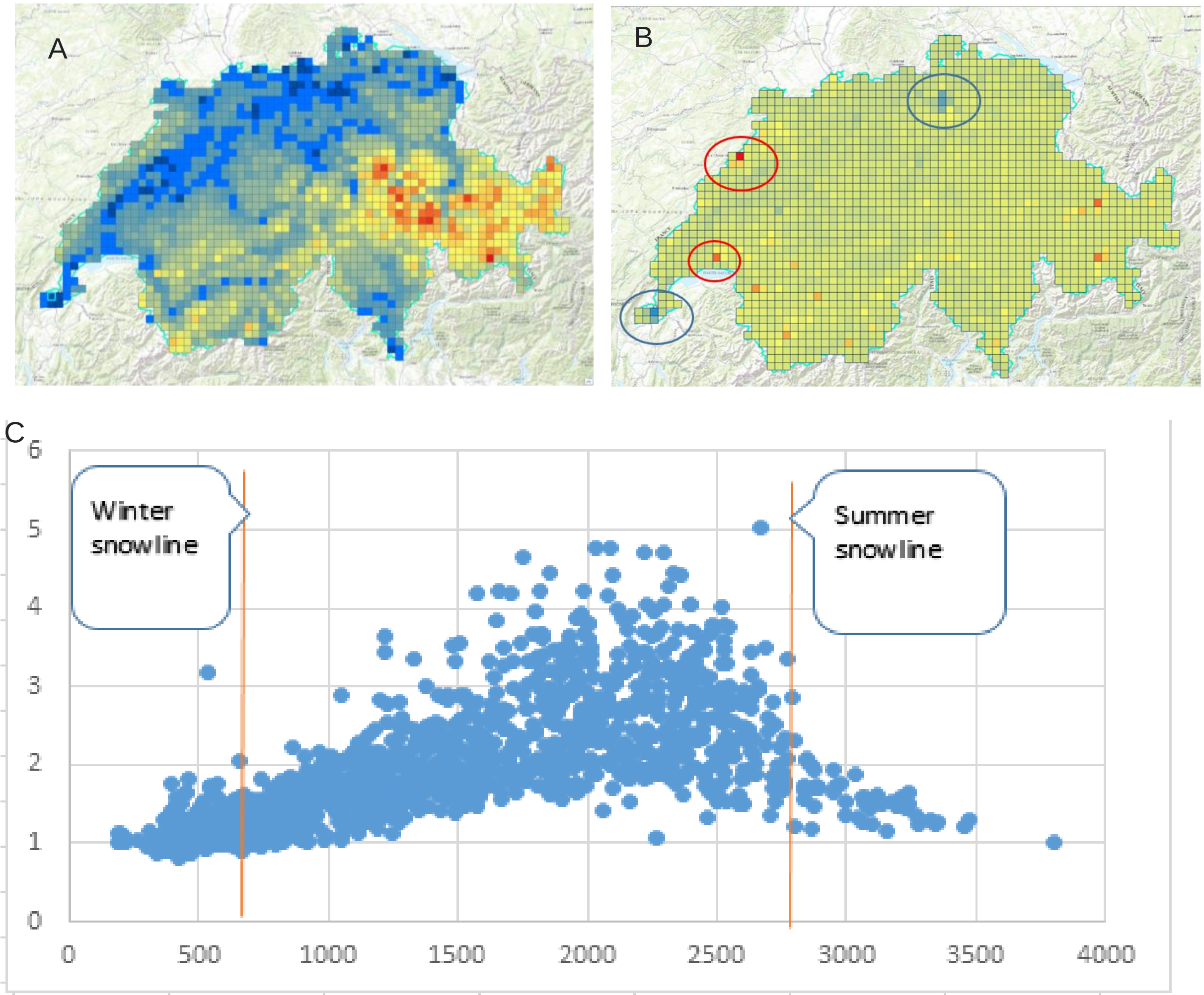


Fig.25 A) A map of the winter/summer ratio in VIIRS emissions at a 5km^2 resolution (blue is low, red is high), B) winter minus summer emissions (blue indicates summer peak, red indicates winter peak), and C) Winter/summer emission ratio (Y axis) vs. altitude (X axis).

In addition, when the winter/summer emission ratio is plotted against altitude, there appears to be a peak between 1000 and 3000mASL (Fig.25 C). This is probably linked to higher surface albedo due to seasonal snow and increased lighting linked to winter sports. At very high altitude snow is present all year round and winter sports are absent, so less seasonal variation in lighting emissions would be expected. This is supported by a temporal breakdown in 500m altitude bands (Fig.26).

These should be considered broad seasonal indicators only, and more sophisticated measures of seasonality could be developed that can account for variation over the whole year e.g. Levin (2017). However, it allowed us to identify locations where we might explore seasonality further. It appears that seasonality in lighting emissions is not evident within lowland cities when sampled at this scale (Fig.27 A), however some clear seasonality exists for lighting emissions from alpine settlements, peaking between December and February (Fig.27 B).

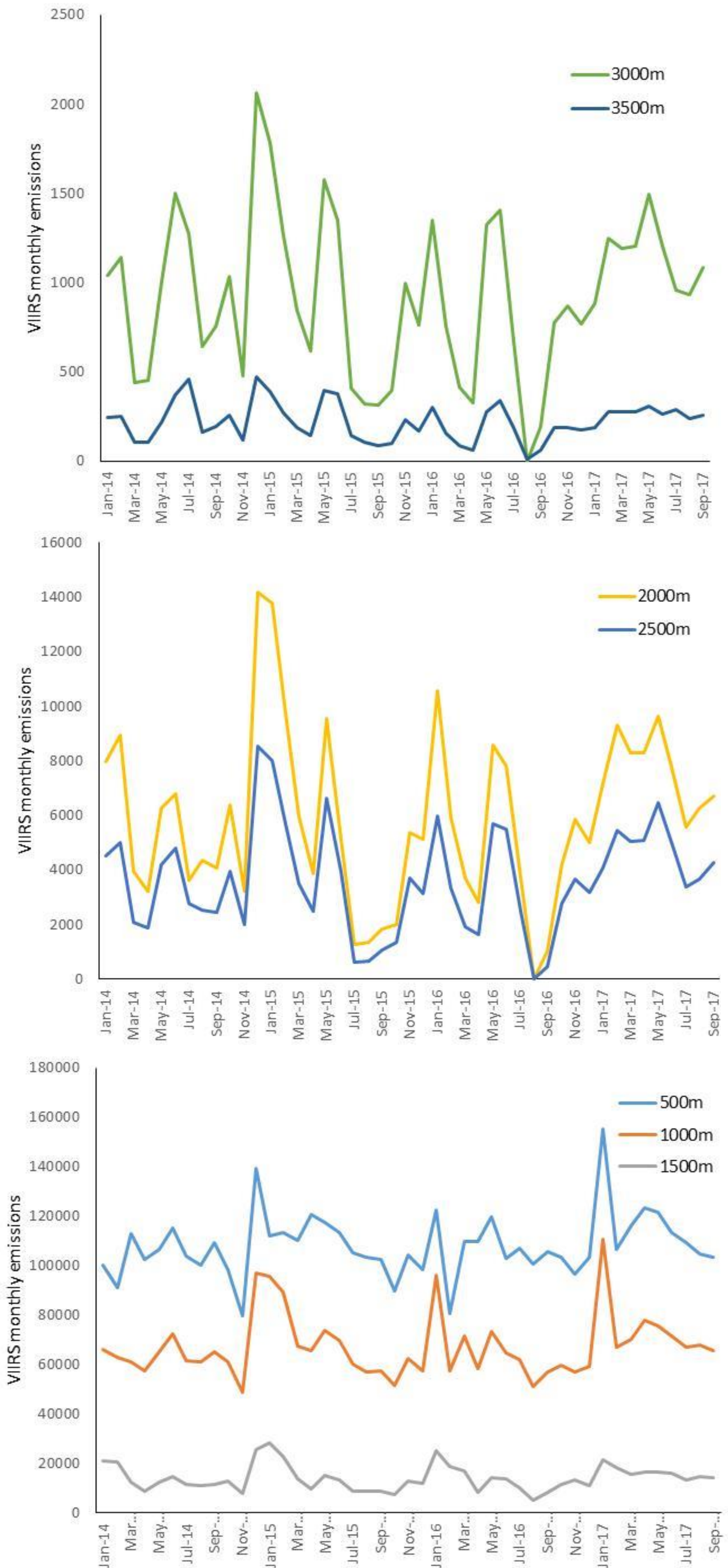


Fig.26 A temporal monthly VIIRS emission breakdown in 500m altitude bands for the whole of Switzerland.

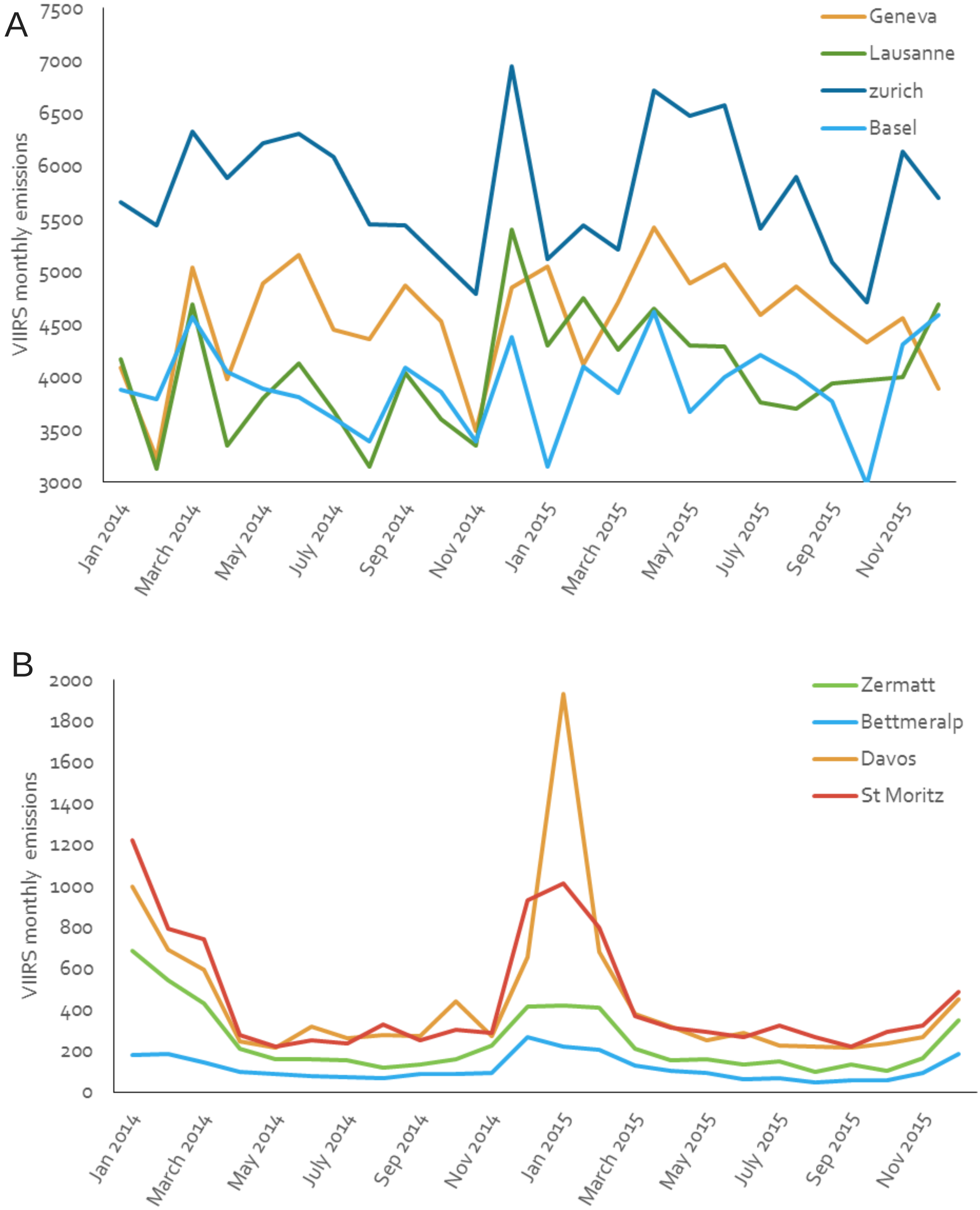
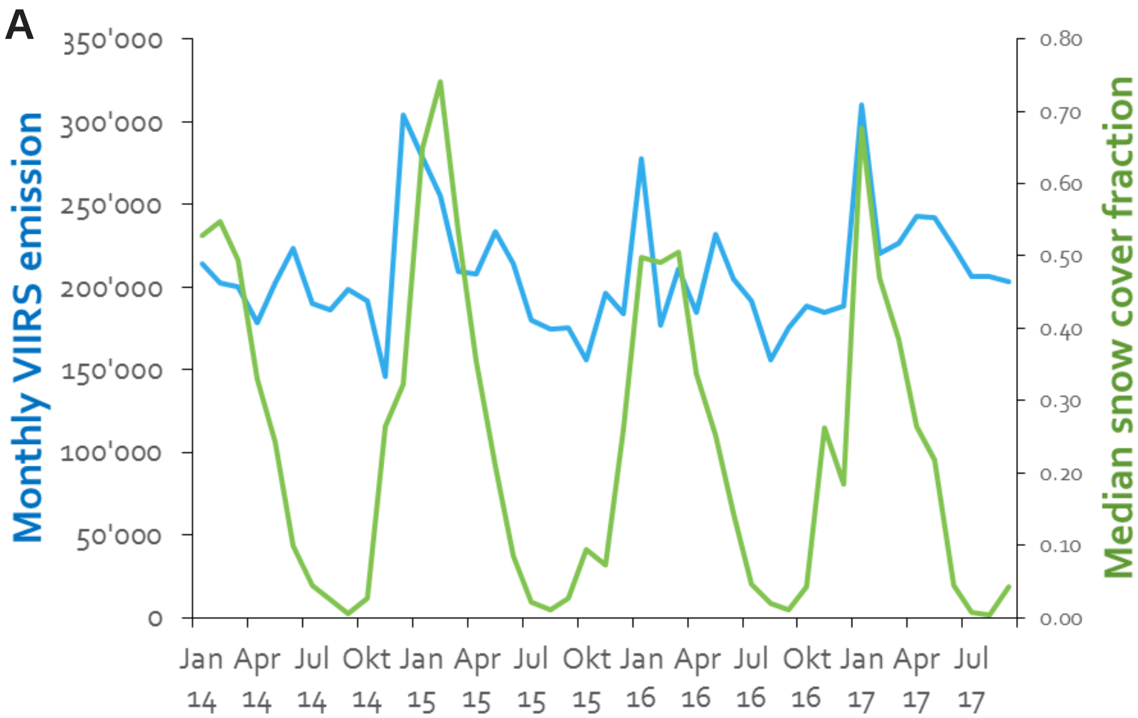


Fig.27 Monthly VIIRS emissions for 5km^2 grid cells covering A) lowland cities and B) alpine settlements

The cause of this seasonal variation in can be partly explained at the national level by comparing VIIRS emissions to monthly median snow cover fraction data (data source Dr. Tobias Jonas, WSL, 2017). (Figures 28 A and B). This sensitivity to snow cover means that yearly emission indicators might be best constructed from summertime data e.g. August VIIRS emissions. This also avoids temporary lighting used for winter sports and festivals.



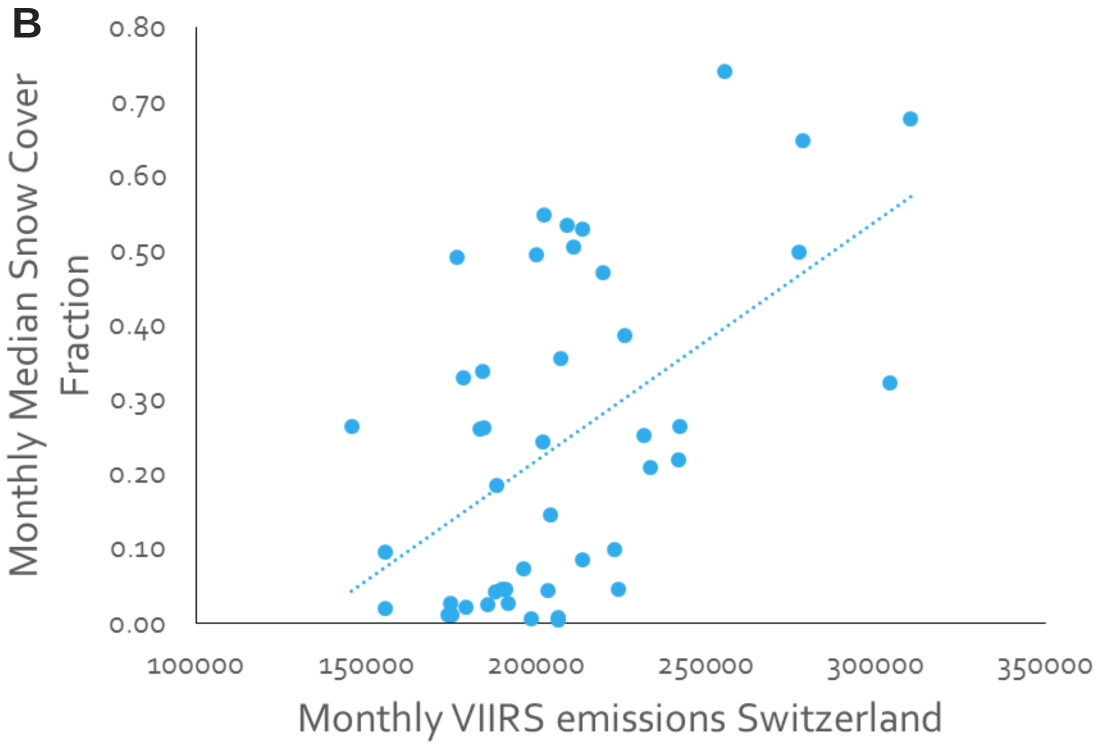


Fig.28 A) VIIRS emissions and median snow cover fraction, plotted as a monthly time series, B) Monthly VIIRS emissions and snow cover fraction plotted against each other.

2.5 Emission indicator development

2.5.1 Existing lighting indicators

A variety of lighting indicators are already in use to support initiatives to promote energy efficiency and better lighting quality for human activities, as well as to reduce negative impacts on human health, astronomical observations and natural systems. Some of these indicators are of value for multiple applications, whilst others have very specific uses. The aims of this section are to briefly highlight the variety of indicators that exist or have been proposed (Table 4), and to draw attention to those that are relevant to the baseline data we have access to.

Table 4. Overview of lighting indicators, divided by lighting dimension and indicator application.

	PROFESSIONAL LIGHTING MANAGEMENT	HUMAN EXPOSURE	ECOLOGICAL IMPACTS	ASTRONOMICAL
SPACE	Uniformity of lighting, extent of lit surface, lighting density e.g. lumens/ha, lamps/ha.	Proximity to nearest lamp, lamp visibility (nuisance)	Proximity to lamp, lamp visibility, lamp density, conflict zones, dark refuges	Whole sky camera measurements, sky visibility (models)
TIME	Lifespan of lamp, av. replacement time, operational times and curfews, change in lit area, radiance and luminous emissions and spectral composition over the night, season and between years.	Exposure duration (circadian impacts), exposure frequency.	Conflict times e.g. Bat emergence, or moth migration season, Exposure duration for circadian impacts	Shifts in sky quality during the night, seasonally and between years.
MAGNITUDE	Total luminous flux, surface luminance (e.g. for safety standards), surface illuminance, radiant flux to the zenith, lumens/Km road, total number of lamps, number of dimmable lamps, energy efficiency e.g. In lumens/watt, total energy use, total emissions CO^2 and CO^2 per lamp	Lux threshold (nuisance, tasks), impact thresholds for certain wavelengths (e.g. circadian disruption)	Lux and radiance thresholds (disturbance)	Sky quality (sky brightness)
SPECTRAL QUALITY	Percentage of broad spectrum lamps, percentage of LED lamps, colour temperature	Emissions within photopic, scotopic and mesopic wavelengths, colour rendering index	Ratio of blue or UV to red light, polarisation, comparison with spectral response of target species vision.	Emissions for wavelengths that are particularly problematic for astronomy.

The two datasets that we have focused our analysis on in Phase 1 are the VIIRS monthly radiance product and the radiance calibrated ISS images. Both of these provide estimates of the radiant flux towards the zenith at a spatial scale that is coarser than the typical spacing of individual street lamps. These are therefore relevant to indicators that make direct use of such measurements e.g. sky quality models. In addition, the colour information available as part of the ISS products could be used to report on indicators related to spectral quality. Considerable variability in the magnitude of emissions and spectral quality can occur within a single hectare of land, yet the ISS products could still be useful to identify certain configurations of lighting e.g. sodium lighting associated with motorways, or broad-spectrum lighting associated with sports fields. To develop the ISS products as lamp type proxies still requires access to data on the fine-scale variability in lamp density and spectral class (e.g. lamp inventories and calibrated aerial night photography. This points to a broader issue, in that many of these indicators depend upon lamp data at a high spatial resolution – Swiss-scale analyses of these is only possible with a national lamp database. More effort should therefore be made to overcome logistical barriers to the creation of a Switzerland-wide lamp inventory. However, to be comprehensive, the use of and citizen science based ground surveys would still be needed to ensure full spatial coverage (e.g. to capture lamps locations in hospital or industrial grounds).

2.5.2 Future Swiss lighting indicators

In Switzerland, the DMSP satellite data has been used to provide a broad indicator of lighting emissions and importantly, has been used to monitor change over time on an annual basis (Kienast *et al.* 2015). This has been valuable for monitoring broad trends, but even ignoring the various questions over data quality, it still has limited value as a proxy for informing indicators that relate to lamp density, lamp proximity or lighting spectrum. This is because of the low spatial and spectral resolution of the DMSP sensor. Given that this temporal DMSP data is no longer available, it would make sense to revise this indicator by using the new VIIRS data. This would also allow a series of sub-indicators to be developed and applied at various spatial and governance scales e.g. seasonality and yearly change in emissions could be reported for the whole of Switzerland, for each biogeographic region and even at the canton or commune scale. In an attempt to provide some continuity with the former DMSP based lighting indicator, a single annual value for yearly Swiss lighting emissions could be extracted from the VIIRS data. This effectively establishes a new baseline year - 2014, against which change direction could be measured (Fig. 29). Yearly change in emissions could be reported for the whole of Switzerland, for each biogeographic region and even at the canton or commune scale.

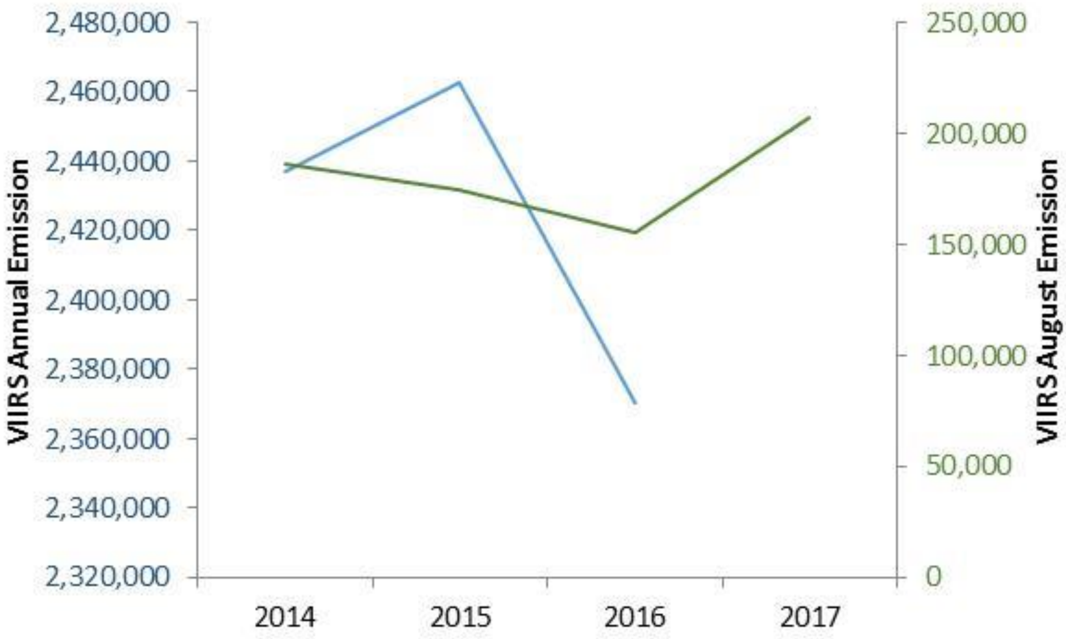


Fig.29 Total annual (blue line) and August (green line) Swiss lighting emission data from VIIRS (Watts/cm^2/sr) for 2014, 2015 and 2016.

This approach gives a reasonable indication of zenith emissions over the whole year. However, as we have shown, these totals are sensitive to winter peaks, likely due to snow cover increases and winter sports. This means that annual summaries may be useful as a broad indicator of vertical emissions for tracking skyglow, but a poor indicator of total stable installed flux/lamp infrastructure. In other words, an increase in annual VIIRS emissions may simply represent a year with greater snowfall, rather than any change to lighting infrastructure. An alternative or additional VIIRS indicator could be developed by extracting the values for August each year as a proxy for installed flux (Fig.29).

However, using the VIIRS data still does not solve the lack of a country-wide indicator for spectral composition of lighting emissions. It seems impractical for such an indicator to be made available on an annual basis due to logistic issues, but a revision of ISS derived data and the self-reported commune street lighting surveys every 5-10 years may be sufficient to fill this gap.

More specific indicators of ecological impacts are introduced in Section 4

3 Literature review on the impacts of artificial lighting on Swiss species and habitats

In Section 2, a variety of datasets were identified that provided spatial and temporal information on outdoor artificial lighting in Switzerland. One of the broad aims of this project is to interpret this baseline lighting data in terms of impacts on Swiss species and habitats. To deliver on this aim, we first had to undertake a review of research on ecological light pollution relevant to the Swiss context, which was then used to inform the spatial analysis of risk locations described later in Section 4.

3.1 Summary

- The ecological impacts of artificial lighting are poorly researched, despite both the rapid spread of outdoor lighting, and the central role of natural day-night, lunar and seasonal lighting cycles in structuring and driving biological systems.
- The past decade has seen a dramatic increase in papers published on this topic, but it is unclear whether there is sufficient evidence to support national-scale recommendations for avoiding or mitigating its impacts.
- For applied nature conservation, we need to understand the links between the characteristics of artificial lighting and its ecological impacts at different biological, geographic and governance scales.
- Reviews at the national geographic scale are needed, as they reflect the scale at which much nature conservation planning is undertaken.
- We therefore searched for research papers which considered the ecological impacts of lighting on species listed as Swiss conservation priorities.
- Just 22 papers were identified as containing relevant information, covering 17 out of 3`603 priority species.
- Despite several high-quality experimental studies, there is generally insufficient evidence to support explicit spatial modelling of impact locations for individual species. This is due to: models for lighting responses not being published in full, and not enough details published on lamp type or proximity to the ecological receptor.
- However, these papers do indicate that artificial lighting deserves serious consideration in terms of the conservation of Swiss priority species. Major research gaps need to be addressed.
- Bats were the most extensively researched groups, with evidence that numerous bat species have a negative reaction to lighting, notably *Rhinolophus hipposideros, Rhinolophus ferrumequinum, Myotis emarginatus* and *Plecotus auritus.* Despite this research, numerous gaps remain.
- No papers on other priority mammal species were identified, which is surprising given that nocturnality is common – a major research gap to be addressed.
- There is some evidence for increased feeding of birds of prey and water birds around artificial lighting, although empirical data is limited. However, there is strong evidence of natural moonlight effects for *Bubo bubo, Tyto alba, Otus scops*, *Tringa tetanus and Vanellus vanellus,* which raises the question of whether these species could also have a sensitivity to artificial skyglow.
- Amphibians are generally considered to be light sensitive, but little research has taken place using Swiss priority species. The notable exception is for *Bufo bufo*, which are attracted to white during spring migration. There is evidence for sensitivity of *B. bufo, Lissotriton vulgaris* and *Triturus cristatus* to moon phase, raising the question of whether these species are also impacted by skyglow. Again, there is a major research gap for this group.

- There is good evidence for impacts on the migratory fish species *Salmo salar and Anguilla Anguilla, something that should be considered* in the design of bridges, fish passes and the management of stream sections within major cities.
- No Lepidoptera studies were identified through our strict search process, although the broad attraction of nocturnal Lepidoptera to lighting is well known. This lack of papers may be because priority species are often grouped with other species for community level lighting studies, therefore net being detected in searches.
- Considerable evidence exists for artificial lighting to impact aquatic insects, yet as with the review of Lepidoptera, many relevant studies of Swiss priority species are likely to have been missed, as species names may have been excluded or relegated to a SI file.
- Impacts on priority species of Plants, Reptiles, Gastropods, Bivalves, Lichens and Fungi, Coleoptera, larval (aquatic) Odonata and Orthoptera are plausible, with research on avoidance behaviour of particular interest for the latter.
- In general there is a need for more research on Swiss priorty species, which needs to explicitly include methodologies and sufficient details to be applied in nature conservation practice.

3.2 Introduction

The ecological impacts of outdoor artificial lighting are poorly researched and recognised in comparison to many other pollutants (Holker et al. 2010b; Lyytimaki 2013), despite the value of both light and darkness as an resource, and the central role of natural day-night cycles, lunar cycles and seasonal changes in day-length in structuring and driving biological systems (Gaston et al. 2013). Several authors have speculated about why so little research has been undertaken on this topic, even though light pollution is extensive (Cinzano et al. 2001), and rapidly growing (Holker et al. 2010a). Of particular note is the book *Ecological Consequences of Artificial Night Lighting* (2006) edited by Catherine Rich and Travis Longcore, who suggest in their introduction that this may be due to the diurnal bias of humans, and to the relatively recent increases in urbanisation and innovation in lighting technology. Subsequent publications have drawn further attention to the broad and increasing threat that artificial lighting poses to nature conservation and ecosystem services (Gaston et al. 2013; Holker et al. 2010b; Lyytimaki 2013; Navara and Nelson 2007; Stanley et al. 2015) and have called for greater research and synthesis (e.g. (Perkin et al. 2011).

Given the recent increase in publications on light pollution, a key question is whether there is now sufficient evidence to support recommendations for avoiding or mitigating its ecological impacts. Several broad options have been suggested based upon the precautionary principle (although informed by selected studies): preventing the spread of lighting sources, limiting the duration of operation, reducing lighting trespass, reducing the intensity of emissions and narrowing the spectral range (Gaston et al. 2012a). However, deciding which actions should be implemented, and where they should be targeted is hampered by potential research biases towards certain taxa and habitats, and by the bias towards the temperate northern hemisphere that is common within ecological studies. This poses the risk of ad-hock, rather than systematic approaches to addressing lighting impacts, as can be seen in biodiversity conservation more generally (Margules and Pressey 2000).

Effective biodiversity conservation should be undertaken at multiple biological and geographic scales (Poiani et al. 2000), and should recognize that relevant decision-making takes place at multiple administrative scales (Paavola et al. 2009). Synthesis of information about the impacts of artificial lighting is therefore needed at the level of genes, species, populations, communities, ecosystems, and landscapes, but also at spatial scales that are relevant to ecological processes and land-use governance. The most comprehensive review of ecological light pollution is a book edited by Rich and Longcore (2006), who point out that until the 1990s, most research was focused upon well-known impacts on individual taxa such as sea turtles or birds. Their book aims to provide a global overview of the state of knowledge for this topic, structured by taxonomic groups: mammals, birds, reptiles and amphibians, fish, invertebrates and plants. In their synthesis, the authors highlight common themes from these chapters, examining them at different levels of ecological hierarchy: physiology, behaviour and population, community, and ecosystem. They draw attention to the lack of physiological studies on animals exposed to lighting in the wild. Whilst lighting is known to disrupt hormones such as melatonin (produced by mammals, birds, amphibians, fish and invertebrates) and is associated with mediating seasonal changes in physiology and behaviour, they concluded that there was insufficient evidence to confirm that this was significant in a *natural* context. However, they consider it plausible that physiological changes associated with breeding, migration and hibernation in wild populations could be impacted by artificial lighting. They found evidence for impacts at the behavioural and population ecology level across taxa, with lighting having both positive and negative effects on orientation, and lamps causing both attraction and repulsion effects. Some evidence was also presented for potential disruption of behaviour linked to lunar cycles and synergistic effects with other factors. Via these mechanisms they present evidence for impacts on higher-level processes such as foraging, reproduction (including pollination), migration and communication. They also highlight impacts at the community level, specifically shifts in resource partitioning between nocturnal species, the encroachment of diurnal communities into the night-light niche, reduced foraging activity due to perceived or actual increased predation threat and broader changes in predator-prey relationships.

3.2.1 Recent research progress

In the past decade, the ecological impacts of artificial lighting have received much greater research attention. Large research projects (e.g. www.verlustdernacht.de/) and networks of researchers (e.g. www.cost-lonne.eu/) have produced numerous publications that need to be translated into conservation practice. Several recent reviews and perspective pieces have provided more information on types of impact, key research gaps and on the dimensions that should be explored further (Davies et al. 2013; Gaston et al. 2015; Stone et al. 2015). However, the review by Longcore and Rich (2006) remains the most comprehensive overview of broad ecological impacts to date. In order to encourage and facilitate synthesis of research findings from diverse disciplines Gaston et al. (2013) propose a common mechanistic framework which cross-factors key dimensions of artificial lighting (variation in space, time and spectrum) with the physiological and behavioural mechanisms through which organisms respond, and which ultimately impact ecological processes and higher level ecosystem functions. They groups these mechanisms as either being light as a resource (photosynthesis, day/night partitioning of activity and dark repair) or light as information (circadian/photoperiodism, visual perception and spatial orientation). They identify major gaps in knowledge about impacts at population and ecosystem levels, the lighting levels at which impacts occur, and the extent of impact zones surrounding individual lamps.

Subsequent publications have drawn attention to additional characteristics of lighting such as the degree of polarisation (Horvath et al.), flickering(Inger et al. 2014), and to the large-scale technological shift towards white LED street lighting (Stanley et al. 2015). Reviews have also been undertaken for specific groups such as bats (Stone et al. 2015) and on processes such as pollination (MacGregor 2015). Almost no reviews have been undertaken for artificial lighting and specific landscape features, habitats or ecosystems (but see Davies et al. (2014) for an overview and discussion of marine light pollution).

There is a tension evident in the literature between the need to understand the impact of lighting on a particular species, habitat or process, within a narrow context, and the desire to identify broad patterns of lighting impact that can inform conservation practice. We argue that such a tension might be resolved by reviewing the evidence at a national level rather than a global one, as this narrows the geographic and cultural context. Nature conservation policy is often developed at a national level, and implemented at the scale of a national park or development site. However, despite calls to do so by nature conservation professionals

(Bruce-White and Shardlow 2011) the ecological impacts of artificial lighting are rarely formally considered as part of professional planning practice, potentially due to a lack of formal detailed guidance at the national level (see (RCEP 2009)). Limiting the geographic scope of a literature review may also bring greater clarity, in comparison to global reviews where the response of an ecosystem type or taxa might vary between regions, preventing the identification of consistent patterns. Similarly, different cultural approaches to installing and managing artificial lighting may result in apparently contradicting results from ecological studies undertaken in different regions.

Switzerland is a particularly interesting case study for exploring how research on ecological light pollution might be used to inform nature conservation. On the positive side, the geographic bias in publications that might be expected towards temperate regions (and Europe in particular) may mean that many of these research papers are relevant to the ecosystems present in Switzerland. On the negative side, it is likely that little research has been undertaken within Europe on the impact of lighting on mountain habitats, which dominate half of the Swiss land-cover. The situation is also further complicated by distinct economic, political and cultural characteristics, which may influence the relevance and applicability of the research. For example, the high average wealth per capita *may* mean that the adoption of new lighting technologies is faster in Switzerland than within the EU. Here we review the evidence for impacts of artificial lighting on species and habitats of conservation concern found within the country of Switzerland. We highlight the existing research that is of direct value for nature conservation within this country, and draw attention to the gaps in the information required for translating research on ecological light pollution into applied conservation.

3.2.2 Scope

Our focus is on interpreting the literature on artificial lighting and ecology for practical nature conservation in Switzerland. Inevitably, some literature on lighting and organisms will not be relevant. For example, the literature on the best lighting regimes for intensive rearing of livestock or greenhouse cultivation will need to be excluded. There is also considerable literature that makes use of animal models for the laboratory study of circadian systems. Whilst this is of course relevant to the broader topic, these references will be excluded unless there are particularly strong links to Swiss species or habitats. Perhaps more difficult to deal with are references that describe variation in the response of individuals, populations or communities to natural cycles of lighting e.g. lunar phase. These papers will be excluded from the broad analysis, but will be included within a secondary analysis and considered in the discussion if they reveal additional potential for disruption. The geographic range of studies that will be included within this review cannot be defined, as some species and habitats found within Switzerland have geographic ranges that extend well outside those of Europe. The names of these species and habitats will therefore be used as a filtering step within the literature search as described below.

3.2.3 Aims of this review

- To review the literature on ecological light pollution directly related to species and habitats of conservation concern within Switzerland.
- To interpret the results of this review to identify plausible impacts within the case-study country.

3.3 Methodology

There are several steps to this review

1. Identify suitable search terms for species and habitats of conservation concern in Switzerland
2. Develop search terms that will help to identify research on ecological light pollution relevant to these species and habitats.

3. Develop additional search terms to use, which relate to natural night-time lighting (e.g. lunar phase), which may indicate susceptibility to artificial lighting.
4. For each broad taxanomic group of Swiss species, search for relevant journal papers in 3 stages: artificial lighting search, natural lighting search, review paper search.
5. Code papers based upon a series of key themes (Light type, habitat, country etc).
6. Summarise findings – what can we apply in practice, and where are the gaps?

3.3.1 Identify species and habitats of conservation concern in Switzerland

This analysis was restricted to the Swiss species listed in the *Liste der National Prioritären Arten* (2011). Whilst we knowledge that additional species may be included in priority lists at the cantonal administration or nature park/reserve level, the national priority list provides a solid starting point for identifying major threats.

3.3.2 Identifying lighting search terms

Research on the topic of artificial nighttime lighting has been undertaken within a wide range of fields. The two research domains of *ecology* and *artificial lighting technology* have given rise to a large sets of relevant keywords and phrases. We therefore need to avoid excluding older papers just because they use a lighting term that is currently out of favour. For example, (Buchanan 1993) published a paper on the effects of *enhanced lighting* on the behaviour of nocturnal frogs, whilst more recent papers would use *artificial lighting* or *artificial light at night* (ALAN). We therefore searched the lighting terms used within a variety of publications e.g. (Falchi et al. 2011; Gaston et al. 2013; Rich and Longcore 2006)to identify a range of key words and search-terms related to outdoor artificial lighting:

- Artificial light/lights/lighting
- Artificial night lighting
- Enhanced lighting
- City light/lights/lighting
- Nighttime light/lights/lighting
- Night-time light/lights/lighting
- Outdoor light/lights/lighting
- Street light/lights/lighting
- Road light/lights/lighting
- Roadway light/lights/lighting
- Street lamp/lamps
- Security light/lights
- Light pollution
- Photopollution
- ALAN
- Light trap

3.3.3 Undertake literature searches

- Priority species were extracted from the *Liste der National Prioritären Arten* (2011) for the following groups (see results section 6 for breakdown by English or Latin names):
- **Wirbeltiere Seitenzahl**: Säugetiere (ohne Fledermäuse), Fledermäuse, Vögel, Reptilien, Amphibien, Fische und Rundmäuler
- **Wirbellose Tiere**, Käfer, Schmetterlinge, Schmetterlingshafte, Libellen, Heuschrecken, Eintagsfliegen, Steinfliegen, Köcherfliegen, Landschnecken und Grossmuscheln, Dekapode Krebse
- **Pflanzen und Armleuchteralgen**: vascular plants, mosses and stoneworts.
- **Flechten und Pilze**: Baum-/Erdbewohnende Flechten, Grosspilze

For each of these broad taxonomic groups, we undertook a broad search within the Web Of Science (WoS), which combined the main lighting search terms with a list of Latin and English species names sourced from the Liste der National Prioritären Arten (2011), www.catalogueoflife.org, www.iucnredlist.org and taxon-specific guides. These search results were filtered to only include relevant journal papers, which were marked and exported as a tab delim file. The following artificial lighting search string was used:

"artificial light*" OR "artificial night light*" OR "enhanced lighting" OR "city light*" OR "night* light*" OR "outdoor light*" OR "street light*" OR "street lamp*" OR "security light*" OR "road* light*" OR "light pollution" OR photopollution OR ALAN OR "light-trap*" OR "light trap*"

A second search was undertaken, replacing the broad lighting terms with those related to natural nocturnal light. The aim was to reveal papers that might indicate the potential sensitivity of a species to the disruption of seasonal cycles in night-time lighting, or to nocturnal lighting cues that may impact navigation/orientation. Again, these were filtered to only include journal papers, marked and exported. The following natural lighting search string was used:
"lunar OR moon OR "stellar orientation" OR "star* navigation".

Finally, a search was undertaken which combined the artificial lighting search terms, the natural nocturnal lighting search terms, a list of Latin and English species names, and the names for the broad taxonomic group of interest. These results were filtered to reveal just the review papers, to identify papers which might provide an overview of the impacts of light for the broad taxonomic group.
The WoS search terms used for each group can be seen in the Appendix

3.3.4 Paper coding

Each paper that was considered to be relevant was entered as a record within an excel sheet, and coded against a range of criteria. This was then used to generate a table indicating the broad number of relevant papers for each group, the lighting type considered, and the impacts recorded. To facilitate the translation of this review into recommendations for nature conservation practice, and to identify key practical knowledge gaps, we coded each paper as follows.

- Season.
- Geographic region.
- Habitat class (urban, forest, etc).
- Biological level (ecosystem, community, population order, family, genus, species, genes)
- Ecological focus - (a large number of ecological processes and functions (e.g. reproduction, photosynthesis, herbivory, migration, dispersal, succession etc).
- Study type (experimental, correlational, and observational/anecdotal).
- Lighting metric (e.g. distance to light, presence of lamp, lux at ground level, etc).
- Light data used in analysis (lamp locations, field measure lux, DMSP, VIIRS etc)
- Lamp type (White LED, specialist LED, mercury vapor, low pressure sodium etc).
- Impact thresholds for lighting (distance, lux, radiance etc).
- Ecological effects (positive, negative, neutral).

3.4 Results

Table 5. Summary of the literature review on the Swiss priority species influenced by artificial and natural light sources at night. Of the 3`603 priority species, 17 species featured in 22 reviewed studies of artificial lighting.

Taxa	No. of relevant (reviewed) studies on ALAN	No. of priority species in ALAN research	No. of (reviewed) studies on NLAN
Mammals (excluding bats)	0	0	3
Bats	9	10	3
Birds	5	2	7
Amphibians	1	1	2
Reptiles	0	0	0
Fish	4	2	7
Coleoptera	3	2	0
Lepidoptera	0	0	2(3)
Odonata	0	0	0
Orthoptera	0	0	0
Ehemeroptera, Tricoptera and Plecoptera			
Gastropds and Bivalves	0	0	0
Decapoda	0	0	1
Fungi and Lichens	0	0	0
Plants	0	0	0

3.4.1 Mammals (excluding bats)

3.4.1.1 Artificial lighting and mammals

No papers on priority mammal species (except bats) and lighting were identified. This represents a major research gap.

3.4.1.2 Natural lighting and mammals

However, 3 studies were identified, linking priority mammal species to natural nocturnal lighting cues. A study of a sub-species of **wolf** *Canis lupus baileyi* within an outdoor enclosure found impacts of moon phase on activity, but interpretation is limited due to potential impacts of captivity e.g. diurnal feeding time, and this being a different sub-species to those found in Switzerland. Finally, two papers consider the effect of moonlight on activity in *Lynx lynx* (**Eurasian lynx**). A study by Kachamakova and Zlatanova (2014) indicates potential changes in activity during with moon phase, but is limited by the use of just two captive individuals. However, (Penteriani et al. 2013) found that for wild individuals, during and immediately after the new (dark) moon, lynx reduced their travelling distances, becoming concentrated in the core areas of their home ranges. The authors conclude this is in response to a more even distribution of their prey, which were found to become more spread out under darker skies. It is therefore plausible that areas of Switzerland which experience levels of skyglow, or surface illumination comparable to moonlight are sub-optimal for Lynx and other predatory mammals. Efforts to reduce skyglow should therefore be focused upon the core areas of these priority mammal species, with the aim of reducing skyglow to below the sky brightness measured with a first quarter moon in the best astronomical sites (0.09mcd/m^2).

3.4.1.3 *Review papers on mammals and lighting*

Two papers (Bennie et al. 2014; Davies et al. 2013) provide an overview of two factors related to artificial lighting that might impact mammals; lighting emissions within their home ranges, and lighting emissions within their spectral sensitivity range. A broader overview is given by Beier (2006) and is dedicated to the effects of artificial lighting on terrestrial mammals. This chapter points to the lack of research in this area, despite the high number of nocturnally active mammals at a global level. Notably, the author points out that most rodents and smaller species of carnivores are nocturnal, and therefore particularly vulnerable to artificial lighting. Despite the lack of research, the anatomy and physiology of many mammals indicates that artificial light could have a negative impact in some way. For example, the retina of a nocturnal mammal is typically dominated by rods (peak sensitivity near 496nm), meaning that exposure to twilight levels of broad-spectrum lighting (approx. 3 lux) will cause rod saturation, resulting in a blinding effect. There is broad evidence to support the impact of natural sources of light on behaviour and circadian patterns in mammals, which may be used as an indicator of sensitivity to artificial lighting. There appears to be a tendency of nocturnal mammals to alter their activity duration and spatial range in response to lunar phase moonlight, which is suggested to be related to predation. In addition, the author points out that lighting changes at dawn and dusk are key cues for maintaining the internal circadian (24h) system of activity (e.g. resting and feeding) in most vertebrates. Natural cycles of lighting are also likely to be an important cue for regulating the circannual (yearly) clock in mammals, although research is limited. In addition, there are few papers that consider the presence of a circalunar clock in mammals, despite clear evidence for behavioural responses to lunar cycles.

3.4.2 Bats

3.4.2.1 *Artificial lighting and bats.*

9 studies were identified that examined the direct impacts of artificial lighting on 10 Swiss priority bat species. Only 2 of these were experimental.

For *Rhinolophus hipposideros* **(Lesser Horseshoe Bat)**, experimental treatment with high pressure sodium (HPS) lighting near to commuting routes of maternity colonies delayed the start of activity and reduced overall activity levels (Stone et al. 2009). Similarly, cool white LED lighting was found to reduce commuting behaviour (Stone et al. 2012), even as low as 3.6 lux (below the lamp). This indicates a high sensitivity to lamp lighting for this species, given that LED street lighting levels are often 20-60 lux when measured in a vertical plane.

For *Rhinolophus ferrumequinum* (**Greater Horseshoe Bat)**, it was found that VIIRS satellite data (a proxy for lighting emissions) was negatively associated with changes in colony size 1.5 and 3.0 km radii from maternity roost (Froidevaux et al. 2017). However, no temporal lighting data were available, meaning that colonies were effectively classified as sitting within landscapes that were lit a certain way, based upon a single measurement taken at the end of the time series. It is also unclear whether these bats are responding to individual points of lighting, or to the resulting skyglow (see Section 2 for a discussion on this). Additional data from (Boldogh et al. 2007) provides more evidence for the sensitivity of this species to artificial lighting. It appears that floodlighting delayed emergence, although lighting details are not provided. Taken together with the sensitivity of its sister species *Rhinolophus hipposideros*, it is reasonable to treat *R. ferrumequinum* as light adverse, and to implement mitigation at both roosts and within their core foraging areas. More research is needed on illumination thresholds for impacts on roost emergence and commuting/foraging. It is interesting to note that this species is recorded as present in several areas with high VIIRS emissions – Geneva, Lausanne and the main valley of Valais, around Sion.

For *Myotis emarginatus* (**Geoffroy's Bat/Geoffroy's Myotis)** there is some evidence of delayed emergence, reduced juvenille body mass and greater sensitivity (compared to *R. ferrumequinum*) as a result of lighting maternity roosts (Boldogh et al. 2007) - however, due to the low number of replicates in this study, further research is needed to confirm this effect, to identify lighting thresholds, distance thresholds and the impact of lamp type.

For *Plecotus auritus* (**Brown Long-Eared Bat**) the introduction of floodlighting to the outside of its roosts within churches is reported to have has a strongly detrimental impact on colony presence (Rydell et al. 2017). This study was based upon a repeated survey of bats in church roosts, with a 25 year gap. Whilst it is possible that colony loss was due to other factors associated with church maintenance/upgrading, the lack of change in control (dark) colonies strongly supports the conclusion that this species is very sensitive to such architectural lighting. This supports earlier finding by Rydell (1992) that *P. auritus* avoids street lamps (when foraging).

For *Eptesicus serotinus* (**Serotine**) negative impacts from lighting have been recorded at broader landscape levels (200, 500, 700 and 1000 m) using VIIRS radiance data (Azam et al. 2016). As discussed previously, there are difficulties interpreting VIIRS data, due to the time of capture, limited spectral range, coarse resolution and its correlation with broader human activities. However, no impacts on commuting Nyctalus/Eptesicus spp were observed by Stone et al. (2012) from cool white LED street lamps. This may suggest that whilst this species is tolerant of individual street lamps, it is deterred by high lamp densities/high emissions within its broader feeding area. This illustrates the difficulty of interpreting some bat research which uses bat calls for identification. Future research would benefit from using tagged/tracked bats to be sure of their identity.

In an early study of the impact of street lighting on bat feeding activity, (Rydell 1992) reported the following species taking advantage of insects congregations arount Mercury Vapor (MV) and sodium lamps: *Vespertilio murinus* (**Particoloured Bat**) *Nyctalus noctula* (**Noctule**) and *Eptesicus nilssoni* (**Northern Bat**). There is also persuasive evidence for a feeding bias towards MV and HPS lamps, due to the greater number of insects attracted.

For *Nyctalus leisleri* (**Lesser Noctule/Leisler's Bat**) it appears to be able to take advantage of insects attracted to street lamps, with greater activity at HPS, low-pressure sodium (LPS) and ‘white’ lamps compared to unlit areas (Mathews et al. 2015). No impacts of lighting were found for this species at broader landscape levels of 200, 500, 700 and 1000 m, (using VIIRS radiance data) (Azam et al. 2016). No impacts were detected on commuting Nyctalus/Eptesicus spp from cool white LED street lamps (Stone 2012).

For *Miniopterus schreibersi* (**Schreiber's Bent-winged Bat/ Schreiber's Long-fingered Bat/Common Bentwing Bat**), radio tracked pregnant and or lactating females from a cave maternity colony were found to travel large distances to forage in urban areas. They preferably foraged in lit areas, always choosing white street lamps over the more abundant orange ones (Vincent et al. 2011). It is assumed that these white lamps were Mercury Vapor (MV) and the orange lamps some form of sodium. This illustrates the difficulty in identifying common themes in the results of these papers if just the broad lamp colour class is given; future studies involving white or amber LED lamps might give very different results.

In terms of applying these research findings to conservation practice, the main barrier is poor reporting of lamp parameters, and a lack of comprehensive lamp database for Switzerland. 2 papers did use VIIRS data as an explanatory variable. At present, the model from (Azam et al. 2016) cannot be used, as partial regression coefficients are supplied for VIIRS effect, but intercepts are not. Also, because surveys were undertaken along 2km transects that had different shapes, the buffers used to sample the lighting will results in polygons of different areas. Most importantly, buffer average values were extracted from the 2012 annual VIIRS product, which used a 2-months composite raster of radiance data. As we have shown using subsequent monthly VIIRS data, there can be high temporal varioability e.g. due to snow. This means summer bat activity might have been modelled in part using winter lighting data, which makes the direct application of these models to the Swiss landscape particularly difficult. It would be easier to apply the *Rhinolophus ferrumequinum* model from (Froidevaux et al. 2017) as they used VIIRS data from July 2014, using buffers around point locations. However, again no model intercepts are provided, making it impossible to apply this to a VIIRS map of Switzerland.

3.4.2.2 Natural lighting and bats

There is little information on the impact of natural lighting cues on bats, particularly relating to lunar cycles. One interesting paper by (Cichocki et al. 2015) describes the apparent relationship between moon phase and changes in activity of **Noctule** bats within a winter hibernacular. This highlights the difficulty any studies of the ecological impacts of moon phase have to address; distinguishing the mechanisms of impact is challenging as light, gravitational and magnetic changes take place during the lunar cycle (Grant 2013). There is some evidence for lunar-phobia in *Myotis daubentonii* (**Daubenton's bat**) (Ciechanowski et al. 2007), a phenomenon that might be more common within bats than generally perceived (Saldaña-Vázquez and Munguía-Rosas 2013). In addition, the timing and location of the setting sun can be important for functions such as emergence and orientation; Holland et al. (2010) and Greif et al. (2014) demonstrate that the bat *Myotis myotis* (**Greater mouse-eared bat**) uses the post-sunset glow on the horizon to calibrate a magnetic compass, although they disagree about whether polarization cues are relevant.

3.4.2.3 Review papers on bats and artificial lighting

Compared to other mammals, there is much greater research on the impact of artificial lighting on bats. Much of the focus has been on the feeding behaviour of some bats on insects attracted to street lamps, with Jens Rydell providing a summary in the book Ecological Consequences of Artificial Night Lighting (Rich and Longcore 2006). Other more recent papers have considered the broader impacts of artificial lighting on bats, notably (Stone et al. 2015). The authors point to the nocturnality of bats and the potential (largely un-researched) threat from the extensive conversion of street lighting to brighter, white LED lights. They also point out that bats show strong behavioural response to natural lighting cues - moonlight and day-length influence foraging activity and emergence time from roosts are influenced by sunset. Evidence is presented for negative impacts of lighting on commuting (barrier effects), roost emergence (delayed) and roost abandonment, with some taxa being particularly sensitive. Importantly, there also appears to be both positive and negative impacts on foraging – some species are able to feed on insects attracted to street lamps, whilst others are either outcompeted by other bats or directly deterred. However, at a landscape level, artificial lighting would be expected to have an overall negative effect on insect populations, resulting in reduced feeding opportunities for bats overall. Lighting type also appears to be important, but rarely have multiple lamp types been tested on a single species of bat. Stone et al. (2015) caution about generalizing impacts, but there does appear to be a pattern, with fast-flying species (of the genera Eptesicus, Nyctalus and Pipistrellus) which use open areas being more able to tolerate and exploit artificial lighting compared to bats that are slower flying or have calls adapted to more complex vegetated habitats (e.g. Rhinolophus and Myotis spp).

3.4.3 Birds

3.4.3.1 Artificial lighting and birds.

A total of 8 papers were identified which directly relate to artificial lighting impacts on Swiss priority bird species: 2 experimental, 3 correlational and 3 observational. There is some evidence that artificial lighting enhances (winter) feeding for *Tringa tetanus* (**Common Redshank**) (Dwyer et al. 2013; Santos et al. 2010). Impact locations cannot be modelled directly as these 2 studies used DMSP satellite or lux data, neither of which are currently available (or up to date) for the full Swiss extent. As this species no longer breeds in Switzerland, it makes sense to look for impacts as they pass through during migration, considering the lighting of stopover habitats. The high VIIRS emissions in Geneva, Lausanne and Neuchâtel appear to overlap records of Redshank occurrence (see www.vogelwarte.ch/de/voegel/voegel-der-schweiz/rotschenkel). Such areas might provide a focus for more research. There is also a record of *Fulica atra* **(Common Coot)** feeding under a street light (Hopkin 1985). We are aware of other unpublished accounts of water birds such as Grey Herons (*Ardea cinerea*) hunting at night by a lit bridge. A paper by (Buchanan et al. 2015) also highlights the effectiveness of using artificial lights to capture waterbirds such as *Anas platyrhynchos* **(Mallards**).

Two papers report observations of birds of prey feeding at night by lights. *Accipiter gentilis* (**Northern Goshawks**) are reported by Rutz (2006) hunting by lamps in an urban area during the summer, and *Asio otus* (**Long-eared Owl**) were observed hunting autumn migrating songbirds (Canario et al. 2012). Predation aided by artificial lighting may be relatively common, as we are aware of other unpublished observations of this behaviour (e.g. Short-eared Owls *Asio flammeus* attracted to lights over sports stadiums). This represents an interesting research opportunity, which may require the use of radar and other tools to clarify where and when this practice is most common.

Interestingly, whilst an experimental study of lighting on winter foraging in common European songbirds (Da Silva et al. 2017) found no impact on the Swiss priority species *Parus palustris* (**Marsh Tit),** impacts on other tit species were detected. Another paper by (Ciach and Frohlich 2017) indicates artificial lighting was associated with higher bird densities for a winter urban bird community that included Swiss priority species. However, the problem here is that no analyses are undertaken for individual species.

These papers provide insufficient evidence to support spatial modelling, but they do indicate that artificial lighting deserves some consideration in terms of the conservation of priority bird species. Future studies might make use of a citizen science approach to identify water birds active under artificial lighting, and radar studies of birds active in the vicinity of strong light sources (e.g. stadiums), particularly during migration seasons. In addition, the bird records of biological recording centres could be screened for artificial lighting key-words, to identify additional observation of activity near lights.

3.4.3.2 Natural lighting and birds

7 papers were identified that highlighted the importance of lunar cycles to the ecology of Swiss priority bird species, particularly owls. Penteriani et al. (2010) found that moon phase influenced calling/displaying of *Bubo bubo* (**Eagle Owls)**, with higher occurrence and frequency of call displays under a full moon, especially for males. Penteriani et al. (2011) report higher movement activity around the time of the full moon compared to new moon for Eagle Owls, which covered greater distances, flew more frequently, and faster, with shorter breaks. In a third study of Eagle Owls, Penteriani et al. (2014) found juvenile dispersal was highest in full moon. This final study is particularly relevant, as the authors imply that moonlight increases the distance over which a bird can see landscape feature, giving them the confidence to cross unfamiliar areas. It might therefore be reasonable to deduce that parts of the landscape with high levels of skyglow might encourage dispersal, calling/displaying and greater activity in this species. Something which might be tested in future research. Mori et al. (2014) also provide evidence of impacts on calling of *Otus scops* (**Eurasian Scops Owls**), which highest during full moon (during breeding season). Again, it would be interesting to test the effect of moon phase on calling behaviour, in areas where skyglow is particularly high. Lunar phase was found to be important for another species of owl - *Tyto alba* (**Western Barn Owl**). Embar et al. (2014) found that hunting activity was greatest under full moon if another predator was present, but in the absence of second predator, moon phase was irrelevant.

In addition to birds of prey, moonlight appears to impact feeding for two other priority bird species. Dwyer et al. (2013) found *Tringa tetanus* (**Redshanks**) took advantage of moonlight on cloudless nights, spending more time on visual rather than tactile foraging. Similarly, Gillings et al. (2007) found that under cold conditions, *Vanellus vanellus* **(Northern Lapwings**) took advantage of moonlight to feed at night, apparently reducing their need to feed during the day.

3.4.3.3 Review papers on birds and artificial lighting

There are several review papers or chapters that address this subject, all of which focus upon bird migration and orientation (Gauthreaux Jr et al. 2006; Muheim et al. 2006; Wiltschko et al. 2010). These highlight the diverse ways that night-migrating birds can be attracted to both natural and artificial sources of lighting. Of particular note is the summary by Gauthreaux Jr et al. (2006) of papers which demonstrate that caged migratory birds (particularly immature ones) orient towards horizon glows from cities. This reveals another opportunity for further research, such as the use of caged migratory birds to identify detection distances for particular emission sources in Switzerland. Another important point is that migratory birds appear to use multiple lighting cues such as sunset polarized light patterns and star fields, which are processed in complex ways with information from geomagnetic fields. This raises the question of whether the highly polarised nature of artificial lighting from cities (Kyba et al. 2011) needs to be accounted for in studies of bird orientation. As with other taxa, impacts of lighting may be greatest where species are bound to a particular location or route, and unable to avoid exposure e.g. at nesting sites.

3.4.4 Amphibians

3.4.4.1 Artificial lighting and amphibians

For the 14 priority species of Amphibians in Switzerland, only 2 papers were found that deal directly with the impacts of lighting. The best evidence is from an experiment by van Grunsven et al. (2017) who found that *Bufo bufo* (**Common Toads**) migrating across roads during spring were most numerous at dark locations and those lit by an experimental red light, and least abundant at white lights. The lights differed in spectrum, but had a common luminous flux (52 lux below the lamp). This supports earlier observations that anurans avoid blue-rich light, but also serves to illustrate that an individuals attraction/repulsion to light may vary depending on the ecological process – *B. bufo* have previously been observed feeding on insects attracted to lights. The second paper (Covaciu-Marcov et al. 2010) describes *Hyla arborea* (**European Tree Frog)** feeding on large numbers of Nematocera, attracted to the walls of a historic building by artificial lights. The nature of the lighting is not disclosed. This is a major research gap, considering this group is highly active at night.

3.4.4.2 Natural lighting and amphibians

Grant et al. (2009) found that large arrival and amplexus events for *B. Bufo* were more frequent around the full moon. Deeming (2008) found the within-pond activity of *Lissotriton vulgaris* (**Smooth Newts)** and *Triturus cristatus* (**Great Crested Newts)** was also linked to moon phase.

3.4.4.3 Review papers on amphibians and lighting

No dedicated review papers were identified, but the broad concerns about these groups being vulnerable to artificial lighting are discussed by Buchanan (Chapter 9) and Wise and Buchanan (Chapter 10) in the book Ecological Consequences of Artificial Night Lighting (Rich and Longcore 2006). They point to an abundance of anecdotal evidence, some indirect information from laboratory studies, but a broad lack of field experiments. For example, anurans are typically nocturnal as adults, have excellent night vision, exhibit seasonality and are often drawn to lights. In contrast, whilst many salamanders are also nocturnal as adults, they seem to show a repulsion effect of lighting. However, phototaxis and nocturnality varies within these groups. One commonly discussed impact for anurans is an increased opportunity for predating invertebrates - some are able to catch prey visually at very low levels of illumination. In addition, there are anecdotal reports of skyglow disturbing breeding choruses and for phototaxis towards blue-rich light. Effects of lighting recorded for salamanders include altered hormone production, metabolism, activity patterns and homing ability. Given the strong dependency of both groups on aquatic habitats for breeding and on moist habitats in general, there is particular concern about lighting near waterbodies e.g. due to increased risk of larval predation by fish.

3.4.5 Reptiles

Reptiles include groups that are diurnal and nocturnal, but few research papers address artificial lighting directly (except for sea turtles). For the 11 priority species of reptiles in Switzerland, a search using the Web of Science database found no papers that deal directly with the impacts of artificial lighting. Additionally, no papers were found when searching for "lunar, moon, stellar orientation and star navigation" terms. Despite this, some impacts of artificial lighting are known for this group (Perry and Fisher 2006), suggesting further research may be useful.

3.4.6 Fish

3.4.6.1 Artificial lighting and fish

4 papers that directly addressed impacts of artificial lighting on Swiss priority species - which considered just 2 species - *Salmo salar* (**Atlantic Salmon)** and *Anguilla anguilla* (**European Eel**). Some authors (Riley et al. 2013; Riley et al. 2015) found evidence for impacts on dispersal timings, diel movement patterns and mass of juvenile *S. salar*, when exposed to 12lux, and on dispersal timings and diel movement patterns at 1lux or greater of artificial light. Riley et al. (2012) also found that the migration of *S. salar* smolts towards the sea was significantly correlated with sunset under control conditions, but timings were random when exposed to street lighting. Given that dispersal at night is linked to predator avoidance, this indicates the potential role that street lighting may play in damaging populations of this species. It also suggests that maintaining dark river corridors may be more effective than dimming measures. For *A. anguilla*, there is some evidence that artificial light may disrupt movement patterns. Hadderingh et al. (1999) found that in the silver eel stage (ready for downstream migration), movements could be deflected with 0.003 - 0.005 lux.

3.4.6.2 Natural lighting and fish

For *A. anguilla,* one of the variables that reduced downstream migration was a strong moon Sandlund et al. (2017) and Barry et al. (2016) also reports an impact of lunar phase. Negative impacts of lunar illumination are reported for adult *Lampetra fluviatilis* (**River Lampreys**) (Aronsuu et al. 2015). Lunar phase also correlates with emergence of *Salmo trutta* (**Brown Trout**) from redds (Radtke 2013), and upstream migration to spawning areas are also lowest under full moon (Slavik et al. 2012). The consumption rates of *S. salar* also increase towards the full moon (Burton and Boisclair 2013), presumably because prey is easier to detect (Fraser and Metcalfe 1997).

3.4.6.3 Review papers on lighting and fish

No reviews focus specifically on lighting and fish, with the best overview provided by Nightingale et al. (2006). The studies identified above are particularly relevant given the current efforts to restore breeding populations of *S. salar* in Switzerland, and the broader efforts to remove migratory barriers. For both species there is therefore a need to pay particular attention to lighting of bridges, dams and fish passes. This needs to be applied where possible to darkening of stream sections within major cities. Again, this is a major research gap. Many species of fish are known to be active at night, commonly related to activities such as dispersal or feeding.

3.4.7 Coleoptera

We identified three papers that demonstrate the potential impacts of lighting on 2 priority beetle species. For the pine beetle *Arhopalus ferus*, there is some evidence of an attraction to UV light and for low attraction to yellow light (Pawson and Watt 2009; Pawson et al. 2009) but the study designs make this difficult to translate into conservation practice. The third paper by (Sustek 1999) is basically an observational report of beetles, including *Amara apricaria* attracted to an advertising board. We found no papers that specifically dealt with the impact of variation in natural lighting on Swiss priority beetle species. However, a review by (Tierney et al. 2017) on lighting and insects supports the concern that artificial lighting may still be impacting many species of the beetle on the Swiss priority list, and may even be a source of evolutionary change.

3.4.8 Lepidoptera

The first two searches revealed no relevant papers. This is probably due to two related factors: 1) research on moths and lighting is probably dominated by community rather than species-specific studies, and 2) if study species are listed in a table or appendix, rather than the abstract or key words, WoS will not detect the papers. One alternative would be to perform a google scholar search which should pick up papers which store species lists within the main manuscript. Another approach is to extract a list of records of Swiss species caught with light traps. However, in both cases, we will end up with lots of light trap papers, which may be of limited use, particularly if we cannot tell what type of light was used.

The search for review papers yielded just 2 results. These serve to highlight the potential impact of lighting at the population/community and functional level, but also highlight the lack of studies addressing this topic. Macgregor et al. (2015) point out that moths are the main nocturnal pollinator of flowers, and calls for research to test for lighting impacts on the pollinator community. We know that since then, this issue has been addressed by others e.g. Knop et al. (2017). Fox (2013) also points to the *potential* impact of light pollution as a driver of historic moth population declines, but also describes the lack of evidence and, calls for more research. This call appears to have been answered by the very recent publication (identified after the literature review) of van Langevelde et al. (2017), who show that populations of nocturnal or light attracted moths are declining much faster than diurnal populations. It should be noted that other papers which compare impacts of light types on moth catches are known to the author, but these were not revealed in the search.

3.4.9 Odonata

No papers were identified in searches 1 or 2, however the broad search revealed that some impacts of lighting have been recorded. For example, Schilling et al. (2009) found aquatic light traps could catch several species of juvenile Odonata. In addition, Feng et al. (2006) describes the attraction of migrating Odonata to lamps. It is suspected that crepuscular adult Odonata might be vulnerable, possibly through being aggregated as they predate on smaller insects that are attracted around the lamp. It seems that impacts on larval (aquatic) Odonata are plausible, but may have gone unnoticed and therefore require more research.

3.4.10 Orthoptera

No directly relevant papers were found. However, we found several papers on impacts of lighting for Orthoptera species that are not on the Swiss priority list e.g. papers on the cricket *Teleogryllus commodus* have shown artificial lighting impacts on mating behaviour, melatonin production and immune function (Botha et al. 2017; Durrant et al. 2015). There are also examples of Orthoptera catches in light traps, but it is not clear how reliable these are as indications of sensitivity to ALAN – no control was used, so they might have been intercepted by the trap irrespective of the light. In addition, lunar effects have been observed on light-trap catch levels for some Orthopterans (Steinbauer et al. 2012) and activity levels in katydids (Lang et al. 2006), implying that avoidance responses to artificial light might also be expected.

3.4.11 Ephemeroptera, Plecoptera and Trichoptera (EPT)

3.4.11.1 Artificial lighting and EPT

These groups were reviewed together due to their common habitat and some common aspects of behaviour. 3 papers considered the impacts of artificial lighting on just 1 species of

Ephemeroptera - the night-swarming mayfly *Ephoron virgo*. Szaz et al. (2015) and Egri et al. (2017) demonstrate that huge numbers of this species can be attracted to (apparently) Sodium and LED lights, and then end up laying eggs on the polarized light reflecting off structures such as bridges. In addition, Whilst the population level impacts are not clear, this should at least be considered as a potential threat to broader Ephemeropteran communities.

3.4.11.2 Natural lighting and review papers for EPT

No papers were identified linking Swiss priority species of EPT to natural lighting cycles. Despite this lack of data, we consider these groups to be a priority area for future research. Lamp catches of aquatic insects appear to be influenced by moon phase, and many species of aquatic insects are known to be attracted to artificial lighting (Perkin et al. 2014), mostly from research involving uncontrolled light trapping (but see Meyer and Sullivan (2013)). A recent large controlled study by Manfrin et al. (2017) in Germany demonstrates the magnitude of this effect. This lack of knowledge is of concern, given that lighting is often installed in close proximity to lakes and rivers, and that over half of the Swiss EPT species are on the national Red List of conservation concern. Whilst there are many studies showing that Ephemeroptera (**Mayflies**) and Trichoptera (**Caddisflies**) are attracted to light traps, almost no records exist for Plecoptera (**Stoneflies**) attracted to lighting. This raises the question of whether we also need to look for repulsion effects for this group. Given the lack of information on how close LED lamps need to be to the riparian area for them to impact the terrestrial adults of these three groups, Masters students from the University of Bern recently undertook a study, with encouraging results (see section 8.1).

3.4.12 Gastropods and Bivalves

No papers were found that directly related to artificial or natural sources of light and Swiss priority species. No reviews were found, although plenty of evidence of crepuscular, diurnal and nocturnal behaviour in these groups (Hickman and Porter 2007; Pimentel-Souza et al. 1984). This represents a major research gap, which in some cases would be relatively easy to address.

3.4.13 Decapoda

No papers were found in the literature review that directly related to artificial sources of light and Swiss priority species within this group. However, there is strong evidence for the synchronisation of moulting with dark phases of the natural lunar cycle in *Astacus astacus* (**European Crayfish, Noble Crayfish or Broad-fingered Crayfish**) (Franke and Hoerstgen-Schwark 2013). This adds to the evidence identified in other parts of this review that some species seek a dark niche in the lunar cycle to avoid predation during vulnerable life stages, and raises questions about the predation risk for this species in areas of high skyglow or direct illumination. Following the review, just prior to completion of this report, we became aware of a study that raised the potential impacts of lighting on crayfish in Switzerland. Comparison of presence/absence data with luminance (estimated from VIIRS data) indicate that no individuals were present in habitats exposed to >0.1 cd·m−2. This represents a promising area for future research, particularly the use of field based lighting measurements to explore fine-resolution effects. Schuler, Lukas D., Rolf Schatz, and Christian D. Berweger. "From global radiance to an increased local political awareness of light pollution." Environmental science & policy 89 (2018): 142-152.

3.4.14 Fungi and Lichens

No papers were found that directly related to artificial or natural sources of light and Swiss priority species. No reviews were found, despite clear evidence for photoperiodism, and for some species releasing spores during the night (Bell-Pedersen et al. 1996). This represents a research gap, which should be addressed.

3.4.15 Plants

No papers were found directly related to artificial/natural sources of light and Swiss priority species. However, there are many known impacts of lighting on plants (Briggs 2006) and plant communities, as lighting not only provides a key resource to plants, but also information on directionality and seasonality (Bennie et al. 2016). In their recent review on the impact of artificial lighting on biological timings, Gaston et al. (2017) point to impacts on plants such causing earlier budburst and flowering, and delaying the onset of leaf loss. An overview of impacts and future research directions of plants and artificial lighting is provided by Bennie et al. (2016) who again flag up the major research gaps. These include understanding the variety of ways that plants are exposed to lighting, the broader ecological (rather than species) impacts, and interactions between direct and indirect impacts. In a review of the application of LED lights to indoor agriculture, Rehman et al. (2017) conclude that LED lamps can impact plant growth in a variety of ways, providing further evidence that wide-scale impacts on plants from new LED lamps is plausible at least. Clearly more research is needed to determine whether there are any direct impacts on Swiss priority plant species, but it should also be noted that indirect impacts via pollinators (Knop et al. 2017) or herbivores (Sanders et al. 2015) should also be considered.

3.5 Discussion

“Light represents one of the most reliable environmental cues in the biological world” (Tierney et al. 2017). Despite the large number of species searched for and the diversity of lighting terms included in our search, it is striking to see from Table 5 that very few papers were identified that addressed Swiss National Priority Species. The narrow approach we have taken in our review was intended to indicate the state of knowledge regarding artificial lighting and Swiss species of conservation concern. Few papers were identified regarding Swiss species impacts, meaning that many gaps exist in our ability to evaluate the ecological risks of artificial lighting at the national level. There are several potential explanations for this, such as the search process missing key papers (due to missing keywords) or that artificial lighting is simply not relevant to the ecology of most priority species. However, we suspect that the main reason for this lack of publications is that light pollution is still a largely unrecognised threat amongst conservation practitioners and the academic community (Lyytimaki 2013). This may result in researchers failing to mention key lighting terms within the title, abstract, or tagging information of their paper. Similarly, a perceived low relevance of light pollution to nature conservation may have led to the publication of studies in low impact journals, which the Web of Science may not include within it’s searches. Biases amongst researchers may have also led to a greater focus upon typically nocturnal species, despite the fact that lighting may also alter the behaviour of diurnal species. In addition, despite the ubiquity of nocturnal activity amongst mammals, a disproportionate level of attention may have been given to Chiroptera. We speculate that this may be due to the obvious behavioural changes associated with some light tolerant species, and may not reflect the actual diversity of impacts… particularly repulsion effects.

There is a recurring problem of how best to measure lighting treatments/thresholds. Many studies failed to measure lighting in a way that could translate easily into conservation action. Typical problems were not reporting the type of street lamp (we can assume this information was not easily available/not easy to measure), not reporting luminous flux (but rather the wattage), reporting an average lux for the study area. The last point is particularly difficult to address, as i) a lamp will result in a gradient of lighting intensity over a surface, so an average value is very sensitive to how the “study area boundaries” are defined. ii) a lux measurement at the exact location where an individual is being recorded would be ideal… but not possible when groups of individuals are feeding, or when one individual is moving through an area. We therefore call for multiple measures of lighting to be reported within future studies, with the aim of making application and replication easier.

- Lamp metrics – distance between sample location and nearest lamp, ground illuminance and irradiance directly below lamp, lamp spectrum
- Exposure metrics – illuminance and irradiance measures at point sampling locations e.g. bird feeder
- Site metrics – publish grids of illuminance and irradiance measurements over a defined study area.

4 Ecological impact mapping

The aim of this final section is to evaluate whether the data on Swiss lighting emissions, and the existing research knowledge relating to ecological impacts, are sufficient to inform practical conservation action. This section also considers how lighting may change in the future, the current knowledge on mitigation, and key recommendations.

4.1 Summary

- Explicit, Swiss-wide identification of places where lighting is causing ecological impacts is not yet possible.
- This is due to a lack of a national street lamp database, and the fact that what little research exists on the impact of lighting on Swiss priority species and does not contain sufficient information to inform mitigation.
- Local/regional scale analyses are more realistic, as street-lamp databases are often accessible, but these inventories would need to be expanded to include private lighting in industrial, commercial and other private land-covers (e.g. university and hospital grounds).
- Such local-scale analyses still require supporting research which explicitly identifies the magnitude of the ecological impact in relation to lamp proximity, and which study lamp types such as white LED that are already common and likely to persist in the medium term. We provide an example of research that identifies the impact of lamp proximity to a stream on the attraction of adult Ephemeroptera to white LED lamps.
- National-scale analyses are still possible using VIIRS data, but in the absence of research on impact thresholds, they are limited to identifying locations of *potential* conflict. In addition, it is unlikely that future ecological research using VIIRS data will be able to reveal the mechanisms of impact, as species could be responding to either a single point source of emission or skyglow that integrates all emissions within an area; one is not always a good proxy for the other.
- Locations of potential conflict can be simply revealed by intersecting maps of high VIIRS emissions with maps of a species range, a key ecological processes or a priority habitat. We provide an example of how VIIRS data could be used to identify potential locations for lighting impacts on migrating passerines.
- However, rather than limiting the analysis to a simple intersection approach, we propose the use of three VIIRS-based indicators which capture a broader range of scales and mechanisms by which species may perceive artificial lighting: close proximity to emission sources, direct-visibility of an emission source, and skyglow.
- Our analysis of the exposure of broad land-uses of ecological value to these three lighting indicators revealed the following:
    - In terms of proximity, 10% of Switzerland and 11% of the land-uses of ecological value are adjacent to locations with at least low levels of lighting emissions (>=2nW/cm2/sr). Large areas of agricultural and wooded land-cover are adjacent to locations with low-medium levels of lighting emissions (2-10nW). However, over 70% of urban green infrastructure in Switzerland is potentially exposed to at least low levels of light emissions, which includes 87% of the total

area of public parks. The percentage for agricultural land is just 16%, but within this, 68% of all vineyards in Switzerland are adjacent to emission of at least 2nW. The percentage for surface water is 18%, a high level of exposure considering that water makes up just 4% of the total Swiss land-cover.

    - In terms of visibility, emissions >=20nW/cm2/sr are visible from 9% the total Swiss landscape. Agricultural and wooded land-cover have the highest area of potential exposure to strongly lit viewsheds. However, as a percentage of total area within each broad habitat class, 40% of urban green infrastructure and 43% of the surface water in Switzerland is potentially exposed to strongly lit viewsheds. Again, these two habitat classes are disproportionately exposed, given their relative scarcity at a national scale. Whilst only 10% of agricultural areas are exposed, the percentage for vineyards is 49%.
    - In terms of Skyglow 90% of all ecological land-use locations are subjected to sky brightness levels sufficient to remove natural lunar lighting cycles. These locations are mostly within the flat lowlands. Agriculture and wooded areas have the highest total area under bright skies, whilst only 9% of unproductive habitats (Rocks, screes, sand, scrub vegetation, unproductive grass and shrubs) were impacted. Unsurprisingly, the majority of urban green infrastructure (GI) in Switzerland is located under bright skies. Regarding agricultural areas, whilst the total figure is 64% this figure rises to 99% for sub-categories of arable land, orchards, horticulture and vineyards. Despite only occupying 4% of the total Swiss land-cover, 84% of Swiss surface water is under bright skies (91% of lakes).

- Our analysis of the exposure of biotopes of national importance to these three lighting indicators revealed the following:
    - In terms of proximity, 11% of priority biotopes are adjacent to locations with at least low levels of lighting emissions. Amphibian spawning locations appear to have the highest level of exposure to low levels of lighting, both in terms of total area of habitat (6,300 ha) and the percentage of total Swiss spawning areas (30%). Fens also appear to be relatively highly exposed, with 12% of all locations adjacent to low levels of lighting. Zurich and Valais have the highest number of biotopes adjacent to bright lighting emissions, but Basel-Stadt has the highest density of these biotopes.
    - In terms of visibility, dry meadows and pasture have the highest total areas of potential exposure to views of bright lighting emissions, which may simply reflect their relative abundance in the landscape. Notably, a relatively high number of amphibian spawning locations are exposed to such views, despite being a rare biotope. This amounts to over 20% of all spawning habitats. Vaud and Valais have the highest number of biotopes with bright viewsheds, but Geneva and Basel-Stadt have the highest density.
    - In terms of Skyglow 50% of all priority biotopes are located under bright skies. Dry meadows and pastures have the highest total area of exposure, whilst 93% of amphibian spawning areas are located under bright skies. Vaud and Bern have the highest number of biotopes with bright skies, but Geneva and Zug have the highest density of these biotopes. In Vaud, almost half the biotope locations with bright skies are dry meadows and pasture, whilst in Bern the majority are amphibian spawning locations.
- Future urban expansion represents a major threat to maintaining dark habitats. Following land-use predictions based upon current past trends, an increase of 11% in built cover for Switzerland might be expected by 2035, mostly in the cantons of Vaud, Bern, Valais, Aargau, Zürich, and Fribourg.
- Under such as scenario, amphibian spawning areas are particularly vulnerable to greater exposure to light pollution, with 29% of habitats adjacent to new urban development.

- A variety of changes to lighting might be expected due to shifts in Social, Technological, Economical, Environmental and Political factors. However, structured interviews are needed with experts in each of these fields in order to better predict the lighting implications.
- Numerous potential mitigation options have been proposed, and even implemented. Therefore there is an urgency to understand their effectiveness before they become broadly adopted. Amber LED lights in particular hold some promise.

4.2 GIS analysis of Swiss lighting vs sensitive habitats

Explicit identification of locations for ecological impacts is not yet possible for several reasons:

- Very limited research has been undertaken on artificial lighting and Swiss priority species and habitats (see Phase 2 section).
- For species where we have evidence of impacts, there are rarely any lighting thresholds reported.
- Where thresholds do exist, it is typically for lamp presence or a lux value – no consistent Swiss-wide lamp database or fine resolution surface illuminance data exists.

The next question is therefore what can be done to identify *potential* ecological impacts, given the data available?

4.2.1 Local lamp databases and fine-scale ecological impacts

Despite the lack of a national lamp database, modelling fine-scale ecological impacts is still possible for small sections of habitat where a lamp inventory can be accessed and expanded to include other lamps e.g. from hospital or university grounds. As discussed in the first section, street-lamp databases (inventories) do exist, although their availability is inconsistent. Some are available for research/practice in full, others are restricted to point locations of lamps, others are restricted entirely. A recent collaboration between the division of Conservation Biology (CB) at the University of Bern and the Naturpark Gantrisch has combined a study of distance thresholds for white LED lamp impacts on aquatic insects, with a survey to identify both pristine and impacted locations. Masters students under the supervision of CB researchers undertook surveys of the terrestrial adults of aquatic insects, using LED lamps as light traps. They found that for Ephemeroptera (of which many are listed as Red Data species in Switzerland), the number caught dropped sharply when the lamp was 40m from their stream habitat (Fig.30), indicating that similar LED lamps within 40m of a stream might cause particular problems for this group. Lamp surveys were then undertaken along waterways within the Gantrisch Nature Park, identifying sections of stream where lamps were absent within 40m (Fig.31), and sections of stream where lamps were close to the stream and which required conservation action.

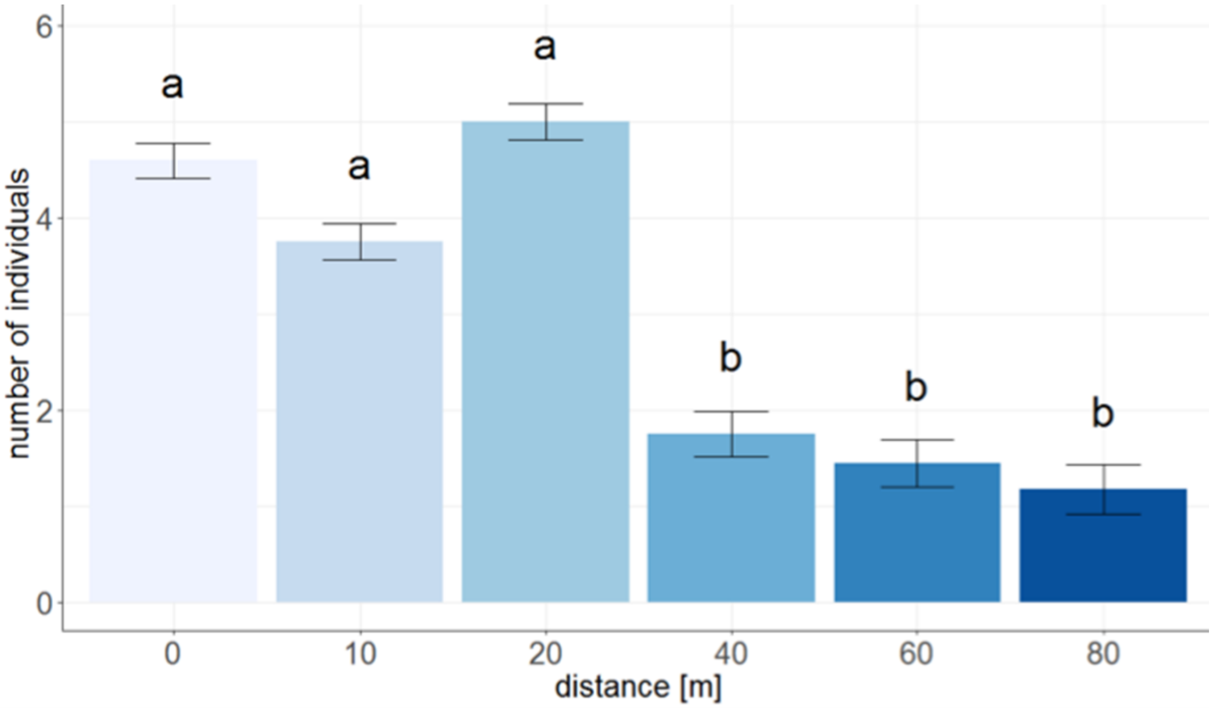


Fig.30 Number of adult Mayflies (Ephemeroptera) captured by and LED light trap at different distances from their natal stream. Data source – C.Blumenstein. Maters Research project, Uni Bern 2017.

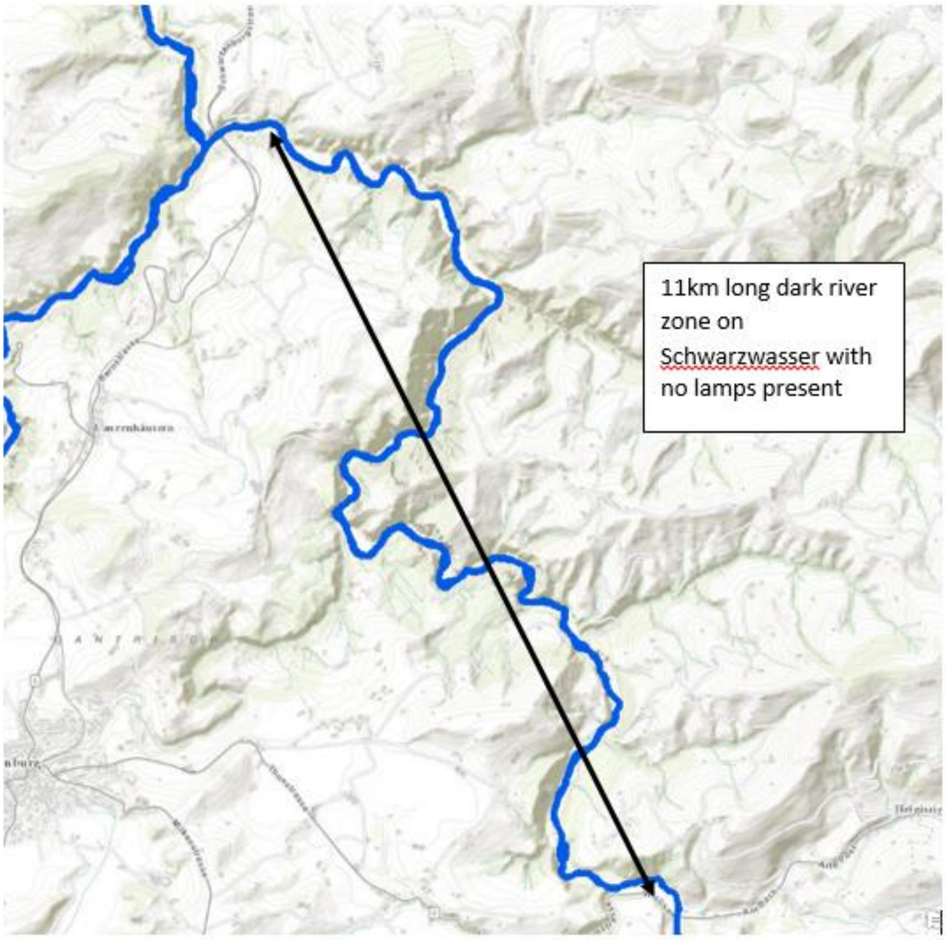


Fig.31 An 11km section of the Schwarzwasser river (canton Bern) which has no artificial lighting within 40m of the stream edge (based upon field surveys).

4.2.2 VIIRS data and locations of potential conflict

VIIRS lighting emission data can still be used to identify locations of *potential* conflict. This can be done simply by overlaying spatial data on priority species occurrence with locations of particularly high emissions. However, it should be noted that the VIIRS data represent vertical emissions, whilst many species will be exposed to lighting below or horizontally from the lamp. As an example, we illustrate how VIIRS data could be used to identify potential impacts on migrating passerines, many of which are Swiss priority species.

Artificial lighting is known to have impacts on passerine bird migration under certain atmospheric conditions. Our aim is to identify locations of high bird density which coincide with locations of high lighting emissions in Switzerland. For this analysis we use data from (Liechti et al. 2013) which models absolute passerine migration intensity (birds per hour) at a $1km^2$ resolution for a grid covering the whole of Switzerland. For both the spring and autumn migration models, we selected the top 10% of locations i.e. the areas with highest predicted bird densities. These were intersected with VIIRS emission rasters for May and October 2016 respectively. Finally a point layer was created for each migration season, indicating locations where high migration intensity coincided with strong VIIRS lighting emissions ($>=20nW/cm^2/sr$).

The results for the spring migration analysis indicate potential conflict locations in Lausanne, Solothurn, Oensingen, Egerkingen, Olten, Aarau, Lugano and Belinzona (Fig. 32 A). The autumn migration analysis indicate potential conflict locations in Luzern, Fribourg, Thun, Lausanne, Geneva (Fig. 32 B). Interestingly, despite their high lighting emissions, Zurich, Basel and Bern do not appear to be areas of potential conflict, as these do not appear to be on the main migration routes.

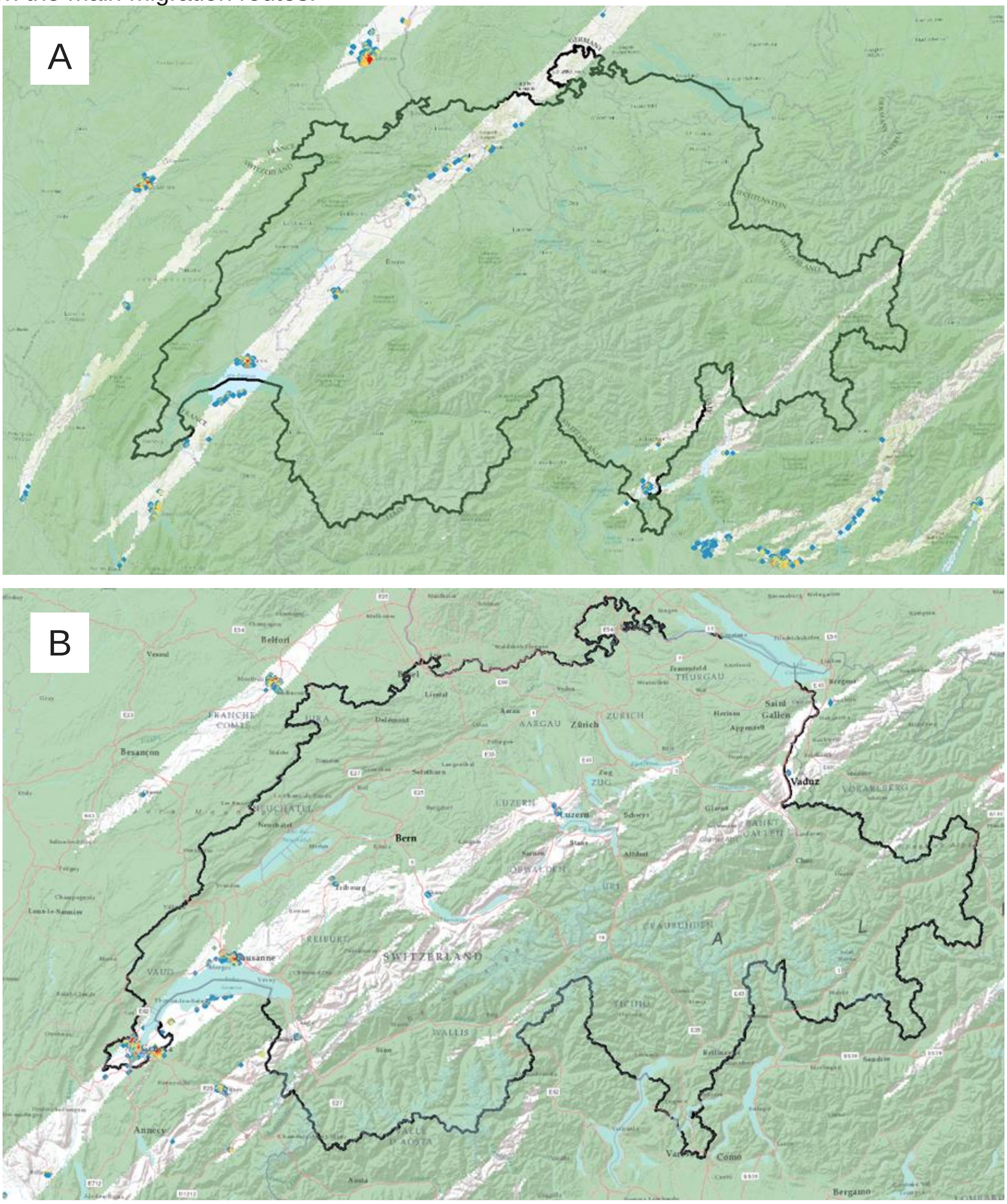


Fig.32 Main spring (A) and autumn (B) passerine migration models, overlain with location of high lighting emissions. White bands indicate the 10% of locations with the highest predicted bids density. Coloured points indicate VIIRS values >=20nW.

There are numerous caveats to this analysis that need to be recognised, to prevent the over-interpretation of this analysis. First we cannot be sure that the VIIRS data is an accurate representation of lighting emissions during the migration period because a) blue wavelengths are not detected, b) this is a monthly cloud-free composite – some strong infrequent point sources of lighting (e.g. from a concert or sporting event) may not be captured if they happen to coincide with a cloudy night, and c) VIIRS data is collected at 01:30, by which time many strong point sources of light may have been switched off. Next, we cannot be sure that the migration model is reliable under future climatic and land-use conditions, an issue that would also be a problem when using species occurrence data. As mentioned, the thresholds chosen are arbitrary – we have identified the brightest locations, but there is likely to be an emission threshold, below which any attraction effects are negligible. Finally, it is not clear at what spatial scale this attraction takes place, and at what resolution birds perceive the source of emissions. For example, a high lighting emission value for a pixel in the VIIRS data may result from many dull lamps, or a single very bright lamp, yet it is possible that these scenarios may have very different levels of attraction. In addition, we have simply identified locations of high bird density which coincide with locations of high lighting emissions, yet it is plausible that birds may detect bright lighting from some distance away, and adjust their flight direction. Despite these caveats, this analysis illustrates the principle of how a basic intersection of VIIRS and ecological data could be useful. It provides a starting point for detection locations of potential conflict, which could then be included in future research or monitoring activities.

4.2.3 3 VIIRS-based indicators of potential ecological impacts

Rather than limiting our analyses to a single intersection approach, we propose the use of three VIIRS-based indicators which capture a broader range of scales and mechanisms by which species may perceive artificial lighting: close proximity to emission sources, direct-visibility of an emission source, and skyglow. In addition, rather than attempting to model the exposure of individual species to these lighting indicators, we have chosen instead to focus upon broad land-uses of ecological value and also on specific biotopes considered national priorities for conservation.

4.2.3.1 Habitats used in analysis

We selected the following land-use types from the 72 category Swiss land use statistics 100m resolution database (Arealstatistik Schweiz – NOAS04 2004), as each potentially contains habitats of ecological value:

- **Urban green infrastructure -** Green motorway environs, Green railway environs**,** Airfields, Green airport environs, Unexploited urban areas, Public parks, Golf courses, Garden allotments, Cemeteries.
- **Agricultural land uses -** Orchards (Intensive orchards + Field fruit trees)**,** Vineyards, Horticulture, Arable land, Lowland grassland (Meadows + Farm pastures + Brush meadows and farm pastures), Alpine grassland (Alpine meadows + Favourable alpine pastures + Brush alpine pastures + Rocky alpine pastures + Sheep pastures).
- **Wooded areas** - Closed forest (Normal dense forest + Forest strips), Open Forest (Afforestation + Felling areas + Damaged forest areas + Open forest on agricultural areas + Open forest on unproductive areas) Brush forest, Other tree cover (Groves, hedges + Clusters of trees on agricultural areas) + Clusters of trees on unproductive areas).
- **Water –** Lakes, Rivers, Wetlands.
- **Low productivity habitats -** Scrub vegetation, Unproductive grass and shrubs, Rocks, Screes + sand.

In addition, we used maps of biotopes of national importance from the Swiss Biodiversity Strategy (2011), to provide an indication of impacts on habitats of particular value:

- **Amphibian spawning areas** (Amphibienlaichgebiete)
- **Fens** (Flachmoore)
- **Dry meadows and pasture** (Trockenwiesen und –weiden)
- **Alluvial** (Auen)
- **Raised bogs** (Hoch- und Übergangsmoore)

4.2.3.2 VIIRS lighting data used in analysis

For the first 2 indicators we chose to use VIIRS data from August (2016), because this appears to be the month where lighting emissions are most consistent between years, and when broad ecological impacts be might expected to be greatest. However, as illustrated above, other months may be more appropriate when modelling for a particular species or ecological process. In the absence of any published VIIRS lighting thresholds for ecological impacts, we chose three emission classes to be used in the first analysis (proximity):

- Low (emission values >=2nW/cm^2/sr)
- Medium (emission values >=10nW/cm^2/sr)
- High (emission values >=20nW/cm^2/sr).

Our justification for these thresholds is that 2nW is a typical emission for part of a small village or low-density residential area, 10NW is typical for high-density residential areas of larger towns, and 20NW is typical of more mixed uses in larger settlements. For reference, the brightest location in Switzerland in August 2016 was Zurich Airport, with a value of 110nW. Examples of the land-covers associated with these emissions are given in Fig. 33. The spatial extent of 2nW and 20nW emissions are shown in Fig. 34.

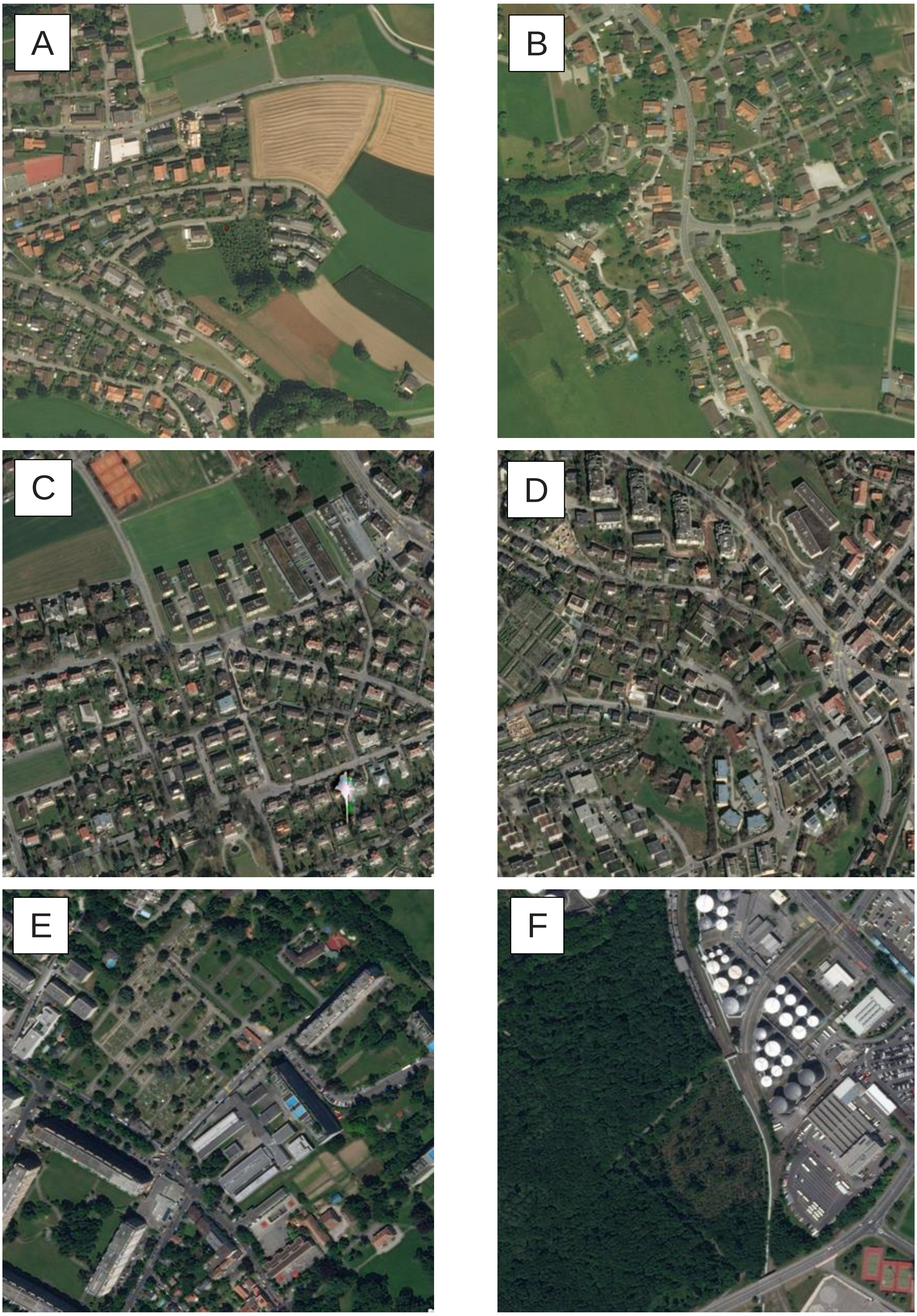


Fig.33 A) 42 white LED street lamps and B) 43 street lamps (30 LPS, 13 white LED), in low-density residential areas. A and B have a VIIRS pixel value of 2nW/cm2/sr. C) 90 and D) 101 High Pressure Sodium street lamps in high density residential areas. Both have a VIIRS pixel value of 10nW/cm^2/sr. E) 84 street lamps in an area of mixed medium-high density development. Additional lamps associated with the colleague in the centre of the image are unknown. F) 54 street lamps and unknown numbers of security and advertising lights

associated with garages and fuel storage on the urban fringe. Both E and F have a VIIRS pixel value of 20nW/cm^2/sr.

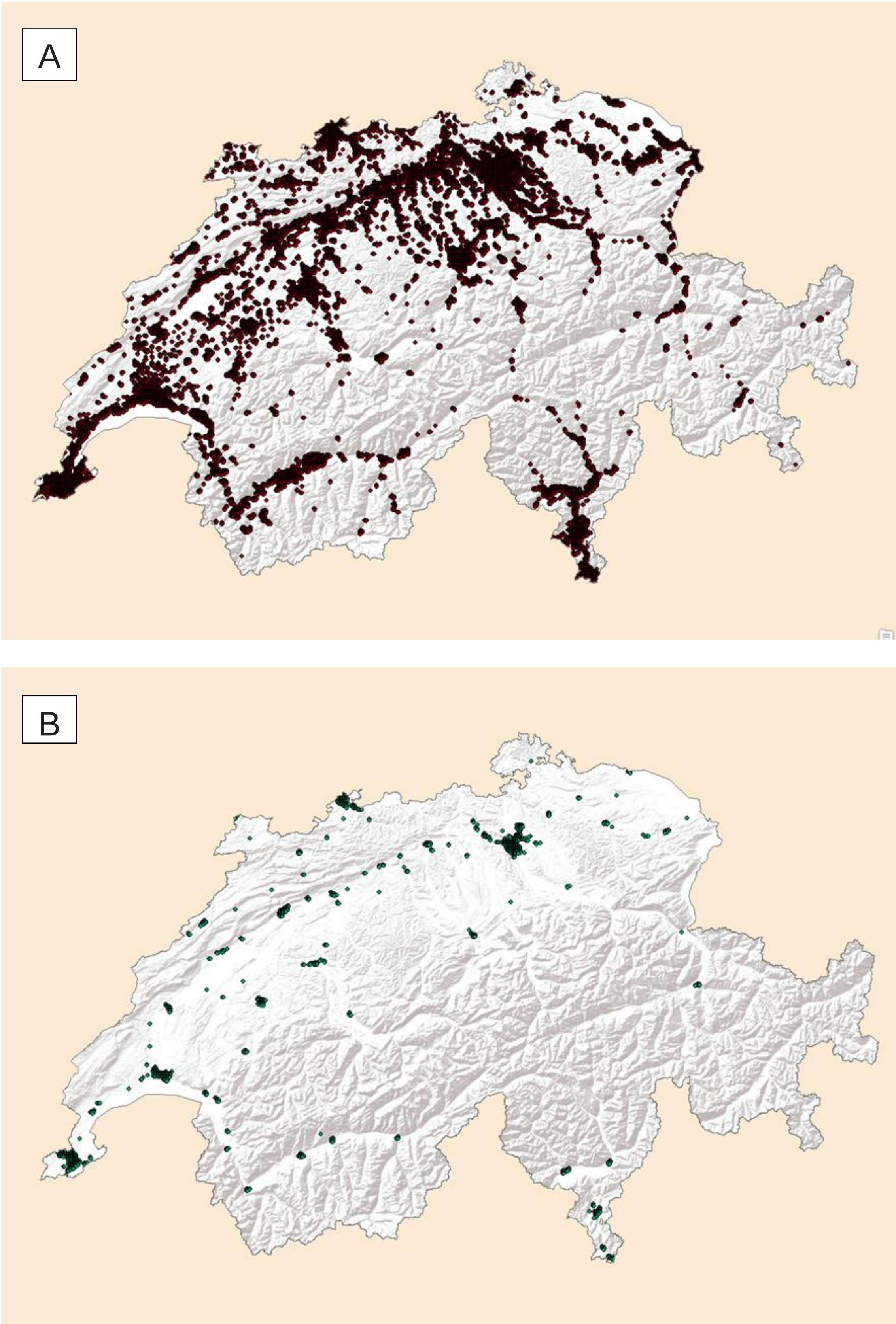


Fig. 34 A) VIIRS emissions of 2NW or more, and B) VIIRS emissions of 20NW or more

4.2.3.3 Proximity indicator analysis

From a lighting and nature conservation perspective, a key question is which habitats are close to sources of high lighting emissions? It is clear that many ecological impacts of lighting depend on proximity - how close the species or habitat is to a source of lighting. However, there is little empirical evidence for distance or emission thresholds, and threshold data that does exist typically relates to individual lamps. In the short-term, a practical and precautionary approach is therefore needed to identify *potential* problem locations – habitats adjacent to lighting sources. As there is currently no database of point sources of lighting covering the entire Swiss territory, the best option is to make use of VIIRS satellite lighting data which covers the Swiss extent on a nightly basis.

To support the monitoring of change in potential ecological disruptors, to help identify habitat types and locations where impacts might be greatest, and those which are darkest, we have developed a lighting proximity indicator using this VIIRS data. The indicator simply identifies habitats that are in close proximity to sources of light emissions. We assume that these habitats are exposed to these light sources, either with individual organisms being able to detect light emissions directly/indirectly whilst within their habitat patch, or having a high chance of encountering this lighting during some form of movement such as foraging, dispersal or migration. Analyses were undertaken in ArcGIS 10.3. Ecologically valuable land-use data were converted to a 100m point grid. Similarly, the biotope data was converted to a 100m point grid, where biotope presence values were assigned if the point was within 49m of a biotope polygon. This resulted in two comparable *habitat* point layers. The VIIRS lighting data was also converted to a point layer (500m grid), and new point layers created for the three emission classes (>=2NW, >=10NW, >=20NW). The proximity analysis was undertaken simply by counting the frequency of habitat points within 500m of VIIRS points for each emission class.

Results for proximity of land-use types of ecological value. 11% of all land-use types considered to have some ecological value are adjacent to locations with at least low levels of lighting emissions. Agriculture and wooded areas seem to have the highest total area of potential exposure, at least for low-medium levels of lighting emissions (Fig.35, Table 6). This agricultural land is mostly composed of arable, meadows and farm pastures, whilst wooded areas are almost exclusively normal dense forest. In contrast, 70% of urban green infrastructure (GI) in Switzerland is potentially exposed to low levels of light emissions. For most classes of Urban GI, exposure is above 50%. Notably, over 80% of Swiss parks, cemeteries, brownfields and garden allotments are adjacent to locations with lighting emissions >= 2nW. Considering this data at an even finer level, 87% of all public parks are adjacent to lighting of 2nW or greater, with 37% adjacent to emissions >=20nW. Regarding agricultural areas, whilst 16% of all agricultural areas are adjacent to at least low levels of light emissions, this figure rises to 35% for orchards, 56% for horticulture and 68% for vineyards. Despite only occupying 4% of the total Swiss land-cover, 18% of Swiss surface water is adjacent to locations with low levels of light pollution. Selected examples are given in Figures 36-43.

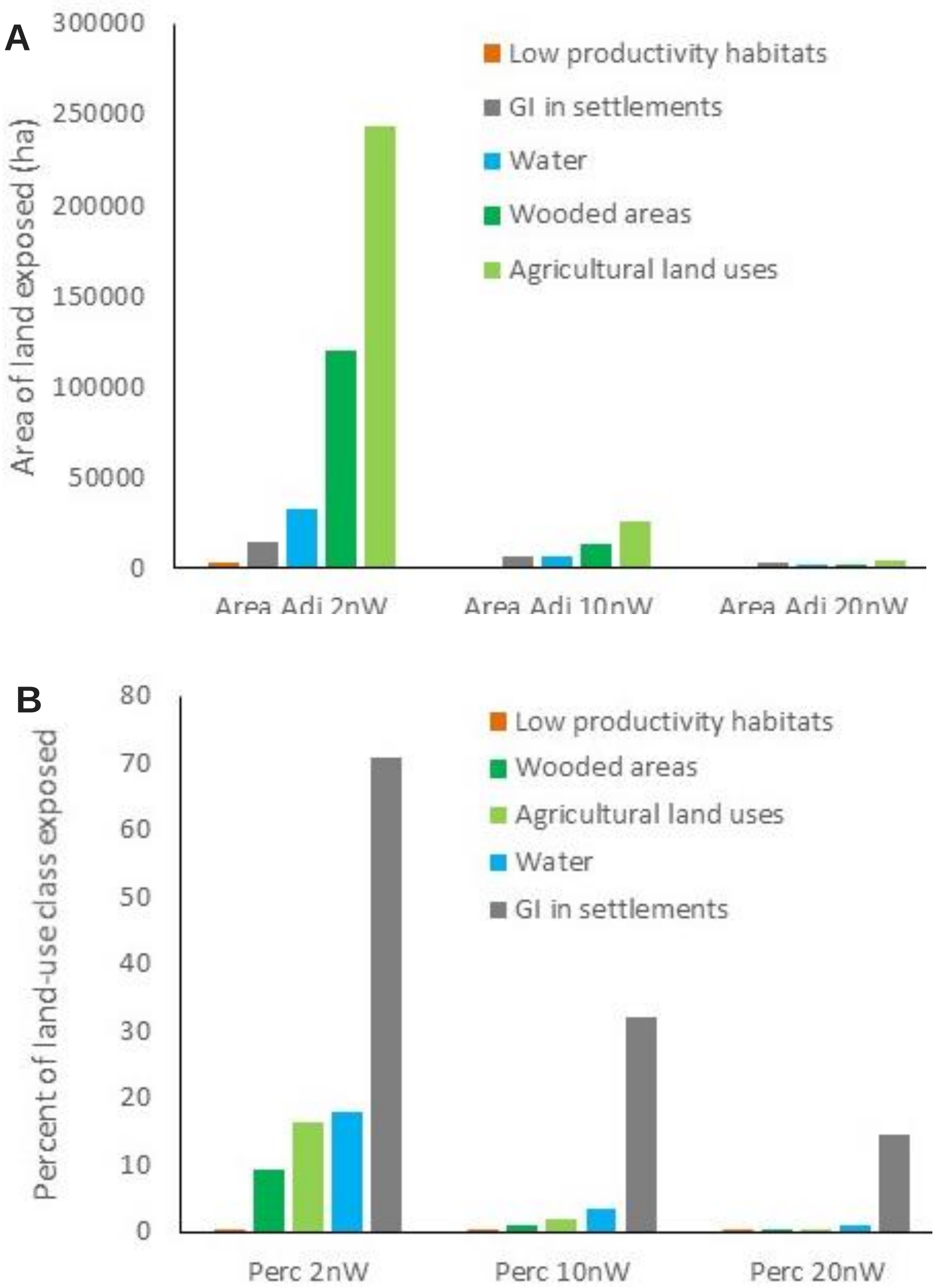


Fig.35 A) Total area of exposed habitat for each ecological land-use class, and B) area of each exposed land-use class as a percentage of total land-use class area.

Table 6 – Summary of ecological land-uses exposed to VIIRS lighting. SWISS LAND-USE AREA (HA) indicates the number of 1ha grid cells where each ecological land-use is present within Switzerland. AREA WITH BRIGHT VIEWSHED indicates the number of cells which have a view of a 20nW emission. PERC 2NW indicated the number of cells which have a view of a 20nW emission, as a percentage of the total number of cells where the ecological land-use is present.

LAND USE THEME	SWISS LAND-USE AREA (HA)	AREA ADJ TO 2NW	AREA ADJ TO 10NW	AREA ADJ TO 20NW
LOW PROD HABITATS	740,284	2,708	276	81
GI IN SETTLEMENTS	19,698	13,937	6,290	2,857
WATER	185,350	33,137	6,264	1,882
WOODED AREAS	1,293,062	120,046	13,196	2,459
AGRICULTURAL LAND USES	1,481,669	243,400	25,458	4,495
ALL ECOLOGICAL LAND-USES	3,720,063	410,520	51,484	11,774
	SWISS LAND-USE PERC	PERC 2NW	PERC 10NW	PERC 20NW
LOW PROD HABITATS	18	0	0	0
GI IN SETTLEMENTS	0	71	32	15
WATER	4	18	3	1
WOODED AREAS	31	9	1	0
AGRICULTURAL LAND-USES	36	16	2	0
ALL ECOLOGICAL LAND-USES	90	11	1	0

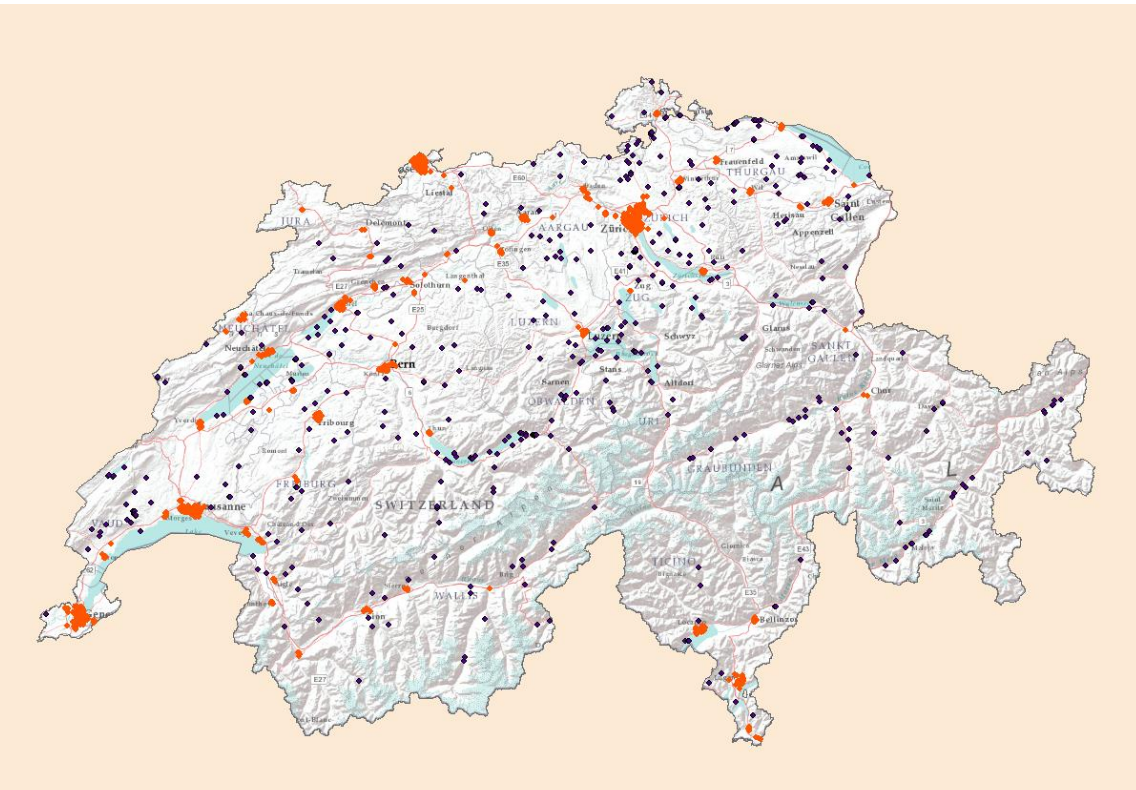


Fig. 36 Dark public parks (black points) adjacent to emissions of < 2nW, and brightly lit parks near to emissions >= 20nW.

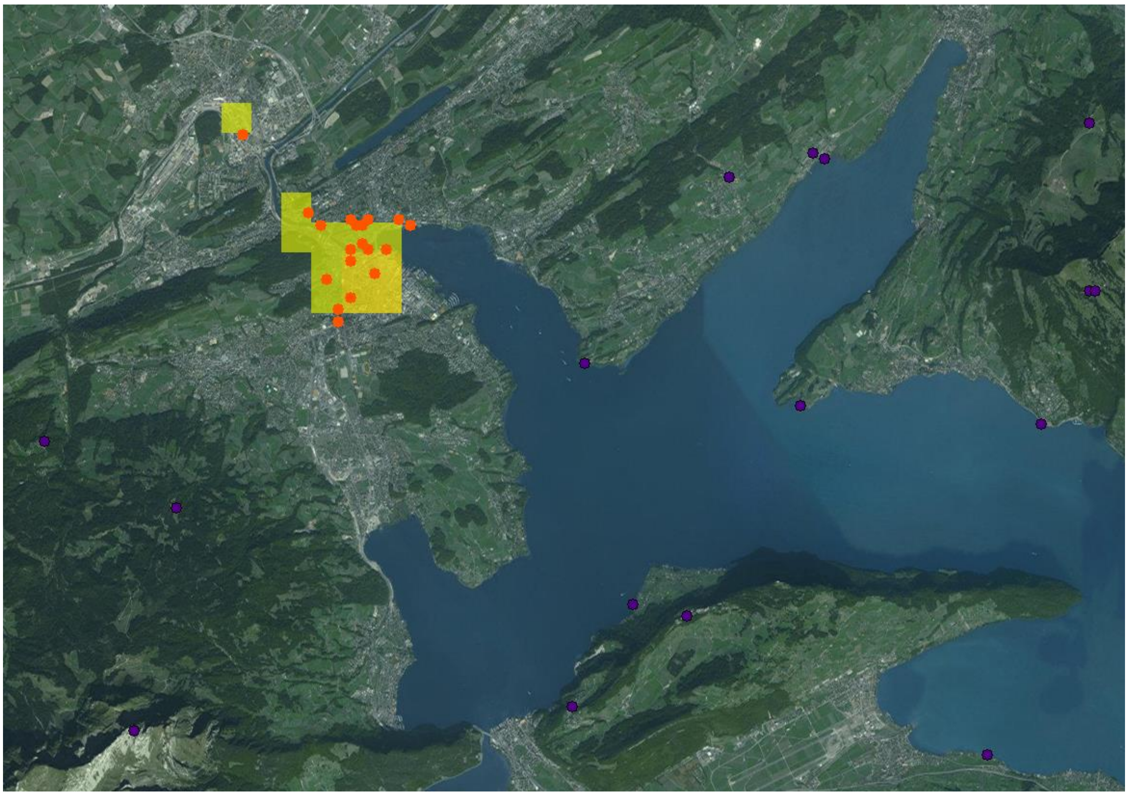


Fig. 37 An example of dark (purple points) and brightly lit public parks (orange points) in Luzern. Yellow pixels indicate locations where the VIIRS Aug 2016 data reveals emissions >= 20nW.

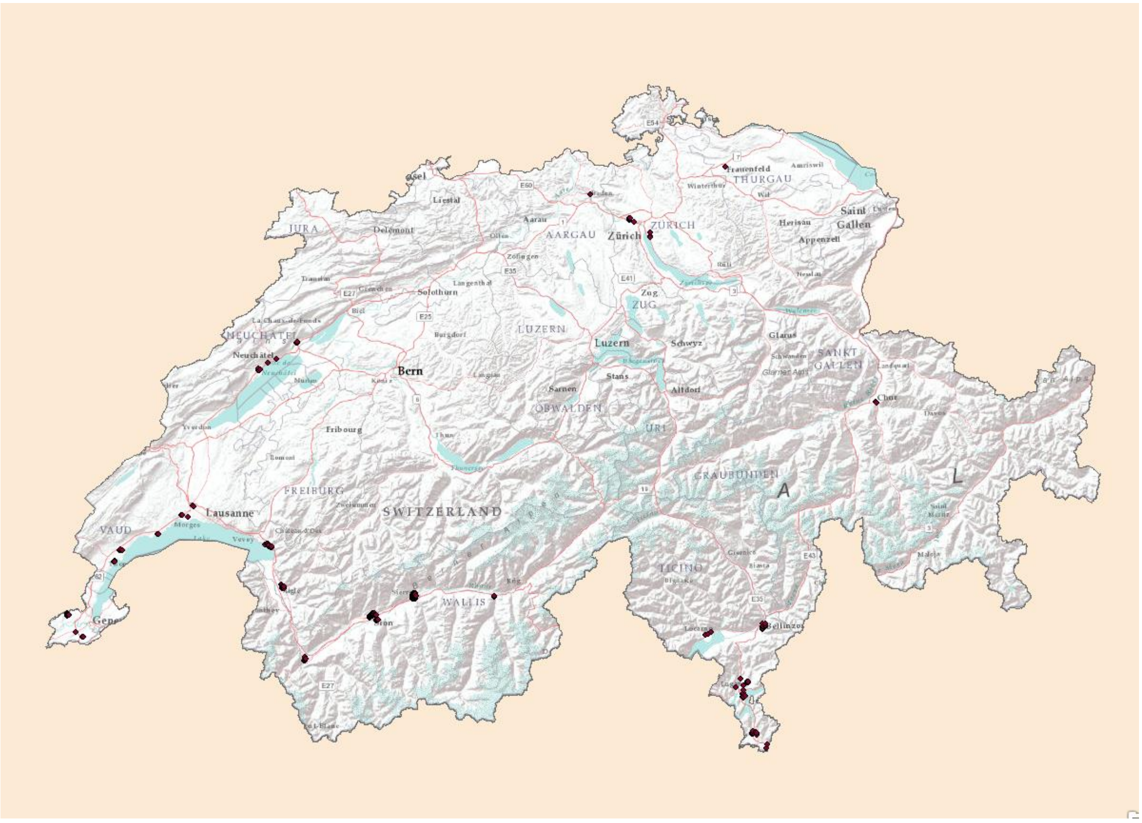


Fig.38 Vineyards adjacent to emissions of 20nW or more.

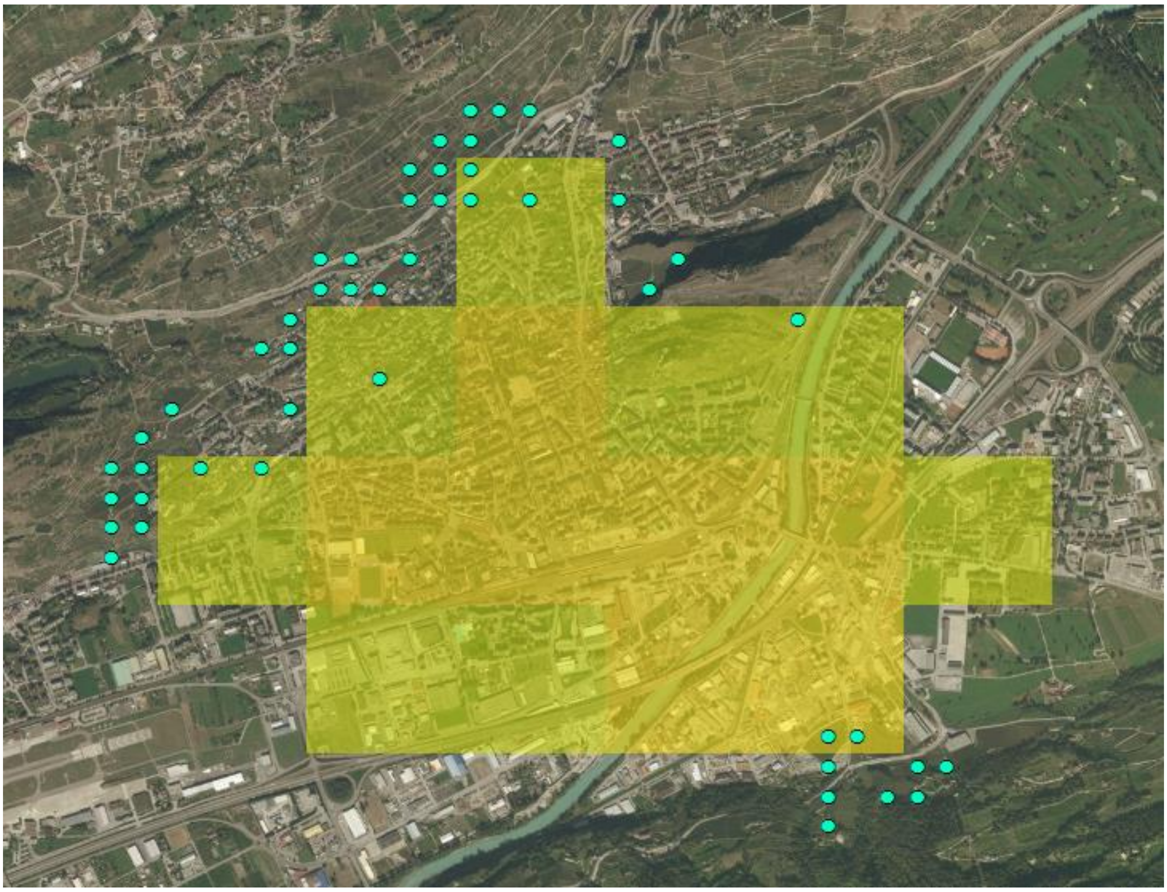


Fig.39 Example of vineyards in Sion adjacent to emissions of 20nW or more.

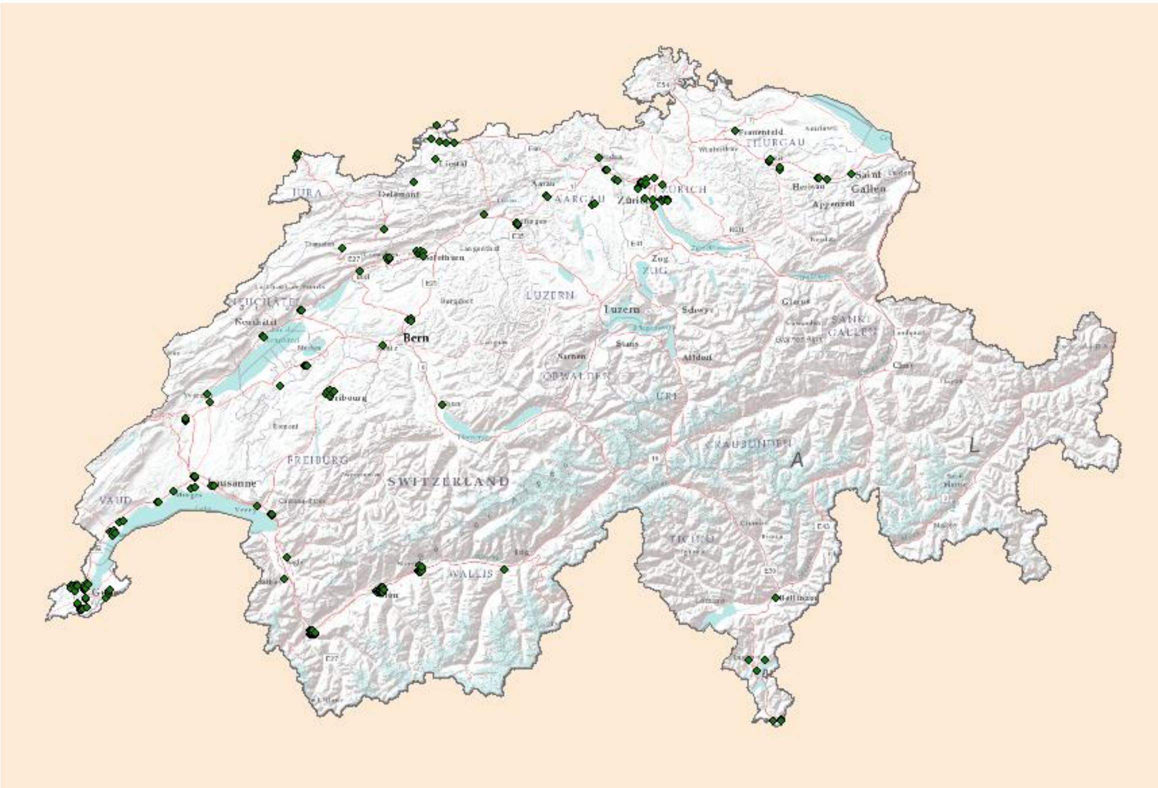


Fig.40 Orchards adjacent to emissions of 20nW or more.

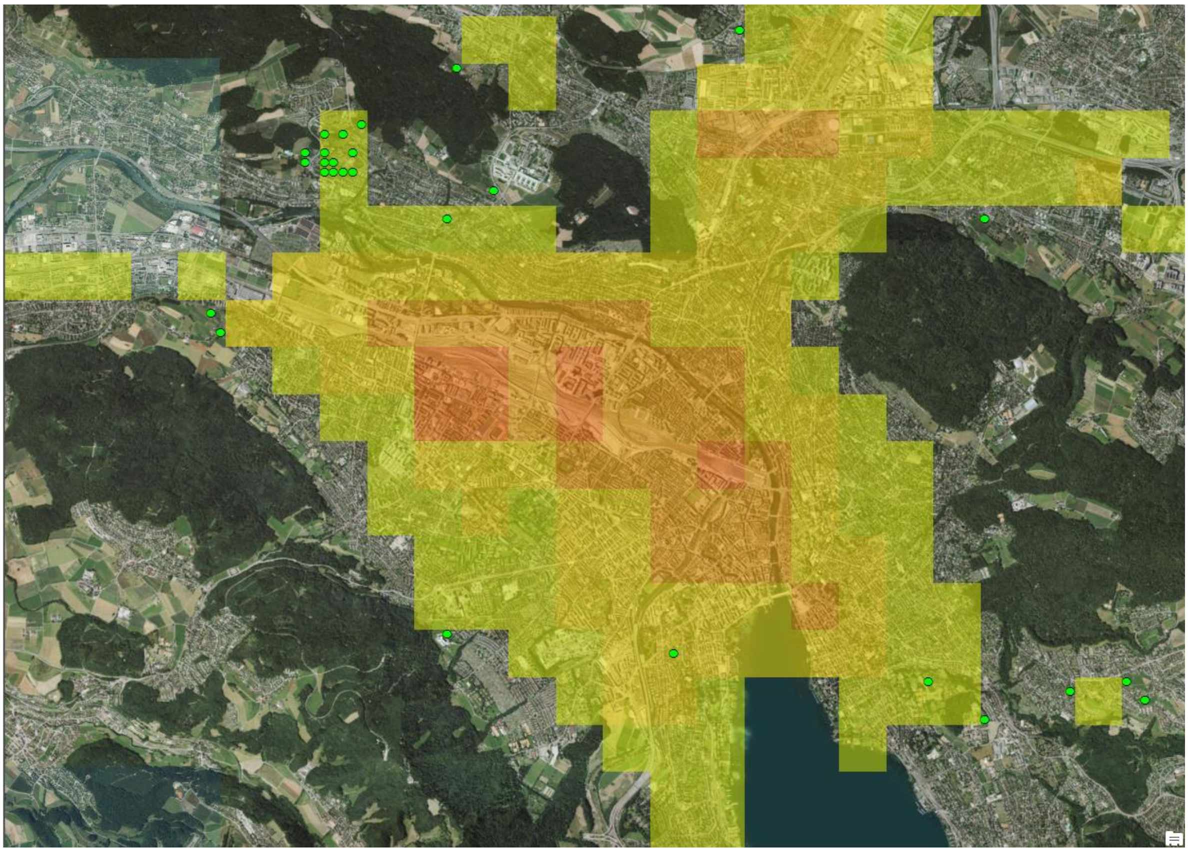


Fig.41 Orchards (green points) in Zurich adjacent to emissions of 20nW or more.

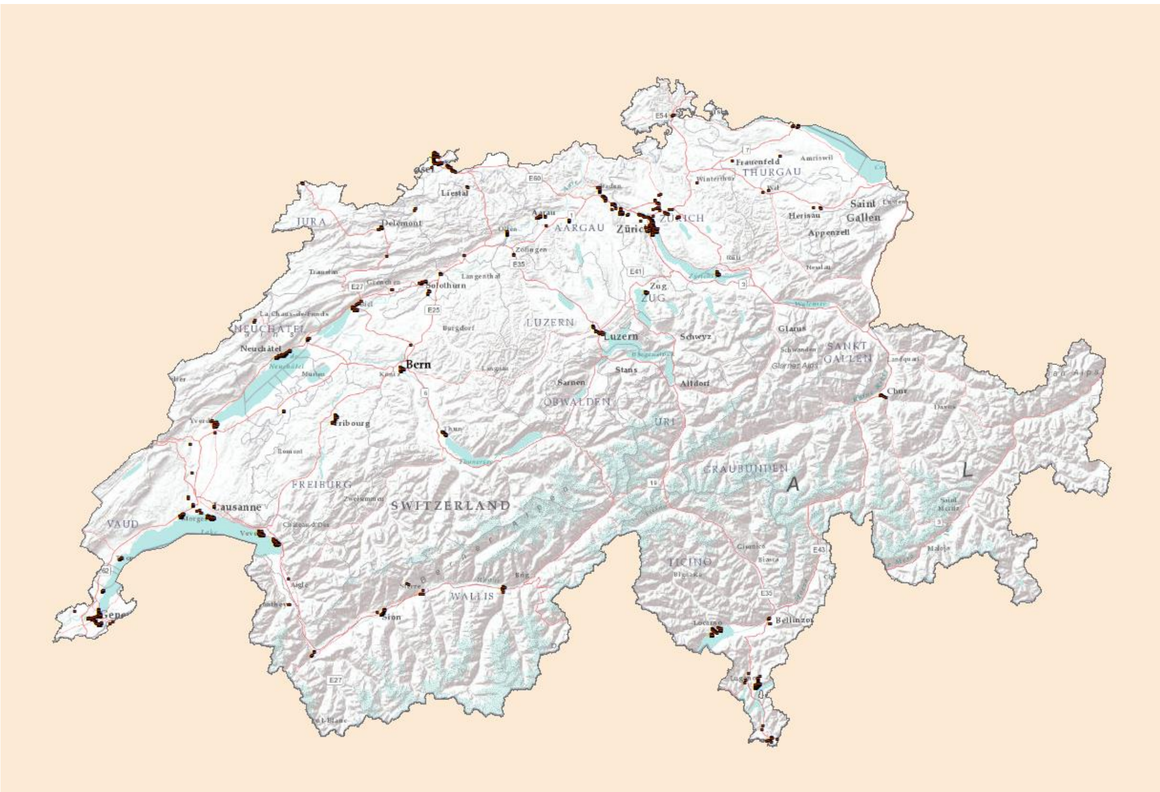


Fig.42 Surface waters adjacent to emissions of 20nW or more.

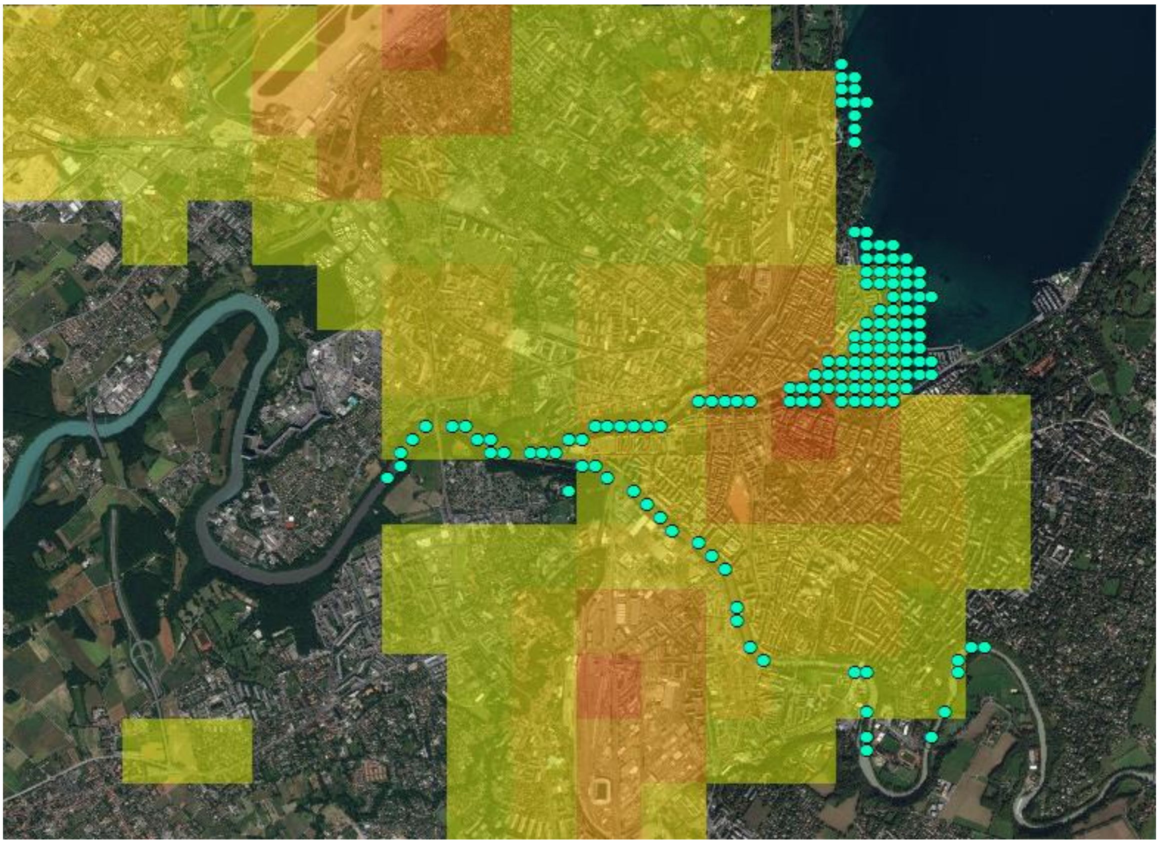


Fig.43 Example of surface waters in Geneva adjacent to emissions of 20nW or more.

Results for proximity of biotopes of national importance. Biotopes of national importance cover 5% of the Swiss land-cover. 11% of these biotopes are adjacent to locations with at least low levels of lighting emissions (Table 7). **Amphibian spawning locations** appear to have the highest level of exposure to low levels of lighting, both in terms of total area of habitat (6,300 ha) and the percentage of total Swiss spawning areas (30%). **Fens** also appear to be relatively highly exposed, with 12% of all locations adjacent to low levels of lighting. Selected examples are given in Figures 44-51. Biotopes exposed to 20nW or more can be seen in Fig. 52. Zurich and Valais have the highest number of biotopes adjacent to bright lighting emissions, but Basel-Stadt has the highest density of these biotopes (Table 8). In Zurich, the majority of biotope locations adjacent to 20nW emissions are amphibian spawning locations and fens (Fig. 53). In Valais and Basel-Stadt, all biotope locations adjacent to 20nW emissions are dry meadow and pasture.

Table 7 – Summary of Biotopes of National Importance exposed to VIIRS lighting. SWISS BIOTOPE AREA (HA) indicates the number of 1ha grid cells where each biotope is present within Switzerland. AREA 2NW indicates the number of cells where the biotope is adjacent to emissions of 2nW or more. PERC 2NW indicated the number of biotope cells that are exposed to 2nW or more, as a percentage of the total number of cells where the biotope is present.

BIOTOPE THEME	SWISS BIOTOPE AREA (HA)	AREA 2NW	AREA 10NW	AREA 20NW
AMPHIBIAN SPAWNING	2,1793	6,306	653	130
FENS	4,9877	6,012	836	168
DRY MEADOWS AND PASTURE	6,4770	4,433	468	151
ALLUVIAL	40,087	2,738	229	23
RAISED BOGS	10,398	577	61	1
ALL BIOTOPES	186,925	20,066	2,247	473
	SWISS BIOTOPE PERC	**PERC 2NW**	**PERC 10NW**	**PERC 20NW**
AMPHIBIAN SPAWNING	0.5	29	3	1
FENS	1.2	12	2	0
DRY MEADOWS AND PASTURE	1.6	7	1	0
ALLUVIAL	1.0	7	1	0
RAISED BOGS	0.3	6	1	0
ALL BIOTOPES	4.5	11	1	0

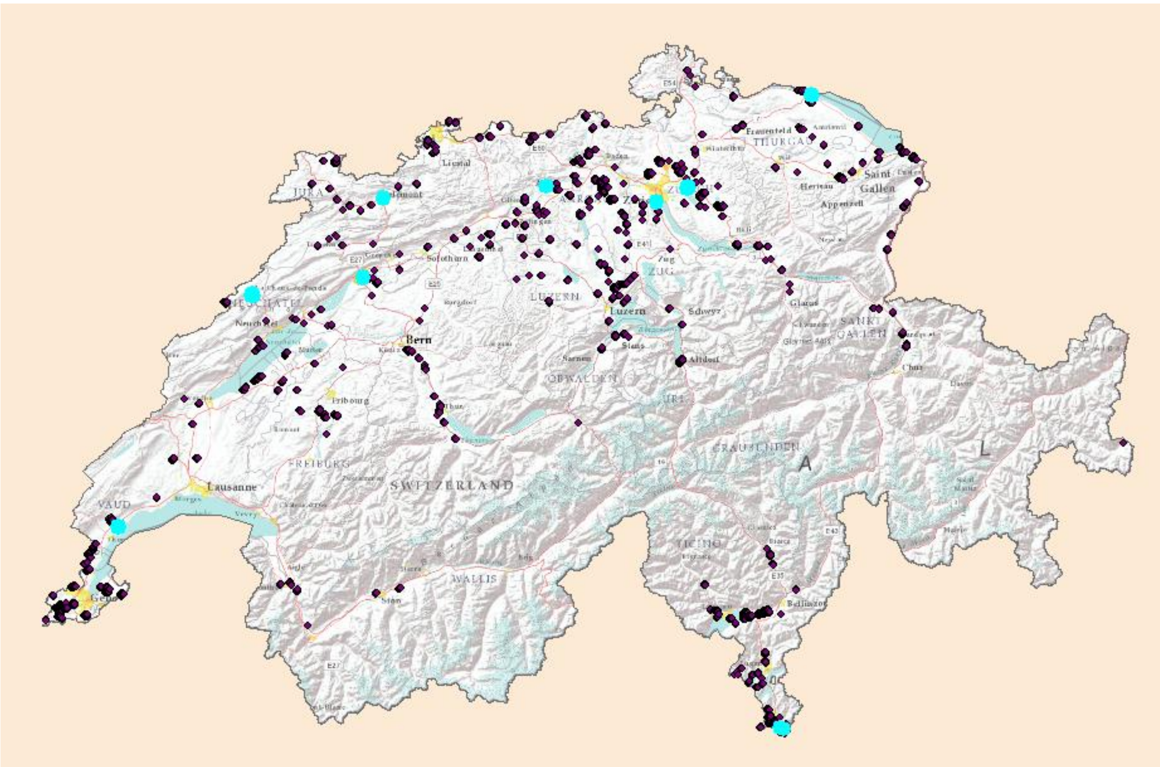


Fig.44 Amphibian spawning areas adjacent to emissions of 2nW or more. Spawning areas adjacent to emission >=20nW are highlighted in blue.

Fig.45 Example of amphibian spawning areas in Kreuzlingen adjacent to with emissions of 2nW or more. Spawning areas adjacent to emission >=20nW are highlighted in blue.

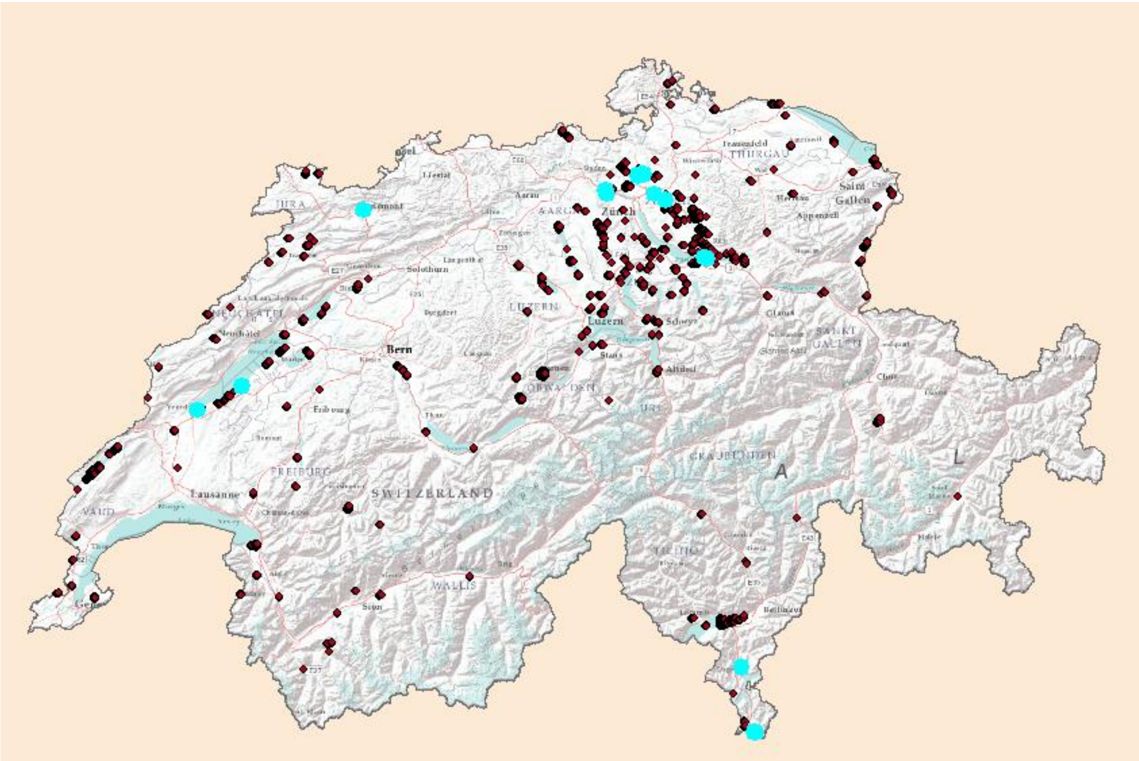


Fig.46 Fens adjacent to emissions of 2NW or more, 20NW+ locations are highlighted in blue

Fig.47 Example of Fens in Yverdon-les-Bains adjacent to emissions > 2nW. Fens adjacent to emission >=20nW are highlighted in blue.

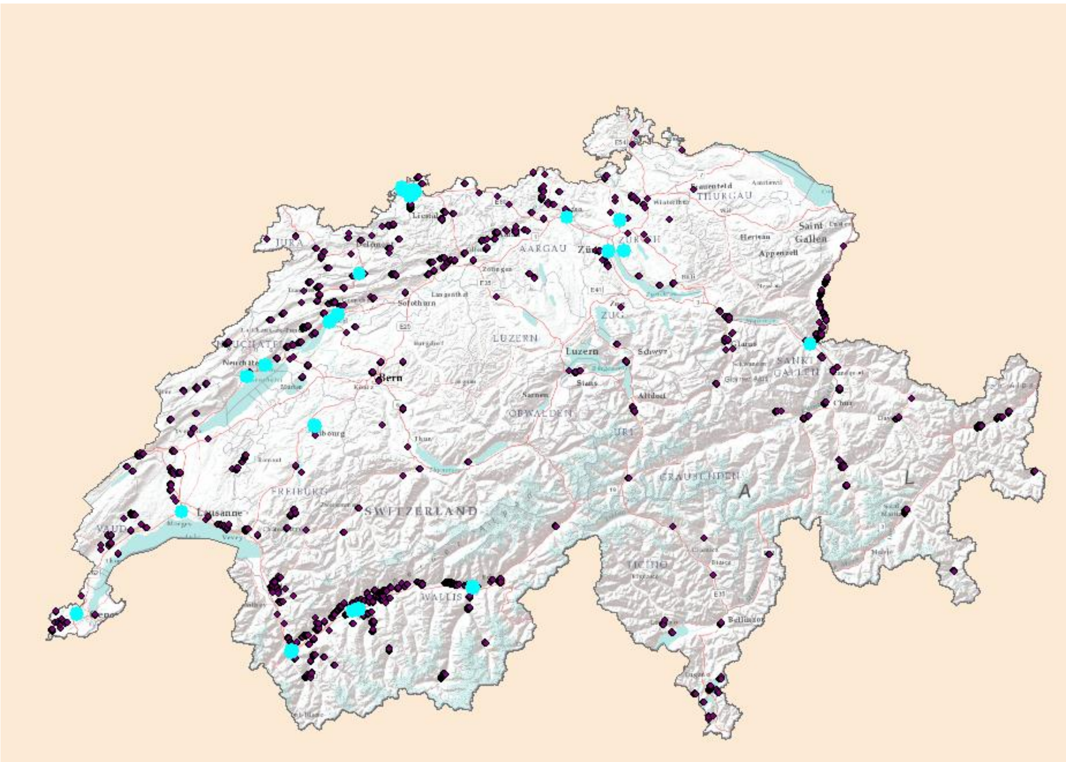


Fig.48 Dry meadows and pastures adjacent to emissions of 2nW or more. Meadows adjacent to emission >=20nW are highlighted in blue.

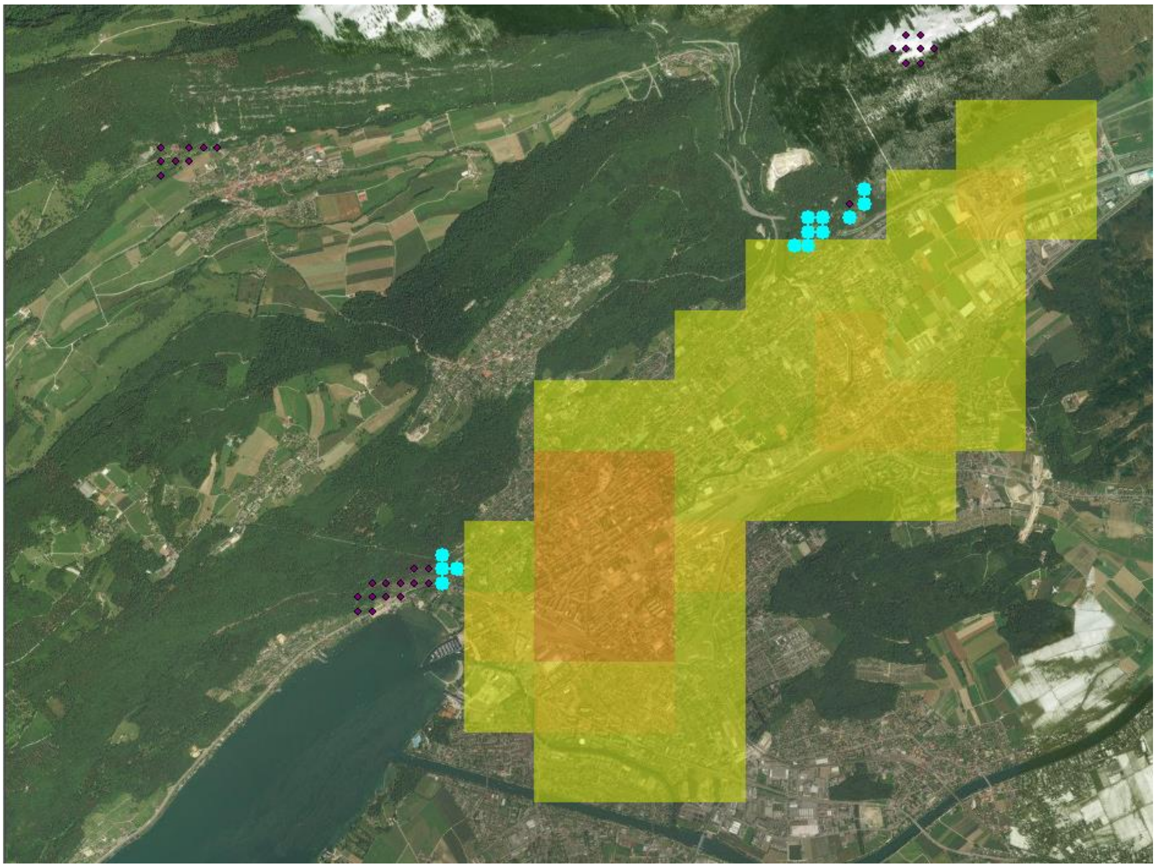


Fig.49 Example of dry meadows and pastures in Biel adjacent to emissions of 2nW or more. Meadows adjacent to emission >=20nW are highlighted in blue.

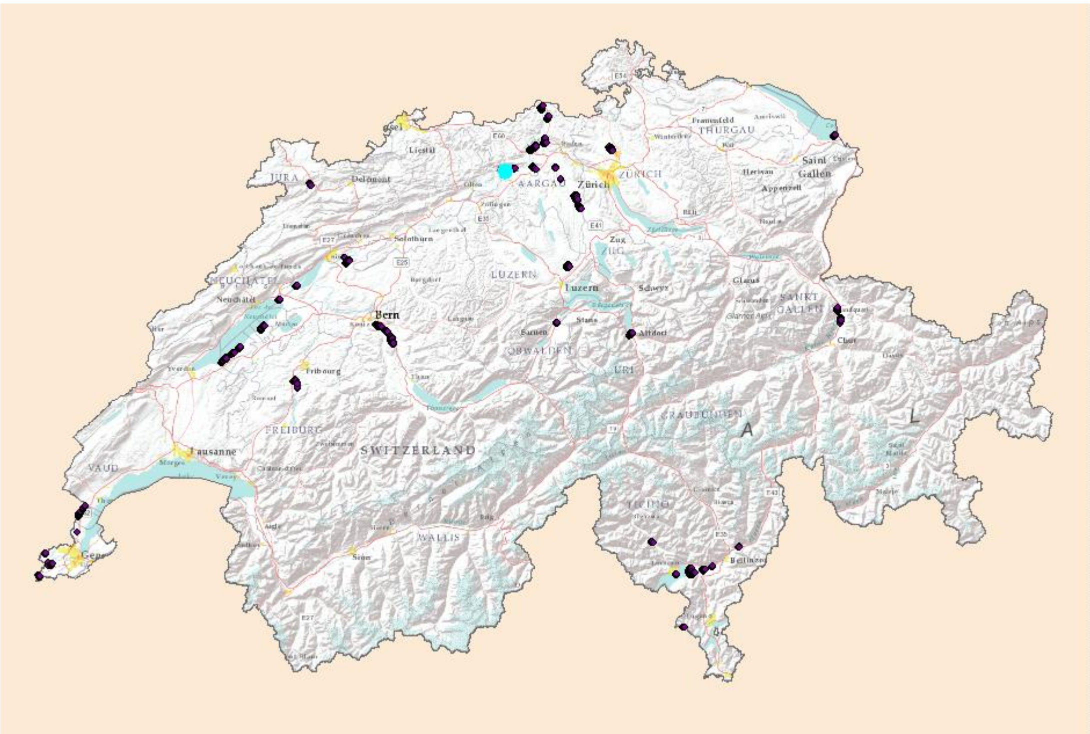


Fig.50 Alluvial zones adjacent to emissions of 2nW or more. Alluvial zones adjacent to emission >=20nW are highlighted in blue.

Fig.51 Example of alluvial zones in Aarau adjacent to emissions of 2nW or more. Alluvial zones adjacent to emission >=20nW are highlighted in blue.

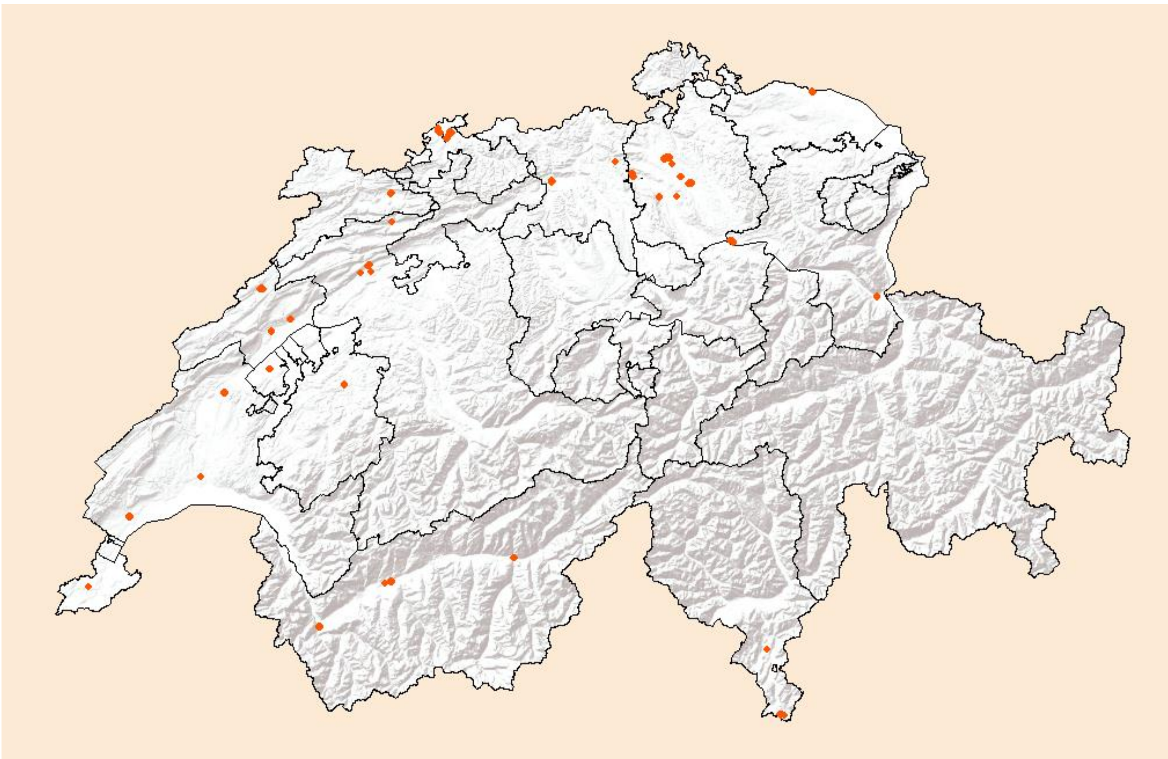


Fig.52 Biotopes adjacent to bright lighting (>=20nW).

Table 8. Number of 1ha cells containing Swiss priority biotypes that are adjacent to bright lighting (>=20nW). Column 3 adjusts for Canton area.

Canton	Canton area km2	No. biotope cells >=20NW	Density (cells/Km2)
Zürich	1729	165	0.10
Valais	5224	64	0.01
Vaud	3212	34	0.01
Neuchâtel	802	31	0.04
Ticino	2812	29	0.01
Aargau	1404	27	0.02
Basel-Stadt	37	25	0.68
Bern	5959	25	0.00
St. Gallen	2031	23	0.01
Fribourg	1671	15	0.01
Jura	839	15	0.02
Thurgau	992	8	0.01
Basel-Landschaft	518	7	0.01
Genève	282	5	0.02

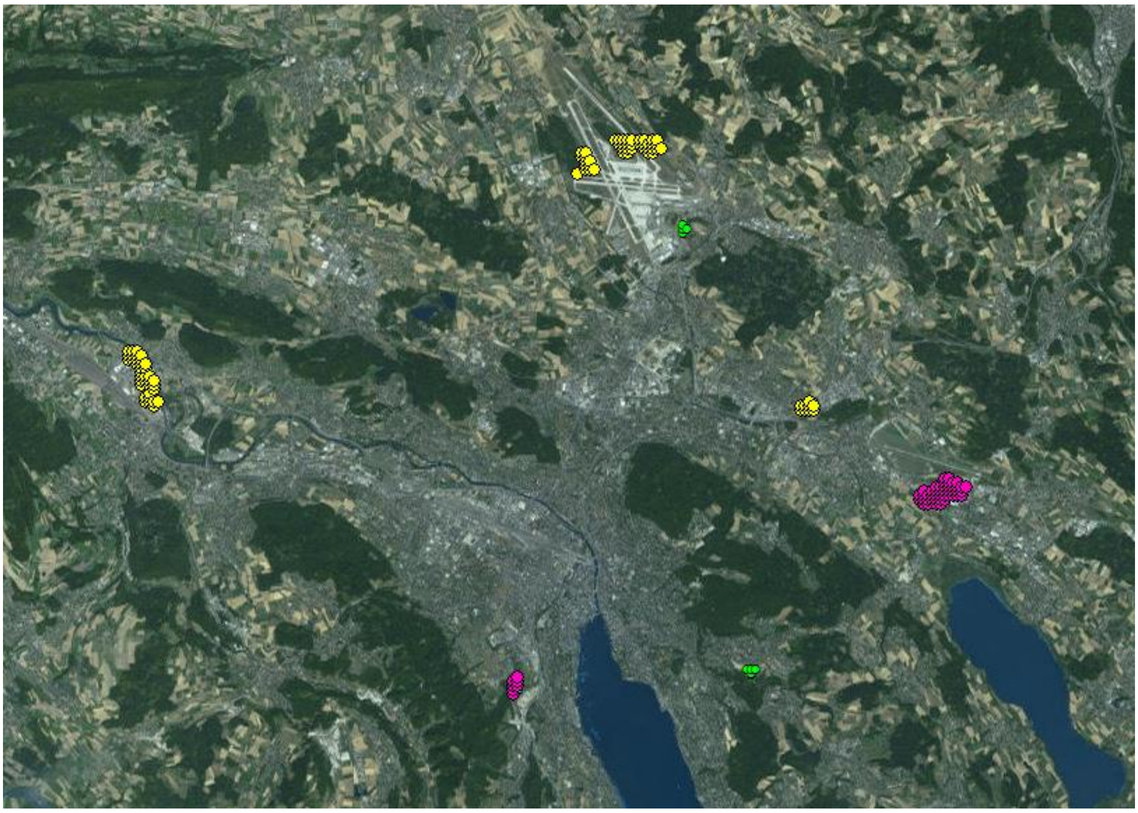


Fig.53 Swiss priority biotypes in Zurich that are adjacent to bright lighting (>=20nW). Yellow points are fens, pink points are amphibian spawning areas.

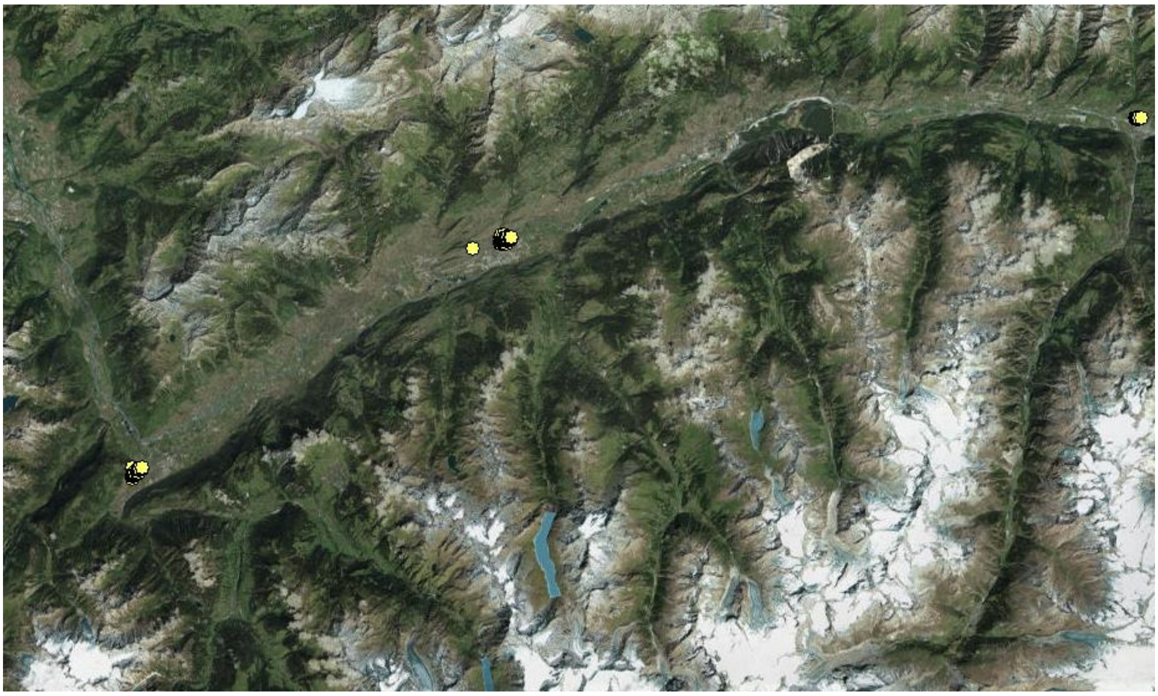


Fig.54 Swiss priority biotypes in Valais that are adjacent to bright lighting (>=20nW). Yellow points are dry meadow and pasture.

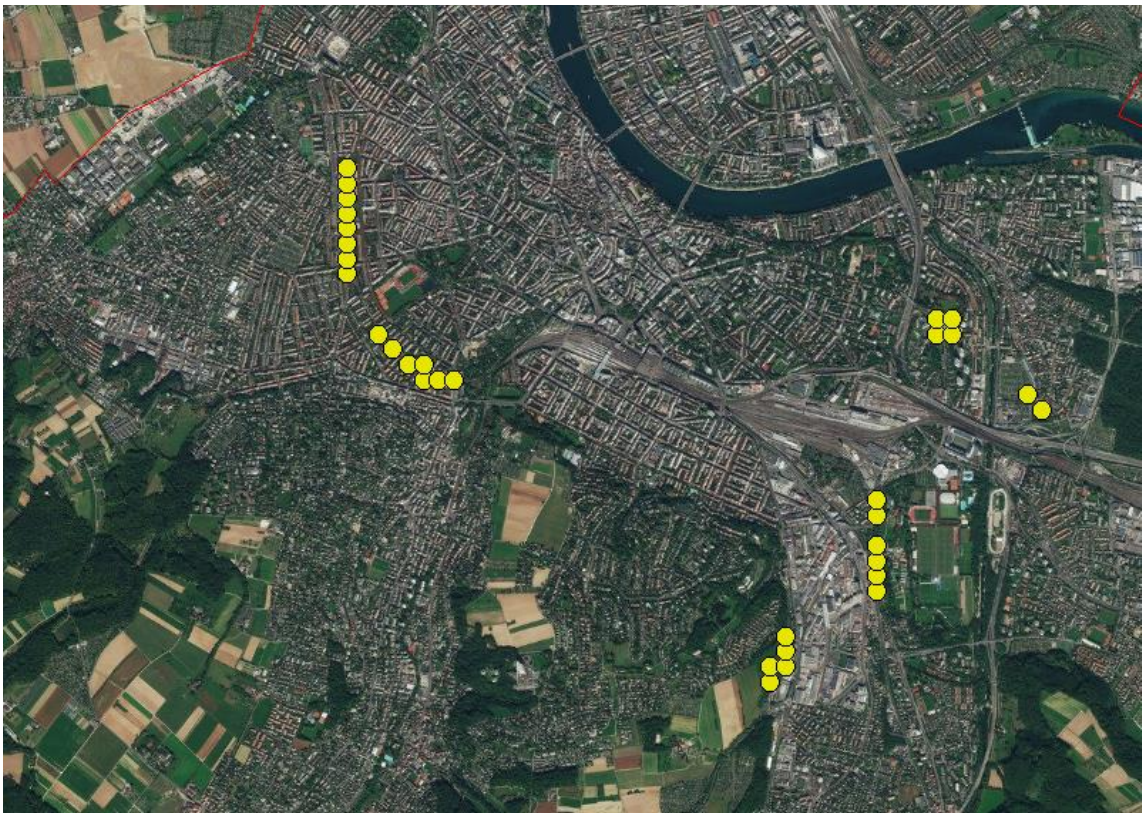


Fig.55 Swiss priority biotypes in Basel-Stadt that are adjacent to bright lighting (>=20nW). Yellow points are dry meadow and pasture.

4.2.3.4 Direct visibility of bright emission locations

Whilst the proximity of artificial lighting to a particularly light-sensitive species is clearly important, this is complicated by topography. Effects such as attraction to, or repulsion from, a strong point source of lighting depend upon the light being visible from the perspective of the species in question. For example, (Greif et al. 2014; Holland et al. 2010) demonstrate that the bat *Myotis myotis* uses the post-sunset glow on the horizon to calibrate a magnetic compass, although they disagree about whether polarization cues are relevant. It is possible that the lighting emissions from settlements at sunset, could potentially be mistaken for a perpetually setting sun, with impacts on orientation. In addition, many species are known to use the moon as a fixed reference point for orientation. However, visibility is not simply a function of the proximity or brightness of a light source; line-of-sight is an additional key variable that has so far not been included in any ecological analyses or light pollution indicator. We therefore developed a lighting indicator that recognises the effect of topography on the visibility of lighting emissions.

Two datasets were uploaded to a map document in ArcGIS. 1) EU-DEM v1.1 – a 25m pixel resolution raster height dataset for Europe produced by the EU for 2011 https://land.copernicus.eu/pan-european/satellite-derived-products/eu-dem/eu-dem-v1.1?tab=metadata. We chose to use this, rather than the Swiss DEM, as for this analysis we needed to include a 10km buffer around the Swiss boarder. 2) VIIRS lighting data for Aug 2016 clipped to a version of the Swiss boundary which had been buffered by 10km. There is little information to indicate thresholds for how bright (or close) a source of lighting needs to be before it has ecological impacts. Therefore, we took a conservative approach, identifying habitat locations where bright sources of lighting can be viewed within a relatively large radius. The VIIRS raster was converted to a 500m grid point file, and a point layer was extracted for values >=20nW/cm^2/sr, which we consider to be a level of lighting emission likely to have ecological impacts. A linear unit of 10km was selected as an arbitrary distance, which we judge to be a reasonable indicator of impact distance for some species. For the purpose of the visibility analysis, the 20nW points were treated as *observer locations*, although we interpreted the resulting map as area where these 20nW points could themselves be observed. A 10m (observer) offset was included for each light emission point, to account for the fact that much of these emissions are associated with lamps and reflecting surfaces that are not directly on the ground. An offset of 2m was included for each landscape pixel to model the viewing position of a species that is active 2m above the ground. The resulting layer was clipped to the Swiss boundary and converted to a binary (lighting visible/invisible) raster. This was then intersected with point layers representing land-uses and biotopes of ecological value and their frequency of exposure was calculated.

The model indicates that locations with emissions >=20nW/cm^2/sr are visible from 9% the total Swiss landscape. When broken down by canton, 20nW emissions are visible throughout the majority of Basel-Stadt (98%) and Zurich (86%). According to this model, no 20nW emissions are visible from within cantons Glarus, Uris or Zug (Fig.56).

Striking differences can be seen in the in models of lighting visibility surrounding flat lowland settlements such as Geneva (Fig.57 A+B), and settlements in mountainous areas such as Visp (Fig.57 C-D). This is driven by the greater abundance of bright lighting sources and flatter terrain in lowland settlements. Of particular note is the high visibility afforded by large lakes.

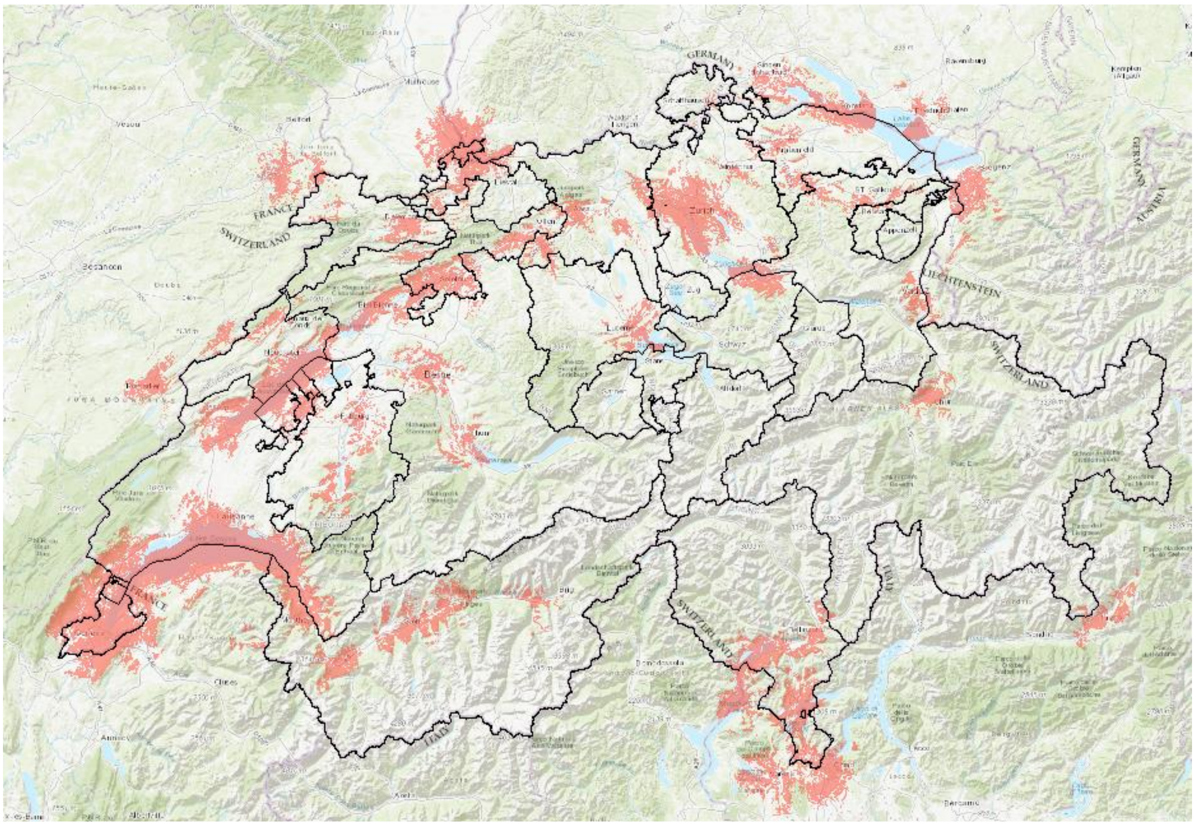
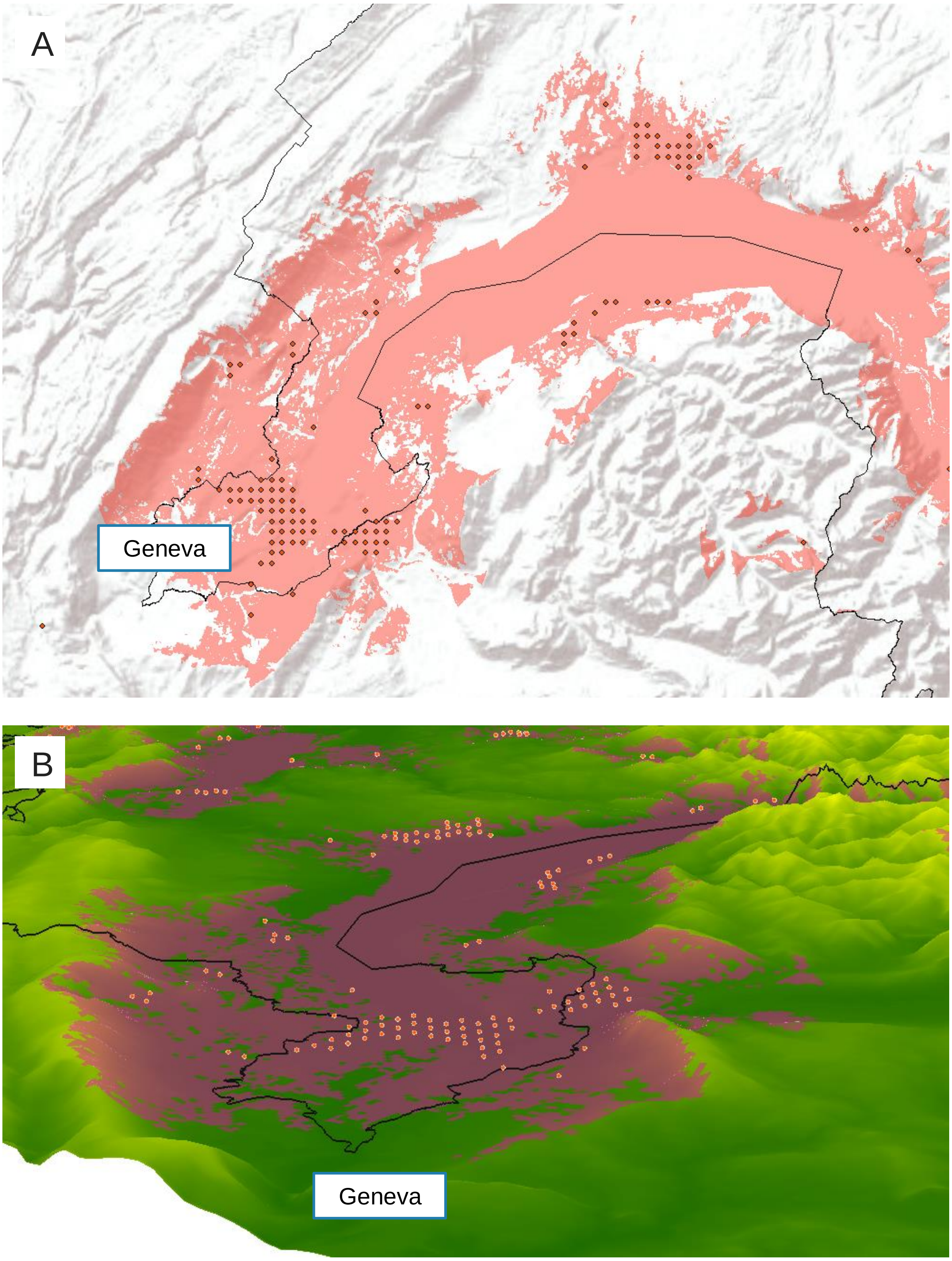


Fig.56 A binary classification of the visibility model for 20nW emission locations.



A
Geneva
B
Geneva

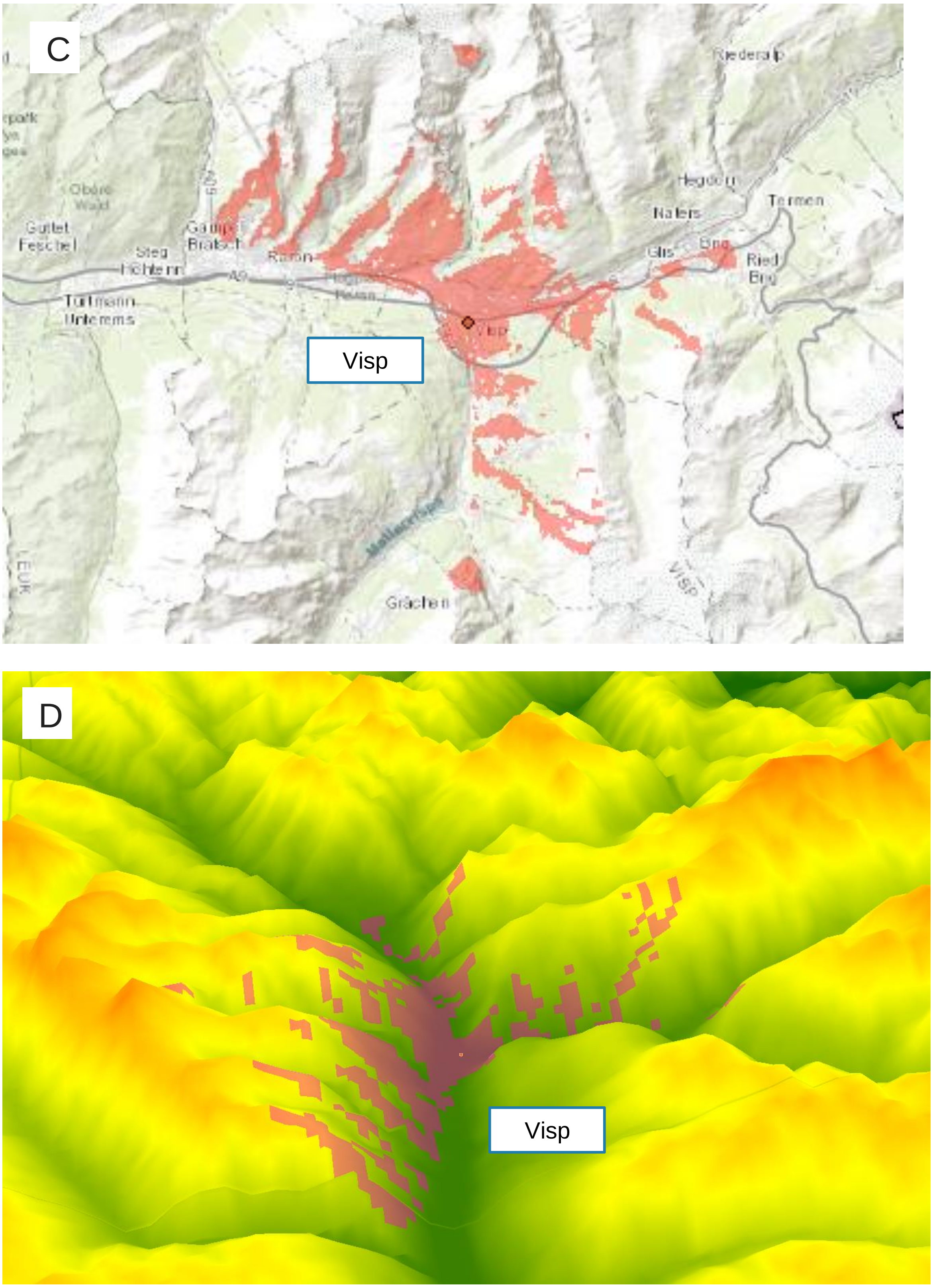


Fig. 57 A+B) Visibility model for 20nW emission locations, displayed for Geneva (lots of emission locations, flat topography) and C+D) Visp (a single 20nW emission point within a mountainous landscape). In both cases, the 3D visualisations are produced from a Westerly observer position.

Results for land-use types of ecological value with bright viewsheds. Agriculture and wooded areas seem to have the highest total areas of potential exposure to views of bright lighting emissions (Table 9). This agricultural land is mostly composed of arable, meadows and farm pastures, whilst wooded areas are almost exclusively normal dense forest. In contrast, bright lighting emissions are visible from 40% of the **urban green infrastructure** (GI) in Switzerland. Notably, this percentage is over 50% for Swiss parks, green airport environs and garden allotments. In addition, bright lighting emissions are visible from 43% of the **surface water** in Switzerland (Fig.58), mostly due to lakes (52% are exposed to such views). Whilst only 10% of agricultural areas are exposed, the percentage for **vineyards** is 49%.

Table 9 – Summary of ecological land-uses with bright viewsheds. SWISS LAND-USE AREA (HA) indicates the number of 1ha grid cells where each ecological land-use is present within Switzerland. AREA WITH BRIGHT VIEWSHED indicates the number of cells which have a view of a 20nW emission. PERC 2NW indicated the number of cells which have a view of a 20nW emission, as a percentage of the total number of cells where the ecological land-use is present.

LAND USE THEME	SWISS LAND-USE AREA (HA)	AREA WITH BRIGHT VIEWSHED	PERC WITH BRIGHT VIEWSHED
GI IN SETTLEMENTS	19'698	7'887	40
AGRICULTURAL LAND USES	1'481'669	143'327	10
WOODED AREAS	1'293'062	138'354	11
WATER	185'350	78'899	43
LOW PROD HABITATS	740'284	7'533	1
ALL ECOLOGICAL LAND-USES	**3'720'063**	**376'000**	**10**

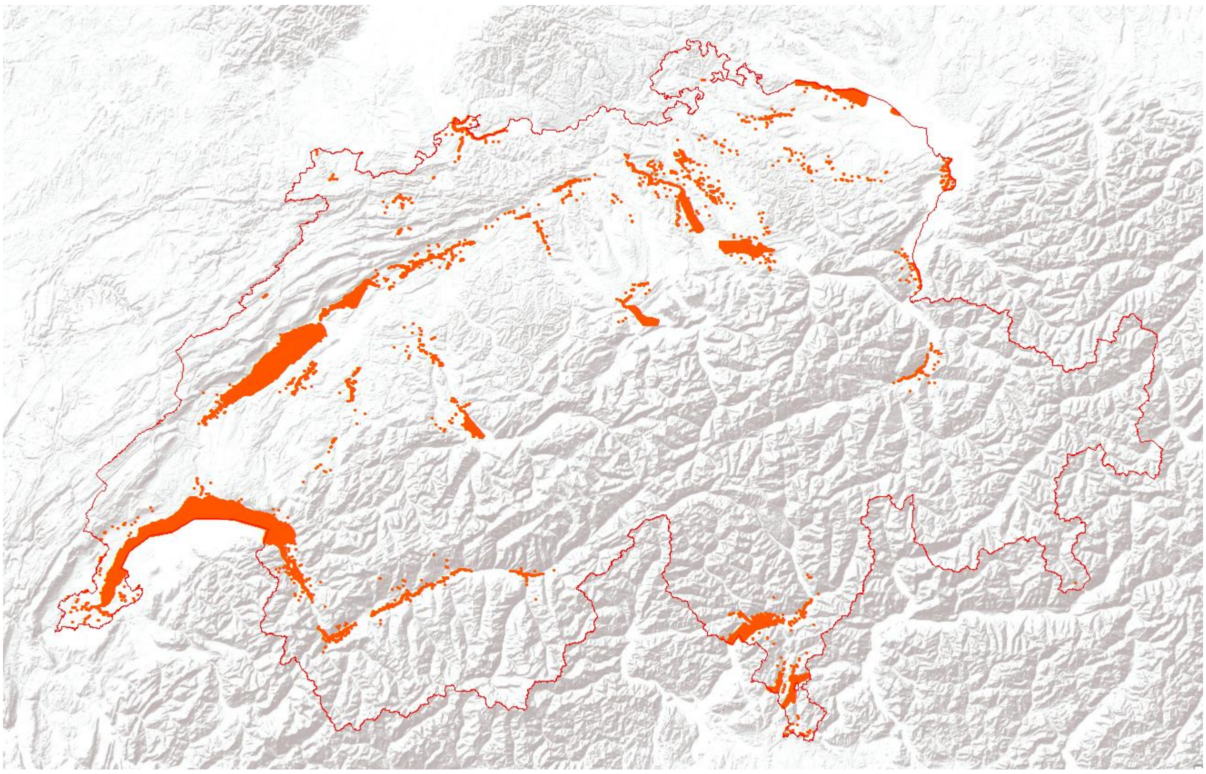


Fig.58 Surface waters in Switzerland with bright viewsheds (20nW emissions visible within 10km).

Results for biotopes with bright viewsheds. Dry meadows and pasture have the highest total areas of potential exposure to views of bright lighting emissions (Table 10). Notably, a relatively high number of amphibian spawning locations are exposed to such views, amounting to over 20% of all such habitats (Fig.59).

Table 10 – Summary of Biotopes of National Importance with bright viewsheds. SWISS BIOTOPE AREA (HA) indicates the number of 1ha grid cells where each biotope is present within Switzerland. AREA WITH BRIGHT VIEWSHED indicates the number of cells which have a view of a 20nW emission. PERC 2NW indicated the number of cells which have a view of a 20nW emission, as a percentage of the total number of cells where the biotope is present.

BIOTOPE THEME	SWISS BIOTOPE AREA (HA)	SWISS BIOTOPE PERC	AREA WITH BRIGHT VIEWSHED	PERC WITH BRIGHT VIEWSHED
DRY MEADOWS AND PASTURE	64'770	1.6	5'592	9
RAISED BOGS	10'398	0.3	111	1
FENS	49'877	1.2	2'878	6
ALLUVIAL	40'087	1.0	4'493	11
AMPHIBIAN SPAWNING	21'793	0.5	4'730	22
ALL BIOTOPES	**186'925**	4.5	**17'804**	**10**

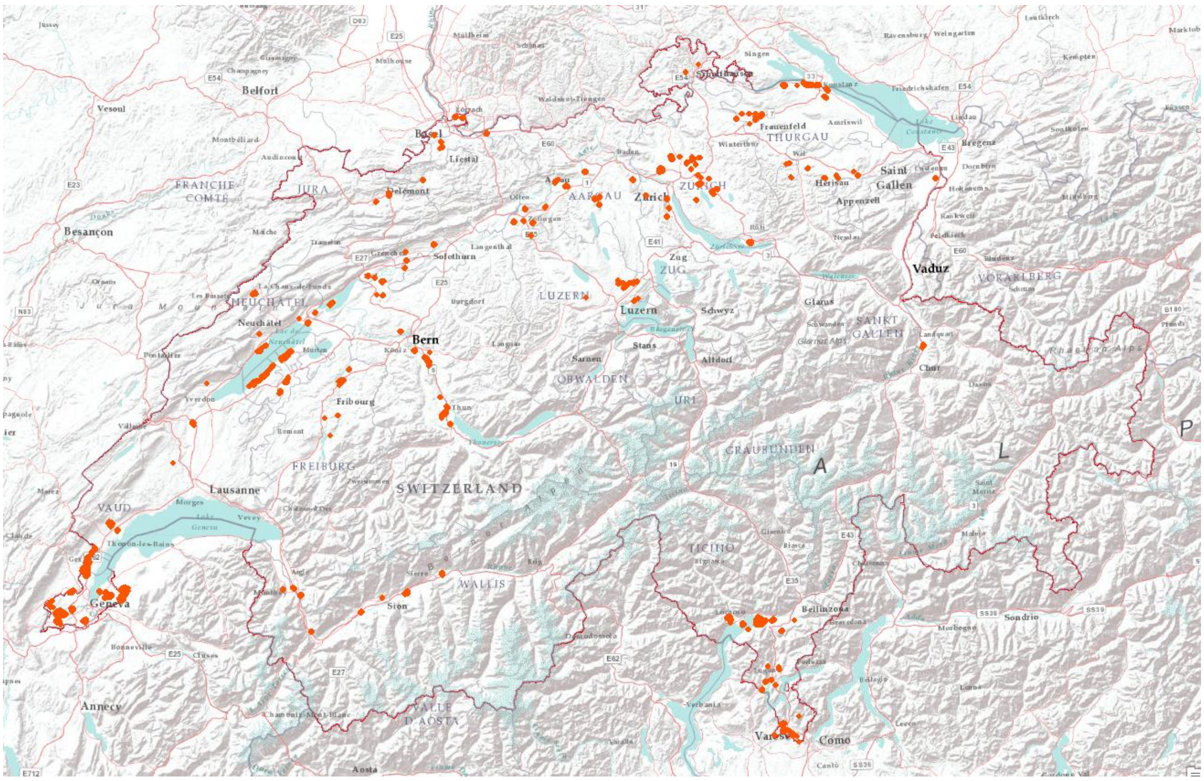


Fig.59 Amphibian spawning locations in Switzerland with bright viewsheds.

Results biotope exposure by Canton. Biotopes with bright viewsheds can be seen on the map below (Fig.60)**.** Vaud and Valais have the highest number of biotopes with bright viewsheds, but Geneva and Basel-Stadt have the highest density of these biotopes (Table 11). In Vaud, almost half the biotope locations with bright viewsheds are alluvial habitats, whilst in Valais the majority are dry meadow and pasture. The majority of exposed biotopes in Geneva are amphibian spawning locations (Fig.61). In Basel-Stadt, have of all exposed biotope locations are dry meadow and pasture and half are amphibian spawning locations.

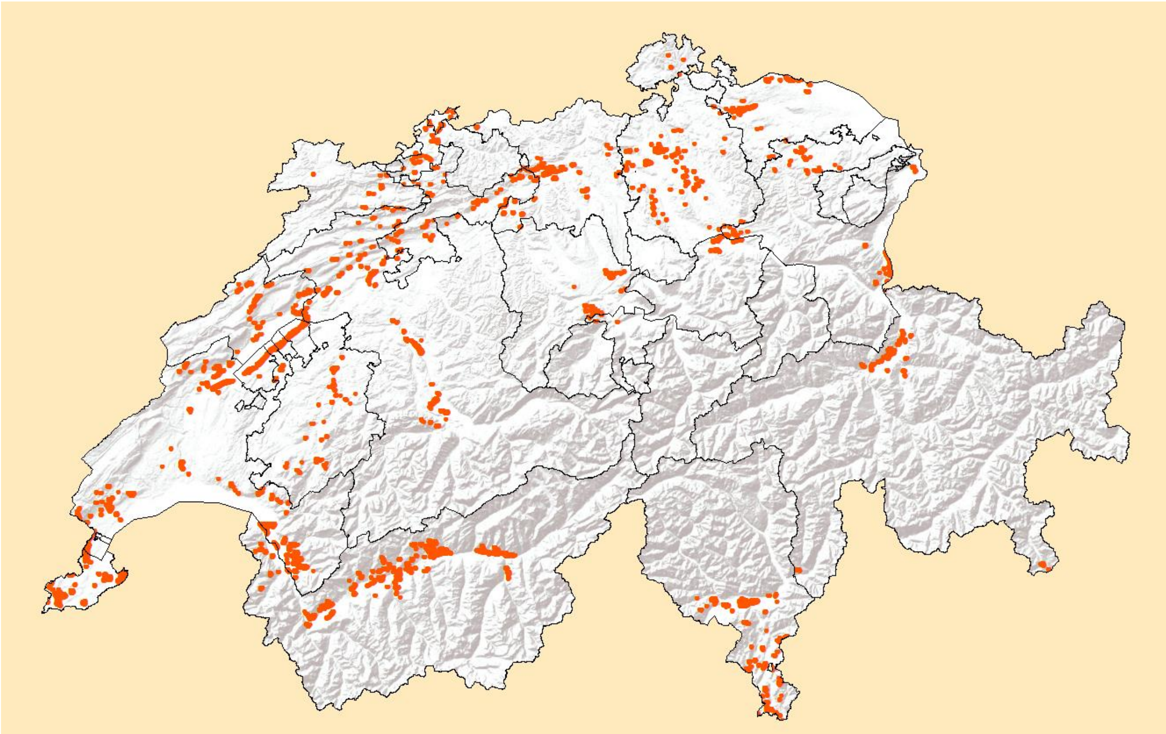


Fig.60 Biotopes with bright viewsheds (20nW emissions visible within 10km).

Table 11. Number of 1ha cells containing Swiss priority biotypes that have bright viewsheds. Column 3 adjusts for Canton area.

Canton	Canton area Km2	No. biotope cells >=20NW	Density (cells/Km2)
Vaud	3'212	4'014	1.25
Valais	5'224	2'403	0.46
Bern	5'959	1'784	0.30
Ticino	2'812	1'780	0.63
Fribourg	1'671	1'460	0.87
Genève	282	1'234	4.37
Zürich	1'729	962	0.56
Thurgau	992	688	0.69
Aargau	1'404	644	0.46
St. Gallen	2'031	489	0.24
Neuchâtel	802	486	0.61
Graubünden	7'105	437	0.06
Solothurn	790	431	0.55
Luzern	1'493	303	0.20
Schwyz	908	246	0.27
Basel-Landschaft	518	214	0.41
Jura	839	119	0.14

Basel-Stadt	37	81	2.19
Schaffhausen	298	11	0.04
Nidwalden	276	9	0.03
Obwalden	491	4	0.01

Fig.61 The majority of exposed biotopes in Geneva are amphibian spawning locations (orange points), with a few fens (yellow).

4.2.3.5 Sky brightness

A key finding from the literature review was that several Swiss priority species were sensitive to changes in the lunar cycle. Therefore, a key question is what parts of Switzerland could be considered to have a natural lunar cycle i.e. that they experience near-natural cycles in night sky brightness. We made use of the 2014 World Atlas of Artificial Sky Brightness (Falchi et al. 2016b), which was introduced in the first section of this report, within the section "Sky visibility measurements and mapping". The raster dataset represents a model of zenith sky radiance (mcd/m^2) a range of thresholds are suggested in the paper (e.g. for radiance values < 1.1 the summer Milky Way still visible), but here we use a value suggested by Cinzano et al. (2001) which suggests locations with artificial sky brightness of <0.09 are darker than a quarter moon. We therefore applied this threshold to the raster data, resulting in a zone located in the alps which we propose as an indicator of locations with a natural lunar sky brightness cycle (Fig.62). This zone was converted to a polygon, and used to identify ecologically valuable land-use locations and priority biotope locations which fell outside this zone.

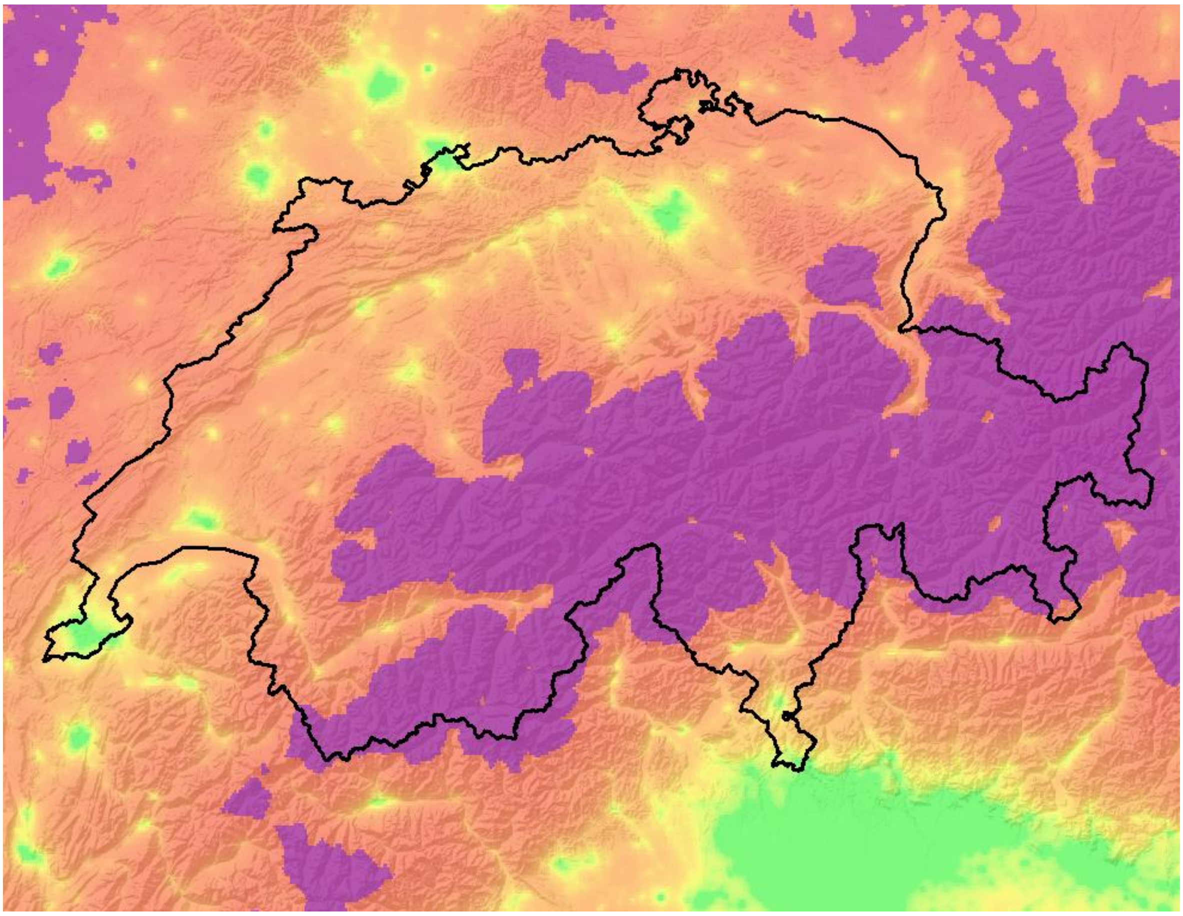


Fig.62 Simulated zenith radiance data (mcd/m^2) from Falchi et al 2016. Radiance values in this image range from 0.02 (red) to 9.91 (green). The purple zone indicates radiance values <0.09 which indicate locations with a natural lunar sky brightness cycle.

Results for sky brightness and land-use types of ecological value. 90% of all ecological land-use locations are located under bright skies, defined here as locations which do not experience natural lunar sky brightness cycles. These are mostly within the flat lowlands. **Agriculture** and **wooded areas** seem to have the highest total area under bright skies (Table 12), whilst only 9% of **unproductive habitats** (Rocks, screes, sand, scrub vegetation, unproductive grass and shrubs) were impacted. Unsurprisingly, the majority of **urban green infrastructure** (GI) in Switzerland is located under bright skies. Regarding agricultural areas, whilst the total figure is 64% this figure rises to 99% for sub-categories of **arable land, orchards**, **horticulture** and **vineyards**. Despite only occupying 4% of the total Swiss land-cover, 84% of Swiss surface water is under bright skies (91% of lakes).

Table 12 – Summary of ecological land-uses exposed to bright night skies. SWISS LAND-USE AREA (HA) indicates the number of 1ha grid cells where each ecological land-use is present within Switzerland. SWISS LAND-USE PERC indicates the area of each land-use class as a percentage of total Swiss area. AREA BRIGHT SKY indicates the number of cells which are beneath a sky where the lighting from natural lunar cycles is disrupted. PERC Bright Sky indicates the number of cells with disrupted lunar lighting cycles, as a percentage of the total number of cells where the ecological land-use is present.

LAND USE THEME	SWISS LAND-USE AREA (HA)	SWISS LAND-USE PERC	AREA BRIGHT SKY	PERC BRIGHT SKY
LOW PROD HABITATS	740'284	18	68'487	9
GI IN SETTLEMENTS	19'698	0	18'299	93
WATER	185'350	4	155'464	84
WOODED AREAS	1'481'669	36	990'775	67
AGRICULTURAL LAND USES	1'293'062	31	829'964	64
ALL ECOLOGICAL LAND-USES	3'720'063	90	2'062'989	55

Results for sky brightness and biotopes of national importance. 50% of all priority biotopes are located under bright skies (Fig.63), defined here as locations which do not experience natural lunar sky brightness cycles. Whilst dry meadows and pastures have the greatest total area impacted, Amphibian spawning areas are again identified as a highly exposed biotope, with majority of sites (93%) located under bright skies (Table 13).

Results biotope exposure by Canton. It is interesting to note that all of the biotopes within the following cantons are exposed to skyglow levels sufficient to disrupt normal lunar lighting cycles: Aargau, Basel-Landschaft, Basel-Stadt, Genève, Jura, Neuchâtel, Schaffhausen, Solothurn, Thurgau, Zug and Zürich. **Vaud and Bern** have the highest number of biotopes with bright skies, but **Geneva** and **Zug** have the highest density of these biotopes (Table 14). In Vaud, almost half the biotope locations with bright skies are dry meadows and pasture, whilst in Bern the majority are amphibian spawning locations.

Table 13 – Summary of priority biotopes exposed to bright night skies. SWISS BIOTOPE AREA (HA) indicates the number of 1ha grid cells where each biotope class is present within Switzerland. SWISS BIOTOPE PERC indicates the area of each land-use class as a percentage of total Swiss area. AREA BRIGHT SKY indicates the number of cells which are beneath a sky where the lighting from natural lunar cycles is disrupted. PERC Bright Sky indicates the number of cells with disrupted lunar lighting cycles, as a percentage of the total number of cells where the ecological land-use is present.

BIOTOPE THEME	SWISS BIOTOPE AREA (HA)	SWISS BIOTOPE PERC	AREA BRIGHT SKY	PERC BRIGHT SKY
AMPHIBIAN SPAWNING	21793	0.5	20205	93
FENS	49877	1.2	20637	41
DRY MEADOWS AND PASTURE	64770	1.6	30704	47
ALLUVIAL	40087	1.0	16675	42
RAISED BOGS	10398	0.3	5366	52
ALL BIOTOPES	186925	4.5	93587	50

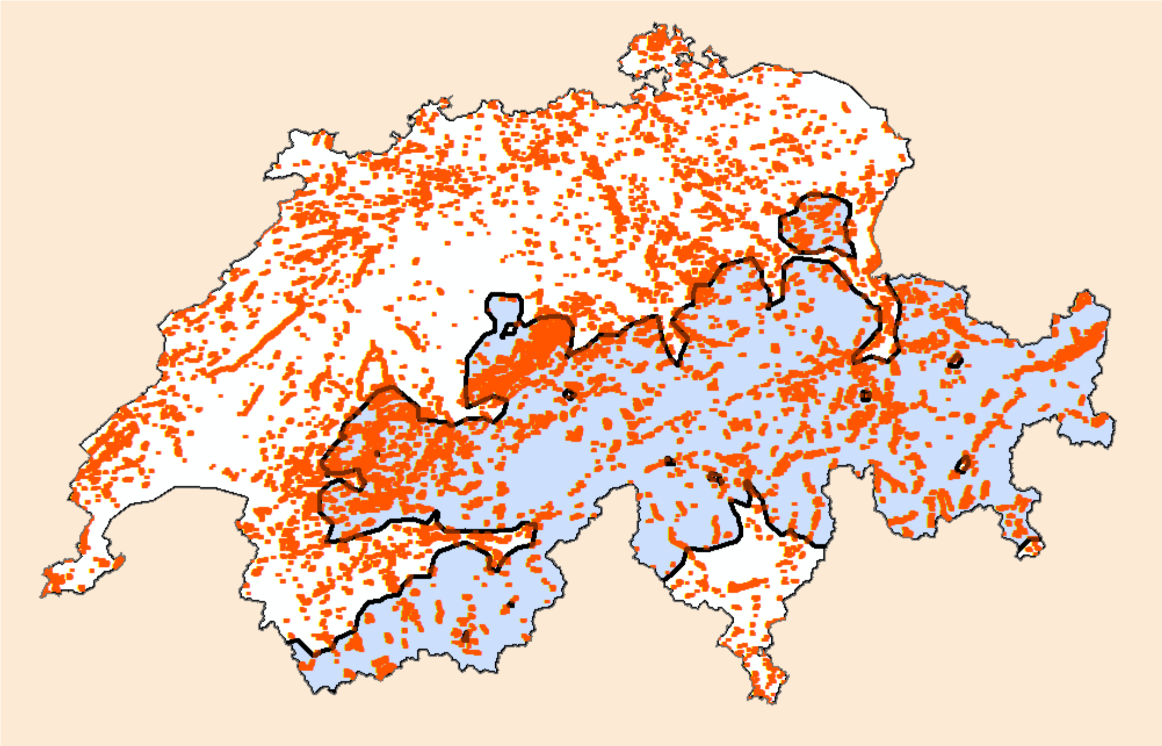


Fig.63 Purple area representing locations with a natural lunar sky brightness cycle, white area with disrupted lunar lighting cycle, overlaid with orange point locations of Swiss priority biotopes.

Table 14. Number of 1ha cells containing Swiss priority biotypes that are in locations without a natural lunar lighting cycle. Column 3 adjusts for Canton area.

Canton	*Canton area km2*	*No. biotope cells bright sky*	*Density (cells/Km2)*
Vaud	3212	14146	4
Bern	5959	10848	2
Valais	5224	7603	1
Fribourg	1671	7275	4
Zürich	1729	6798	4
Aargau	1404	5947	4
Schwyz	908	5387	6
St. Gallen	2031	5172	3
Ticino	2812	4531	2
Jura	839	3301	4
Thurgau	992	2830	3
Luzern	1493	2781	2
Neuchâtel	802	2605	3
Genève	282	2326	8
Solothurn	790	2155	3
Graubünden	7105	1998	0
Zug	239	1996	8
Basel-Landschaft	518	1198	2
Schaffhausen	298	1168	4
Obwalden	491	784	2
Glarus	685	680	1
Appenzell Innerrhoden	172	633	4

Nidwalden	276	597	2
Uri	1077	443	0
Appenzell Ausserrhoden	243	281	1

4.2.3.6 Discussion of VIIRS indicator analysis results

We know that many of the species within these habitats (and also several key processes) are disrupted by some forms of artificial lighting, and we know that many more are sensitive to some form of natural lighting cues. In the absence of detailed knowledge of the mechanisms or thresholds by which lighting impacts these habitats, we have used proximity to high lighting emissions, the presence of a bright viewshed (visibility) and sky brightness, as indicators of ecological disruption. However, an outstanding question is whether the VIIRS data is a suitable proxy for actual exposure of these habitats to artificial lighting. There are a number of factors that must be considered here. The level of direct/indirect habitat exposure does not just relate to the total luminous flux of the artificial lighting, but also to how well individual lamps are shielded, the shielding effect of buildings, vegetation and topography and the contribution of lighting sources at multiple distances. It also depends upon directionality – VIIRS data is based on upward lighting emissions from lighting directed above the horizontal plane, or reflected upward from surfaces. However, lamps shielded to prevent upward emissions would not contribute much to increase the VIIRS value (or sky brightness), but may well impact nearby habitats that are below the lamp height. Another major limitation of the VIIRS data is does not include blue light emissions – any analysis underestimates actual exposure as a result. Finally, the VIIRS data is unable to detect lighting from a few scattered streetlamps, so areas that appear dark from a VIIRS perspective, may still have some low levels of lighting. This means that for a biotope to be considered truly dark, a fourth indicator – number of lamps within a particular distance – would be needed.

Despite these limitations, it is our view that VIIRS data is probably sufficient to indicate some forms of ecological disruption, and could be a valuable strategic tool for identifying problem locations at the national scale. The next question is how to interpret the results of the analysis. Two sub-indicators are reported in the results: 1) total number of hectares of habitat potentially exposed to a particular level of lighting and 2) the % of the total Swiss habitat class exposed. The total area exposed may give an indication of habitats where lighting impacts might be most extensive/common, whilst the % of habitats impacted could give an indication of which habitats rarely experience dark conditions.

- From a **monitoring perspective**, these indicators may provide a way to detect how exposure of key habitats to lighting is changing.
- From a **nature conservation perspective**, it provides a list of locations where mitigation might be targeted, and additional protections sought. For example, consideration should be given to reducing emissions and/or screening of lighting near to several dry meadows and pastures identified in Basel-Stadt that are located near to locations with very high emissions.
- From a **planning perspective**, a list of the darkest priority biotopes would also be useful – with the aim of restricting the lighting within any new, adjacent developments.
- From a **research perspective**, protecting the darkest biotopes would provide a useful set of control locations, which could be used to support future comparative or experimental work on light pollution impacts.

That a large area of **agricultural and wooded land-uses** are potentially exposed to nearby lighting, bright viewsheds and high sky brightness raises the question of whether known impacts of lighting on processes such as pollination within fields, or species movement along forest edges, is a widespread problem. Until recently, there has been relatively little research into the impact of lighting on these habitats, and this has been restricted to the impact of experimental lamps (Knop et al. 2017). There is therefore a need to explore whether the lighting emissions used in this analysis can actually be detected in adjacent agricultural and forest habitats, and whether any broad-scale ecological impacts can be identified (e.g. is the start of nocturnal foraging delayed under conditions of high skyglow?). It is also important to check whether the VIIRS indicators used here correlate well with ground-based measurements (e.g. by using and all-sky camera to record lit viewsheds at every biotope).

Whilst **urban parks** are not typically important sites for nature conservation, they provide a valuable habitat, particularly from the perspective of cultural ecosystem services. Information on lighting exposure is particularly relevant to informing future ecological enhancement initiatives within urban areas. For example, the parts of parks that are still dark (according to these indicators) might therefore be more suitable for targeting enhancements for light-sensitive species, such as habitat structures for mammals.

Surface waters in Switzerland would appear to be disproportionately exposed to nearby lighting, strongly lit viewsheds and sky brightness. This is likely driven by the location of several large settlements adjacent to lakes and rivers, and also their flat surfaces and surrounding topography – ensuring that even distant lighting is visible from surface waters and their riparian habitats. Given the known impacts of lighting on many aquatic and semi-aquatic species, these habitats are likely to be particularly impacted and should be the focus of greater research and mitigation efforts.

It is interesting to observe that **vineyards and orchards** are also highly exposed to these lighting indicators, much more so than the broader agricultural category. This may well be because as higher value and higher maintenance crops, they tend to be located close to settlements. This raises a series of questions about the potential ecological impacts. In particular, these land-uses provide a range of habitats for Swiss species of conservation concern, which are already being studied by several research groups (e.g. Woodlarks in Valais vineyards). It is plausible that these species may experience direct disruption (e.g. to circadian rhythms), or be impacted indirectly through impacts on food-webs (e.g. loss of insect prey to lamps). Such potential impacts need further investigation.

Light naïve habitats clearly exist in Switzerland according to the coarse VIIRS exposure indicators. In particular, low productivity habitats such as raised bogs have low levels of exposure. If they also have low densities of lamps, these would represent unusual light naïve habitats that should have this status protected. In addition, it is unclear whether the open nature of these habitats, combined with light naïve communities make them more sensitive in comparison to other land-uses.

It is also notable that the nature of possible impact varies with region. For example, In **Zurich**, most biotopes adjacent to bright lighting are amphibian spawning locations and fens, whilst dry meadow and pasture are exposed in **Valais**. In terms of the total number/area of biotopes impacted, **Bern**, **Valais, Vaud** and **Zurich** score highly. However, when corrected for canton size, **Geneva** and **Basel-Stad** have the highest density of impacted biotopes. This has implications for questions about light pollution mitigation and governance scales; mitigating lighting impacts might be a local priority for the canton of Geneva, but a national mitigation strategy might do better to focus on larger cantons such as Bern.

4.3 Exploration of the impact of future lighting scenarios

4.3.1 Predicting locations of change in artificial lighting emissions

Urban expansion represents a major threat to maintaining dark habitats. Whilst the nature of lighting within cities is hugely variable, it is a fair assumption that any new urban development will be accompanied by artificial lighting. To identify locations where urban expansion may threaten ecological communities, we made use of Swiss land-use scenarios developed by (Price et al. 2015). By differencing the 2009 Swiss Arealstatistik urban land-cover data from the Trend scenario for urban land-cover in 2035, we were able to identify locations in Switzerland which may be particularly at risk of urbanisation. The Trend scenario predicts an increase of 11% in built cover for Switzerland as a whole. Further analysis revealed that the greatest increases would be in the cantons of Vaud, Bern, Valais, Aargau, Zürich, and Fribourg. This suggests these cantons should be particularly careful to ensure lighting emissions are kept to a minimum. To get an indication of how many priority biotopes might be placed under additional lighting pressure due to this urban expansion, the locations of new urban areas predicted by this scenario were buffered by 500m and intersected with the biotope point locations. This revealed that amphibian spawning areas are particularly vulnerable to greater exposure to light pollution under this land-use scenario, with 29% of locations placed under additional pressure (Table 15).

Table 15. Priority biotopes within 500m of new urban development, predicted by the Trends scenario for 2035.

BIOTOPE THEME	SWISS BIOTOPE AREA (HA)	BIOTOPE AREA EXPOSED TO NEW URBAN DEV	PERC BIOTOPES EXPOSED
AMPHIBIAN SPAWNING	21'793	6'319	29
FENS	49'877	3'159	6
DRY MEADOWS AND PASTURE	64'770	6'966	11
ALLUVIAL	40'087	5'751	14
RAISED BOGS	10'398	507	5
ALL BIOTOPES	186'925	22'702	12

4.3.2 Exploring other future changes in lighting emissions

Artificial lighting is highly diverse, both in terms of its nature and application. This presents a major challenge when seeking to explore how it may change in the future. The broad question we are asking is *how might Swiss outdoor lighting emissions change in the future?*
We are interested in all types of artificial outdoor lighting which include emissions from:

- Street lamps
- Security lighting
- Sports field lighting
- Advertising and information signage
- Motor vehicles and other small forms of transport
- Lighting for outdoor work
- Decorative lighting/arts installations
- Lighting escaping from within buildings
- Specific land uses e.g. airports

We are also interested in how key characteristics of lighting may change, such as:

- Spectrum/colour temperature
- Spatial extent
- Strength of emission/luminous flux
- Temporal aspects (switch off, part-time lighting, flickering)
- Polarization
- Directionality (e.g. upward emissions)

Ideally the broad question could be addressed through undertaking structured interviews with experts from a range of fields, who may be able highlight future changes that will directly or indirectly impact outdoor lighting. These experts could be selected to cover the themes of STEEP (Social, Technological, Economical, Environmental and Political). Such interviews are outside the scope of this analysis, but we have attempted to identify a range of possible changes as outlined below.

Social. Lighting is inextricably linked to human behavior; shifts in lifestyles, social and cultural values or consumer behavior will inevitably impact outdoor lighting. Shifts are already evident in architectural lighting, whilst lighting within the Alps to support nocturnal winter sports (e.g. nighttime skiing) is relatively common. The advances in cheap solar powered LED lighting technology raise the question of whether architectural/artistic lighting will expand into new locations and whether people will identify new applications.

Technological. Whilst a range of advances are taking place in lighting design (e.g. more efficient, better shielding), other technological advances may well have indirect lighting effects. For example, with the push for driverless cars, one might expect a reduction in the need for fixed post road lighting, and the strength of car headlights. In addition, as the use of drones expands to commercial applications (e.g. small parcel delivery) one might expect that they are routed through green corridors and required to be lit, purely for safety reasons. This would therefore pose a clear risk to some species and habitats. Additional risks include a range of developments around the idea of luminous pavements which are charged by sunlight in the day, and glow during the night.

Economical. The use of lighting for fixed advertisements is commonplace, but lighting also appears to be a common component of marketing strategies for exhibitions, sporting events and even product launches. Temporary lighting installations have become relatively common within cities (e.g. projecting images on the side of buildings), but there is evidence that lighting of mountain-sides or structures in rural areas such as bridges and castles are now being undertaken as part of these marketing activities. See www.hofstetter-marketing.com/lightart.html Other shifts in areas such as agriculture may also increase lighting emissions, particularly a growth in the use of intensive greenhouse production with supplementary lighting.

Environmental. The push for a shift towards LED street lighting is driven by a range of factors. Whilst economic arguments are strong, LED lighting is also being promoted as a low-carbon form of lighting. One of the concerns with this argument is the so-called rebound effect. In the context of lighting, this means that whilst the carbon emissions required to produce one lumen of lighting are falling, more/brighter lamps are being installed because they are cheaper to run. Evidence for a lighting rebound effect is already emerging (Kyba et al. 2017).

Political. Policies have the potential to change rapidly in Switzerland, and local or national initiatives in response to any of the above drivers may result in rapid lighting change. For example, the decision to convert the street lighting within an entire canton to white LED may be implemented rapidly, with little opportunity to look at alternative lighting near to sensitive habitats. Another issue that is likely to remain in the near future is concerns about boarder security and terrorism; responses to both of these issues often involve more lighting, irrespective of whether this is evidence based.

4.4 Mitigation options

A range of lighting mitigation options are available. These include lamp removal, shielding, dimming, part-night lighting, and changing the spectra (Gaston et al. 2012b; Stone et al. 2015). However, few have been adequately tested and for some, the ecological impacts might be counter-intuitive. In the absence of strong evidence, the precautionary principle of limiting lighting applies. Broadly, this means removing unnecessary lighting, limiting the installed flux, reducing the spectral range (e.g. avoiding white lighting or lighting rich in UV), limiting the spatial extent of lighting (both in terms of the lighting spread of an individual lamp, and the density of lamps within a landscape), and limiting its duration (so called switch-off or curfew).

One technological advancement that deserves more research attention is the use of reactive lighting (e.g. in Trubschachen, Emmental). These street lights can be configured to power up, only when a vehicle or a pedestrian is nearby. We are unaware of any empirical data on their effectiveness in reducing ecological impacts. However, it is plausible that there is a threshold in their operation (how often they are activated), above which they act to repel some light sensitive species. Whilst pure speculation, it is possible that such lamps might act as ecological traps, creating dark spaces which are used as a refuge by light sensitive species… but then are suddenly lit.

Another advancement is the use of amber LED lights. Whilst the spectral signature of amber lamps can vary, an amber LED is broadly taken to have a colour temperature of less than 3000k – with low levels of blue light. They appear similar to a low pressure sodium lamp, and are now being promoted as more nature-friendly forms of lighting (see https://www.aargauerzeitung.ch/aargau/kanton-aargau/kein-scherz-in-scherz-gibts-nun-eine-strassen-lampe-fuer-fledermaeuse-129010893). It is unlikely that these lamps will be worse than the lamps they replace. However, more research is needed in order to validate some of the ecological claims made, and to test them in a broader range of habitats.

One of the problems with artificial lighting is that ecological impacts may occur far from the source of the lighting itself. Most options for removing lighting trespass or mitigating its impacts are related to individual lamps, but few solutions relate to reducing lit viewsheds or skyglow. For example, to reduce skyglow over a particular sensitive biotope would require modelling to identify the main cause (which could be a city 20km away in another canton or country) and then negotiation with the lighting managers to reduce emissions. More research is also required to explore the effectiveness of using vegetation to shield sensitive habitats from lighting, and the effectiveness of dark corridors in functionally connecting light-sensitive populations.

Interestingly, Egri et al. (2017) test the use polarized LED lights located near the water surface to attract Ephemeroptera away from an ecological (light) trap on a nearby bridge. The use of lighting to mitigate the impacts of other lights is an interesting idea that could be explored in the future. In general, reducing the level of polarized light (e.g. by reducing lighting adjacent to smooth polished surfaces) should reduce the attraction of aquatic species.

5 Report recommendations

Our recommendations are as follows:

Lighting data

- VIIRS data should be used as the replacement LABES annual indicator for lighting emissions.
- Consideration should be given to developing an additional indicator of stable luminous flux that uses just the VIIRS data from August each year, avoiding signal variation due to snow cover.
- Lamp inventories are the main tool by which research on ecological light pollution will be used in practice, but their quality, consistency and availability must be improved.
- A goal of developing and managing a Swiss-wide lamp database should be established, and citizen science approaches should be considered for supporting the mapping of lamps in semi-private land-uses or sensitive land-use types.

Ecological research

- Known impacts on priority species need to be publicised e.g. through raising awareness via national nature conservation groups.
- Lots of research gaps need addressing, particularly for mammals (other than bats), nocturnally active birds, aquatic insects, fish and amphibians.
- For priority mammal species (other than bats) any research would be welcomed!
- For bats, more research on illumination thresholds for impacts on roost emergence would be useful, given that roosts in built structures are often subjected to lighting.
- Future research on Myotis bats would benefit from using tagged/tracked individuals to be sure of their identity.
- More research is needed to look at the feeding activity of birds of prey near strong light sources, especially during passerine migration. This may require the use of radar and other tools to clarify where and when this activity is most common.
- Given the largely observational evidence of impacts on passerine bird migration, this is an area that deserves more exploration.
- Future studies could make use of a citizen science approach to survey water birds active under artificial lighting, and radar studies of birds active in the vicinity of strong light sources (e.g. stadiums), particularly during migration seasons.
- Given the impacts of moonlight on feeding, calling and dispersal for several bird species, it would be useful to understand whether such activity is triggered in parts of the landscape with high levels of skyglow.
- Given the potential strong selection pressure of lighting on some species, the opportunity should be taken to compare populations in light naïve vs. light polluted habitats.
- More research is needed to understand actual attraction distances for flying insects to individual lamps e.g. powder marking or the use of flight mills.
- Given the logistic difficulties involved in extracting individual insect species responses from community studies, an alternative would be to make direct comparisons between community level impacts of lighting in different habitat types.
- Research should focus on situations where priority species are bound to a particular location or route, and are unable to avoid exposure e.g. at nesting sites.
- Future research on Swiss priority species and lighting needs to use appropriate methodologies and publish sufficient detail, to ensure that the results are easy for practitioners to apply.
- Studies should report multiple lighting metrics, with the aim of making application and replication easier e.g.

    - Lamp metrics – distance between sample location and nearest lamp, ground illuminance and irradiance directly below lamp, lamp spectrum, lamp type/colour class
    - Exposure metrics – illuminance and irradiance measures at point sampling locations e.g. a bird feeder
    - Site metrics – publish grids of illuminance and irradiance measurements over a defined study area.
- More experimental work is needed, to give greater confidence in cause and effect.
- Given the rapid installation of LED street lights, studies should prioritise the use of white LED lamps, and compare the impact of white vs. amber LED.

Ecological impact locations and mitigation

- Better use could be made of monthly VIIRS data as a predictor variable in ecological studies, and for strategic planning for lighting mitigation.
- A national lamp databases (inventories) should be collected for habitats with known high exposure and sensitive species e.g. waterways. This would make it easier to apply much of the new and existing research results, which tend to be based around lamp presence or proximity.
- ISS images should be used to identify point sources of lighting in the vicinity of sensitive habitats, to target future research e.g. for bird migration.
- Focus mitigation and related research on locations and habitats where conflicts are likely, at present and in the future.
- Surface waters and amphibian spawning areas are disproportionately exposed to various classes of light pollution. Given the known sensitivity of amphibians, and other aquatic groups, this habitat should be prioritized for future attention.
- It appears that vineyards and orchards may also experience high levels of lighting exposure, whose ecological impacts should be explored.
- More discussion is needed about where to respond strategically – is it more effective to focus effort on protecting dark biotopes, or trying to darken ones already lit!?!
- Consider additional protection against lighting for biotopes which are currently “dark” according to the three VIIRS indicators, which may also be valuable in the future as dark control/reference locations.
- Manage risks of a rebound effect due to the cheaper cost of lighting from LED lamps, through greater awareness raising with environmental NGOs
- Close work is needed with cantons Vaud, Bern, Valais, Aargau, Zürich, and Fribourg as current and future ecological impacts are predicted to be highest here.
- Undertake structured interviews with experts from a range of fields, to clarify which future changes are likely to directly or indirectly impact outdoor lighting.
- Numerous ecological mitigation options have been proposed, but few have been tested. Therefore there is an urgency to understand their effectiveness before they become broadly adopted. Amber LED lights in particular hold some promise, but need to be fully evaluated.

6 References

Aronsuu, K., Marjomaki, T.J., Tuohino, J., Wennman, K., Vikstrom, R., Ojutkangas, E., 2015. Migratory behaviour and holding habitats of adult river lampreys (Lampetra fluviatilis) in two Finnish rivers. Boreal Environment Research 20, 120-143.

Azam, C., Le Viol, I., Julien, J.F., Bas, Y., Kerbiriou, C., 2016. Disentangling the relative effect of light pollution, impervious surfaces and intensive agriculture on bat activity with a national-scale monitoring program. Landscape Ecology 31, 2471-2483.

Barry, J., Newton, M., Dodd, J., Lucas, M., Boylan, P., Adams, C., 2016. Freshwater and coastal migration patterns in the silver-stage eel Anguilla anguilla. Journal of fish biology 88, 676-689.

Bay, C.J., Terrill, T.J., Rasmussen, B.P., Asme, 2014. AUTONOMOUS LIGHTING AUDITS: PART 1-BUILDING NAVIGATION AND MAPPING.

Beier, P., 2006. Effects of artificial night lighting on terrestrial mammals. Ecological consequences of artificial night lighting, 19-42.

Bell-Pedersen, D., Garceau, N., Loros, J.J., 1996. Circadian rhythms in fungi. Journal of Genetics 75, 387-401.

Bennie, J., Davies, T.W., Cruse, D., Gaston, K.J., 2016. Ecological effects of artificial light at night on wild plants. Journal of Ecology 104, 611-620.

Bennie, J.J., Duffy, J.P., Inger, R., Gaston, K.J., 2014. Biogeography of time partitioning in mammals. Proceedings of the National Academy of Sciences 111, 13727-13732.

Boldogh, S., Dobrosi, D., Samu, P., 2007. The effects of the illumination of buildings on house-dwelling bats and its conservation consequences. Acta Chiropterologica 9, 527-534.

Botha, L.M., Jones, T.M., Hopkins, G.R., 2017. Effects of lifetime exposure to artificial light at night on cricket (Teleogryllus commodus) courtship and mating behaviour. Animal Behaviour 129, 181-188.

Briggs, W.R., 2006. Physiology of plant responses to artificial lighting. Ecological consequences of artificial night lighting, 281-304.

Bruce-White, C., Shardlow, M., 2011. A review of the impact of artificial light on invertebrates. Buglife-The Invertebrate Conservation Trust.

Buchanan, B.W., 1993. Effects of enhanced lighting on the behaviour of nocturnal frogs. Animal Behaviour 45, 893-899.

Buchanan, T., Brook, R.W., Purvis, M.P., Davies, J.C., 2015. Quantifying Moonlight and Wind Effects on Flighted Waterfowl Capture Success During Night-Lighting. Wildlife Society Bulletin 39, 169-173.

Burton, F., Boisclair, D., 2013. Prediction of the consumption rates for juvenile Atlantic salmon (Salmo salar L.) on the scale of habitat patches: Development of empirical models based on stomach contents. Limnologica 43, 332-338.

Canario, F., Leitao, A.H., Tome, R., 2012. PREDATION ATTEMPTS BY SHORT-EARED AND LONG-EARED OWLS ON MIGRATING SONGBIRDS ATTRACTED TO ARTIFICIAL LIGHTS. Journal of Raptor Research 46, 232-234.

Ciach, M., Frohlich, A., 2017. Habitat type, food resources, noise and light pollution explain the species composition, abundance and stability of a winter bird assemblage in an urban environment. Urban Ecosystems 20, 547-559.

Cichocki, J., Lupicki, D., Bojarski, J., Wazna, A., 2015. The impact of the moon phases on winter activity of the noctule bats Nyctalus noctula. Polish Journal of Ecology 63, 616-622.

Ciechanowski, M., Zajac, T., Bitas, A., Dunajski, R., 2007. Spatiotemporal variation in activity of bat species differing in hunting tactics: effects of weather, moonlight, food abundance, and structural clutter. Canadian Journal of Zoology-Revue Canadienne De Zoologie 85, 1249-1263.

Cinzano, P., Falchi, F., Elvidge, C.D., 2001. The first World Atlas of the artificial night sky brightness. Monthly Notices of the Royal Astronomical Society 328, 689-707.

Covaciu-Marcov, S.D., Cupsa, D., Ferenti, S., David, A., Dimancea, N., 2010. Human Influence or Natural Differentiation in Food Composition of four Amphibian Species from Histria Fortress, Romania? Acta Zoologica Bulgarica 62, 307-313.

Da Silva, A., Diez-Mendez, D., Kempenaers, B., 2017. Effects of experimental night lighting on the daily timing of winter foraging in common European songbirds. Journal of Avian Biology 48, 862-871.

Davies, T.W., Bennie, J., Inger, R., Ibarra, N.H., Gaston, K.J., 2013. Artificial light pollution: are shifting spectral signatures changing the balance of species interactions? Global Change Biology 19, 1417-1423.

Davies, T.W., Duffy, J.P., Bennie, J., Gaston, K.J., 2014. The nature, extent, and ecological implications of marine light pollution. Frontiers in Ecology and the Environment 12, 347-355.

Deeming, D.C., 2008. Capture of smooth newts (Lissotriton vulgaris) and great crested newts (Triturus cristatus) correlates with the lunar cycle. Herpetological Journal 18, 171-174.

Durrant, J., Michaelides, E.B., Rupasinghe, T., Tull, D., Green, M.P., Jones, T.M., 2015. Constant illumination reduces circulating melatonin and impairs immune function in the cricket Teleogryllus commodus. Peerj 3.

Dwyer, R.G., Bearhop, S., Campbell, H.A., Bryant, D.M., 2013. Shedding light on light: benefits of anthropogenic illumination to a nocturnally foraging shorebird. Journal of Animal Ecology 82, 478-485.

Egri, A., Szaz, D., Farkas, A., Pereszlenyi, A., Horvath, G., Kriska, G., 2017. Method to improve the survival of night-swarming mayflies near bridges in areas of distracting light pollution. Royal Society Open Science 4.

Elvidge, C.D., Baugh, K.E., Zhizhin, M., Hsu, F.-C., 2013. Why VIIRS data are superior to DMSP for mapping nighttime lights. Proceedings of the Asia-Pacific Advanced Network 35, 62-69.

Embar, K., Raveh, A., Hoffmann, I., Kotler, B.P., 2014. Predator facilitation or interference: a game of vipers and owls. Oecologia 174, 1301-1309.

Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C., Elvidge, C., Baugh, K., Portnov, B., Rybnikova, N., Furgoni, R., 2016a. Supplement to: The new world atlas of artificial night sky brightness. GFZ Data Services.

Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C.C., Elvidge, C.D., Baugh, K., Portnov, B.A., Rybnikova, N.A., Furgoni, R., 2016b. The new world atlas of artificial night sky brightness. Science Advances 2, e1600377.

Falchi, F., Cinzano, P., Elvidge, C.D., Keith, D.M., Haim, A., 2011. Limiting the impact of light pollution on human health, environment and stellar visibility. Journal of Environmental Management 92, 2714-2722.

Feng, H.Q., Wu, K.M., Ni, Y.X., Cheng, D.F., Guo, Y.Y., 2006. Nocturnal migration of dragonflies over the Bohai Sea in northern China. Ecological Entomology 31, 511-520.

Fox, R., 2013. The decline of moths in Great Britain: a review of possible causes. Insect Conservation and Diversity 6, 5-19.

Franke, R., Hoerstgen-Schwark, G., 2013. Lunar-Rhythmic Molting in Laboratory Populations of the Noble Crayfish Astacus astacus (Crustacea, Astacidea): An Experimental Analysis. Plos One 8.

Fraser, N.H.C., Metcalfe, N.B., 1997. The costs of becoming nocturnal: Feeding efficiency in relation to light intensity in juvenile Atlantic Salmon. Functional Ecology 11, 385-391.

Froidevaux, J.S.P., Boughey, K.L., Barlow, K.E., Jones, G., 2017. Factors driving population recovery of the greater horseshoe bat (Rhinolophus ferrumequinum) in the UK: implications for conservation. Biodiversity and Conservation 26, 1601-1621.

Gaston, K.J., Bennie, J., Davies, T.W., Hopkins, J., 2013. The ecological impacts of nighttime light pollution: a mechanistic appraisal. Biological Reviews 88, 912-927.

Gaston, K.J., Davies, T.W., Bennie, J., Hopkins, J., 2012a. Reducing the ecological consequences of night-time light pollution: options and developments. Journal of Applied Ecology 49, 1256-1266.

Gaston, K.J., Davies, T.W., Bennie, J., Hopkins, J., 2012b. REVIEW: Reducing the ecological consequences of night-time light pollution: options and developments. Journal of Applied Ecology 49, 1256-1266.

Gaston, K.J., Davies, T.W., Nedelec, S.L., Holt, L.A., 2017. Impacts of Artificial Light at Night on Biological Timings, In Annual Review of Ecology, Evolution, and Systematics, Vol 48. ed. D.J. Futuyma, pp. 49-+.

Gaston, K.J., Visser, M.E., Hölker, F., 2015. The biological impacts of artificial light at night: the research challenge. The Royal Society.

Gauthreaux Jr, S.A., Belser, C.G., Rich, C., Longcore, T., 2006. Effects of artificial night lighting on migrating birds. Ecological consequences of artificial night lighting, 67-93.

Gillings, S., Fuller, R.J., Sutherland, W.J., 2007. Winter field use and habitat selection by Eurasian Golden Plovers Pluvialis apricaria and Northern Lapwings Vanellus vanellus on arable farmland. Ibis 149, 509-520.

Grant, R.A., Chadwick, E.A., Halliday, T., 2009. The lunar cycle: a cue for amphibian reproductive phenology? Animal Behaviour 78, 349-357.

Greif, S., Borissov, I., Yovel, Y., Holland, R.A., 2014. A functional role of the sky's polarization pattern for orientation in the greater mouse-eared bat. Nature Communications 5.

Hadderingh, R.H., Van Aerssen, G., De Beijer, R., Van der Velde, G., 1999. Reaction of silver eels to artificial light sources and water currents: An experimental deflection study. Regulated Rivers-Research & Management 15, 365-371.

Hale, J.D., Davies, G., Fairbrass, A.J., Matthews, T.J., Rogers, C.D., Sadler, J.P., 2013. Mapping lightscapes: spatial patterning of artificial lighting in an urban landscape. Plos One 8, e61460.

Hickman, C.S., Porter, S.S., 2007. Nocturnal swimming, aggregation at light traps, and mass spawning of scissurellid gastropods (Mollusca: Vetigastropoda). Invertebrate Biology 126, 10-17.

Holker, F., Moss, T., Griefahn, B., Kloas, W., Voigt, C.C., Henckel, D., Hanel, A., Kappeler, P.M., Volker, S., Schwope, A., Franke, S., Uhrlandt, D., Fischer, J., Klenke, R., Wolter, C., Tockner, K., 2010a. The Dark Side of Light: A Transdisciplinary Research Agenda for Light Pollution Policy. Ecology and Society 15.

Holker, F., Wolter, C., Perkin, E.K., Tockner, K., 2010b. Light pollution as a biodiversity threat. Trends in Ecology & Evolution 25, 681-682.

Holland, R.A., Borissov, I., Siemers, B.M., 2010. A nocturnal mammal, the greater mouse-eared bat, calibrates a magnetic compass by the sun. Proceedings of the National Academy of Sciences of the United States of America 107, 6941-6945.

Hopkin, P.J., 1985. COOT FEEDING BY ARTIFICIAL-LIGHT IN URBAN AREA DURING HARD WEATHER. British Birds 78, 108-109.

Horvath, G., Kriska, G., Malik, P., Robertson, B., Polarized light pollution: a new kind of ecological photopollution.

Inger, R., Bennie, J., Davies, T.W., Gaston, K.J., 2014. Potential Biological and Ecological Effects of Flickering Artificial Light. Plos One 9.

Kachamakova, M., Zlatanova, D., 2014. Behaviour of Eurasian Lynx, Lynx lynx (L.), in Captivity during the Breeding Season. Acta Zoologica Bulgarica 66, 365-371.

Knop, E., Zoller, L., Ryser, R., Gerpe, C., Hörler, M., Fontaine, C., 2017. Artificial light at night as a new threat to pollination. Nature 548, 206.

Kuechly, H.U., Kyba, C.C., Ruhtz, T., Lindemann, C., Wolter, C., Fischer, J., Hölker, F., 2012. Aerial survey and spatial analysis of sources of light pollution in Berlin, Germany. Remote Sensing of Environment 126, 39-50.

Kyba, C.C., Ruhtz, T., Fischer, J., Hölker, F., 2011. Lunar skylight polarization signal polluted by urban lighting. Journal of Geophysical Research: Atmospheres 116.

Kyba, C.C.M., Kuester, T., de Miguel, A.S., Baugh, K., Jechow, A., Holker, F., Bennie, J., Elvidge, C.D., Gaston, K.J., Guanter, L., 2017. Artificially lit surface of Earth at night increasing in radiance and extent. Science Advances 3.

Lang, A.B., Kalko, E.K.V., Romer, H., Bockholdt, C., Dechmann, D.K.N., 2006. Activity levels of bats and katydids in relation to the lunar cycle. Oecologia 146, 659-666.

Levin, N., 2017. The impact of seasonal changes on observed nighttime brightness from 2014 to 2015 monthly VIIRS DNB composites. Remote Sensing of Environment 193, 150-164.

Levin, N., Johansen, K., Hacker, J.M., Phinn, S., 2014. A new source for high spatial resolution night time images — The EROS-B commercial satellite. Remote Sensing of Environment 149, 1-12.

Liechti, F., Guélat, J., Komenda-Zehnder, S., 2013. Modelling the spatial concentrations of bird migration to assess conflicts with wind turbines. Biological Conservation 162, 24-32.

Luginbuhl, C.B., Lockwood, G.W., Davis, D.R., Pick, K., Selders, J., 2009. From the ground up I: light pollution sources in Flagstaff, Arizona. Publications of the Astronomical Society of the Pacific 121, 185.

Lyytimaki, J., 2013. Nature's nocturnal services: Light pollution as a non-recognised challenge for ecosystem services research and management. Ecosystem Services 3, E44-E48.

Macgregor, C.J., Pocock, M.J.O., Fox, R., Evans, D.M., 2015. Pollination by nocturnal Lepidoptera, and the effects of light pollution: a review. Ecological Entomology 40, 187-198.

Manfrin, A., Singer, G., Larsen, S., Weiss, N., van Grunsven, R.H., Weiss, N.-S., Wohlfahrt, S., Monaghan, M.T., Hölker, F., 2017. Artificial light at night affects organism flux across ecosystem boundaries and drives community structure in the recipient ecosystem. Frontiers in Environmental Science 5, 61.

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243-253.

Massey, P., Foltz, C.B., 2000. The spectrum of the night sky over Mount Hopkins and Kitt Peak: Changes after a decade. Publications of the Astronomical Society of the Pacific 112, 566.

Mathews, F., Roche, N., Aughney, T., Jones, N., Day, J., Baker, J., Langton, S., 2015. Barriers and benefits: implications of artificial night-lighting for the distribution of common bats in Britain and Ireland. Philosophical Transactions of the Royal Society B-Biological Sciences 370.

Meyer, L.A., Sullivan, S.M.P., 2013. Bright lights, big city: influences of ecological light pollution on reciprocal stream–riparian invertebrate fluxes. Ecological applications 23, 1322-1330.

Miller, S.D., Straka, W., Mills, S.P., Elvidge, C.D., Lee, T.F., Solbrig, J., Walther, A., Heidinger, A.K., Weiss, S.C., 2013. Illuminating the capabilities of the suomi national polar-orbiting partnership (NPP) visible infrared imaging radiometer suite (VIIRS) day/night band. Remote Sensing 5, 6717-6766.

Mori, E., Menchetti, M., Ferretti, F., 2014. Seasonal and environmental influences on the calling behaviour of Eurasian Scops Owls. Bird Study 61, 277-281.

Muheim, R., Moore, F.R., Phillips, J.B., 2006. Calibration of magnetic and celestial compass cues in migratory birds - a review of cue-conflict experiments. Journal of Experimental Biology 209, 2-17.

Navara, K.J., Nelson, R.J., 2007. The dark side of light at night: physiological, epidemiological, and ecological consequences. Journal of pineal research 43, 215-224.

Nightingale, B., Longcore, T., Simenstad, C.A., 2006. Artificial night lighting and fishes. Ecological consequences of artificial night lighting, 257-276.

Paavola, J., Gouldson, A., Kluvánková-Oravská, T., 2009. Interplay of actors, scales, frameworks and regimes in the governance of biodiversity. Environmental Policy and Governance 19, 148-158.

Pawson, S.M., Watt, M.S., 2009. An experimental test of a visual-based push-pull strategy for control of wood boring phytosanitary pests. Agricultural and Forest Entomology 11, 239-245.

Pawson, S.M., Watt, M.S., Brockerhoff, E.G., 2009. Using Differential Responses to Light Spectra As a Monitoring and Control Tool for Arhopalus ferus (Coleoptera: Cerambycidae) and Other Exotic Wood-Boring Pests. Journal of Economic Entomology 102, 79-85.

Penteriani, V., Delgado, M.D., Campioni, L., Lourenco, R., 2010. Moonlight Makes Owls More Chatty. Plos One 5.

Penteriani, V., Delgado, M.D., Kuparinen, A., Saurola, P., Valkama, J., Salo, E., Toivola, J., Aebischer, A., Arlettaz, R., 2014. Bright moonlight triggers natal dispersal departures. Behavioral Ecology and Sociobiology 68, 743-747.

Penteriani, V., Kuparinen, A., Delgado, M.D., Lourenco, R., Campioni, L., 2011. Individual status, foraging effort and need for conspicuousness shape behavioural responses of a predator to moon phases. Animal Behaviour 82, 413-420.
Penteriani, V., Kuparinen, A., Delgado, M.D., Palomares, F., Lopez-Bao, J.V., Fedriani, J.M., Calzada, J., Moreno, S., Villafuerte, R., Campioni, L., Lourenco, R., 2013. Responses of a top and a meso predator and their prey to moon phases. Oecologia 173, 753-766.
Perkin, E.K., Hölker, F., Richardson, J.S., Sadler, J.P., Wolter, C., Tockner, K., 2011. The influence of artificial light on stream and riparian ecosystems: questions, challenges, and perspectives. Ecosphere 2, 1-16.
Perkin, E.K., Hölker, F., Tockner, K., 2014. The effects of artificial lighting on adult aquatic and terrestrial insects. Freshwater Biology 59, 368-377.
Perry, G., Fisher, R.N., 2006. Night lights and reptiles: observed and potential effects. Ecological consequences of artificial night lighting, 169-191.
Pimentel-Souza, F., Schall, V.T., Lautner Jr, R., Campos Barbosa, N.D., Schettino, M., Fernandes, N., 1984. Behavior of Biomphalaria glabrata (Gastropoda: Pulmonata) under different lighting conditions. Canadian Journal of Zoology 62, 2328-2334.
Poiani, K.A., Richter, B.D., Anderson, M.G., Richter, H.E., 2000. Biodiversity conservation at multiple scales: functional sites, landscapes, and networks. BioScience 50, 133-146.
Price, B., Kienast, F., Seidl, I., Ginzler, C., Verburg, P.H., Bolliger, J., 2015. Future landscapes of Switzerland: Risk areas for urbanisation and land abandonment. Applied Geography 57, 32-41.
Radtke, G., 2013. Effects of substrate composition and water temperature on the emergence success of lacustrine brown trout Salmo trutta m. lacustris L. fry from natural redds. Folia Zoologica 62, 247-256.
RCEP, 2009. Artificial Light in the Environment: Royal Commission on Environmental Pollution, p. 43, UK.
Rehman, M., Ullah, S., Bao, Y.N., Wang, B., Peng, D.X., Liu, L.J., 2017. Light-emitting diodes: whether an efficient source of light for indoor plants? Environmental Science and Pollution Research 24, 24743-24752.
Rich, C., Longcore, T., 2006. Ecological consequences of artificial night lighting. Island Press.
Riley, W.D., Bendall, B., Ives, M.J., Edmonds, N.J., Maxwell, D.L., 2012. Street lighting disrupts the diel migratory pattern of wild Atlantic salmon, Salmo salar L., smolts leaving their natal stream. Aquaculture 330, 74-81.
Riley, W.D., Davison, P.I., Maxwell, D.L., Bendall, B., 2013. Street lighting delays and disrupts the dispersal of Atlantic salmon (Salmo salar) fry. Biological Conservation 158, 140-146.
Riley, W.D., Davison, P.I., Maxwell, D.L., Newman, R.C., Ives, M.J., 2015. A laboratory experiment to determine the dispersal response of Atlantic salmon (Salmo salar) fry to street light intensity. Freshwater Biology 60, 1016-1028.
Rutz, C., 2006. Home range size, habitat use, activity patterns and hunting behaviour of urban-breeding Northern Goshawks Accipiter gentilis. Ardea 94, 185-202.
Rydell, J., 1992. Exploitation of insects around streetlamps by bats in Sweden. Functional Ecology, 744-750.
Rydell, J., Eklöf, J., Sánchez-Navarro, S., 2017. Age of enlightenment: long-term effects of outdoor aesthetic lights on bats in churches. Open Science 4, 161077.
Saldaña-Vázquez, R.A., Munguía-Rosas, M.A., 2013. Lunar phobia in bats and its ecological correlates: a meta-analysis. Mammalian Biology-Zeitschrift für Säugetierkunde 78, 216-219.
Sánchez de Miguel, A., 2015. Variación espacial, temporal y espectral de la contaminación lumínica y sus fuentes: Metodología y resultados.
Sánchez de Miguel, A., Aubé, M., Zamorano, J., Kocifaj, M., Roby, J., Tapia, C., 2017. Sky Quality Meter measurements in a colour-changing world. Monthly Notices of the Royal Astronomical Society 467, 2966-2979.
Sanders, D., Kehoe, R., Tiley, K., Bennie, J., Cruse, D., Davies, T.W., van Veen, F.J.F., Gaston, K.J., 2015. Artificial nighttime light changes aphid-parasitoid population dynamics. Scientific Reports 5.

Sandlund, O.T., Diserud, O.H., Poole, R., Bergesen, K., Dillane, M., Rogan, G., Durif, C., Thorstad, E.B., Vollestad, L.A., 2017. Timing and pattern of annual silver eel migration in two European watersheds are determined by similar cues. Ecology and Evolution 7, 5956-5966.
Santos, C.D., Miranda, A.C., Granadeiro, J.P., Lourenco, P.M., Saraiva, S., Palmeirim, J.M., 2010. Effects of artificial illumination on the nocturnal foraging of waders. Acta Oecologica-International Journal of Ecology 36, 166-172.
Schilling, E.G., Loftin, C.S., Huryn, A.D., 2009. Macroinvertebrates as indicators of fish absence in naturally fishless lakes. Freshwater Biology 54, 181-202.
Slavik, O., Horky, P., Randak, T., Balvin, P., Bily, M., 2012. Brown Trout Spawning Migration in Fragmented Central European Headwaters: Effect of Isolation by Artificial Obstacles and the Moon Phase. Transactions of the American Fisheries Society 141, 673-680.
Stanley, M.C., Beggs, J.R., Bassett, I.E., Burns, B.R., Dirks, K.N., Jones, D.N., Linklater, W.L., Macinnis-Ng, C., Simcock, R., Souter-Brown, G., Trowsdale, S.A., Gaston, K.J., 2015. Emerging threats in urban ecosystems: a horizon scanning exercise. Frontiers in Ecology and the Environment 13, 553-560.
Steinbauer, M.J., Haslem, A., Edwards, E.D., 2012. Using meteorological and lunar information to explain catch variability of Orthoptera and Lepidoptera from 250 W Farrow light traps. Insect Conservation and Diversity 5, 367-380.
Stone, E.L., Harris, S., Jones, G., 2015. Impacts of artificial lighting on bats: a review of challenges and solutions. Mammalian Biology 80, 213-219.
Stone, E.L., Jones, G., Harris, S., 2009. Street Lighting Disturbs Commuting Bats. Current Biology 19, 1123-1127.
Stone, E.L., Jones, G., Harris, S., 2012. Conserving energy at a cost to biodiversity? Impacts of LED lighting on bats. Global Change Biology 18, 2458-2465.
Sustek, Z., 1999. Light attraction of carabid beetles and their survival in the city centre. Biologia 54, 539-551.
Szaz, D., Horvath, G., Barta, A., Robertson, B.A., Farkas, A., Egri, A., Tarjanyi, N., Racz, G., Kriska, G., 2015. Lamp-Lit Bridges as Dual Light-Traps for the Night-Swarming Mayfly, Ephoron virgo: Interaction of Polarized and Unpolarized Light Pollution. Plos One 10.
Tierney, S.M., Friedrich, M., Humphreys, W.F., Jones, T.M., Warrant, E.J., Wcislo, W.T., 2017. Consequences of evolutionary transitions in changing photic environments. Austral Entomology 56, 23-46.
van Grunsven, R.H.A., Creemers, R., Joosten, K., Donners, M., Veenendaal, E.M., 2017. Behaviour of migrating toads under artificial lights differs from other phases of their life cycle. Amphibia-Reptilia 38, 49-55.
van Langevelde, F., Braamburg-Annegarn, M., Huigens, M.E., Groendijk, R., Poitevin, O., van Deijk, J.R., Ellis, W.N., van Grunsven, R.H., de Vos, R., Vos, R.A., 2017. Declines in moth populations stress the need for conserving dark nights. Global Change Biology.
Vincent, S., Nemoz, M., Aulagnier, S., 2011. ACTIVITY AND FORAGING HABITATS OF MINIOPTERUS SCHREIBERSII (CHIROPTERA, MINIOPTERIDAE) IN SOUTHERN FRANCE: IMPLICATIONS FOR ITS CONSERVATION. Hystrix-Italian Journal of Mammalogy 22, 57-72.
Wiltschko, R., Stapput, K., Thalau, P., Wiltschko, W., 2010. Directional orientation of birds by the magnetic field under different light conditions. Journal of the Royal Society Interface 7, S163-S177.

7 Appendices

7.1 Appendix 1 - Accompanying group for the project

- Danielle Hofmann, Species and Habitats section, Bundesamt für Umwelt (BAFU/FOEN)
- Dr. Martin K. Obrist, Biodiversity and Conservation Biology (Biodiversität u Naturschutzbiologie), Swiss Federal Research Institute WSL
- PD Dr. Janine Bolliger, Landscape ecology (Landschaftsökologie), Swiss Federal Research Institute WSL.
- Prof. Dr. Felix Kienast, Landscape Dynamics and Landscape Ecology (Landschaftsdynamik Landschaftsökologie), ETH Zurich and WSL
- Dr. Hubert Krättli, Bat Conservation Switzerland (Stiftung Fledermausschutz)
- Aline Blaser, Head of biological corridors, Département de l'environnement, des transports et de l'agriculture (DETA). Canton de Geneva
- Giuse Togni, Energy efficiency and street lighting, S.A.F.E.- Schweizerische Agentur für Energieeffizienz, Projektleiterin Strassenbeleuchtung
- Professor Arnaud Zufferey, Decision support systems for energy transition, Institut informatique de gestion, HES, Wallis
- Dr. Lukas Schuler, President Dark-Sky Switzerland
- Rolf Schatz, Dark-Sky Switzerland
- Benedict Wyss , Non-Ionising Radiation Section, Bundesamt für Umwelt (BAFU/FOEN)
- Dr. Eva Knop. Group leader Community Ecology, Institute of Ecology and Evolution, University of Bern

7.2 *Appendix 2 – search terms used for WoS (Web of Science) search*

Mammals (excluding bats)
Artificial lighting search
TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“ AND ("Canis lupus" OR "Gray Wolf" OR "Arctic Wolf" OR "Common Wolf" OR "Grey Wolf" OR "Mexican Wolf" OR "Plains Wolf" OR "Timber Wolf" OR "Tundra Wolf" OR "Wolf" OR "Castor fiber" OR "Eurasian beaver" OR "Crocidura leucodon" OR "Bicolored Shrew" OR "Bicoloured White-toothed Shrew" OR "Crocidura suaveolens" OR "Lesser Shrew" OR "Lesser White-toothed Shrew" OR "Felis silvestris" OR "Wild Cat" OR "Wildcat" OR "Lepus europaeus" OR "European Hare" OR "Brown Hare" OR "European Brown Hare" OR "Lutra lutra" OR "Eurasian Otter" OR "Common Otter" OR "European Otter" OR "European River Otter" OR "Old World Otter" OR "Lynx lynx" OR "Eurasian Lynx" OR "Micromys minutus" OR "Eurasian Harvest Mouse" OR "Harvest Mouse" OR "Muscardinus avellanarius" OR "Hazel Dormouse" OR "Common Dormouse" OR "Mustela nivalis" OR "Least Weasel" OR "Weasel" OR "Mustela putorius" OR "Western Polecat" OR "European Polecat" OR "Neomys anomalus" OR "Southern Water Shrew" OR "Mediterranean Water Shrew" OR "Miller's Water Shrew" OR "Neomys fodiens" OR "Eurasian Water Shrew" OR "Northern Water Shrew" Or "Water Shrew" OR "Pitymys multiplex" OR "Common Pine Vole English" OR "European Pine Vole" OR "Rattus rattus" OR "House Rat" OR "Black Rat" OR "Roof Rat" OR "Ship Rat" OR "Ursus arctos" OR "Brown Bear" OR "Grizzly Bear")))

Natural lighting search
TS=(((lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Canis lupus" OR "Gray Wolf" OR "Arctic Wolf" OR "Common Wolf" OR "Grey Wolf" OR "Mexican Wolf" OR "Plains Wolf" OR "Timber Wolf" OR "Tundra Wolf" OR "Wolf" OR "Castor fiber" OR "Eurasian beaver" OR "Crocidura leucodon" OR "Bicolored Shrew" OR "Bicoloured White-toothed Shrew" OR "Crocidura suaveolens" OR "Lesser Shrew" OR "Lesser White-toothed Shrew" OR "Felis silvestris" OR "Wild Cat" OR "Wildcat" OR "Lepus europaeus" OR "European Hare" OR "Brown Hare" OR "European Brown Hare" OR "Lutra lutra" OR "Eurasian Otter" OR "Common Otter" OR "European Otter" OR "European River Otter" OR "Old World Otter" OR "Lynx lynx" OR "Eurasian Lynx" OR "Micromys minutus" OR "Eurasian Harvest Mouse" OR "Harvest Mouse" OR "Muscardinus avellanarius" OR "Hazel Dormouse" OR "Common Dormouse" OR "Mustela nivalis" OR "Least Weasel" OR "Weasel" OR "Mustela putorius" OR "Western Polecat" OR "European Polecat" OR "Neomys anomalus" OR "Southern Water Shrew" OR "Mediterranean Water Shrew" OR "Miller's Water Shrew" OR "Neomys fodiens" OR "Eurasian Water Shrew" OR "Northern Water Shrew" Or "Water Shrew" OR "Pitymys multiplex" OR "Common Pine Vole English" OR "European Pine Vole" OR "Rattus rattus" OR "House Rat" OR "Black Rat" OR "Roof Rat" OR "Ship Rat" OR "Ursus arctos" OR "Brown Bear" OR "Grizzly Bear")))

Relevant reviews
TS=(((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR “photopollution” OR ALAN OR “light-trap*“ OR “light trap*” OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND (mammal*)))

Bats
Artificial lighting search
1) TS=(((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR “photopollution” OR ALAN OR “light-trap*“ OR “light trap*“) AND ("Barbastella barbastellus" OR "Western Barbastelle" OR "Barbastelle" OR "Eptesicus

nilssonii" OR "Northern Bat" OR "Eptesicus serotinus" OR "Serotine" OR "Hypsugo savii" OR "Savi's Pipistrelle" OR "Miniopterus schreibersii" OR "Schreiber's Bent-winged Bat" OR "Common Bentwing Bat" OR "Schreiber's Long-fingered Bat" OR "Myotis bechsteinii" OR "Bechstein's Myotis" OR "Bechstein's Bat" OR "Bechstein's Myotis" OR "Myotis blythii" OR "Lesser Mouse-eared Myotis" OR "Lesser Mouse-eared Bat" OR "Myotis brandtii" OR "Brandt's Myotis" OR "Brandt's Bat" OR "Myotis emarginatus" OR "Geoffroy's Bat" OR "Geoffroy's Myotis" OR "Myotis myotis" OR "Greater Mouse-eared Bat" OR "Large Mouse-eared Bat" OR "Mouse-eared Bat" OR "Mouse-eared Myotis" OR "Myotis mystacinus" OR "Whiskered Myotis" OR "Whiskered Bat" OR "Whiskered Myotis" OR "Myotis nattereri" OR "Natterer's Bat" OR "Nyctalus lasiopterus" OR "Giant Noctule" OR "Greater Noctule Bat" OR "Nyctalus leisleri" OR "Lesser Noctule" OR "Leisler's Bat" OR "Nyctalus noctula" OR "Noctule" OR "Plecotus auritus" OR "Brown Big-eared Bat" OR "Brown Long-eared Bat" OR "Plecotus austriacus" OR "Gray Big-eared Bat" OR "Grey Long-eared Bat" OR "Plecotus macrobullaris" OR "Mountain Long-eared Bat" OR "Rhinolophus ferrumequinum" OR "Greater Horseshoe Bat" OR "Rhinolophus hipposideros" OR "Lesser Horseshoe Bat" OR "Tadarida teniotis" OR "European Free-tailed Bat" OR "Vespertilio murinus" OR "Particoloured Bat")))

Natural lighting search

TS=(((lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Barbastella barbastellus" OR "Western Barbastelle" OR "Barbastelle" OR "Eptesicus nilssonii" OR "Northern Bat" OR "Eptesicus serotinus" OR "Serotine" OR "Hypsugo savii" OR "Savi's Pipistrelle" OR "Miniopterus schreibersii" OR "Schreiber's Bent-winged Bat" OR "Common Bentwing Bat" OR "Schreiber's Long-fingered Bat" OR "Myotis bechsteinii" OR "Bechstein's Myotis" OR "Bechstein's Bat" OR "Bechstein's Myotis" OR "Myotis blythii" OR "Lesser Mouse-eared Myotis" OR "Lesser Mouse-eared Bat" OR "Myotis brandtii" OR "Brandt's Myotis" OR "Brandt's Bat" OR "Myotis emarginatus" OR "Geoffroy's Bat" OR "Geoffroy's Myotis" OR "Myotis myotis" OR "Greater Mouse-eared Bat" OR "Large Mouse-eared Bat" OR "Mouse-eared Bat" OR "Mouse-eared Myotis" OR "Myotis mystacinus" OR "Whiskered Myotis" OR "Whiskered Bat" OR "Whiskered Myotis" OR "Myotis nattereri" OR "Natterer's Bat" OR "Nyctalus lasiopterus" OR "Giant Noctule" OR "Greater Noctule Bat" OR "Nyctalus leisleri" OR "Lesser Noctule" OR "Leisler's Bat" OR "Nyctalus noctula" OR "Noctule" OR "Plecotus auritus" OR "Brown Big-eared Bat" OR "Brown Long-eared Bat" OR "Plecotus austriacus" OR "Gray Big-eared Bat" OR "Grey Long-eared Bat" OR "Plecotus macrobullaris" OR "Mountain Long-eared Bat" OR "Rhinolophus ferrumequinum" OR "Greater Horseshoe Bat" OR "Rhinolophus hipposideros" OR "Lesser Horseshoe Bat" OR "Tadarida teniotis" OR "European Free-tailed Bat" OR "Vespertilio murinus" OR "Particoloured Bat")))

Relevant reviews

TS=(((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR “photopollution” OR ALAN OR “light-trap*“ OR “light trap*” OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND (bat* OR Chiropter*)))

Birds

Artificial lighting search

TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“) AND ("Accipiter gentilis" OR "Northern Goshawk" OR "Eurasian Goshawk" OR "Goshawk" OR "Accipiter nisus" OR "Eurasian Sparrowhawk" OR "European Sparrowhawk" OR "Sparrowhawk" OR "Acrocephalus arundinaceus" OR "Great Reed-warbler" OR "Actitis hypoleucos" OR "Common Sandpiper" OR "Aegolius funereus" OR "Boreal Owl" OR "Tengmalm's Owl" OR "Alauda arvensis" OR "Eurasian Skylark" OR "Skylark" OR "Sky Lark" OR "Alcedo atthis" OR "Common Kingfisher" OR "European Kingfisher" OR "Kingfisher" OR "Alectoris graeca" OR "Rock Partridge" OR "Alectoris rufa" OR "Red-legged Partridge" OR

"Anas platyrhynchos" OR "Mallard" OR "Common Mallard" OR "Northern Mallard" OR "Anas strepera" OR "Gadwall" OR "Anthus pratensis" OR "Meadow Pipit" OR "Anthus spinoletta" OR "Water Pipit" OR "Rock Pipit" OR "Water Pipit" OR "Apus apus" OR "Common Swift" OR "European Swift" OR "Swift" OR "Apus melba" OR "Alpine Swift" OR "Aquila chrysaetos" OR "Golden Eagle" OR "Ardea purpurea" OR "Purple Heron" OR "Asio otus" OR "Northern Long-eared Owl" OR "Athene noctua" OR "Little Owl" OR "Aythya ferina" OR "Common Pochard" OR "Northern Pochard" OR "Pochard" OR "Aythya fuligula" OR "Tufted Duck" OR "Bonasa bonasia" OR "Hazel Grouse" OR "Bubo bubo" OR "Eurasian Eagle-owl" OR "Eurasian Eagle Owl" OR "Eurasian Eagle-Owl" OR "Buteo buteo" OR "Eurasian Buzzard" OR "Common Buzzard" OR "Caprimulgus europaeus" OR "European Nightjar" OR "European Nightjar" OR "Nightjar" OR "Carduelis cannabina" OR "Common Linnet" OR "Eurasian Linnet" OR "Linnet" OR "Certhia familiaris" OR "Eurasian Treecreeper" OR "Charadrius dubius" OR "Little Ringed Plover" OR "Ciconia ciconia" OR "White Stork" OR "Cinclus cinclus" OR "White-throated Dipper" OR "Dipper" OR "Corvus corone" OR "Carrion Crow" OR "Corvus monedula" OR "Eurasian Jackdaw" OR "Jackdaw" OR "Western Jackdaw" OR "Crex crex" OR "Corncrake" OR "Corn Crake" OR "Cuculus canorus" OR "Common Cuckoo" OR "Cuckoo" OR "European Cuckoo" OR "Delichon urbicum" OR "Northern House Martin" OR "Dendrocopos medius" OR "Middle Spotted Woodpecker" OR "Emberiza calandra" OR "Corn Bunting" OR "Emberiza cirlus" OR "Cirl Bunting" OR "Emberiza hortulana" OR "Ortolan Bunting" OR "Emberiza schoeniclus" OR "Reed Bunting" OR "Common Reed Bunting" OR "Falco peregrinus" OR "Peregrine Falcon" OR "Falco subbuteo" OR "Eurasian Hobby" OR "European Hobby" OR "Hobby" OR "Falco tinnunculus" OR "Common Kestrel" OR "Eurasian Kestrel" OR "Kestrel" OR "Ficedula albicollis" OR "Collared Flycatcher" OR "Fringilla montifringilla" OR "Brambling" OR "Fulica atra" OR "Common Coot" OR "Coot" OR "Eurasian Coot" OR "European Coot" OR "Galerida cristata" OR "Crested Lark" OR "Gallinago gallinago" OR "Common Snipe" OR "Glaucidium passerinum" OR "Eurasian Pygmy-owl" OR "Eurasian Pygmy Owl" OR "Eurasian Pygmy-Owl" OR "Pygmy Owl" OR "Gypaetus barbatus" OR "Bearded Vulture" OR "Lammergeyer" OR "Hippolais icterina" OR "Icterine Warbler" OR "Hippolais polyglotta" OR "Melodious Warbler" OR "Ixobrychus minutus" OR "Common Little Bittern" OR "Little Bittern" OR "Jynx torquilla" OR "Eurasian Wryneck" OR "European Wryneck" OR "Wryneck" OR "Lagopus muta" OR "Rock Ptarmigan" OR "Ptarmigan" OR "Lanius excubitor" OR "Great Grey Shrike" OR "Lanius minor" OR " Lesser Grey Shrike" OR "Lanius senator" OR "Woodchat Shrike" OR "Larus ridibundus" OR "Black-headed Gull" OR "Common Black-headed Gull" OR "Locustella luscinioides" OR "Savi's Warbler" OR "Locustella naevia" OR "Common Grasshopper-warbler" OR "Common Grasshopper Warbler" OR "Common Grasshopper-Warbler" OR "Grasshopper Warbler" OR "Loxia curvirostra" OR "Red Crossbill" OR "Common Crossbill" OR "Crossbill" OR "Lullula arborea" OR "Woodlark" OR "Wood Lark" OR "Luscinia megarhynchos" OR "Common Nightingale" OR "Nightingale" OR "Mergus merganser" OR "Goosander" OR "Goosander" OR "Milvus migrans" OR "Black Kite" OR "Milvus milvus" OR "Red Kite" OR "Monticola saxatilis" OR "Rufous-tailed Rock-thrush" OR "European Rock Thrush" OR "Rock Thrush" OR "Rufous-tailed Rock Thrush" OR "Rufous-tailed Rock-Thrush" OR "Monticola solitarius" OR "Blue Rock-thrush" OR "Blue Rock Thrush" OR "Blue Rock-Thrush" OR "Montifringilla nivalis" OR "White-winged Snowfinch" OR "Motacilla flava" OR "Western Yellow Wagtail" OR "Netta rufina" OR "Red-crested Pochard" OR "Nucifraga caryocatactes" OR "Northern Nutcracker" OR "Numenius arquata" OR "Eurasian Curlew" OR "Curlew" OR "Otus scops" OR "Eurasian Scops-owl" OR "Eurasian Scops Owl" OR "European Scops Owl" OR "Pandion haliaetus" OR "Osprey" OR "Panurus biarmicus" OR "Bearded Reedling" OR "Bearded Parrotbill" OR "Bearded Tit" OR "Parus ater" OR "Coal Tit" OR "Parus cristatus" OR "Crested Tit" OR "Parus palustris" OR "Marsh Tit" OR "Perdix perdix" OR "Grey Partridge" OR "Gray Partridge" OR "Partridge" OR "Pernis apivorus" OR "European Honey-buzzard" OR "European Honey Buzzard" OR "Honey Buzzard" OR "Phalacrocorax carbo" OR "Great Cormorant" OR "Black Shag" OR "Cormorant" OR "White-breasted Cormorant" OR "Phoenicurus ochruros" OR "Black Redstart" OR "Phoenicurus phoenicurus" OR "Common Redstart" OR "Redstart" OR "Phylloscopus sibilatrix" OR "Wood Warbler" OR "Phylloscopus trochilus" OR "Willow Warbler" OR "Picoides tridactylus" OR "Three-toed Woodpecker" OR "Picus canus" OR "Grey-faced Woodpecker" OR "Grey-headed woodpecker" OR "Grey-headed Woodpecker" OR "Podiceps cristatus" OR "Great Crested Grebe" OR "Podiceps nigricollis" OR "Black-necked Grebe" OR "Eared Grebe" OR "Prunella collaris" OR "Alpine Accentor" OR "Ptyonoprogne rupestris" OR "Eurasian Crag Martin" OR "Crag Martin" OR "Eurasian Crag-martin" OR "Eurasian Crag-Martin" OR "European Crag Martin" OR "Pyrrhocorax graculus" OR "Alpine Chough" OR "Yellow-billed Chough" OR "Pyrrhocorax pyrrhocorax" OR "Red-billed Chough" OR "Chough" OR "Pyrrhula pyrrhula" OR "Eurasian Bullfinch" OR "Regulus ignicapilla" OR "Common Firecrest" OR "Firecrest" OR "Regulus regulus" OR "Goldcrest" OR "Riparia riparia" OR "Collared Sand Martin" OR "Bank Swallow" OR "Sand Martin" OR "Saxicola rubetra" OR "Whinchat" OR "Saxicola torquatus" OR "Common Stonechat" OR "Eurasian Stonechat" OR "Stonechat" OR "Scolopax rusticola" OR "Eurasian Woodcock" OR "Woodcock" OR "Serinus citrinella" OR "Citril Finch" OR "Alpine Citril Finch" OR "Sterna hirundo" OR "Common Tern" OR "Streptopelia turtur" OR "European Turtle-dove" OR "European Turtle Dove" OR "European Turtle-Dove" OR "Turtle Dove" OR "Sylvia borin" OR "Garden Warbler" OR "Sylvia communis" OR "Common Whitethroat" OR "Greater Whitethroat" OR "Whitethroat" OR "Tachybaptus ruficollis" OR "Little Grebe" OR "Tetrao tetrix" OR "Black Grouse" OR "Tetrao urogallus" OR "Western Capercaillie" OR "Capercaillie" OR "Tichodroma muraria" OR "Wallcreeper" OR "Tringa totanus" OR "Common Redshank" OR "Redshank" OR "Turdus pilaris" OR "Fieldfare" OR "Turdus torquatus" OR "Ring Ouzel" OR "Turdus viscivorus" OR "Mistle Thrush" OR "Tyto alba" OR "Common Barn-owl" OR "Upupa epops" OR "Common Hoopoe" OR "Hoopoe" OR "Vanellus vanellus" OR "Northern Lapwing" OR "Lapwing"))

Natural lighting search
TS=((lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Accipiter gentilis" OR "Northern Goshawk" OR "Eurasian Goshawk" OR "Goshawk" OR "Accipiter nisus" OR "Eurasian Sparrowhawk" OR "European Sparrowhawk" OR "Sparrowhawk" OR "Acrocephalus arundinaceus" OR "Great Reed-warbler" OR "Actitis hypoleucos" OR "Common Sandpiper" OR "Aegolius funereus" OR "Boreal Owl" OR "Tengmalm's Owl" OR "Alauda arvensis" OR "Eurasian Skylark" OR "Skylark" OR "Sky Lark" OR "Alcedo atthis" OR "Common Kingfisher" OR "European Kingfisher" OR "Kingfisher" OR "Alectoris graeca" OR "Rock Partridge" OR "Alectoris rufa" OR "Red-legged Partridge" OR "Anas platyrhynchos" OR "Mallard" OR "Common Mallard" OR "Northern Mallard" OR "Anas strepera" OR "Gadwall" OR "Anthus pratensis" OR "Meadow Pipit" OR "Anthus spinoletta" OR "Water Pipit" OR "Rock Pipit" OR "Water Pipit" OR "Apus apus" OR "Common Swift" OR "European Swift" OR "Swift" OR "Apus melba" OR "Alpine Swift" OR "Aquila chrysaetos" OR "Golden Eagle" OR "Ardea purpurea" OR "Purple Heron" OR "Asio otus" OR "Northern Long-eared Owl" OR "Athene noctua" OR "Little Owl" OR "Aythya ferina" OR "Common Pochard" OR "Northern Pochard" OR "Pochard" OR "Aythya fuligula" OR "Tufted Duck" OR "Bonasa bonasia" OR "Hazel Grouse" OR "Bubo bubo" OR "Eurasian Eagle-owl" OR "Eurasian Eagle Owl" OR "Eurasian Eagle-Owl" OR "Buteo buteo" OR "Eurasian Buzzard" OR "Common Buzzard" OR "Caprimulgus europaeus" OR "European Nightjar" OR "European Nightjar" OR "Nightjar" OR "Carduelis cannabina" OR "Common Linnet" OR "Eurasian Linnet" OR "Linnet" OR "Certhia familiaris" OR "Eurasian Treecreeper" OR "Charadrius dubius" OR "Little Ringed Plover" OR "Ciconia ciconia" OR "White Stork" OR "Cinclus cinclus" OR "White-throated Dipper" OR "Dipper" OR "Corvus corone" OR "Carrion Crow" OR "Corvus monedula" OR "Eurasian Jackdaw" OR "Jackdaw" OR "Western Jackdaw" OR "Crex crex" OR "Corncrake" OR "Corn Crake" OR "Cuculus canorus" OR "Common Cuckoo" OR "Cuckoo" OR "European Cuckoo" OR "Delichon urbicum" OR "Northern House Martin" OR "Dendrocopos medius" OR "Middle Spotted Woodpecker" OR "Emberiza calandra" OR "Corn Bunting" OR "Emberiza cirlus" OR "Cirl Bunting" OR "Emberiza hortulana" OR "Ortolan Bunting" OR "Emberiza schoeniclus" OR "Reed Bunting" OR "Common Reed Bunting" OR "Falco peregrinus" OR "Peregrine Falcon" OR "Falco subbuteo" OR "Eurasian Hobby" OR "European Hobby" OR "Hobby" OR "Falco tinnunculus" OR "Common Kestrel" OR "Eurasian Kestrel" OR "Kestrel" OR "Ficedula albicollis" OR "Collared Flycatcher" OR "Fringilla montifringilla" OR "Brambling" OR "Fulica atra" OR "Common Coot" OR "Coot" OR "Eurasian Coot" OR "European Coot" OR "Galerida cristata" OR "Crested Lark" OR "Gallinago gallinago" OR "Common Snipe" OR "Glaucidium

passerinum" OR "Eurasian Pygmy-owl" OR "Eurasian Pygmy Owl" OR "Eurasian Pygmy-Owl" OR "Pygmy Owl" OR "Gypaetus barbatus" OR "Bearded Vulture" OR "Lammergeyer" OR "Hippolais icterina" OR "Icterine Warbler" OR "Hippolais polyglotta" OR "Melodious Warbler" OR "Ixobrychus minutus" OR "Common Little Bittern" OR "Little Bittern" OR "Jynx torquilla" OR "Eurasian Wryneck" OR "European Wryneck" OR "Wryneck" OR "Lagopus muta" OR "Rock Ptarmigan" OR "Ptarmigan" OR "Lanius excubitor" OR "Great Grey Shrike" OR "Lanius minor" OR " Lesser Grey Shrike" OR "Lanius senator" OR "Woodchat Shrike" OR "Larus ridibundus" OR "Black-headed Gull" OR "Common Black-headed Gull" OR "Locustella luscinioides" OR "Savi's Warbler" OR "Locustella naevia" OR "Common Grasshopper-warbler" OR "Common Grasshopper Warbler" OR "Common Grasshopper-Warbler" OR "Grasshopper Warbler" OR "Loxia curvirostra" OR "Red Crossbill" OR "Common Crossbill" OR "Crossbill" OR "Lullula arborea" OR "Woodlark" OR "Wood Lark" OR "Luscinia megarhynchos" OR "Common Nightingale" OR "Nightingale" OR "Mergus merganser" OR "Goosander" OR "Goosander" OR "Milvus migrans" OR "Black Kite" OR "Milvus milvus" OR "Red Kite" OR "Monticola saxatilis" OR "Rufous-tailed Rock-thrush" OR "European Rock Thrush" OR "Rock Thrush" OR "Rufous-tailed Rock Thrush" OR "Rufous-tailed Rock-Thrush" OR "Monticola solitarius" OR "Blue Rock-thrush" OR "Blue Rock Thrush" OR "Blue Rock-Thrush" OR "Montifringilla nivalis" OR "White-winged Snowfinch" OR "Motacilla flava" OR "Western Yellow Wagtail" OR "Netta rufina" OR "Red-crested Pochard" OR "Nucifraga caryocatactes" OR "Northern Nutcracker" OR "Numenius arquata" OR "Eurasian Curlew" OR "Curlew" OR "Otus scops" OR "Eurasian Scops-owl" OR "Eurasian Scops Owl" OR "European Scops Owl" OR "Pandion haliaetus" OR "Osprey" OR "Panurus biarmicus" OR "Bearded Reedling" OR "Bearded Parrotbill" OR "Bearded Tit" OR "Parus ater" OR "Coal Tit" OR "Parus cristatus" OR "Crested Tit" OR "Parus palustris" OR "Marsh Tit" OR "Perdix perdix" OR "Grey Partridge" OR "Gray Partridge" OR "Partridge" OR "Pernis apivorus" OR "European Honey-buzzard" OR "European Honey Buzzard" OR "Honey Buzzard" OR "Phalacrocorax carbo" OR "Great Cormorant" OR "Black Shag" OR "Cormorant" OR "White-breasted Cormorant" OR "Phoenicurus ochruros" OR "Black Redstart" OR "Phoenicurus phoenicurus" OR "Common Redstart" OR "Redstart" OR "Phylloscopus sibilatrix" OR "Wood Warbler" OR "Phylloscopus trochilus" OR "Willow Warbler" OR "Picoides tridactylus" OR "Three-toed Woodpecker" OR "Picus canus" OR "Grey-faced Woodpecker" OR "Grey-headed woodpecker" OR "Grey-headed Woodpecker" OR "Podiceps cristatus" OR "Great Crested Grebe" OR "Podiceps nigricollis" OR "Black-necked Grebe" OR "Eared Grebe" OR "Prunella collaris" OR "Alpine Accentor" OR "Ptyonoprogne rupestris" OR "Eurasian Crag Martin" OR "Crag Martin" OR "Eurasian Crag-martin" OR "Eurasian Crag-Martin" OR "European Crag Martin" OR "Pyrrhocorax graculus" OR "Alpine Chough" OR "Yellow-billed Chough" OR "Pyrrhocorax pyrrhocorax" OR "Red-billed Chough" OR "Chough" OR "Pyrrhula pyrrhula" OR "Eurasian Bullfinch" OR "Regulus ignicapilla" OR "Common Firecrest" OR "Firecrest" OR "Regulus regulus" OR "Goldcrest" OR "Riparia riparia" OR "Collared Sand Martin" OR "Bank Swallow" OR "Sand Martin" OR "Saxicola rubetra" OR "Whinchat" OR "Saxicola torquatus" OR "Common Stonechat" OR "Eurasian Stonechat" OR "Stonechat" OR "Scolopax rusticola" OR "Eurasian Woodcock" OR "Woodcock" OR "Serinus citrinella" OR "Citril Finch" OR "Alpine Citril Finch" OR "Sterna hirundo" OR "Common Tern" OR "Streptopelia turtur" OR "European Turtle-dove" OR "European Turtle Dove" OR "European Turtle-Dove" OR "Turtle Dove" OR "Sylvia borin" OR "Garden Warbler" OR "Sylvia communis" OR "Common Whitethroat" OR "Greater Whitethroat" OR "Whitethroat" OR "Tachybaptus ruficollis" OR "Little Grebe" OR "Tetrao tetrix" OR "Black Grouse" OR "Tetrao urogallus" OR "Western Capercaillie" OR "Capercaillie" OR "Tichodroma muraria" OR "Wallcreeper" OR "Tringa totanus" OR "Common Redshank" OR "Redshank" OR "Turdus pilaris" OR "Fieldfare" OR "Turdus torquatus" OR "Ring Ouzel" OR "Turdus viscivorus" OR "Mistle Thrush" OR "Tyto alba" OR "Common Barn-owl" OR "Upupa epops" OR "Common Hoopoe" OR "Hoopoe" OR "Vanellus vanellus" OR "Northern Lapwing" OR "Lapwing"))

Relevant reviews

TS=(((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR “photopollution” OR ALAN OR “light-trap*“ OR “light trap*” OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND (Bird* OR aves))

Reptiles and amphibians

Artificial lighting search

TS=(((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR “photopollution”) AND ("Dice Snake" OR "Tessellated Water Snake" OR "Vipera aspis" OR "Asp Viper" OR "Vipera berus" OR "Adder" OR "Northern Viper" OR "Northern Viper" OR "Zamenis longissimus" OR "Aesculapean Snake" OR "Aesculapian Ratsnake" OR "Lacerta agilis" OR "Sand Lizard" OR "Lacerta bilineata" OR "Western Green Lizard" OR "Alytes obstetricans" OR "Common Midwife Toad" OR "Bombina variegata" OR "Yellow–bellied Toad" OR "Bufo bufo" OR "Common Toad" OR "Bufo calamita" OR "Epidalea calamita" OR "Natterjack Toad" OR "Hyla arborea" OR "European Tree Frog" OR "Hyla intermedia" OR "Italian Tree Frog" OR "Rana dalmatina" OR "Agile Frog" OR "Rana latastei" OR "Italian Agile Frog" OR "Salamandra atra" OR "Alpine Salamander" OR "Golden Salamander" OR "Salamandra salamandra" OR "Common Fire Salamander" OR "Fire Salamander" OR "Triturus carnifex" OR "Italian Crested Newt" OR "Triturus cristatus" OR "Great Crested Newt" OR "Northern Crested Newt" OR "Lissotriton helveticus" OR "Palmate Newt" OR "Lissotriton vulgaris" OR "Smooth Newt")))

Natural lighting search

TS=(((lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Dice Snake" OR "Tessellated Water Snake" OR "Vipera aspis" OR "Asp Viper" OR "Vipera berus" OR "Adder" OR "Northern Viper" OR "Northern Viper" OR "Zamenis longissimus" OR "Aesculapean Snake" OR "Aesculapian Ratsnake" OR "Lacerta agilis" OR "Sand Lizard" OR "Lacerta bilineata" OR "Western Green Lizard" OR "Alytes obstetricans" OR "Common Midwife Toad" OR "Bombina variegata" OR "Yellow–bellied Toad" OR "Bufo bufo" OR "Common Toad" OR "Bufo calamita" OR "Epidalea calamita" OR "Natterjack Toad" OR "Hyla arborea" OR "European Tree Frog" OR "Hyla intermedia" OR "Italian Tree Frog" OR "Rana dalmatina" OR "Agile Frog" OR "Rana latastei" OR "Italian Agile Frog" OR "Salamandra atra" OR "Alpine Salamander" OR "Golden Salamander" OR "Salamandra salamandra" OR "Common Fire Salamander" OR "Fire Salamander" OR "Triturus carnifex" OR "Italian Crested Newt" OR "Triturus cristatus" OR "Great Crested Newt" OR "Northern Crested Newt" OR "Lissotriton helveticus" OR "Palmate Newt" OR "Lissotriton vulgaris" OR "Smooth Newt")))

Relevant reviews

TS=(((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR “photopollution” OR ALAN OR “light-trap*“ OR “light trap*” OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND (Amphib* OR Reptil*)))

Fish

Artificial lighting search

TS=(((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR “photopollution”) AND ("Acipenser sturio" OR "Atlantic Sturgeon" OR "Baltic Sturgeon" OR "Common Sturgeon" OR "Alburnoides bipunctatus" OR "Alburnoides bipunctatus" OR "Alburnus arborella" OR "Alburnus arborella" OR "Alosa agone" OR "Alosa agone" OR "Alosa alosa" OR "Alosa alosa" OR "Alosa fallax" OR "Alosa fallax" OR "Anguilla anguilla" OR "Anguilla anguilla" OR "Barbus barbus" OR "Barbus barbus" OR "Barbus caninus" OR "Barbus caninus" OR "Barbus plebejus" OR "Barbus plebejus" OR "Chondrostoma nasus" OR "Chondrostoma nasus" OR "Chondrostoma soetta" OR

"Chondrostoma soetta" OR "Cobitis taenia" OR "Cobitis taenia" OR "Coregonus sp." OR "Coregonus sp." OR "Cottus gobio" OR "Cottus gobio" OR "Hucho hucho" OR "Hucho hucho" OR "Lampetra fluviatilis" OR "Lampetra fluviatilis" OR "Lampetra planeri" OR "Lampetra planeri" OR "Misgurnus fossilis" OR "Misgurnus fossilis" OR "Padogobius bonelli" OR "Padogobius bonelli" OR "Parachondrostoma toxostoma" OR "Parachondrostoma toxostoma" OR "Rhodeus amarus" OR "Rhodeus amarus" OR "Rutilus pigus" OR "Rutilus pigus" OR "Rutilus aula" OR "Rutilus aula" OR "Salmo salar" OR "Salmo salar" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salvelinus umbla" OR "Salvelinus umbla" OR "Telestes muticellus" OR "Telestes muticellus" OR "Telestes souffia" OR "Telestes souffia" OR "Thymallus thymallus" OR "Thymallus thymallus" OR "Zingel asper" OR "Zingel asper")))

Natural lighting and fish
TS=((lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Acipenser sturio" OR "Atlantic Sturgeon" OR "Baltic Sturgeon" OR "Common Sturgeon" OR "Alburnoides bipunctatus" OR "Alburnoides bipunctatus" OR "Alburnus arborella" OR "Alburnus arborella" OR "Alosa agone" OR "Alosa agone" OR "Alosa alosa" OR "Alosa alosa" OR "Alosa fallax" OR "Alosa fallax" OR "Anguilla anguilla" OR "Anguilla anguilla" OR "Barbus barbus" OR "Barbus barbus" OR "Barbus caninus" OR "Barbus caninus" OR "Barbus plebejus" OR "Barbus plebejus" OR "Chondrostoma nasus" OR "Chondrostoma nasus" OR "Chondrostoma soetta" OR "Chondrostoma soetta" OR "Cobitis taenia" OR "Cobitis taenia" OR "Coregonus sp." OR "Coregonus sp." OR "Cottus gobio" OR "Cottus gobio" OR "Hucho hucho" OR "Hucho hucho" OR "Lampetra fluviatilis" OR "Lampetra fluviatilis" OR "Lampetra planeri" OR "Lampetra planeri" OR "Misgurnus fossilis" OR "Misgurnus fossilis" OR "Padogobius bonelli" OR "Padogobius bonelli" OR "Parachondrostoma toxostoma" OR "Parachondrostoma toxostoma" OR "Rhodeus amarus" OR "Rhodeus amarus" OR "Rutilus pigus" OR "Rutilus pigus" OR "Rutilus aula" OR "Rutilus aula" OR "Salmo salar" OR "Salmo salar" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salmo trutta" OR "Salvelinus umbla" OR "Salvelinus umbla" OR "Telestes muticellus" OR "Telestes muticellus" OR "Telestes souffia" OR "Telestes souffia" OR "Thymallus thymallus" OR "Thymallus thymallus" OR "Zingel asper" OR "Zingel asper"))

Relevant reviews
TS=(((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR “photopollution” OR ALAN OR “light-trap*“ OR “light trap*” OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND (Fish*)))

Beetles
Artificial lighting search
TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“) AND ("Abax oblongus" OR "Acanthocinus griseus" OR "Acanthocinus reticulatus" OR "Acmaeodera degener degener" OR "Acmaeoderella flavofasciata" OR "Acmaeops marginatus" OR "Acmaeops pratensis" OR "Acmaeops septentrionis" OR "Acmaeops smaragdula" OR "Acupalpus brunnipes" OR "Acupalpus exiguus" OR "Acupalpus maculatus" OR "Acupalpus parvulus" OR "Aesalus scarabaeoides" OR "Agapanthia pannonica" OR "Agonum carbonarium" OR "Agonum ericeti" OR "Agonum gracile" OR "Agonum impressum" OR "Agonum monachum" OR "Agonum scitulum" OR "Agonum viridicupreum" OR "Agrilus antiquus" OR "Agrilus derasofasciatus" OR "Agrilus lineola" OR "Agrilus pseudocyaneus" OR "Agrilus salicis" OR "Amara apricaria" OR "Amara concinna" OR "Amara fulva" OR "Amara fusca" OR "Amara infuscata" OR "Amara messae" OR "Amara nigricornis" OR "Amara proxima" OR "Amara sabulosa" OR "Amara schimperi" OR "Amara spreta" OR "Amara tibialis" OR "Amblystomus niger" OR "Anastrangalia reyi" OR "Anchomenus cyaneus" OR "Anoplodera

rufipes" OR "Anthaxia candens" OR "Anthaxia chevrieri" OR "Anthaxia cichorii" OR "Anthaxia istriana" OR "Anthaxia manca" OR "Anthaxia nigrojubata incognita" OR "Anthaxia sepulchralis" OR "Aphanisticus elongatus" OR "Aphanisticus emarginatus" OR "Aphanisticus pusillus" OR "Arhopalus ferus" OR "Badister collaris" OR "Badister dilatatus" OR "Badister unipustulatus" OR "Bembidion atrocaeruleum" OR "Bembidion bruxellense" OR "Bembidion elongatum" OR "Bembidion eques" OR "Bembidion fluviatile" OR "Bembidion foraminosum" OR "Bembidion humerale" OR "Bembidion laticolle" OR "Bembidion latinum" OR "Bembidion litorale" OR "Bembidion lunatum" OR "Bembidion modestum" OR "Bembidion obliquum" OR "Bembidion penninum" OR "Bembidion prasinum" OR "Bembidion stephensii" OR "Bembidion striatum" OR "Bembidion velox" OR "Bembidion virens" OR "Blethisa multipunctata" OR "Boldoriella tedeschii" OR "Brachinus elegans" OR "Brachinus immaculicornis" OR "Brachinus sclopeta" OR "Bradycellus ruficollis" OR "Calamobius filum" OR "Calathus circumseptus" OR "Calathus rotundicollis" OR "Calathus rubripes" OR "Callidium coriaceum" OR "Callimus angulatus" OR "Calosoma inquisitor" OR "Calosoma maderae" OR "Calosoma sycophanta" OR "Capnodis tenebrionis" OR "Carabus convexus convexus" OR "Carabus creutzeri kircheri" OR "Carabus nodulosus" OR "Cerambyx cerdo" OR "Cerambyx miles" OR "Ceruchus chrysomelinus" OR "Chalcophora mariana" OR "Chlaenius olivieri" OR "Chlaenius sulcicollis" OR "Chlaenius tristis" OR "Chlaenius velutinus" OR "Chlorophorus pilosus" OR "Chlorophorus trifasciatus" OR "Chrysobothris solieri" OR "Cicindela sylvatica" OR "Clytus rhamni" OR "Clytus tropicus" OR "Coraebus elatus" OR "Coraebus rubi" OR "Coraebus undatus" OR "Cornumutila quadrivittata" OR "Cortodera femorata" OR "Cortodera humeralis" OR "Corymbia cordigera" OR "Corymbia erythroptera" OR "Corymbia scutellata" OR "Cychrus angustatus" OR "Cychrus cordicollis" OR "Cylindera arenaria" OR "Cylindera germanica" OR "Cymindis angularis" OR "Cymindis axillaris" OR "Cymindis miliaris" OR "Cyrtoclytus capra" OR "Demetrias imperialis" OR "Dicerca alni" OR "Dicerca berolinensis" OR "Dicerca moesta" OR "Dicheirotrichus placidus" OR "Dorcadion aethiops" OR "Dorcadion fuliginator" OR "Dorcatypus tristis" OR "Dromius schneideri" OR "Drypta dentata" OR "Duvalius longhii" OR "Dyschirius abditus" OR "Dyschirius angustatus" OR "Dyschirius intermedius" OR "Dyschirius laeviusculus" OR "Dyschirius minutus" OR "Dyschirius politus" OR "Dyschirius substriatus" OR "Dyschirius thoracicus" OR "Elaphrus aureus" OR "Elaphrus cupreus" OR "Elaphrus riparius" OR "Elaphrus uliginosus" OR "Ergates faber" OR "Eurythyrea micans" OR "Eurythyrea quercus" OR "Gnorimus variabilis" OR "Harpalus flavescens" OR "Harpalus froelichii" OR "Harpalus fuscipalpis" OR "Harpalus marginellus" OR "Harpalus politus" OR "Harpalus smaragdinus" OR "Harpalus xanthopus winkleri" OR "Harpalus zabroides" OR "Judolia sexmaculata" OR "Laemostenus macropus" OR "Laemostenus terricola" OR "Lamia textor" OR "Lamprodila festiva festiva" OR "Lebia cyanocephala" OR "Lebia marginata" OR "Lebia scapularis" OR "Lebia trimaculata" OR "Leioderes kollari" OR "Leistus montanus montanus" OR "Leistus montanus rhaeticus" OR "Leistus spinibarbis" OR "Leistus terminatus" OR "Leptura aethiops" OR "Leptura arcuata" OR "Lepturobosca virens" OR "Licinus cassideus" OR "Lophyra flexuosa" OR "Lucanus cervus" OR "Megopis scabricornis" OR "Menesia bipunctata" OR "Mesosa curculionoides" OR "Miscodera arctica" OR "Molops elatus" OR "Molorchus kiesenwetteri" OR "Molorchus marmottani" OR "Monochamus sartor" OR "Nebria cordicollis crypticola" OR "Nebria cordicollis escheri" OR "Nebria cordicollis gracilis" OR "Nebria cordicollis heeri" OR "Nebria cordicollis ticinensis" OR "Nebria cordicollis tenuissima" OR "Nebria crenatostriata" OR "Nebria livida" OR "Nebria psammodes" OR "Necydalis major" OR "Notiophilus germinyi" OR "Notiophilus substriatus" OR "Oberea erythrocephala" OR "Obrium cantharinum" OR "Odacantha melanura" OR "Olisthopus rotundatus" OR "Olisthopus sturmii" OR "Omophron limbatum" OR "Oodes helopioides helepioides" OR "Ophonus cribricollis" OR "Ophonus sabulicola" OR "Ophonus stictus" OR "Oplosia fennica" OR "Oryctes nasicornis" OR "Osmoderma eremita" OR "Pachyta lamed" OR "Pachytodes erraticus" OR "Panagaeus bipustulatus" OR "Paradromius longiceps" OR "Paradromius ruficollis" OR "Patrobus australis" OR "Pedostrangalia pubescens" OR "Pedostrangalia revestita" OR "Phaenops formaneki" OR "Philorhizus quadrisignatus" OR "Philorhizus sigma" OR "Phymatodes glabratus" OR "Phymatodes pusillus" OR "Phytoecia nigripes" OR "Plagionotus detritus" OR "Plagionotus floralis" OR "Platyderus rufus" OR "Platynus complanatus" OR "Platynus longiventris" OR "Poecilonota variolosa" OR "Poecilus kugelanni" OR "Poecilus sericeus" OR "Protaetia aeruginosa" OR "Protaetia affinis" OR "Protaetia angustata" OR "Protaetia fieberi" OR "Protaetia marmorata" OR "Protaetia morio" OR "Pterostichus aterrimus" OR "Pterostichus cribratus" OR "Pterostichus flavofemoratus" OR "Pterostichus honnoratii" OR "Pterostichus macer" OR "Pterostichus quadrifoveolatus" OR "Pterostichus rutilans" OR "Ptosima flavoguttata" OR "Purpuricenus kaehleri" OR "Rhamnusium bicolor" OR "Ropalopus ungaricus" OR "Rosalia alpina" OR "Saperda octopunctata" OR "Saperda perforata" OR "Saperda punctata" OR "Saperda similis" OR "Saphanus piceus" OR "Scintillatrix mirifica" OR "Scintillatrix rutilans" OR "Semanotus undatus" OR "Sericoda quadripunctata" OR "Sphenoptera barbarica barbarica" OR "Sphodrus leucophthalmus" OR "Stenocorus quercus" OR "Stenolophus discophorus" OR "Stenolophus skrimshiranus" OR "Stenopterus ater" OR "Stomis rostratus" OR "Strangalia attenuata" OR "Tanythrix edurus" OR "Tetropium fuscum" OR "Tetropium gabrieli" OR "Trachypteris picta decastigma" OR "Trachys fabricii" OR "Tragosoma depsarium" OR "Trechus laevipes" OR "Trechus pertyi" OR "Trechus pochoni" OR "Trechus rubens" OR "Trichaphaenops sollaudi jurassicus" OR "Trichius rosaceus" OR "Trichius sexualis" OR "Trichoferus cinereus" OR "Trichotichnus rimanus" OR "Xylotrechus arvicola" OR "Xylotrechus rusticus" OR "Zabrus tenebrionides"))

Natural lighting search

TS=((lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Abax oblongus" OR "Acanthocinus griseus" OR "Acanthocinus reticulatus" OR "Acmaeodera degener degener" OR "Acmaeoderella flavofasciata" OR "Acmaeops marginatus" OR "Acmaeops pratensis" OR "Acmaeops septentrionis" OR "Acmaeops smaragdula" OR "Acupalpus brunnipes" OR "Acupalpus exiguus" OR "Acupalpus maculatus" OR "Acupalpus parvulus" OR "Aesalus scarabaeoides" OR "Agapanthia pannonica" OR "Agonum carbonarium" OR "Agonum ericeti" OR "Agonum gracile" OR "Agonum impressum" OR "Agonum monachum" OR "Agonum scitulum" OR "Agonum viridicupreum" OR "Agrilus antiquus" OR "Agrilus derasofasciatus" OR "Agrilus lineola" OR "Agrilus pseudocyaneus" OR "Agrilus salicis" OR "Amara apricaria" OR "Amara concinna" OR "Amara fulva" OR "Amara fusca" OR "Amara infuscata" OR "Amara messae" OR "Amara nigricornis" OR "Amara proxima" OR "Amara sabulosa" OR "Amara schimperi" OR "Amara spreta" OR "Amara tibialis" OR "Amblystomus niger" OR "Anastrangalia reyi" OR "Anchomenus cyaneus" OR "Anoplodera rufipes" OR "Anthaxia candens" OR "Anthaxia chevrieri" OR "Anthaxia cichorii" OR "Anthaxia istriana" OR "Anthaxia manca" OR "Anthaxia nigrojubata incognita" OR "Anthaxia sepulchralis" OR "Aphanisticus elongatus" OR "Aphanisticus emarginatus" OR "Aphanisticus pusillus" OR "Arhopalus ferus" OR "Badister collaris" OR "Badister dilatatus" OR "Badister unipustulatus" OR "Bembidion atrocaeruleum" OR "Bembidion bruxellense" OR "Bembidion elongatum" OR "Bembidion eques" OR "Bembidion fluviatile" OR "Bembidion foraminosum" OR "Bembidion humerale" OR "Bembidion laticolle" OR "Bembidion latinum" OR "Bembidion litorale" OR "Bembidion lunatum" OR "Bembidion modestum" OR "Bembidion obliquum" OR "Bembidion penninum" OR "Bembidion prasinum" OR "Bembidion stephensii" OR "Bembidion striatum" OR "Bembidion velox" OR "Bembidion virens" OR "Blethisa multipunctata" OR "Boldoriella tedeschii" OR "Brachinus elegans" OR "Brachinus immaculicornis" OR "Brachinus sclopeta" OR "Bradycellus ruficollis" OR "Calamobius filum" OR "Calathus circumseptus" OR "Calathus rotundicollis" OR "Calathus rubripes" OR "Callidium coriaceum" OR "Callimus angulatus" OR "Calosoma inquisitor" OR "Calosoma maderae" OR "Calosoma sycophanta" OR "Capnodis tenebrionis" OR "Carabus convexus convexus" OR "Carabus creutzeri kircheri" OR "Carabus nodulosus" OR "Cerambyx cerdo" OR "Cerambyx miles" OR "Ceruchus chrysomelinus" OR "Chalcophora mariana" OR "Chlaenius olivieri" OR "Chlaenius sulcicollis" OR "Chlaenius tristis" OR "Chlaenius velutinus" OR "Chlorophorus pilosus" OR "Chlorophorus trifasciatus" OR "Chrysobothris solieri" OR "Cicindela sylvatica" OR "Clytus rhamni" OR "Clytus tropicus" OR "Coraebus elatus" OR "Coraebus rubi" OR "Coraebus undatus" OR "Cornumutila quadrivittata" OR "Cortodera femorata" OR "Cortodera humeralis" OR "Corymbia cordigera" OR "Corymbia erythroptera" OR "Corymbia scutellata" OR "Cychrus angustatus" OR "Cychrus cordicollis" OR "Cylindera arenaria" OR "Cylindera germanica" OR "Cymindis angularis" OR "Cymindis axillaris" OR "Cymindis miliaris" OR "Cyrtoclytus capra" OR "Demetrias imperialis" OR "Dicerca alni" OR "Dicerca berolinensis" OR "Dicerca moesta" OR "Dicheirotrichus placidus" OR "Dorcadion aethiops" OR "Dorcadion fuliginator" OR "Dorcatypus tristis" OR "Dromius schneideri" OR "Drypta dentata" OR "Duvalius longhii" OR "Dyschirius abditus" OR "Dyschirius angustatus" OR "Dyschirius intermedius" OR "Dyschirius laeviusculus" OR "Dyschirius minutus" OR "Dyschirius politus" OR "Dyschirius substriatus" OR "Dyschirius thoracicus" OR "Elaphrus aureus" OR "Elaphrus cupreus" OR "Elaphrus riparius" OR "Elaphrus uliginosus" OR "Ergates faber" OR "Eurythyrea micans" OR "Eurythyrea quercus" OR "Gnorimus variabilis" OR "Harpalus flavescens" OR "Harpalus froelichii" OR "Harpalus fuscipalpis" OR "Harpalus marginellus" OR "Harpalus politus" OR "Harpalus smaragdinus" OR "Harpalus xanthopus winkleri" OR "Harpalus zabroides" OR "Judolia sexmaculata" OR "Laemostenus macropus" OR "Laemostenus terricola" OR "Lamia textor" OR "Lamprodila festiva festiva" OR "Lebia cyanocephala" OR "Lebia marginata" OR "Lebia scapularis" OR "Lebia trimaculata" OR "Leioderes kollari" OR "Leistus montanus montanus" OR "Leistus montanus rhaeticus" OR "Leistus spinibarbis" OR "Leistus terminatus" OR "Leptura aethiops" OR "Leptura arcuata" OR "Lepturobosca virens" OR "Licinus cassideus" OR "Lophyra flexuosa" OR "Lucanus cervus" OR "Megopis scabricornis" OR "Menesia bipunctata" OR "Mesosa curculionoides" OR "Miscodera arctica" OR "Molops elatus" OR "Molorchus kiesenwetteri" OR "Molorchus marmottani" OR "Monochamus sartor" OR "Nebria cordicollis crypticola" OR "Nebria cordicollis escheri" OR "Nebria cordicollis gracilis" OR "Nebria cordicollis heeri" OR "Nebria cordicollis ticinensis" OR "Nebria cordicollis tenuissima" OR "Nebria crenatostriata" OR "Nebria livida" OR "Nebria psammodes" OR "Necydalis major" OR "Notiophilus germinyi" OR "Notiophilus substriatus" OR "Oberea erythrocephala" OR "Obrium cantharinum" OR "Odacantha melanura" OR "Olisthopus rotundatus" OR "Olisthopus sturmii" OR "Omophron limbatum" OR "Oodes helopioides helepioides" OR "Ophonus cribricollis" OR "Ophonus sabulicola" OR "Ophonus stictus" OR "Oplosia fennica" OR "Oryctes nasicornis" OR "Osmoderma eremita" OR "Pachyta lamed" OR "Pachytodes erraticus" OR "Panagaeus bipustulatus" OR "Paradromius longiceps" OR "Paradromius ruficollis" OR "Patrobus australis" OR "Pedostrangalia pubescens" OR "Pedostrangalia revestita" OR "Phaenops formaneki" OR "Philorhizus quadrisignatus" OR "Philorhizus sigma" OR "Phymatodes glabratus" OR "Phymatodes pusillus" OR "Phytoecia nigripes" OR "Plagionotus detritus" OR "Plagionotus floralis" OR "Platyderus rufus" OR "Platynus complanatus" OR "Platynus longiventris" OR "Poecilonota variolosa" OR "Poecilus kugelanni" OR "Poecilus sericeus" OR "Protaetia aeruginosa" OR "Protaetia affinis" OR "Protaetia angustata" OR "Protaetia fieberi" OR "Protaetia marmorata" OR "Protaetia morio" OR "Pterostichus aterrimus" OR "Pterostichus cribratus" OR "Pterostichus flavofemoratus" OR "Pterostichus honnoratii" OR "Pterostichus macer" OR "Pterostichus quadrifoveolatus" OR "Pterostichus rutilans" OR "Ptosima flavoguttata" OR "Purpuricenus kaehleri" OR "Rhamnusium bicolor" OR "Ropalopus ungaricus" OR "Rosalia alpina" OR "Saperda octopunctata" OR "Saperda perforata" OR "Saperda punctata" OR "Saperda similis" OR "Saphanus piceus" OR "Scintillatrix mirifica" OR "Scintillatrix rutilans" OR "Semanotus undatus" OR "Sericoda quadripunctata" OR "Sphenoptera barbarica barbarica" OR "Sphodrus leucophthalmus" OR "Stenocorus quercus" OR "Stenolophus discophorus" OR "Stenolophus skrimshiranus" OR "Stenopterus ater" OR "Stomis rostratus" OR "Strangalia attenuata" OR "Tanythrix edurus" OR "Tetropium fuscum" OR "Tetropium gabrieli" OR "Trachypteris picta decastigma" OR "Trachys fabricii" OR "Tragosoma depsarium" OR "Trechus laevipes" OR "Trechus pertyi" OR "Trechus pochoni" OR "Trechus rubens" OR "Trichaphaenops sollaudi jurassicus" OR "Trichius rosaceus" OR "Trichius sexualis" OR "Trichoferus cinereus" OR "Trichotichnus rimanus" OR "Xylotrechus arvicola" OR "Xylotrechus rusticus" OR "Zabrus tenebrionides"))

Relevant reviews

TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“ OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND (Beetle* OR carabidae))

Lepidoptera
Artificial lighting search

TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“) AND ("Adscita albanica" OR "Adscita statices" OR "Aglaope infausta" OR "Apatura ilia" OR "Arctia flavia" OR "Arctia villica" OR "Arethusana arethusa" OR "Aricia agestis" OR "Aricia nicias" OR "Bembecia albanensis" OR "Bijugis bombycella helvetica f. retiferella" OR "Bijugis bombycella rotundella" OR "Boloria aquilonaris" OR "Boloria thore" OR "Brevantennia siederi" OR "Brintesia circe" OR "Callimorpha dominula" OR "Calliteara fascelina" OR "Canephora hirsuta" OR "Carcharodus alceae" OR "Carcharodus baeticus" OR "Carcharodus floccifera" OR "Carcharodus lavatherae" OR "Cerura erminea" OR "Cerura vinula" OR "Chamaesphecia dumonti" OR "Chazara briseis" OR "Chelis maculosa" OR "Chelis simplonica" OR "Cilix glaucata" OR "Clostera anachoreta" OR "Coenonympha darwiniana" OR "Coenonympha glycerion" OR "Coenonympha hero" OR "Coenonympha oedippus" OR "Coenonympha tullia" OR "Colias palaeno" OR "Coscinia cribraria" OR "Coscinia striata" OR "Cupido alcetas" OR "Cupido argiades" OR "Cupido osiris" OR "Cybosia mesomella" OR "Dahlica goppensteinensis" OR "Dahlica leoi" OR "Dahlica simplonica" OR "Dahlica ticinensis" OR "Dahlica vaudella" OR "Dahlica wehrlii" OR "Diaphora sordida" OR "Dicranura ulmi" OR "Drepana curvatula" OR "Drymonia querna" OR "Drymonia velitaris" OR "Dysauxes ancilla" OR "Dysauxes punctata" OR "Eilema lutarella" OR "Eilema pygmaeola" OR "Endromis versicolora" OR "Epichnopterix kovacsi" OR "Epichnopterix pontbrillantella" OR "Epichnopterix sieboldi" OR "Erebia christi" OR "Erebia flavofasciata" OR "Erebia meolans" OR "Erebia nivalis" OR "Erebia styx" OR "Erebia sudetica" OR "Erebia triaria" OR "Eriogaster catax" OR "Eriogaster lanestris" OR "Euphydryas aurinia aurinia" OR "Euphydryas intermedia" OR "Euplagia quadripunctaria" OR "Euthrix potatoria" OR "Falcaria lacertinaria" OR "Furcula bicuspis" OR "Furcula bifida" OR "Gastropacha populifolia" OR "Gastropacha quercifolia" OR "Glaucopsyche alexis" OR "Grammia quenselii" OR "Hemaris tityus" OR "Heteropterus morpheus" OR "Hipparchia fagi" OR "Hipparchia semele" OR "Hipparchia statilinus" OR "Holoarctia cervini" OR "Hyles euphorbiae" OR "Hyles hippophaes" OR "Hyles vespertilio" OR "Hyphoraia aulica" OR "Hyponephele lycaon" OR "Iolana iolas" OR "Iphiclides podalirius" OR "Jordanita globulariae" OR "Jordanita notata" OR "Jordanita subsolana" OR "Lasiocampa trifolii" OR "Lemonia dumi" OR "Lemonia taraxaci" OR "Leucodonta bicoloria" OR "Limenitis populi" OR "Limenitis reducta" OR "Lopinga achine" OR "Lycaena alciphron" OR "Lycaena helle" OR "Maculinea alcon" OR "Maculinea arion" OR "Maculinea nausithous" OR "Maculinea rebeli" OR "Maculinea teleius" OR "Malacosoma castrensis" OR "Megalophanes turatii" OR "Melitaea asteria" OR "Melitaea aurelia" OR "Melitaea cinxia" OR "Melitaea deione" OR "Melitaea parthenoides" OR "Melitaea phoebe" OR "Minois dryas" OR "Notodonta torva" OR "Notodonta tritopha" OR "Nymphalis antiopa" OR "Nymphalis polychloros" OR "Ocnogyna parasita" OR "Odonestis pruni" OR "Odontosia carmelita" OR "Orgyia recens" OR "Paranthrene insolita" OR "Parnassius apollo" OR "Parnassius mnemosyne" OR "Pelosia muscerda" OR "Pelosia obtusa" OR "Pericallia matronula" OR "Phalaecropterix praecellens" OR "Phragmatobia luctifera" OR "Phyllodesma ilicifolia" OR "Phyllodesma tremulifolia" OR "Pieris mannii" OR "Plebeius argyrognomon" OR "Plebeius trappi" OR "Polyommatus damon" OR "Polyommatus daphnis" OR "Polyommatus escheri" OR "Polyommatus thersites" OR "Polyploca ridens" OR "Pontia edusa" OR "Proserpinus proserpinus" OR "Pseudobankesia alpestrella" OR "Pseudobankesia contractella" OR "Pseudophilotes baton" OR "Ptilocephala albida" OR "Ptilocephala pyrenaella" OR "Pyrgus armoricanus" OR "Pyrgus carthami" OR "Pyrgus cirsii" OR "Pyrgus onopordi" OR "Pyrgus warrenensis" OR "Pyronia tithonus" OR "Pyropteron chrysidiformis" OR "Rebelia ferruginans" OR "Rebelia herrichiella" OR "Rebelia sapho" OR "Rebelia thomanni" OR "Rhagades pruni" OR "Rhyparia purpurata" OR "Sabra harpagula" OR "Saturnia pavonia" OR "Saturnia pyri" OR "Satyrium acaciae" OR "Satyrium ilicis" OR "Satyrium pruni" OR "Satyrium spini" OR "Scolitantides orion" OR "Setina irrorella" OR "Setina roscida" OR "Smerinthus ocellata" OR "Spilosoma urticae" OR "Synansphecia affinis" OR "Synansphecia muscaeformis" OR "Synanthedon conopiformis" OR "Synanthedon loranthi" OR "Synanthedon polaris" OR "Synanthedon scoliaeformis" OR "Synanthedon stomoxiformis" OR "Tethea ocularis" OR "Tetheella fluctuosa" OR "Thumatha senex" OR "Thymelicus acteon" OR "Tyria jacobaeae" OR "Watsonarctia deserta" OR "Zygaena carniolica" OR "Zygaena fausta" OR "Zygaena minos" OR "Zygaena osterodensis" OR "Zygaena trifolii" OR "Zygaena viciae" OR “Libelloides coccajus” OR “Libelloides longicornis”))

Natural lighting search

TS=((lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Adscita albanica" OR "Adscita statices" OR "Aglaope infausta" OR "Apatura ilia" OR "Arctia flavia" OR "Arctia villica" OR "Arethusana arethusa" OR "Aricia agestis" OR "Aricia nicias" OR "Bembecia albanensis" OR "Bijugis bombycella helvetica f. retiferella" OR "Bijugis bombycella rotundella" OR "Boloria aquilonaris" OR "Boloria thore" OR "Brevantennia siederi" OR "Brintesia circe" OR "Callimorpha dominula" OR "Calliteara fascelina" OR "Canephora hirsuta" OR "Carcharodus alceae" OR "Carcharodus baeticus" OR "Carcharodus floccifera" OR "Carcharodus lavatherae" OR "Cerura erminea" OR "Cerura vinula" OR "Chamaesphecia dumonti" OR "Chazara briseis" OR "Chelis maculosa" OR "Chelis simplonica" OR "Cilix glaucata" OR "Clostera anachoreta" OR "Coenonympha darwiniana" OR "Coenonympha glycerion" OR "Coenonympha hero" OR "Coenonympha oedippus" OR "Coenonympha tullia" OR "Colias palaeno" OR "Coscinia cribraria" OR "Coscinia striata" OR "Cupido alcetas" OR "Cupido argiades" OR "Cupido osiris" OR "Cybosia mesomella" OR "Dahlica goppensteinensis" OR "Dahlica leoi" OR "Dahlica simplonica" OR "Dahlica ticinensis" OR "Dahlica vaudella" OR "Dahlica wehrlii" OR "Diaphora sordida" OR "Dicranura ulmi" OR "Drepana curvatula" OR "Drymonia querna" OR "Drymonia velitaris" OR "Dysauxes ancilla" OR "Dysauxes punctata" OR "Eilema lutarella" OR "Eilema pygmaeola" OR "Endromis versicolora" OR "Epichnopterix kovacsi" OR "Epichnopterix pontbrillantella" OR "Epichnopterix sieboldi" OR "Erebia christi" OR "Erebia flavofasciata" OR "Erebia meolans" OR "Erebia nivalis" OR "Erebia styx" OR "Erebia sudetica" OR "Erebia triaria" OR "Eriogaster catax" OR "Eriogaster lanestris" OR "Euphydryas aurinia aurinia" OR "Euphydryas intermedia" OR "Euplagia quadripunctaria" OR "Euthrix potatoria" OR "Falcaria lacertinaria" OR "Furcula bicuspis" OR "Furcula bifida" OR "Gastropacha populifolia" OR "Gastropacha quercifolia" OR "Glaucopsyche alexis" OR "Grammia quenselii" OR "Hemaris tityus" OR "Heteropterus morpheus" OR "Hipparchia fagi" OR "Hipparchia semele" OR "Hipparchia statilinus" OR "Holoarctia cervini" OR "Hyles euphorbiae" OR "Hyles hippophaes" OR "Hyles vespertilio" OR "Hyphoraia aulica" OR "Hyponephele lycaon" OR "Iolana iolas" OR "Iphiclides podalirius" OR "Jordanita globulariae" OR "Jordanita notata" OR "Jordanita subsolana" OR "Lasiocampa trifolii" OR "Lemonia dumi" OR "Lemonia taraxaci" OR "Leucodonta bicoloria" OR "Limenitis populi" OR "Limenitis reducta" OR "Lopinga achine" OR "Lycaena alciphron" OR "Lycaena helle" OR "Maculinea alcon" OR "Maculinea arion" OR "Maculinea nausithous" OR "Maculinea rebeli" OR "Maculinea teleius" OR "Malacosoma castrensis" OR "Megalophanes turatii" OR "Melitaea asteria" OR "Melitaea aurelia" OR "Melitaea cinxia" OR "Melitaea deione" OR "Melitaea parthenoides" OR "Melitaea phoebe" OR "Minois dryas" OR "Notodonta torva" OR "Notodonta tritopha" OR "Nymphalis antiopa" OR "Nymphalis polychloros" OR "Ocnogyna parasita" OR "Odonestis pruni" OR "Odontosia carmelita" OR "Orgyia recens" OR "Paranthrene insolita" OR "Parnassius apollo" OR "Parnassius mnemosyne" OR "Pelosia muscerda" OR "Pelosia obtusa" OR "Pericallia matronula" OR "Phalaecropterix praecellens" OR "Phragmatobia luctifera" OR "Phyllodesma ilicifolia" OR "Phyllodesma tremulifolia" OR "Pieris mannii" OR "Plebeius argyrognomon" OR "Plebeius trappi" OR "Polyommatus damon" OR "Polyommatus daphnis" OR "Polyommatus escheri" OR "Polyommatus thersites" OR "Polyploca ridens" OR "Pontia edusa" OR "Proserpinus proserpinus" OR "Pseudobankesia alpestrella" OR "Pseudobankesia contractella" OR "Pseudophilotes baton" OR "Ptilocephala albida" OR "Ptilocephala pyrenaella" OR "Pyrgus armoricanus" OR "Pyrgus carthami" OR "Pyrgus cirsii" OR "Pyrgus onopordi" OR "Pyrgus warrenensis" OR "Pyronia tithonus" OR "Pyropteron chrysidiformis" OR "Rebelia ferruginans" OR "Rebelia herrichiella" OR "Rebelia sapho" OR "Rebelia thomanni" OR "Rhagades pruni" OR "Rhyparia purpurata" OR "Sabra harpagula" OR "Saturnia pavonia" OR "Saturnia pyri" OR "Satyrium acaciae" OR "Satyrium ilicis" OR "Satyrium pruni" OR "Satyrium spini" OR "Scolitantides orion" OR "Setina irrorella" OR "Setina roscida" OR "Smerinthus ocellata" OR "Spilosoma urticae" OR "Synansphecia affinis" OR "Synansphecia muscaeformis" OR "Synanthedon conopiformis" OR "Synanthedon loranthi" OR "Synanthedon polaris" OR "Synanthedon scoliaeformis" OR "Synanthedon stomoxiformis" OR "Tethea ocularis" OR "Tetheella fluctuosa" OR "Thumatha senex" OR "Thymelicus acteon" OR "Tyria jacobaeae" OR "Watsonarctia deserta" OR "Zygaena carniolica" OR "Zygaena fausta" OR "Zygaena minos" OR "Zygaena osterodensis" OR "Zygaena trifolii" OR "Zygaena viciae" OR “Libelloides coccajus” OR “Libelloides longicornis”))

Relevant reviews
TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“ OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND (Lepidop* OR moth* OR Butterfl*))

Odonata
Artificial lighting search
TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“) AND ("Aeshna caerulea" OR "Aeshna subarctica elisabethae" OR "Boyeria irene" OR "Calopteryx virgo meridionalis" OR "Ceriagrion tenellum" OR "Coenagrion hastulatum" OR "Coenagrion lunulatum" OR "Coenagrion mercuriale" OR "Coenagrion ornatum" OR "Epitheca bimaculata" OR "Gomphus pulchellus" OR "Gomphus simillimus" OR "Lestes dryas" OR "Lestes virens vestalis" OR "Leucorrhinia albifrons" OR "Leucorrhinia caudalis" OR "Leucorrhinia dubia" OR "Leucorrhinia pectoralis" OR "Nehalennia speciosa" OR "Onychogomphus forcipatus unguiculatus" OR "Onychogomphus uncatus" OR "Ophiogomphus cecilia" OR "Orthetrum albistylum" OR "Oxygastra curtisii" OR "Somatochlora arctica" OR "Sympecma paedisca" OR "Sympetrum depressiusculum" OR "Sympetrum flaveolum" OR "Sympetrum pedemontanum"))

Natural lighting search
TS=((lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Aeshna caerulea" OR "Aeshna subarctica elisabethae" OR "Boyeria irene" OR "Calopteryx virgo meridionalis" OR "Ceriagrion tenellum" OR "Coenagrion hastulatum" OR "Coenagrion lunulatum" OR "Coenagrion mercuriale" OR "Coenagrion ornatum" OR "Epitheca bimaculata" OR "Gomphus pulchellus" OR "Gomphus simillimus" OR "Lestes dryas" OR "Lestes virens vestalis" OR "Leucorrhinia albifrons" OR "Leucorrhinia caudalis" OR "Leucorrhinia dubia" OR "Leucorrhinia pectoralis" OR "Nehalennia speciosa" OR "Onychogomphus forcipatus unguiculatus" OR "Onychogomphus uncatus" OR "Ophiogomphus cecilia" OR "Orthetrum albistylum" OR "Oxygastra curtisii" OR "Somatochlora arctica" OR "Sympecma paedisca" OR "Sympetrum depressiusculum" OR "Sympetrum flaveolum" OR "Sympetrum pedemontanum"))

Relevant reviews
TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“ OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND (Dragonfl* OR Anisoptera OR damselfly* OR Zygoptera OR Odonata))

Orthoptera
Artificial lighting search
TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR

“road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“) AND ("Aeropedellus variegatus" OR "Aiolopus thalassinus" OR "Anonconotus alpinus" OR "Antaxius difformis" OR "Arcyptera fusca" OR "Bryodemella tuberculata" OR "Calliptamus barbarus" OR "Calliptamus italicus" OR "Calliptamus siciliae" OR "Chorthippus montanus" OR "Chorthippus pullus" OR "Conocephalus dorsalis" OR "Conocephalus fuscus" OR "Epacromius tergestinus" OR "Ephippiger ephippiger diurnus" OR "Ephippiger terrestris bormansi" OR "Ephippiger vicheti" OR "Euchorthippus declivus" OR "Locusta migratoria cinerascens" OR "Melanogryllus desertus" OR "Metrioptera bicolor" OR "Myrmeleotettix maculatus" OR "Oedaleus decorus" OR "Oedipoda germanica" OR "Pachytrachis striolatus" OR "Phaneroptera falcata" OR "Pholidoptera littoralis insubrica" OR "Platycleis tessellata" OR "Podismopsis keisti" OR "Psophus stridulus" OR "Pteronemobius heydenii" OR "Pteronemobius lineolatus" OR "Saga pedo" OR "Sphingonotus caerulans" OR "Stenobothrus nigromaculatus" OR "Stenobothrus stigmaticus" OR "Stethophyma grossum" OR "Tetrix ceperoi" OR "Tetrix tuerki" OR "Tettigonia caudata" OR "Uvarovitettix depressus" OR "Xya variegata"))

Natural lighting search
TS=((lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Aeropedellus variegatus" OR "Aiolopus thalassinus" OR "Anonconotus alpinus" OR "Antaxius difformis" OR "Arcyptera fusca" OR "Bryodemella tuberculata" OR "Calliptamus barbarus" OR "Calliptamus italicus" OR "Calliptamus siciliae" OR "Chorthippus montanus" OR "Chorthippus pullus" OR "Conocephalus dorsalis" OR "Conocephalus fuscus" OR "Epacromius tergestinus" OR "Ephippiger ephippiger diurnus" OR "Ephippiger terrestris bormansi" OR "Ephippiger vicheti" OR "Euchorthippus declivus" OR "Locusta migratoria cinerascens" OR "Melanogryllus desertus" OR "Metrioptera bicolor" OR "Myrmeleotettix maculatus" OR "Oedaleus decorus" OR "Oedipoda germanica" OR "Pachytrachis striolatus" OR "Phaneroptera falcata" OR "Pholidoptera littoralis insubrica" OR "Platycleis tessellata" OR "Podismopsis keisti" OR "Psophus stridulus" OR "Pteronemobius heydenii" OR "Pteronemobius lineolatus" OR "Saga pedo" OR "Sphingonotus caerulans" OR "Stenobothrus nigromaculatus" OR "Stenobothrus stigmaticus" OR "Stethophyma grossum" OR "Tetrix ceperoi" OR "Tetrix tuerki" OR "Tettigonia caudata" OR "Uvarovitettix depressus" OR "Xya variegata"))

Relevant reviews
TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“ OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND (Orthoptera* OR Grasshopper* OR Locust* Or Cricket* OR katydid* OR weta*))

Ephemeroptera, Plecoptera and Trichoptera
Combined lighting search
TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“ OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Acentrella sinaica" OR "Ameletus inopinatus" OR "Baetis buceratus" OR "Baetis liebenauae" OR "Baetis melanonyx" OR "Baetis nexus" OR "Baetis nubecularis" OR "Caenis beskidensis" OR "Caenis lactea" OR "Caenis pusilla" OR "Caenis rivulorum" OR "Choroterpes picteti" OR "Ecdyonurus alpinus" OR "Ecdyonurus dispar" OR "Ecdyonurus insignis" OR "Ecdyonurus parahelveticus" OR "Ephemera glaucops" OR "Ephemera lineata" OR "Ephemera vulgata" OR "Ephemerella notata" OR "Ephoron virgo" OR "Habroleptoides auberti" OR "Habrophlebia eldae" OR "Habrophlebia fusca" OR "Heptagenia coerulans" OR "Heptagenia longicauda" OR "Leptophlebia marginata" OR "Leptophlebia vespertina" OR "Metreletus balcanicus" OR "Nigrobaetis niger" OR "Oligoneuriella rhenana" OR "Procloeon bifidum" OR "Procloeon pennulatum" OR "Rhithrogena allobrogica" OR "Rhithrogena beskidensis" OR "Rhithrogena

dorieri" OR "Rhithrogena germanica" OR "Rhithrogena grischuna" OR "Rhithrogena landai" OR "Rhithrogena nivata" OR "Siphlonurus aestivalis" OR "Torleya major" OR "Acrophylax zerberus" OR "Adicella filicornis" OR "Adicella reducta" OR "Agapetus laniger" OR "Agapetus nimbulus" OR "Agrypnia obsoleta" OR "Agrypnia picta" OR "Allogamus antennatus" OR "Allogamus mendax" OR "Allotrichia pallicornis" OR "Anabolia brevipennis" OR "Anabolia lombarda" OR "Anisogamus difformis" OR "Annitella obscurata" OR "Anomalopterygella chauviniana" OR "Apatania fimbriata" OR "Apatania helvetica" OR "Apatania muliebris" OR "Athripsodes bilineatus" OR "Athripsodes leucophaeus" OR "Beraeamyia squamosa" OR "Beraeodes minutus" OR "Brachycentrus maculatus" OR "Brachycentrus montanus" OR "Brachycentrus subnubilus" OR "Catagapetus nigrans" OR "Ceraclea annulicornis" OR "Ceraclea aurea" OR "Ceraclea fulva" OR "Ceraclea nigronervosa" OR "Ceraclea riparia" OR "Ceraclea senilis" OR "Chaetopterygopsis maclachlani" OR "Chaetopteryx gessneri" OR "Chaetopteryx major" OR "Chimarra marginata" OR "Consorophylax consors" OR "Cryptothrix nebulicola" OR "Cyrnus flavidus" OR "Diplectrona atra" OR "Drusus alpinus" OR "Drusus melanchaetes" OR "Drusus mixtus" OR "Drusus muelleri" OR "Drusus nigrescens" OR "Enoicyla reichenbachi" OR "Ernodes articularis" OR "Erotesis baltica" OR "Glossosoma bifidum" OR "Grammotaulius nigropunctatus" OR "Hagenella clathrata" OR "Halesus tesselatus" OR "Helicopsyche sperata" OR "Holocentropus dubius" OR "Holocentropus picicornis" OR "Holocentropus stagnalis" OR "Hydatophylax infumatus" OR "Hydropsyche bulbifera" OR "Hydropsyche doehleri" OR "Hydropsyche exocellata" OR "Hydropsyche fulvipes" OR "Hydropsyche guttata" OR "Hydropsyche modesta" OR "Hydropsyche saxonica" OR "Hydroptila brissaga" OR "Hydroptila dampfi" OR "Hydroptila insubrica" OR "Hydroptila ivisa" OR "Hydroptila martini" OR "Hydroptila occulta" OR "Hydroptila pulchricornis" OR "Hydroptila rheni" OR "Hydroptila simulans" OR "Hydroptila tigurina" OR "Hydroptila valesiaca" OR "Ironoquia dubia" OR "Ithytrichia clavata" OR "Ithytrichia lamellaris" OR "Lepidostoma basale" OR "Limnephilus affinis" OR "Limnephilus algosus" OR "Limnephilus binotatus" OR "Limnephilus bipunctatus" OR "Limnephilus borealis" OR "Limnephilus elegans" OR "Limnephilus flavospinosus" OR "Limnephilus germanus" OR "Limnephilus griseus" OR "Limnephilus helveticus" OR "Limnephilus incisus" OR "Limnephilus italicus" OR "Limnephilus nigriceps" OR "Limnephilus politus" OR "Limnephilus sericeus" OR "Limnephilus subcentralis" OR "Limnephilus vittatus" OR "Lithax obscurus" OR "Metanoea flavipennis" OR "Metanoea rhaetica" OR "Micrasema minimum" OR "Micrasema morosum" OR "Micrasema setiferum" OR "Micropterna fissa" OR "Microptila minutissima" OR "Molanna albicans" OR "Mystacides nigra" OR "Nemotaulius punctatolineatus" OR "Notidobia ciliaris" OR "Oecetis furva" OR "Oligostomis reticulata" OR "Orthotrichia angustella" OR "Oxyethira falcata" OR "Oxyethira simplex" OR "Philopotamus montanus" OR "Platyphylax frauenfeldi" OR "Plectrocnemia appennina" OR "Polycentropus corniger" OR "Polycentropus irroratus" OR "Polycentropus kingi" OR "Polycentropus morettii" OR "Potamophylax luctuosus" OR "Potamophylax rotundipennis" OR "Psychomyia fragilis" OR "Rhadicoleptus ucenorum" OR "Rhyacophila aquitanica" OR "Rhyacophila aurata" OR "Rhyacophila bonaparti" OR "Rhyacophila glareosa" OR "Rhyacophila laevis" OR "Rhyacophila meyeri" OR "Rhyacophila orobica" OR "Rhyacophila pascoei" OR "Rhyacophila philopotamoides" OR "Rhyacophila praemorsa" OR "Rhyacophila rectispina" OR "Rhyacophila simulatrix" OR "Rhyacophila stigmatica" OR "Sericostoma galeatum" OR "Silo piceus" OR "Stactobia eatoniella" OR "Stactobia moselyi" OR "Stactobiella risi" OR "Stenophylax mucronatus" OR "Synagapetus iridipennis" OR "Tinodes antonioi" OR "Tinodes luscinia" OR "Tinodes maclachlani" OR "Tinodes maculicornis" OR "Tinodes pallidulus" OR "Tinodes sylvia" OR "Tinodes zelleri" OR "Triaenodes bicolor" OR "Tricholeiochiton fagesii" OR "Trichostegia minor" OR "Wormaldia mediana" OR "Wormaldia pulla" OR "Wormaldia subnigra" OR "Wormaldia variegata" OR "Besdolus imhoffi" OR "Besdolus ventralis" OR "Brachyptera braueri" OR "Brachyptera monilicornis" OR "Brachyptera seticornis" OR "Brachyptera trifasciata" OR "Capnia bifrons" OR "Dinocras ferreri" OR "Dinocras megacephala" OR "Isogenus nubecula" OR "Isoperla carbonaria" OR "Isoperla lugens" OR "Isoperla obscura" OR "Isoperla orobica" OR "Isoperla oxylepis" OR "Leuctra ameliae" OR "Leuctra armata" OR "Leuctra autumnalis" OR "Leuctra dolasilla" OR "Leuctra elisabethae" OR "Leuctra festai" OR "Leuctra helvetica" OR "Leuctra hexacantha" OR "Leuctra insubrica" OR "Leuctra meridionalis" OR "Leuctra niveola" OR

"Leuctra pseudorosinae" OR "Leuctra ravizzai" OR "Leuctra schmidi" OR "Leuctra sesvenna" OR "Leuctra subalpina" OR "Leuctra vinconi aubertorum" OR "Leuctra zwicki" OR "Nemoura avicularis" OR "Nemoura dubitans" OR "Nemoura obtusa" OR "Nemoura palliventris" OR "Nemoura pesarinii" OR "Nemoura sciurus" OR "Nemoura sinuata" OR "Nemoura uncinata" OR "Nemoura undulata" OR "Perla abdominalis" OR "Perlodes dispar" OR "Perlodes jurassicus" OR "Protonemura algovia" OR "Protonemura meyeri" OR "Protonemura nimborella" OR "Rhabdiopteryx alpina" OR "Rhabdiopteryx harperi" OR "Taeniopteryx hubaulti" OR "Taeniopteryx nebulosa" OR "Taeniopteryx schoenemundi" OR "Xanthoperla apicalis"))

Decapods
Combined lighting search
TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“ OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Astacus astacus” OR “Austropotamobius pallipes” OR “Austropotamobius torrentium”))

Gastropods and Bivalves
Combined lighting search
TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“ OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Acicula lineolata" OR "Anodonta anatina" OR "Anodonta anatina aggr." OR "Argna ferrari" OR "Arion intermedius" OR "Arion rufus" OR "Balea biplicata" OR "Balea perversa" OR "Bulgarica cana" OR "Candidula unifasciata unifasciata" OR "Causa holosericea" OR "Cecilioides veneta" OR "Charpentieria dyodon" OR "Charpentieria itala albopustalata" OR "Charpentieria thomasiana studeri" OR "Chilostoma achates achates" OR "Chilostoma adelezona adelezona" OR "Chilostoma adelezona rhaeticum" OR "Chilostoma cingulatum tigrinum" OR "Chilostoma cingulatum cingulatum" OR "Chilostoma glacialis" OR "Chilostoma zonatum" OR "Chondrina generosensis" OR "Chondrina megacheilos" OR "Chondrula tridens" OR "Cochlicopa nitens" OR "Cochlodina comensis" OR "Cochlodina orthostoma" OR "Daudebardia brevipes" OR "Daudebardia rufa" OR "Deroceras juranum" OR "Drepanostoma nautiliforme" OR "Eucobresia glacialis" OR "Eucobresia nivalis" OR "Eucobresia pegorarii" OR "Granaria frumentum" OR "Granaria illyrica" OR "Granaria variabilis" OR "Granopupa granum" OR "Helicodonta angigyra" OR "Jaminia quadridens" OR "Lauria cylindracea" OR "Lauria sempronii" OR "Lehmannia rupicola" OR "Mediterranea adamii" OR "Microcondylaea bonellii" OR "Neostyriaca strobel" OR "Oligolimax annularis" OR "Oxychilus clarus" OR "Oxychilus mortilleti" OR "Pagodulina austeniana adamii" OR "Phenacolimax major" OR "Pomatias elegans" OR "Pupilla alpicola" OR "Pupilla bigranata" OR "Quickella arenaria" OR "Retinella hiulca" OR "Ruthenica filograna" OR "Semilimax kotulae" OR "Semilimax semilimax" OR "Solatopupa similis" OR "Sphyradium doliolum" OR "Tandonia nigra" OR "Trochulus biconicus" OR "Trochulus caelatus" OR "Trochulus montanus" OR "Trochulus piccardi" OR "Truncatellina claustralis" OR "Truncatellina monodon" OR "Unio crassus" OR "Unio mancus" OR "Unio pictorum" OR "Unio tumidus" OR "Vallonia declivis" OR "Vallonia enniensis" OR "Vertigo angustior" OR "Vertigo antivertigo" OR "Vertigo genesii" OR "Vertigo geyeri" OR "Vertigo modesta arctica" OR "Vertigo moulinsiana" OR "Vertigo substriata" OR "Vitrinobrachium breve" OR "Xerocrassa geyeri" OR "Zebrina detrita" OR "Zoogenetes harpa"))

Fungi and lichens
Combined lighting search
TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“

OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Acarospora schleicheri" OR "Acorospora nodulosa" OR "Agonimia octospora" OR "Anaptychia bryorum" OR "Anaptychia ciliaris" OR "Anaptychia crinalis" OR "Arthonia apatetica" OR "Arthonia byssacea" OR "Arthonia cinereopruinosa" OR "Arthonia dispersa" OR "Arthonia elegans" OR "Arthonia faginea" OR "Arthonia fuliginosa" OR "Arthonia helvola" OR "Arthonia leucopellaea" OR "Arthonia medusula" OR "Arthonia pruinata" OR "Arthonia reniformis" OR "Arthonia vinosa" OR "Arthothelium spectabile" OR "Arthrorhaphis vacillans" OR "Arthrosporum populorum" OR "Bacidia auerswaldii" OR "Bacidia biatorina" OR "Bacidia circumspecta" OR "Bacidia fraxinea" OR "Bacidia friesiana" OR "Bacidia hegetschweileri" OR "Bacidia incompta" OR "Bacidia laurocerasi" OR "Bacidia polychroa" OR "Bacidia rosella" OR "Bactrospora dryina" OR "Biatora ocelliformis" OR "Biatora rufidula" OR "Biatoridium delitescens" OR "Bryoria bicolor" OR "Bryoria nadvornikiana" OR "Bryoria simplicior" OR "Buellia alboatra" OR "Buellia arnoldii" OR "Buellia asterella" OR "Buellia elegans" OR "Buellia epigaea" OR "Buellia erubescens" OR "Buellia triphragmioides" OR "Byssoloma marginatum" OR "Calicium adaequatum" OR "Calicium adspersum" OR "Calicium lenticulare" OR "Calicium parvum" OR "Calicium quercinum" OR "Caloplaca alnetorum" OR "Caloplaca assigena" OR "Caloplaca chrysophthalma" OR "Caloplaca flavorubescens" OR "Caloplaca lobulata" OR "Caloplaca lucifuga" OR "Caloplaca obscurella" OR "Caloplaca pollinii" OR "Candelariella subdeflexa" OR "Candelariella viae-lacteae" OR "Catapyrenium daedaleum" OR "Catapyrenium psoromoides" OR "Catillaria alba" OR "Catillaria pulverea" OR "Catinaria papillosa" OR "Catolechia wahlenbergii" OR "Cetraria laureri" OR "Cetraria oakesiana" OR "Cetraria sepincola" OR "Cetrelia chicitae" OR "Cetrelia olivetorum" OR "Chaenotheca chlorella" OR "Chaenotheca cinerea" OR "Chaenotheca hispidula" OR "Chaenotheca laevigata" OR "Chaenotheca phaeocephala" OR "Chaenotheca subroscida" OR "Cheiromycina flabelliformis" OR "Chromatochlamys muscorum" OR "Cladonia acuminata" OR "Cladonia caespiticia" OR "Cladonia cariosa" OR "Cladonia cervicornis" OR "Cladonia ciliata" OR "Cladonia decorticata" OR "Cladonia foliacea aggr." OR "Cladonia furcata ssp. subrangiformis" OR "Cladonia incrassata" OR "Cladonia peziziformis" OR "Cladonia polycarpoides" OR "Cladonia portentosa" OR "Cladonia rangiformis" OR "Cladonia rei" OR "Cladonia stellaris" OR "Cladonia strepsilis" OR "Cladonia stygia" OR "Cladonia turgida" OR "Cladonia uliginosa" OR "Cliostomum leprosum" OR "Cliostomum pallens" OR "Collema conglomeratum" OR "Collema fasciculare" OR "Collema fragrans" OR "Collema furfuraceum" OR "Collema ligerinum" OR "Collema nigrescens" OR "Collema occultatum" OR "Collema subflaccidum" OR "Cyphelium karelicum" OR "Cyphelium lucidum" OR "Cyphelium pinicola" OR "Dactylina ramulosa" OR "Dimerella lutea" OR "Eopyrenula leucoplaca" OR "Fellhanera gyrophorica" OR "Fellhanera subtilis" OR "Fellhaneropsis myrtillicola" OR "Fellhaneropsis vezdae" OR "Fulgensia desertorum" OR "Fulgensia fulgens" OR "Fulgensia subbracteata" OR "Fuscidea arboricola" OR "Gomphillus calycioides" OR "Graphis elegans" OR "Gyalecta flotowii" OR "Gyalecta foveolaris" OR "Gyalecta peziza" OR "Gyalecta truncigena" OR "Gyalecta ulmi" OR "Heppia adglutinata" OR "Heppia lutosa" OR "Heterodermia leucomelos" OR "Heterodermia obscurata" OR "Heterodermia speciosa" OR "Hypocenomyce friesii" OR "Hypocenomyce praestabilis" OR "Hypogymnia vittata" OR "Japewia subaurifera" OR "Lecanactis abietina" OR "Lecanactis amylacea" OR "Lecania fuscella" OR "Lecania koerberiana" OR "Lecanora cinereofusca" OR "Lecanora leptacina" OR "Lecanora praesistens" OR "Lecanora vinetorum" OR "Lecidea betulicola" OR "Lecidea erythrophaea" OR "Lecidea margaritella" OR "Lecidella laureri" OR "Leprocaulon microscopicum" OR "Leptochidium albociliatum" OR "Leptogium burnetiae" OR "Leptogium cyanescens" OR "Leptogium hildenbrandii" OR "Leptogium teretiusculum" OR "Lobaria amplissima" OR "Lobaria pulmonaria" OR "Lobaria scrobiculata" OR "Lobaria virens" OR "Lopadium disciforme" OR "Loxospora cismonica" OR "Macentina stigonemoides" OR "Maronea constans" OR "Massalongia carnosa" OR "Megalospora pachycarpa" OR "Menegazzia terebrata" OR "Micarea adnata" OR "Micarea coppinsii" OR "Moelleropsis nebulosa" OR "Mycobilimbia carneoalbida" OR "Mycobilimbia sphaeroides" OR "Mycoblastus affinis" OR "Mycoblastus caesius" OR "Nephroma expallidum" OR "Nephroma laevigatum" OR "Nephroma resupinatum" OR "Ochrolechia pallescens" OR "Ochrolechia subviridis" OR "Ochrolechia szatalaensis" OR "Opegrapha ochrocheila" OR "Pachyphiale carneola" OR "Pachyphiale fagicola" OR "Pachyphiale ophiospora" OR "Pannaria conoplea" OR "Pannaria rubiginosa" OR "Parmelia laciniatula" OR "Parmelia laevigata" OR "Parmelia minarum" OR "Parmelia reticulata" OR "Parmelia septentrionalis" OR "Parmelia sinuosa" OR "Parmelia taylorensis" OR "Parmotrema arnoldii" OR "Parmotrema chinense" OR "Parmotrema crinitum" OR "Parmotrema stuppeum" OR "Peltigera hymenina" OR "Peltigera kristinsonnii" OR "Pertusaria alpina" OR "Pertusaria borealis" OR "Pertusaria coccodes" OR "Pertusaria constricta" OR "Pertusaria coronata" OR "Pertusaria flavida" OR "Pertusaria hemisphaerica" OR "Pertusaria multipuncta" OR "Pertusaria oculata" OR "Pertusaria ophthalmiza" OR "Pertusaria pertusa" OR "Pertusaria pustulata" OR "Pertusaria sommerfeltii" OR "Pertusaria trachythallina" OR "Phaeophyscia hispidula" OR "Phaeophyscia insignis" OR "Phaeophyscia poeltii" OR "Physcia clementei" OR "Physcia vitii" OR "Polychidium muscicola" OR "Psora vallesciaca" OR "Ramalina dilacerata" OR "Ramalina fastigiata" OR "Ramalina obtusata" OR "Ramalina panizzei" OR "Ramalina roesleri" OR "Ramalina sinensis" OR "Ramalina thrausta" OR "Rinodina colobina" OR "Rinodina conradii" OR "Rinodina efflorescens" OR "Rinodina intermedia" OR "Rinodina isidioides" OR "Rinodina laxa" OR "Rinodina mucronatula" OR "Rinodina plana" OR "Rinodina polyspora" OR "Rinodina polysporoides" OR "Rinodina roboris" OR "Rinodina sheardii" OR "Rinodina ventricosa" OR "Santessoniella arctophila" OR "Schismatomma decolorans" OR "Schismatomma graphidioides" OR "Sclerophora nivea" OR "Scoliciosporum curvatum" OR "Scoliciosporum pruinosum" OR "Solorinella asteriscus" OR "Sphaerophorus globosus" OR "Sphaerophorus melanocarpus" OR "Squamarina lentigera" OR "Stereocaulon capitellatum" OR "Stereocaulon glareosum" OR "Stereocaulon incrustatum" OR "Stereocaulon rivulorum" OR "Stereocaulon tomentosum" OR "Sticta fuliginosa" OR "Sticta limbata" OR "Sticta sylvatica" OR "Strangospora deplanata" OR "Strangospora ochrophora" OR "Strangospora pinicola" OR "Strigula glabra" OR "Strigula jamesii" OR "Strigula mediterranea" OR "Teloschistes chrysophthalmus" OR "Thelenella modesta" OR "Thelenidia monosporella" OR "Thelocarpon imperceptum" OR "Thelopsis flaveola" OR "Thelopsis rubella" OR "Thelotrema lepadinum" OR "Toninia coelestina" OR "Toninia lutosa" OR "Toninia opuntioides" OR "Toninia physaroides" OR "Toninia tristis" OR "Trapelia corticola" OR "Usnea ceratina" OR "Usnea cornuta" OR "Usnea florida" OR "Usnea fulvoreagens" OR "Usnea glabrata" OR "Usnea glabrescens" OR "Usnea longissima" OR "Usnea madeirensis" OR "Usnea rigida" OR "Usnea wasmuthii" OR "Vezdaea stipitata" OR "Zamenhofia hibernica" OR "Abortiporus biennis" OR "Agaricus altipes" OR "Agaricus benesii" OR "Agaricus excellens" OR "Agaricus lanipes" OR "Agaricus leucotrichus" OR "Agaricus luteomaculatus" OR "Agaricus lutosus" OR "Agaricus macrocarpus" OR "Agaricus maleolens" OR "Agaricus nivescens" OR "Agaricus porphyrizon" OR "Agaricus subperonatus" OR "Agrocybe elatella" OR "Agrocybe firma" OR "Agrocybe vervacti" OR "Aleurocystidiellum subcruentatum" OR "Aleurodiscus amorphus" OR "Aleurodiscus aurantius" OR "Amanita beckeri" OR "Amanita caesarea" OR "Amanita eliae" OR "Amanita franchetii" OR "Amanita friabilis" OR "Amanita lividopallescens" OR "Amanita magnivolvata" OR "Amanita nivalis" OR "Amanita pachyvolvata" OR "Amanita solitaria" OR "Amanita verna" OR "Amyloporiella crassa" OR "Amylostereum laevigatum" OR "Antrodia albida" OR "Antrodia lenis" OR "Antrodia malicola" OR "Antrodia ramentacea" OR "Antrodia sinuosa" OR "Antrodiella semisupina" OR "Arcangeliella stephensii" OR "Armillaria ectypa" OR "Arrhenia roseola" OR "Ascozonus woolhopensis" OR "Asterostroma cervicolor" OR "Asterostroma laxum" OR "Astraeus hygrometricus" OR "Aurantioporus fissilis" OR "Bankera fuligineoalba" OR "Bankera violascens" OR "Basidiodendron cinereum" OR "Biscogniauxia marginata" OR "Boidinia furfuracea" OR "Boidinia subasperisporum" OR "Bolbitius pluteoides" OR "Boletopsis grisea" OR "Boletus aereus" OR "Boletus dupainii" OR "Boletus fechtneri" OR "Boletus impolitus" OR "Boletus junquilleus" OR "Boletus pseudoregius" OR "Boletus queletii" OR "Boletus regius" OR "Boletus rhodopurpureus" OR "Boletus rhodoxanthus" OR "Boletus torosus" OR "Botryotinia calthae" OR "Botryotinia ranunculi" OR "Bovista limosa" OR "Bovista paludosa" OR "Bovista pusilla" OR "Bovista tomentosa" OR "Byssonectria terrestris" OR "Calocybe obscurissima" OR "Calocybe onychina" OR "Caloscypha fulgens" OR "Camarophyllopsis atropuncta" OR "Camarophyllopsis foetens" OR "Camarophyllopsis micacea" OR "Camarophyllopsis phaeophylla" OR "Camarophyllopsis schulzeri" OR "Camarophyllus berkeleyi" OR "Camarophyllus cinereus" OR "Camarophyllus flavipes" OR "Camarophyllus fuscescens" OR "Camarophyllus lacmus" OR "Camarophyllus russocoriaceus" OR "Candelabrochaete septocystidia" OR "Cantharellula umbonata" OR "Cantharellus ianthinoxanthus" OR "Cantharellus melanoxeros" OR "Ceriporiopsis gilvescens" OR "Ceriporiopsis resinascens" OR "Chalciporus amarellus" OR "Chalciporus pseudorubinus" OR "Chamonixia caespitosa" OR "Cheilymenia theleboloides" OR "Cheilymenia vitellina" OR "Ciboria viridifusca" OR "Clavaria argillacea" OR "Clavaria candida" OR "Clavaria fumosa" OR "Clavaria incarnata" OR "Clavaria rosea" OR "Clavaria zollingeri" OR "Clavicorona pyxidata" OR "Clavulicium macounii" OR "Clavulina amethystina" OR "Clavulinopsis fusiformis" OR "Clavulinopsis luteoalba" OR "Clitocybe barbularum" OR "Clitocybe bresadolana" OR "Clitocybe collina" OR "Clitocybe elegantula" OR "Clitocybe ericetorum" OR "Clitocybe favrei" OR "Clitocybe festiva" OR "Clitocybe fuligineipes" OR "Clitocybe glareosa" OR "Clitocybe lateritia" OR "Clitocybe lituus" OR "Clitocybe marginella" OR "Clitocybe martiorum" OR "Clitocybe maxima" OR "Clitocybe pseudoobbata" OR "Clitocybe subsalmonea" OR "Clitocybe truncicola" OR "Clitocybe tuba" OR "Clitocybula abundans" OR "Collybia fodiens" OR "Collybia hybrida" OR "Collybia nivalis" OR "Collybia oreadoides" OR "Collybia prolixa" OR "Conocybe antipus" OR "Conocybe aurea" OR "Coprinus echinosporus" OR "Coprinus latisporus" OR "Coprinus martinii" OR "Coprinus narcoticus" OR "Coprinus phaeosporus" OR "Coprinus truncorum" OR "Cordyceps michiganensis" OR "Cordyceps sphecocephala" OR "Cortinarius allutus" OR "Cortinarius arcuatorum" OR "Cortinarius argutus" OR "Cortinarius armillatus" OR "Cortinarius arquatus" OR "Cortinarius aureofulvus" OR "Cortinarius aureopulverulentus" OR "Cortinarius avellaneocoeruleus" OR "Cortinarius azureovelatus" OR "Cortinarius azureus" OR "Cortinarius balteatoalbus" OR "Cortinarius balteatocumatilis" OR "Cortinarius betulinus" OR "Cortinarius bulbosus" OR "Cortinarius bulliardii" OR "Cortinarius caerulescentium" OR "Cortinarius caesiocanescens" OR "Cortinarius caesiocortinatus" OR "Cortinarius caesiocyaneus" OR "Cortinarius caesiostramineus" OR "Cortinarius causticus" OR "Cortinarius cephalixus" OR "Cortinarius cinnabarinus" OR "Cortinarius citrinoolivaceus" OR "Cortinarius citrinus" OR "Cortinarius cliduchus" OR "Cortinarius corrosus" OR "Cortinarius cotoneus" OR "Cortinarius crassus" OR "Cortinarius croceocoeruleus" OR "Cortinarius croceoconus" OR "Cortinarius cumatilis" OR "Cortinarius cyaneus" OR "Cortinarius cyanites" OR "Cortinarius dibaphus" OR "Cortinarius elegantissimus" OR "Cortinarius emollitus" OR "Cortinarius fulmineus" OR "Cortinarius glandicolor" OR "Cortinarius guttatus" OR "Cortinarius haematochelis" OR "Cortinarius herpeticus" OR "Cortinarius humicola" OR "Cortinarius largus" OR "Cortinarius lignicolus" OR "Cortinarius lividoviolaceus" OR "Cortinarius mairei" OR "Cortinarius malachioides" OR "Cortinarius miniatopus" OR "Cortinarius moenne-loccozii" OR "Cortinarius papulosus" OR "Cortinarius paracephalixus" OR "Cortinarius phoeniceus" OR "Cortinarius pholideus" OR "Cortinarius phrygianus" OR "Cortinarius porphyropus" OR "Cortinarius prasinus" OR "Cortinarius psammocephalus" OR "Cortinarius pseudocyanites" OR "Cortinarius pseudoglaucopus" OR "Cortinarius pseudosulphureus" OR "Cortinarius pumilus" OR "Cortinarius rapaceus" OR "Cortinarius raphanoides" OR "Cortinarius rufoolivaceus" OR "Cortinarius saniosus" OR "Cortinarius saporatus" OR "Cortinarius scutulatus" OR "Cortinarius sebaceus" OR "Cortinarius sodagnitus" OR "Cortinarius spadiceus" OR "Cortinarius subannulatus" OR "Cortinarius subferrugineus" OR "Cortinarius subporphyropus" OR "Cortinarius subpurpurascens" OR "Cortinarius talus" OR "Cortinarius tophaceus" OR "Cortinarius triumphans" OR "Cortinarius turmalis" OR "Cortinarius variegatus" OR "Cortinarius vespertinus" OR "Cortinarius vulpinus" OR "Cortinarius xanthophyllus" OR "Cortinarius zinziberatus" OR "Cotylidia undulata" OR "Creolophus cirrhatus" OR "Crepidotus autochthonus" OR "Crepidotus ehrendorferi" OR "Crinipellis scabella" OR "Cristinia gallica" OR "Cudoniella clavus" OR "Cyphella digitalis" OR "Cyphellostereum laeve" OR "Cystoderma superbum" OR "Cystoderma terrei" OR "Cystolepiota moelleri" OR "Dacryobolus sudans" OR "Daldinia occidentalis" OR "Dentipellis fragilis" OR "Dermoloma cuneifolium" OR "Dermoloma pseudocuneifolium" OR "Dichomitus campestris" OR "Diplomitoporus flavescens" OR "Discina leucoxantha" OR "Discina melaleuca" OR "Disciseda bovista" OR "Disciseda candida" OR "Encoelia fascicularis" OR "Entoloma alpicola" OR "Entoloma aprile" OR "Entoloma asprellum" OR "Entoloma atrocoeruleum" OR "Entoloma atrosericeum" OR "Entoloma bloxamii" OR "Entoloma caccabus" OR "Entoloma carneogriseum" OR "Entoloma clandestinum" OR "Entoloma corvinum" OR "Entoloma costatum" OR "Entoloma cuspidiferum" OR "Entoloma dichroum" OR "Entoloma dysthaloides" OR "Entoloma elodes" OR "Entoloma exile" OR

"Entoloma favrei" OR "Entoloma griseocyaneum" OR "Entoloma griseoluridum" OR "Entoloma griseorubidum" OR "Entoloma infula" OR "Entoloma jubatum" OR "Entoloma lanicum" OR "Entoloma lepidissimum" OR "Entoloma lividocyanulum" OR "Entoloma majaloides" OR "Entoloma minutum" OR "Entoloma neglectum" OR "Entoloma phaeocyathus" OR "Entoloma placidum" OR "Entoloma plebejum" OR "Entoloma porphyrophaeum" OR "Entoloma prunuloides" OR "Entoloma pseudocoelestinum" OR "Entoloma pseudoturbidum" OR "Entoloma rhodocylix" OR "Entoloma roseum" OR "Entoloma saepium" OR "Entoloma saundersii" OR "Entoloma scabiosum" OR "Entoloma sericatum" OR "Entoloma sordidulum" OR "Entoloma sphagnorum" OR "Entoloma tjallingiorum" OR "Entoloma turci" OR "Entoloma versatile" OR "Entoloma vinaceum" OR "Entoloma xanthochroum" OR "Erythricium laetum" OR "Exidia cartilaginea" OR "Exobasidium karstenii" OR "Exobasidium pachysporum" OR "Exobasidium vaccinii-uliginosi" OR "Fibroporia vaillantii" OR "Flammulaster carpophilus" OR "Flammulaster ferrugineus" OR "Flammulaster granulosus" OR "Flammulaster limulatus" OR "Flammulaster muricatus" OR "Flammulina fennae" OR "Floccularia straminea" OR "Galerina cinctula" OR "Galerina jaapii" OR "Galerina pseudomniophila" OR "Galerina pseudotundrae" OR "Galerina salicicola" OR "Galzinia incrustans" OR "Ganoderma resinaceum" OR "Ganoderma valesiacum" OR "Gastrosporium simplex" OR "Gautieria mexicana" OR "Geastrum coronatum" OR "Geastrum melanocephalum" OR "Geastrum nanum" OR "Geoglossum cookeianum" OR "Geoglossum glutinosum" OR "Geopyxis foetida" OR "Gerronema brevibasidiatum" OR "Gerronema chrysophyllum" OR "Gerronema josserandii" OR "Gerronema marchantiae" OR "Gerronema prescotii" OR "Gerronema strombodes" OR "Gloeocystidiellum lactescens" OR "Gloeocystidiellum ochraceum" OR "Gloeoporus dichrous" OR "Gomphidius roseus" OR "Guepiniopsis buccina" OR "Gymnopilus flavus" OR "Gymnopilus odini" OR "Gymnopilus picreus" OR "Gymnopilus stabilis" OR "Gymnopilus subsphaerosporus" OR "Gyromitra accumbens" OR "Gyromitra parma" OR "Gyroporus castaneus" OR "Haasiella venustissima" OR "Hebeloma claviceps" OR "Hebeloma fastibile" OR "Hebeloma helodes" OR "Hebeloma minus" OR "Hebeloma perpallidum" OR "Hebeloma pumilum" OR "Hebeloma remyi" OR "Hebeloma sinuosum" OR "Hebeloma strophosum" OR "Hebeloma syrjense" OR "Hebeloma tomentosum" OR "Hebeloma versipelle" OR "Helvella dissingii" OR "Helvella phlebophora" OR "Helvella queletii" OR "Hemimycena crispata" OR "Hemimycena mairei" OR "Hemimycena ochrogaleata" OR "Hericium coralloides" OR "Hericium erinaceum" OR "Hericium flagellum" OR "Hohenbuehelia auriscalpium" OR "Hohenbuehelia grisea" OR "Hohenbuehelia longipes" OR "Hohenbuehelia mastrucata" OR "Hydnellum auratile" OR "Hydnellum compactum" OR "Hydnellum geogenium" OR "Hydnellum spongiosipes" OR "Hydnocystis piligera" OR "Hydnum albidum" OR "Hydropus atramentosus" OR "Hydropus scabripes" OR "Hygrocybe calciphila" OR "Hygrocybe calyptriformis" OR "Hygrocybe ceracea" OR "Hygrocybe coccineocrenata" OR "Hygrocybe fornicata" OR "Hygrocybe helobia" OR "Hygrocybe ingrata" OR "Hygrocybe insipida" OR "Hygrocybe konradii" OR "Hygrocybe laeta" OR "Hygrocybe mucronella" OR "Hygrocybe nitrata" OR "Hygrocybe obrussea" OR "Hygrocybe ovina" OR "Hygrocybe parvula" OR "Hygrocybe punicea" OR "Hygrocybe reidii" OR "Hygrocybe spadicea" OR "Hygrocybe subglobispora" OR "Hygrocybe turunda" OR "Hygrophorus arbustivus" OR "Hygrophorus atramentosus" OR "Hygrophorus calophyllus" OR "Hygrophorus hedrychii" OR "Hygrophorus latitabundus" OR "Hygrophorus leporinus" OR "Hygrophorus leucophaeus" OR "Hygrophorus ligatus" OR "Hygrophorus lindtneri" OR "Hygrophorus mesotephrus" OR "Hygrophorus persicolor" OR "Hygrophorus pleurotoides" OR "Hygrophorus poetarum" OR "Hygrophorus purpurascens" OR "Hygrophorus russula" OR "Hygrophorus spodoleucus" OR "Hymenochaete cruenta" OR "Hymenochaete tabacina" OR "Hymenogaster vulgaris" OR "Hymenoscyphus equisetinus" OR "Hymenoscyphus imberbis" OR "Hymenoscyphus rhodoleucus" OR "Hyphoderma capitatum" OR "Hyphoderma roseocremeum" OR "Hyphoderma transiens" OR "Hyphodermella corrugata" OR "Hyphodontia abieticola" OR "Hyphodontia quercina" OR "Hyphodontia spathulata" OR "Hypholoma ericaeoides" OR "Hypholoma laeticolor" OR "Hypholoma polytrichi" OR "Hypholoma subericaeum" OR "Hypochnicium detriticum" OR "Hypocreopsis lichenoides" OR "Hypoxylon howeianum" OR "Hypoxylon serpens" OR "Hypsizygus ulmarius" OR "Hysterangium separabile" OR "Inocybe agardhii" OR "Inocybe albovelutipes" OR "Inocybe alnea" OR "Inocybe amblyspora" OR "Inocybe auricoma" OR "Inocybe bresadolae"

OR "Inocybe calospora" OR "Inocybe concinnula" OR "Inocybe curvipes" OR "Inocybe decipiens" OR "Inocybe dunensis" OR "Inocybe flavella" OR "Inocybe frigidula" OR "Inocybe geraniodora" OR "Inocybe griseovelata" OR "Inocybe hirtelloides" OR "Inocybe humilis" OR "Inocybe hygrophorus" OR "Inocybe hystrix" OR "Inocybe leptocystis" OR "Inocybe luteipes" OR "Inocybe maculipes" OR "Inocybe margaritispora" OR "Inocybe melanopus" OR "Inocybe monochroa" OR "Inocybe mundula" OR "Inocybe oblectabilis" OR "Inocybe ovatocystis" OR "Inocybe perlata" OR "Inocybe phaeosticta" OR "Inocybe proximella" OR "Inocybe pseudohiulca" OR "Inocybe relicina" OR "Inocybe rhacodes" OR "Inocybe salicis" OR "Inocybe sambucina" OR "Inocybe squamata" OR "Inocybe strigiceps" OR "Inocybe tabacina" OR "Inocybe tenebrosa" OR "Inocybe tricolor" OR "Inocybe xanthomelas" OR "Inonotus cuticularis" OR "Inonotus obliquus" OR "Inonotus rheades" OR "Ischnoderma resinosum" OR "Ischnoderma trogii" OR "Jahnoporus hirtus" OR "Lachnum nudipes" OR "Lachnum pygmaeum" OR "Lacrymaria pyrotricha" OR "Lactarius acerrimus" OR "Lactarius aspideus" OR "Lactarius azonites" OR "Lactarius bertillonii" OR "Lactarius citriolens" OR "Lactarius controversus" OR "Lactarius dryadophilus" OR "Lactarius fascinans" OR "Lactarius flavidus" OR "Lactarius flexuosus" OR "Lactarius glaucescens" OR "Lactarius helvus" OR "Lactarius hepaticus" OR "Lactarius hysginus" OR "Lactarius lacunarum" OR "Lactarius luteolus" OR "Lactarius mairei" OR "Lactarius mammosus" OR "Lactarius musteus" OR "Lactarius omphaliformis" OR "Lactarius quieticolor" OR "Lactarius repraesentaneus" OR "Lactarius resimus" OR "Lactarius romagnesii" OR "Lactarius rostratus" OR "Lactarius salicis-herbaceae" OR "Lactarius salicis-reticulatae" OR "Lactarius scoticus" OR "Lactarius serifluus" OR "Lactarius spinosulus" OR "Lactarius subumbonatus" OR "Laricifomes officinalis" OR "Leccinum crocipodium" OR "Leccinum duriusculum" OR "Leccinum holopus" OR "Leccinum molle" OR "Leccinum piceinum" OR "Leccinum quercinum" OR "Leccinum vulpinum" OR "Lentinus cyathiformis" OR "Lenzites warnieri" OR "Lepiota alba" OR "Lepiota echinacea" OR "Lepiota griseovirens" OR "Lepiota hystrix" OR "Lepiota ignicolor" OR "Lepiota lilacea" OR "Lepiota ochraceofulva" OR "Lepiota oreadiformis" OR "Lepiota parvannulata" OR "Lepiota pseudoasperula" OR "Lepiota pseudofelina" OR "Lepiota subalba" OR "Lepiota tomentella" OR "Lepista caespitosa" OR "Lepista densifolia" OR "Lepista ricekii" OR "Lepista rickenii" OR "Leptoporus mollis" OR "Leucoagaricus badhamii" OR "Leucoagaricus pulverulentus" OR "Leucoagaricus wichanskyi" OR "Leucopaxillus macrocephalus" OR "Leucopaxillus mirabilis" OR "Leucopaxillus pinicola" OR "Leucopaxillus rhodoleucus" OR "Limacella delicata" OR "Limacella vinosorubescens" OR "Litschauerella clematidis" OR "Lobulicium occultum" OR "Lycoperdon altimontanum" OR "Lycoperdon decipiens" OR "Lycoperdon ericaeum" OR "Lycoperdon frigidum" OR "Lycoperdon lividum" OR "Lycoperdon mammiforme" OR "Lyophyllum favrei" OR "Lyophyllum incarnatobrunneum" OR "Lyophyllum macrosporum" OR "Lyophyllum ochraceum" OR "Lyophyllum tenebrosum" OR "Macrolepiota heimii" OR "Macrolepiota olivascens" OR "Macrolepiota permixta" OR "Macrolepiota puellaris" OR "Macrolepiota venenata" OR "Macrotyphula tremula" OR "Marasmiellus candidus" OR "Marasmiellus tricolor" OR "Marasmius anomalus" OR "Marasmius buxi" OR "Marasmius capillipes" OR "Marasmius chordalis" OR "Marasmius collinus" OR "Marasmius epidryas" OR "Marasmius graminum" OR "Marasmius hudsonii" OR "Marasmius quercophilus" OR "Marasmius saccharinus" OR "Marasmius tenuiparietalis" OR "Marasmius tremulae" OR "Melanoleuca subpulverulenta" OR "Melanophyllum eyrei" OR "Melanotus phillipsii" OR "Membranomyces spurius" OR "Metulodontia nivea" OR "Microglossum viride" OR "Mollisia palustris" OR "Mucronella calva" OR "Mycena adonis" OR "Mycena adscendens" OR "Mycena alphitophora" OR "Mycena avenacea" OR "Mycena clavicularis" OR "Mycena fagetorum" OR "Mycena favrei" OR "Mycena floridula" OR "Mycena grisellina" OR "Mycena latifolia" OR "Mycena mucor" OR "Mycena niveipes" OR "Mycena olida" OR "Mycena olivaceomarginata" OR "Mycena pearsoniana" OR "Mycena pseudopicta" OR "Mycena purpureofusca" OR "Mycena smithiana" OR "Mycena urania" OR "Mycenella favreana" OR "Mycenella margaritispora" OR "Mycenella trachyspora" OR "Myriosclerotinia sulcata" OR "Myriostoma coliforme" OR "Naucoria alnetorum" OR "Naucoria bohemica" OR "Neottiella rutilans" OR "Neottiella vivida" OR "Octaviania asterosperma" OR "Octospora phagospora" OR "Omphalina fusconigra" OR "Omphalina griseopallida" OR "Omphalina obscurata" OR "Omphalina oniscus" OR "Omphalina philonotis" OR "Omphalina pyxidata" OR "Omphalina rustica" OR

"Omphalina sphagnicola" OR "Omphalotus olearius" OR "Onnia triqueter" OR "Ossicaulis lignatilis" OR "Otidea alutacea" OR "Otidea bufonia" OR "Otidea leporina" OR "Oxyporus latemarginatus" OR "Oxyporus obducens" OR "Pachykytospora tuberculosa" OR "Panaeolus acuminatus" OR "Panaeolus cinctulus" OR "Panaeolus fontinalis" OR "Panaeolus guttulatus" OR "Panaeolus olivaceus" OR "Panaeolus reticulatus" OR "Panaeolus retirugis" OR "Panellus ringens" OR "Panus suavissimus" OR "Panus tigrinus" OR "Paullicorticium niveocremeum" OR "Peniophora piceae" OR "Peniophora polygonia" OR "Peniophora proxima" OR "Peniophora violaceolivida" OR "Perenniporia medullapanis" OR "Peziza limnaea" OR "Peziza moravecii" OR "Phaeocollybia arduennensis" OR "Phaeocollybia cidaris" OR "Phaeocollybia festiva" OR "Phaeocollybia jennyae" OR "Phaeogalera oedipus" OR "Phaeogalera stagnina" OR "Phaeomarasmius erinaceus" OR "Phallogaster saccatus" OR "Phallus hadriani" OR "Phanerochaete leprosa" OR "Phanerochaete martelliana" OR "Phellinus chrysoloma" OR "Phellinus ferreus" OR "Phellinus ferrugineofuscus" OR "Phellinus hippophaecola" OR "Phellinus laevigatus" OR "Phellinus lundellii" OR "Phellinus nigricans" OR "Phellinus nigrolimitatus" OR "Phellinus pini" OR "Phellinus rhamni" OR "Phellinus torulosus" OR "Phellinus tremulae" OR "Phellinus viticola" OR "Phellinus vorax" OR "Phellodon confluens" OR "Phellodon melaleucus" OR "Phellodon niger" OR "Phlebiella pseudotsugae" OR "Pholiota alnicola" OR "Pholiota henningsii" OR "Pholiota heteroclita" OR "Pholiota limonella" OR "Pholiota lucifera" OR "Pholiota myosotis" OR "Pholiota nematolomoides" OR "Pholiota tuberculosa" OR "Pholiotina aeruginosa" OR "Pholiotina cyanopus" OR "Picoa carthusiana" OR "Pithya cupressina" OR "Plectania melastoma" OR "Pleurocybella porrigens" OR "Pleurotus cornucopiae" OR "Pleurotus eryngii" OR "Pluteus aurantiorugosus" OR "Pluteus chrysophaeus" OR "Pluteus cyanopus" OR "Pluteus ephebeus" OR "Pluteus granulatus" OR "Pluteus hiatulus" OR "Pluteus luctuosus" OR "Pluteus mammifer" OR "Pluteus minutissimus" OR "Pluteus pellitus" OR "Pluteus poliocnemis" OR "Pluteus pseudorobertii" OR "Pluteus thomsonii" OR "Polyporus rhizophilus" OR "Poronia punctata" OR "Porpoloma metapodium" OR "Porpoloma pescaprae" OR "Porpoloma spinulosum" OR "Protodontia piceicola" OR "Psathyrella canoceps" OR "Psathyrella caputmedusae" OR "Psathyrella cernua" OR "Psathyrella chondroderma" OR "Psathyrella cotonea" OR "Psathyrella friesii" OR "Psathyrella pennata" OR "Psathyrella sacchariolens" OR "Psathyrella spadicea" OR "Psathyrella sphagnicola" OR "Psathyrella spintrigera" OR "Psathyrella typhae" OR "Pseudoclitocybe obbata" OR "Pseudomerulius aureus" OR "Pseudoomphalina kalchbrenneri" OR "Pseudoplectania vogesiaca" OR "Pseudorhizina sphaerospora" OR "Psilocybe coprophila" OR "Psilocybe velifera" OR "Pulveroboletus gentilis" OR "Pulveroboletus hemichrysus" OR "Pulveroboletus lignicola" OR "Ramaria apiculata" OR "Ramaria bataillei" OR "Ramaria botrytis" OR "Ramaria broomei" OR "Ramaria curta" OR "Ramaria flavescens" OR "Ramaria flavobrunnescens" OR "Ramaria ignicolor" OR "Ramaria myceliosa" OR "Ramaria neoformosa" OR "Ramaria roellinii" OR "Ramaria subbotrytis" OR "Ramaria testaceoflava" OR "Ramariopsis pulchella" OR "Resinicium furfuraceum" OR "Rhizopogon obtextus" OR "Rhodocybe ardosiaca" OR "Rhodocybe fallax" OR "Rhodocybe hirneola" OR "Rhodocybe melleopallens" OR "Rhodocybe popinalis" OR "Rhodocybe stangliana" OR "Rhodoscypha ovilla" OR "Rhytisma salicinum" OR "Rickenella mellea" OR "Ripartites albidoincarnata" OR "Ripartites serotinus" OR "Russula amoenicolor" OR "Russula amoenolens" OR "Russula anatina" OR "Russula brunneoviolacea" OR "Russula carminipes" OR "Russula cicatricata" OR "Russula claroflava" OR "Russula consobrina" OR "Russula cremeoavellanea" OR "Russula cuprea" OR "Russula curtipes" OR "Russula dryadicola" OR "Russula elaeodes" OR "Russula emeticicolor" OR "Russula faginea" OR "Russula fuscorubra" OR "Russula galochroa" OR "Russula graveolens" OR "Russula griseascens" OR "Russula lilacea" OR "Russula livescens" OR "Russula lundellii" OR "Russula maculata" OR "Russula medullata" OR "Russula melliolens" OR "Russula melzeri" OR "Russula odorata" OR "Russula pallidospora" OR "Russula pectinata" OR "Russula persicina" OR "Russula postiana" OR "Russula pseudointegra" OR "Russula roseipes" OR "Russula rubra" OR "Russula sororia" OR "Russula subfoetens" OR "Russula taeniospora" OR "Russula urens" OR "Russula velenovskyi" OR "Russula versicolor" OR "Russula veternosa" OR "Russula vinosobrunnea" OR "Rutstroemia elatina" OR "Sarcodon fennicus" OR "Sarcodon fuligineoviolaceus" OR "Sarcodon glaucopus" OR "Sarcodon joeides" OR "Sarcodon leucopus" OR "Sarcodon martioflavus" OR "Sarcodon scabrosus" OR "Sarcodon versipellis" OR "Sarcodontia crocea" OR "Sarcoleotia globosa" OR "Sarcoleotia turficola" OR "Scleroderma fuscum" OR "Scleroderma polyrhizum" OR "Scleroderma verrucosum" OR "Scutellinia mirabilis" OR "Scutellinia nigrohirtula" OR "Scutellinia paludicola" OR "Scutellinia setosa" OR "Scutiger cristatus" OR "Scutiger pescaprae" OR "Sebacina dimitica" OR "Sericeomyces serenus" OR "Sericeomyces sericatus" OR "Simocybe haustellaris" OR "Simocybe laevigata" OR "Simocybe reducta" OR "Simocybe sumptuosa" OR "Sistotrema confluens" OR "Skeletocutis lilacina" OR "Sowerbyella imperialis" OR "Sowerbyella radiculata" OR "Spathularia neesii" OR "Spongipellis pachyodon" OR "Spongipellis spumeus" OR "Spongiporus balsameus" OR "Squamanita odorata" OR "Squamanita paradoxa" OR "Squamanita schreieri" OR "Steccherinum bourdotii" OR "Steccherinum dichroum" OR "Steccherinum oreophilum" OR "Stigmatolemma conspersum" OR "Stigmatolemma urceolatum" OR "Stropharia albocyanea" OR "Stropharia hornemannii" OR "Stropharia melasperma" OR "Suillus flavidus" OR "Suillus plorans" OR "Suillus sibiricus" OR "Tectella patellaris" OR "Tephrocybe admissa" OR "Tephrocybe mephitica" OR "Tephrocybe palustris" OR "Tephrocybe putida" OR "Thelephora anthocephala" OR "Thuemenidium atropurpureum" OR "Tomentella subclavigera" OR "Trechispora confinis" OR "Trechispora fastidiosa" OR "Trechispora microspora" OR "Trechispora praefocata" OR "Trechispora stellulata" OR "Trechispora sulphurea" OR "Tricholoma acerbum" OR "Tricholoma apium" OR "Tricholoma arvernense" OR "Tricholoma bresadolianum" OR "Tricholoma caligatum" OR "Tricholoma colossus" OR "Tricholoma focale" OR "Tricholoma fucatum" OR "Tricholoma inocybeoides" OR "Tricholoma inodermeum" OR "Tricholoma pessundatum" OR "Tricholoma roseoacerbum" OR "Tricholoma stans" OR "Tricholoma sudum" OR "Tricholoma sulphurescens" OR "Tricholoma triste" OR "Tricholoma ustaloides" OR "Tricholoma viridifucatum" OR "Tricholomopsis flammula" OR "Tricholomopsis ornata" OR "Trichophaeopsis paludosa" OR "Tubaria confragosa" OR "Tubaria dispersa" OR "Tubaria pallidispora" OR "Tubaria praestans" OR "Tuber borchii" OR "Tulasnella eichleriana" OR "Tulostoma brumale" OR "Tulostoma fimbriatum" OR "Tulostoma melanocyclum" OR "Tulostoma petrii" OR "Tulostoma squamosum" OR "Tylospora asterophora" OR "Tyromyces chioneus" OR "Tyromyces floriformis" OR "Tyromyces placenta" OR "Urnula craterium" OR "Verpa bohemica" OR "Volvariella bombycina" OR "Volvariella caesiotincta" OR "Volvariella taylori" OR "Xenasma pruinosum" OR "Xenasma pulverulentum" OR "Xerocomus armeniacus" OR "Xerocomus moravicus" OR "Xerocomus parasiticus" OR "Xerocomus porosporus" OR "Xerula caussei" OR "Xylaria filiformis" OR "Xylobolus frustulatus"))

Plants

Combined lighting search

TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“ OR lunar OR moon OR "stellar orientation" OR "star* navigation") AND ("Achillea clavenae" OR "Achillea collina" OR "Aconitum anthora" OR "Aconitum variegatum s.str." OR "Aconitum variegatum ssp. rostratum" OR "Adenophora liliifolia" OR "Adiantum capillus-veneris" OR "Adonis aestivalis" OR "Adonis flammea" OR "Adonis vernalis" OR "Aethionema saxatile" OR "Agrimonia procera" OR "Agrostemma githago" OR "Aira caryophyllea" OR "Aira elegantissima" OR "Alisma gramineum" OR "Alisma lanceolatum" OR "Allium angulosum" OR "Allium lineare" OR "Allium rotundum" OR "Allium scorodoprasum" OR "Allium suaveolens" OR "Alopecurus aequalis" OR "Alopecurus geniculatus" OR "Alyssum alpestre" OR "Alyssum montanum" OR "Anacamptis pyramidalis var. tanayensis" OR "Anagallis minima" OR "Anagallis tenella" OR "Androsace brevis" OR "Androsace maxima" OR "Androsace pubescens" OR "Androsace septentrionalis" OR "Androsace villosa" OR "Anemone sylvestris" OR "Anogramma leptophylla" OR "Anthemis arvensis" OR "Anthemis cotula" OR "Anthemis triumfettii" OR "Anthriscus caucalis" OR "Anthriscus cerefolium" OR "Anthyllis montana s.str." OR "Anthyllis vulneraria ssp. polyphylla" OR "Apera interrupta" OR "Aphanes australis" OR "Apium nodiflorum" OR "Apium repens" OR "Aquilegia alpina" OR "Aquilegia einseleana" OR

"Arabis auriculata" OR "Arabis collina" OR "Arabis nemorensis" OR "Arabis sagittata" OR "Arabis scabra" OR "Arabis serpillifolia" OR "Arctium minus ssp. pubens" OR "Arenaria bernensis" OR "Arenaria gothica" OR "Arenaria grandiflora" OR "Aristolochia clematitis" OR "Aristolochia rotunda" OR "Armeria alpina var. purpurea" OR "Armeria arenaria" OR "Arnoseris minima" OR "Artemisia borealis" OR "Artemisia glacialis" OR "Artemisia nivalis" OR "Artemisia vallesiaca" OR "Arum italicum" OR "Asparagus tenuifolius" OR "Asperula arvensis" OR "Asperula tinctoria" OR "Asphodelus albus" OR "Asplenium adulterinum" OR "Asplenium billotii" OR "Asplenium cuneifolium" OR "Asplenium foreziense" OR "Astragalus depressus" OR "Astragalus exscapus" OR "Astragalus leontinus" OR "Atriplex prostrata" OR "Baldellia ranunculoides" OR "Ballota nigra s.str." OR "Betula humilis" OR "Betula nana" OR "Bidens cernua" OR "Bidens radiata" OR "Biscutella cichoriifolia" OR "Blackstonia acuminata" OR "Blackstonia perfoliata" OR "Bolboschoenus maritimus" OR "Botrychium lanceolatum" OR "Botrychium matricariifolium" OR "Botrychium multifidum" OR "Botrychium simplex" OR "Botrychium virginianum" OR "Brachypodium rupestre" OR "Brassica rapa ssp. campestris" OR "Bromus arvensis" OR "Bromus commutatus" OR "Bromus grossus" OR "Bromus japonicus" OR "Bromus racemosus" OR "Bromus secalinus" OR "Bufonia paniculata" OR "Bunias erucago" OR "Bupleurum longifolium" OR "Bupleurum ranunculoides ssp. caricinum" OR "Bupleurum rotundifolium" OR "Butomus umbellatus" OR "Calamagrostis canescens" OR "Calamagrostis phragmitoides" OR "Calamintha ascendens" OR "Caldesia parnassifolia" OR "Calendula arvensis" OR "Calepina irregularis" OR "Calla palustris" OR "Callianthemum coriandrifolium" OR "Callitriche hamulata" OR "Callitriche obtusangula" OR "Camelina alyssum" OR "Camelina microcarpa" OR "Camelina pilosa" OR "Camelina sativa" OR "Campanula bertolae" OR "Campanula bononiensis" OR "Campanula cervicaria" OR "Campanula excisa" OR "Campanula glomerata ssp. farinosa" OR "Cardamine asarifolia" OR "Cardamine dentata" OR "Cardamine matthioli" OR "Cardamine trifolia" OR "Carduus defloratus ssp. crassifolius" OR "Carex atrofusca" OR "Carex baldensis" OR "Carex bicolor" OR "Carex bohemica" OR "Carex buxbaumii" OR "Carex cespitosa" OR "Carex chordorrhiza" OR "Carex depauperata" OR "Carex diandra" OR "Carex fimbriata" OR "Carex hartmanii" OR "Carex heleonastes" OR "Carex juncella" OR "Carex maritima" OR "Carex microglochin" OR "Carex norvegica" OR "Carex otrubae" OR "Carex pseudocyperus" OR "Carex riparia" OR "Carex vaginata" OR "Carex vulpina" OR "Carpesium cernuum" OR "Carthamus lanatus" OR "Catabrosa aquatica" OR "Caucalis platycarpos" OR "Centaurea maculosa" OR "Centaurea nemoralis" OR "Centaurea pseudophrygia" OR "Centaurea rhaetica" OR "Centaurea splendens" OR "Centaurea stoebe" OR "Centaurea valesiaca" OR "Centaurium pulchellum" OR "Cephalaria alpina" OR "Cerastium arvense ssp. suffruticosum" OR "Cerastium austroalpinum" OR "Cerastium brachypetalum ssp. tenoreanum" OR "Cerastium glutinosum" OR "Ceratophyllum demersum" OR "Ceratophyllum submersum" OR "Chaerophyllum elegans" OR "Chamaecytisus supinus" OR "Chenopodium botrys" OR "Chenopodium murale" OR "Chenopodium opulifolium" OR "Chenopodium strictum" OR "Chenopodium urbicum" OR "Chenopodium vulvaria" OR "Chimaphila umbellata" OR "Chondrilla chondrilloides" OR "Cicuta virosa" OR "Cirsium canum" OR "Cirsium montanum" OR "Cirsium tuberosum" OR "Cistus salviifolius" OR "Cleistogenes serotina" OR "Clypeola jonthlaspi" OR "Cnidium silaifolium" OR "Cochlearia pyrenaica" OR "Conium maculatum" OR "Consolida regalis" OR "Coronilla minima" OR "Coronopus squamatus" OR "Crepis foetida" OR "Crepis froelichiana" OR "Crepis praemorsa" OR "Crepis rhaetica" OR "Crepis tectorum" OR "Crepis terglouensis" OR "Cruciata pedemontana" OR "Crupina vulgaris" OR "Cucubalus baccifer" OR "Cuscuta cesatiana" OR "Cuscuta epilinum" OR "Cynoglossum germanicum" OR "Cynosurus echinatus" OR "Cyperus flavescens" OR "Cyperus fuscus" OR "Cyperus glomeratus" OR "Cyperus longus" OR "Cyperus michelianus" OR "Cyperus rotundus" OR "Cyperus serotinus" OR "Cypripedium calceolus" OR "Cytisus decumbens" OR "Cytisus emeriflorus" OR "Dactylis polygama" OR "Dactylorhiza cruenta" OR "Dactylorhiza incarnata ssp. ochroleuca" OR "Dactylorhiza lapponica" OR "Dactylorhiza maculata [s.str. prov.]" OR "Dactylorhiza savogiensis" OR "Danthonia alpina" OR "Daphne cneorum" OR "Deschampsia littoralis" OR "Dianthus gratianopolitanus" OR "Dictamnus albus" OR "Diphasiastrum complanatum" OR "Diphasiastrum tristachyum" OR "Diphasiastrum x issleri" OR "Dipsacus pilosus" OR "Doronicum pardalianches" OR "Dorycnium germanicum" OR "Dorycnium herbaceum" OR

"Draba incana" OR "Draba ladina" OR "Draba muralis" OR "Draba nemorosa" OR "Draba thomasii" OR "Dracocephalum austriacum" OR "Dracocephalum ruyschiana" OR "Drosera anglica" OR "Drosera intermedia" OR "Drosera x obovata" OR "Dryopteris cristata" OR "Echinops sphaerocephalus" OR "Elatine alsinastrum" OR "Elatine hexandra" OR "Elatine hydropiper" OR "Eleocharis acicularis" OR "Eleocharis atropurpurea" OR "Eleocharis mamillata" OR "Eleocharis ovata" OR "Empetrum nigrum s.str." OR "Ephedra helvetica" OR "Epilobium duriaei" OR "Epilobium lanceolatum" OR "Epipactis distans" OR "Epipactis placentina" OR "Epipactis rhodanensis" OR "Epipactis stellifera" OR "Equisetum x trachyodon" OR "Erica vagans" OR "Eriophorum gracile" OR "Erodium pilosum" OR "Eruca sativa" OR "Eryngium alpinum" OR "Eryngium campestre" OR "Erysimum hieraciifolium" OR "Erysimum ochroleucum" OR "Erysimum virgatum" OR "Erythronium dens-canis" OR "Euphorbia carniolica" OR "Euphorbia falcata" OR "Euphorbia palustris" OR "Euphrasia christii" OR "Euphrasia cisalpina" OR "Euphrasia drosocalyx" OR "Falcaria vulgaris" OR "Festuca stenantha" OR "Festuca ticinensis" OR "Filago arvensis" OR "Filago gallica" OR "Filago lutescens" OR "Filago minima" OR "Filago pyramidata" OR "Filago vulgaris" OR "Filipendula vulgaris" OR "Fimbristylis annua" OR "Fragaria moschata" OR "Fritillaria meleagris" OR "Fumaria capreolata" OR "Fumaria schleicheri" OR "Fumaria vaillantii" OR "Gagea minima" OR "Gagea pratensis" OR "Gagea saxatilis" OR "Gagea villosa" OR "Galeopsis bifida" OR "Galeopsis segetum" OR "Galeopsis speciosa" OR "Galium glaucum" OR "Galium parisiense" OR "Galium saxatile" OR "Galium tricornutum" OR "Galium triflorum" OR "Gaudinia fragilis" OR "Genista pilosa" OR "Genista radiata" OR "Gentiana alpina" OR "Gentiana amarella" OR "Gentiana anisodonta" OR "Gentiana aspera" OR "Gentiana campestris ssp. baltica" OR "Gentiana cruciata" OR "Gentiana engadinensis" OR "Gentiana insubrica" OR "Gentiana pannonica" OR "Gentiana pneumonanthe" OR "Gentiana prostrata" OR "Gentiana schleicheri" OR "Geranium bohemicum" OR "Geranium divaricatum" OR "Geranium lucidum" OR "Gladiolus imbricatus" OR "Gladiolus italicus" OR "Gladiolus palustris" OR "Glyceria declinata" OR "Glyceria maxima" OR "Gnaphalium luteoalbum" OR "Gratiola officinalis" OR "Gypsophila muralis" OR "Hammarbya paludosa" OR "Helianthemum apenninum" OR "Helianthemum canum" OR "Helianthemum salicifolium" OR "Heliotropium europaeum" OR "Heracleum austriacum" OR "Heteropogon contortus" OR "Hieracium alpicola" OR "Hieracium bauhinii" OR "Hieracium caespitosum" OR "Hieracium racemosum agg." OR "Hierochloë odorata" OR "Himantoglossum hircinum" OR "Holoschoenus romanus s.str." OR "Holoschoenus romanus ssp. holoschoenus" OR "Hottonia palustris" OR "Hugueninia tanacetifolia" OR "Hydrocharis morsus-ranae" OR "Hydrocotyle vulgaris" OR "Hymenolobus pauciflorus" OR "Hyoscyamus niger" OR "Hypericum coris" OR "Hypericum pulchrum" OR "Hypericum richeri" OR "Hypochaeris glabra" OR "Iberis amara" OR "Iberis intermedia" OR "Iberis pinnata" OR "Iberis saxatilis" OR "Illecebrum verticillatum" OR "Inula britannica" OR "Inula helvetica" OR "Inula hirta" OR "Inula spiraeifolia" OR "Iris graminea" OR "Iris sibirica" OR "Isoëtes echinospora" OR "Isoëtes lacustris" OR "Isolepis setacea" OR "Isopyrum thalictroides" OR "Juncus ambiguus" OR "Juncus arcticus" OR "Juncus bulbosus" OR "Juncus capitatus" OR "Juncus castaneus" OR "Juncus sphaerocarpus" OR "Juncus squarrosus" OR "Juncus stygius" OR "Juncus tenageia" OR "Knautia dipsacifolia ssp. sixtina" OR "Knautia godetii" OR "Knautia purpurea" OR "Knautia transalpina" OR "Kobresia simpliciuscula" OR "Lactuca saligna" OR "Lactuca viminea" OR "Lactuca virosa" OR "Lappula deflexa" OR "Laserpitium gaudinii" OR "Laserpitium prutenicum" OR "Lathyrus bauhinii" OR "Lathyrus hirsutus" OR "Lathyrus nissolia" OR "Lathyrus palustris" OR "Lathyrus sphaericus" OR "Lathyrus tuberosus" OR "Lathyrus venetus" OR "Leersia oryzoides" OR "Legousia hybrida" OR "Legousia speculum-veneris" OR "Lemna gibba" OR "Leontodon crispus" OR "Leontodon incanus ssp. tenuiflorus" OR "Leonurus cardiaca" OR "Leucanthemum heterophyllum" OR "Leucojum aestivum" OR "Ligusticum lucidum" OR "Lilium bulbiferum s.str." OR "Lilium bulbiferum ssp. croceum" OR "Limosella aquatica" OR "Linaria alpina ssp. petraea" OR "Linaria repens" OR "Lindernia procumbens" OR "Liparis loeselii" OR "Littorella uniflora" OR "Lolium remotum" OR "Lolium rigidum" OR "Lolium temulentum" OR "Lomatogonium carinthiacum" OR "Lomelosia graminifolia" OR "Lonicera etrusca" OR "Ludwigia palustris" OR "Lycopodiella inundata" OR "Lycopodium dubium" OR "Lycopus europaeus ssp. mollis" OR "Lysimachia thyrsiflora" OR "Lythrum hyssopifolia" OR "Lythrum portula" OR "Malaxis monophyllos" OR "Marrubium vulgare" OR "Marsilea quadrifolia" OR "Matteuccia struthiopteris" OR "Matthiola valesiaca" OR "Melampyrum arvense" OR "Melampyrum nemorosum" OR "Melica transsilvanica" OR "Mentha pulegium" OR "Mercurialis ovata" OR "Micropus erectus" OR "Micropyrum tenellum" OR "Minuartia biflora" OR "Minuartia capillacea" OR "Minuartia cherlerioides ssp. rionii" OR "Minuartia hybrida" OR "Minuartia stricta" OR "Minuartia viscosa" OR "Misopates orontium" OR "Moenchia erecta" OR "Moenchia mantica" OR "Montia fontana s.str." OR "Montia fontana ssp. amporitana" OR "Montia fontana ssp. chondrosperma" OR "Murbeckiella pinnatifida" OR "Muscari botryoides" OR "Muscari neglectum" OR "Myosotis cespitosa" OR "Myosotis discolor" OR "Myosotis rehsteineri" OR "Myosurus minimus" OR "Myriophyllum alterniflorum" OR "Myriophyllum heterophyllum" OR "Najas flexilis" OR "Najas marina" OR "Najas minor" OR "Narcissus x verbanensis" OR "Nasturtium microphyllum" OR "Nepeta cataria" OR "Nepeta nuda" OR "Neslia paniculata s.str." OR "Nigella arvensis" OR "Nigritella rubra" OR "Notholaena marantae" OR "Nuphar pumila" OR "Odontites vernus" OR "Odontites viscosus" OR "Odontites vulgaris" OR "Oenanthe aquatica" OR "Oenanthe fistulosa" OR "Oenanthe lachenalii" OR "Oenanthe peucedanifolia" OR "Onopordum acanthium" OR "Onosma helvetica" OR "Onosma pseudoarenaria s.l." OR "Ophioglossum vulgatum" OR "Ophrys apifera s.str." OR "Ophrys apifera ssp. botteronii" OR "Ophrys araneola" OR "Ophrys holosericea s.str." OR "Ophrys holosericea ssp. elatior" OR "Ophrys sphegodes" OR "Orchis coriophora" OR "Orchis laxiflora" OR "Orchis palustris" OR "Orchis papilionacea" OR "Orchis provincialis" OR "Orchis spitzelii" OR "Orchis tridentata" OR "Orlaya grandiflora" OR "Ornithogalum gussonei" OR "Ornithogalum nutans" OR "Orobanche alsatica s.str." OR "Orobanche alsatica ssp. libanotidis" OR "Orobanche arenaria" OR "Orobanche elatior" OR "Orobanche gracilis" OR "Orobanche laserpitii-sileris" OR "Orobanche lucorum" OR "Orobanche lutea" OR "Orobanche picridis" OR "Orobanche purpurea" OR "Orobanche ramosa" OR "Orobanche salviae" OR "Osmunda regalis" OR "Oxytropis fetida" OR "Oxytropis neglecta" OR "Paeonia officinalis" OR "Papaver argemone" OR "Papaver hybridum" OR "Papaver occidentale" OR "Papaver sendtneri" OR "Pedicularis aspleniifolia" OR "Pedicularis gyroflexa" OR "Pedicularis rostratospicata s.l." OR "Pedicularis sylvatica" OR "Peucedanum austriacum ssp. rablense" OR "Peucedanum carvifolia" OR "Peucedanum venetum" OR "Phleum paniculatum" OR "Phyteuma hedraianthifolium" OR "Phyteuma humile" OR "Phyteuma scorzonerifolium" OR "Picris echioides" OR "Pilularia globulifera" OR "Pinguicula grandiflora s.str." OR "Pisum sativum ssp. Biflorum" OR "Poa badensis" OR "Poa glauca" OR "Poa remota" OR "Poa trivialis ssp. sylvicola" OR "Polycarpon tetraphyllum" OR "Polycnemum arvense" OR "Polycnemum majus" OR "Polygala calcarea" OR "Polygonum lapathifolium ssp. brittingeri" OR "Polystichum braunii" OR "Potamogeton acutifolius" OR "Potamogeton coloratus" OR "Potamogeton filiformis" OR "Potamogeton friesii" OR "Potamogeton gramineus" OR "Potamogeton helveticus" OR "Potamogeton nodosus" OR "Potamogeton obtusifolius" OR "Potamogeton polygonifolius" OR "Potamogeton praelongus" OR "Potamogeton pusillus" OR "Potamogeton trichoides" OR "Potamogeton x angustifolius" OR "Potamogeton x nitens" OR "Potentilla alba" OR "Potentilla alpicola" OR "Potentilla grammopetala" OR "Potentilla heptaphylla" OR "Potentilla incana" OR "Potentilla inclinata" OR "Potentilla leucopolitana" OR "Potentilla multifida" OR "Potentilla nivea" OR "Potentilla praecox" OR "Potentilla thuringiaca" OR "Primula daonensis" OR "Primula glutinosa" OR "Primula halleri" OR "Primula latifolia" OR "Prunella laciniata" OR "Pseudostellaria europaea" OR "Pteris cretica" OR "Ptychotis saxifraga" OR "Pulicaria vulgaris" OR "Pulmonaria helvetica" OR "Pulmonaria montana ssp. jurana" OR "Pulsatilla alpina ssp. austriaca" OR "Pulsatilla halleri" OR "Pulsatilla rubra" OR "Pulsatilla vulgaris" OR "Pyrola chlorantha" OR "Pyrus nivalis" OR "Ranunculus allemannii" OR "Ranunculus aquatilis" OR "Ranunculus arvensis" OR "Ranunculus circinatus" OR "Ranunculus gramineus" OR "Ranunculus lingua" OR "Ranunculus peltatus" OR "Ranunculus pygmaeus" OR "Ranunculus reptans" OR "Ranunculus rionii" OR "Ranunculus sceleratus" OR "Ranunculus seguieri" OR "Rapistrum rugosum" OR "Reseda luteola" OR "Reseda phyteuma" OR "Rhamnus saxatilis" OR "Rhinanthus angustifolius" OR "Rhinanthus antiquus" OR "Rhynchospora fusca" OR "Rorippa amphibia" OR "Rorippa stylosa" OR "Rorippa x anceps" OR "Rosa chavinii" OR "Rosa gallica" OR "Rosa majalis" OR "Rosa mollis" OR "Rosa rhaetica" OR "Rosa sherardii" OR "Rosa stylosa" OR "Rosa tomentella" OR "Rubia tinctorum" OR "Rumex aquaticus" OR "Rumex hydrolapathum" OR "Rumex maritimus" OR "Rumex pulcher" OR "Sagina apetala s.str." OR "Sagina glabra" OR "Sagina nodosa" OR "Sagina subulata" OR "Sagittaria sagittifolia" OR "Salix alpina" OR "Salix apennina" OR "Salix caesia" OR "Salix glabra" OR "Salix laggeri" OR "Salix myrtilloides" OR "Salix phylicifolia" OR "Salix x hegetschweileri" OR "Salvinia natans" OR "Samolus valerandi" OR "Saponaria lutea" OR "Saussurea alpina ssp. depressa" OR "Saxifraga biflora ssp. macropetala" OR "Saxifraga bulbifera" OR "Saxifraga cernua" OR "Saxifraga diapensioides" OR "Saxifraga granulata" OR "Saxifraga hirculus" OR "Saxifraga oppositifolia ssp. amphibia" OR "Saxifraga retusa s.str." OR "Scandix pecten-veneris" OR "Scheuchzeria palustris" OR "Schoenoplectus mucronatus" OR "Schoenoplectus pungens" OR "Schoenoplectus supinus" OR "Schoenoplectus tabernaemontani" OR "Schoenoplectus triqueter" OR "Scleranthus annuus s.str." OR "Scleranthus annuus ssp. polycarpos" OR "Scleranthus annuus ssp. verticillatus" OR "Scrophularia auriculata" OR "Sedum rubens" OR "Sedum villosum" OR "Selinum carvifolia" OR "Sempervivum grandiflorum" OR "Sempervivum wulfenii" OR "Senecio erraticus" OR "Senecio halleri" OR "Senecio incanus ssp. insubricus" OR "Senecio sylvaticus" OR "Serapias vomeracea" OR "Seseli annuum s.str." OR "Seseli montanum" OR "Sesleria sphaerocephala" OR "Setaria verticilliformis" OR "Sideritis hyssopifolia" OR "Silene flos-jovis" OR "Silene gallica" OR "Silene italica" OR "Silene noctiflora" OR "Silene saxifraga" OR "Silene suecica" OR "Silene vallesia" OR "Sison amomum" OR "Sisymbrium strictissimum" OR "Sisymbrium supinum" OR "Sium latifolium" OR "Solanum villosum s.str." OR "Sonchus arvensis ssp. uliginosus" OR "Sonchus palustris" OR "Sorbus domestica" OR "Sparganium angustifolium" OR "Sparganium emersum" OR "Sparganium erectum ssp. microcarpum" OR "Sparganium erectum ssp. neglectum" OR "Sparganium natans" OR "Spergula arvensis" OR "Spergularia segetalis" OR "Spiranthes aestivalis" OR "Stachys alopecuros" OR "Stachys annua" OR "Stachys arvensis" OR "Stachys germanica" OR "Stachys officinalis ssp. serotina" OR "Stachys recta ssp. grandiflora" OR "Staphylea pinnata" OR "Stellaria holostea" OR "Stellaria longifolia" OR "Stellaria pallida" OR "Stellaria palustris" OR "Stemmacantha rhapontica s.str." OR "Stemmacantha rhapontica ssp. lamarckii" OR "Subularia aquatica" OR "Symphytum bulbosum" OR "Taraxacum ceratophorum agg." OR "Taraxacum cucullatum agg." OR "Taraxacum dissectum" OR "Taraxacum fontanum agg." OR "Taraxacum pacheri" OR "Teesdalia nudicaulis" OR "Telephium imperati" OR "Tephroseris capitata" OR "Tephroseris helenitis" OR "Tephroseris integrifolia" OR "Tephroseris tenuifolia" OR "Teucrium scordium" OR "Thalictrum alpinum" OR "Thalictrum flavum" OR "Thalictrum lucidum" OR "Thalictrum minus ssp. saxatile" OR "Thalictrum simplex" OR "Thelypteris palustris" OR "Thesium linophyllon" OR "Thesium rostratum" OR "Thlaspi rotundifolium ssp. corymbosum" OR "Thlaspi sylvium" OR "Thlaspi virens" OR "Thymelaea passerina" OR "Tofieldia pusilla" OR "Torilis arvensis" OR "Tragopogon pratensis ssp. minor" OR "Tragus racemosus" OR "Trapa natans" OR "Trientalis europaea" OR "Trifolium fragiferum" OR "Trifolium ochroleucon" OR "Trifolium patens" OR "Trifolium repens ssp. prostratum" OR "Trifolium saxatile" OR "Trifolium scabrum" OR "Trifolium spadiceum" OR "Trifolium striatum" OR "Trigonella monspeliaca" OR "Trinia glauca" OR "Trisetum cavanillesii" OR "Trochiscanthes nodiflora" OR "Tulipa sylvestris s.str." OR "Tulipa sylvestris ssp. australis" OR "Turgenia latifolia" OR "Typha minima" OR "Typha shuttleworthii" OR "Umbilicus rupestris" OR "Utricularia bremii" OR "Utricularia intermedia" OR "Utricularia minor" OR "Utricularia ochroleuca" OR "Utricularia vulgaris" OR "Vaccaria hispanica" OR "Vaccinium microcarpum" OR "Valeriana celtica" OR "Valeriana pratensis" OR "Valeriana saliunca" OR "Valeriana saxatilis" OR "Valeriana wallrothii" OR "Valerianella dentata" OR "Valerianella eriocarpa" OR "Valerianella rimosa" OR "Veratrum album s.str." OR "Veratrum nigrum" OR "Verbascum blattaria" OR "Verbascum chaixii s.str." OR "Verbascum phlomoides" OR "Verbascum pulverulentum" OR "Veronica acinifolia" OR "Veronica anagalloides" OR "Veronica austriaca" OR "Veronica catenata" OR "Veronica dillenii" OR "Veronica prostrata s.str." OR "Veronica prostrata ssp. scheereri" OR "Veronica scutellata" OR "Veronica triphyllos" OR "Vicia lathyroides" OR "Vicia orobus" OR "Vicia pisiformis" OR "Vicia sativa ssp. cordata" OR "Vicia villosa s.str." OR "Vicia villosa ssp. varia" OR "Viola alba ssp. scotophylla" OR "Viola canina ssp. schultzii" OR "Viola cenisia" OR "Viola elatior" OR "Viola kitaibeliana" OR "Viola persicifolia" OR "Viola pinnata" OR "Viola pumila" OR "Viola suavis" OR "Vitis sylvestris" OR "Woodsia alpina" OR "Woodsia ilvensis" OR "Woodsia pulchella" OR

"Xeranthemum inapertum" OR "Zannichellia palustris" OR TS=((“artificial light*” OR “artificial night light*” OR “enhanced lighting” OR “city light*” OR “night* light*” OR “outdoor light*” OR “street light*” OR “street lamp*” OR “security light*” OR “road* light*” OR “light pollution” OR photopollution OR ALAN OR “light-trap*“ OR “light trap*“) AND ("Chara aspera" OR "Chara delicatula" OR "Chara hispida" OR "Chara intermedia" OR "Chara polyacantha" OR "Chara strigosa" OR "Chara tenuispina" OR "Chara tomentosa" OR "Chara vulgaris" OR "Nitella batrachosperma" OR "Nitella capillaris" OR "Nitella flexilis" OR "Nitella gracilis" OR "Nitella hyalina" OR "Nitella mucronata" OR "Nitella opaca" OR "Nitella syncarpa" OR "Nitella tenuissima" OR "Nitellopsis obtusa" OR "Tolypella glomerata" OR "Tolypella intricata" OR "Acaulon muticum" OR "Acaulon triquetrum" OR "Aloina aloides" OR "Aloina brevirostris" OR "Aloina rigida" OR "Amblyodon dealbatus" OR "Amblystegium compactum" OR "Amblystegium fluviatile" OR "Amblystegium humile" OR "Amblystegium saxatile" OR "Anacamptodon splachnoides" OR "Anastrepta orcadensis" OR "Anastrophyllum assimile" OR "Anastrophyllum hellerianum" OR "Andreaea crassinervia" OR "Andreaea frigida" OR "Andreaea heinemannii" OR "Andreaea rothii falcata" OR "Andreaea rothii rothii" OR "Anoectangium hornschuchianum" OR "Anomodon rostratus" OR "Anthelia julacea julacea" OR "Aongstroemia longipes" OR "Archidium alternifolium" OR "Arctoa fulvella" OR "Asterella gracilis" OR "Asterella saccata" OR "Athalamia hyalina" OR "Aulacomnium androgynum" OR "Barbilophozia atlantica" OR "Barbula acuta icmadophila" OR "Barbula asperifolia" OR "Barbula bicolor" OR "Barbula cordata cordata" OR "Barbula ehrenbergii" OR "Barbula enderesii" OR "Barbula johansenii" OR "Barbula revoluta" OR "Barbula rigidula andreaeoides" OR "Barbula rigidula glauca" OR "Barbula rigidula verbana" OR "Barbula sinuosa" OR "Barbula vinealis cylindrica" OR "Barbula vinealis vinealis" OR "Bartramia subulata" OR "Blasia pusilla" OR "Blindia caespiticia" OR "Brachydontium trichodes" OR "Brachythecium campestre" OR "Brachythecium geheebii" OR "Brachythecium latifolium" OR "Brachythecium trachypodium" OR "Braunia alopecura" OR "Breutelia chrysocoma" OR "Brotherella lorentziana" OR "Bryoerythrophyllum recurvirostre alpigenum" OR "Bryoerythrophyllum rubrum" OR "Bryum algovicum" OR "Bryum archangelicum" OR "Bryum arcticum" OR "Bryum argenteum veronense" OR "Bryum blindii" OR "Bryum funckii" OR "Bryum gemmiferum" OR "Bryum gemmiparum" OR "Bryum intermedium" OR "Bryum knowltonii" OR "Bryum mildeanum" OR "Bryum muehlenbeckii" OR "Bryum neodamense" OR "Bryum radiculosum" OR "Bryum ruderale" OR "Bryum rutilans" OR "Bryum sauteri" OR "Bryum stirtonii" OR "Bryum uliginosum uliginosum" OR "Bryum versicolor" OR "Buxbaumia aphylla" OR "Buxbaumia viridis" OR "Callicladium haldanianum" OR "Calliergon cordifolium" OR "Calliergon richardsonii" OR "Calypogeia sphagnicola" OR "Campylium elodes" OR "Campylium polygamum" OR "Campylopus oerstedianus" OR "Campylopus pilifer" OR "Campylopus subulatus" OR "Campylostelium saxicola" OR "Catoscopium nigritum" OR "Cephalozia leucantha" OR "Cephalozia loitlesbergeri" OR "Cephalozia macrostachya" OR "Cephaloziella arctica" OR "Cephaloziella elachista" OR "Cephaloziella elegans" OR "Cephaloziella grimsulana" OR "Cephaloziella hampeana" OR "Cephaloziella integerrima" OR "Cephaloziella massalongi" OR "Cephaloziella phyllacantha" OR "Cephaloziella stellulifera" OR "Cephaloziella subdentata" OR "Ceratodon purpureus conicus" OR "Cinclidotus aquaticus" OR "Cinclidotus mucronatus" OR "Cirriphyllum germanicum" OR "Cirriphyllum reichenbachianum" OR "Cladopodiella francisci" OR "Cnestrum alpestre" OR "Cololejeunea rossettiana" OR "Corsinia coriandrina" OR "Crossidium aberrans" OR "Crossidium squamiferum" OR "Cryphaea heteromalla" OR "Ctenidium procerrimum" OR "Cynodontium bruntonii bruntonii" OR "Cynodontium gracilescens" OR "Cynodontium tenellum" OR "Cyrtomnium hymenophylloides" OR "Desmatodon cernuus" OR "Desmatodon laureri" OR "Desmatodon systylius" OR "Dichelyma falcatum" OR "Dicranella cerviculata" OR "Dicranella grevilleana" OR "Dicranella howei" OR "Dicranella rufescens" OR "Dicranodontium asperulum" OR "Dicranodontium uncinatum" OR "Dicranum flagellare" OR "Dicranum spurium" OR "Distichophyllum carinatum" OR "Ditrichum lineare" OR "Ditrichum pallidum" OR "Ditrichum pusillum" OR "Drepanocladus lycopodioides" OR "Drepanocladus pseudostramineus" OR "Drepanocladus sendtneri" OR "Encalypta affinis affinis" OR "Encalypta longicolla" OR "Entodon cladorrhizans cladorrhizans" OR "Entodon cladorrhizans schleicheri" OR "Ephemerum cohaerens" OR "Ephemerum recurvifolium" OR "Ephemerum serratum" OR "Epipterygium tozeri" OR "Eurhynchium pumilum" OR "Fabronia ciliaris" OR

"Fabronia pusilla" OR "Fissidens bryoides curnovii" OR "Fissidens celticus" OR "Fissidens grandifrons" OR "Fissidens rivularis" OR "Fissidens rufulus" OR "Fontinalis hypnoides" OR "Fontinalis squamosa" OR "Fossombronia angulosa" OR "Fossombronia foveolata" OR "Fossombronia incurva" OR "Fossombronia pusilla" OR "Fossombronia wondraczekii" OR "Frullania cesatiana" OR "Frullania inflata" OR "Frullania parvistipula" OR "Funaria attenuata" OR "Funaria fascicularis" OR "Funaria microstoma" OR "Funaria muhlenbergii" OR "Funaria obtusa" OR "Funaria pulchella" OR "Geocalyx graveolens" OR "Grimmia apiculata" OR "Grimmia atrata" OR "Grimmia crinita" OR "Grimmia decipiens" OR "Grimmia elongata" OR "Grimmia teretinervis" OR "Gymnomitrion apiculatum" OR "Gymnomitrion obtusum" OR "Gymnostomum viridulum" OR "Habrodon perpusillus" OR "Haplohymenium triste" OR "Haplomitrium hookeri" OR "Harpalejeunea ovata" OR "Harpanthus flotovianus" OR "Harpanthus scutatus" OR "Hedwigia stellata" OR "Herzogiella striatella" OR "Homalia besseri" OR "Hygrobiella laxifolia" OR "Hygrohypnum alpestre" OR "Hygrohypnum alpinum" OR "Hygrohypnum cochlearifolium" OR "Hygrohypnum eugyrium" OR "Hygrohypnum molle" OR "Hygrohypnum norvegicum" OR "Hygrohypnum ochraceum" OR "Hygrohypnum smithii" OR "Hygrohypnum styriacum" OR "Hyophila involuta" OR "Hypnum bambergeri" OR "Hypnum cupressiforme ericetorum" OR "Hypnum cupressiforme imponens" OR "Hypnum fertile" OR "Hypnum hamulosum" OR "Hypnum sauteri" OR "Jamesoniella autumnalis" OR "Jamesoniella undulifolia" OR "Jungermannia borealis" OR "Jungermannia caespiticia" OR "Jungermannia exsertifolia cordifolia" OR "Jungermannia leiantha" OR "Jungermannia pumila" OR "Jungermannia subelliptica" OR "Kurzia pauciflora" OR "Kurzia trichoclados" OR "Lejeunea lamacerina" OR "Leptodon smithii" OR "Leptodontium styriacum" OR "Lophozia bicrenata" OR "Lophozia capitata laxa" OR "Lophozia gillmanii" OR "Lophozia grandiretis" OR "Lophozia perssonii" OR "Lophozia turbinata" OR "Mannia androgyna" OR "Mannia fragrans" OR "Mannia pilosa" OR "Mannia triandra" OR "Marchantia paleacea" OR "Marsupella adusta" OR "Marsupella alpina" OR "Marsupella boeckii" OR "Marsupella commutata" OR "Marsupella revoluta" OR "Marsupella sparsifolia" OR "Meesia longiseta" OR "Metzleria alpina" OR "Mielichhoferia elongata" OR "Mielichhoferia mielichhoferiana" OR "Moerckia hibernica" OR "Mylia taylorii" OR "Nardia breidleri" OR "Nardia insecta" OR "Neckera menziesii" OR "Neckera pennata pennata" OR "Neckera pumila" OR "Octodiceras fontanum" OR "Odontoschisma macounii" OR "Odontoschisma sphagni" OR "Oncophorus wahlenbergii" OR "Oreas martiana" OR "Oreoweisia torquescens" OR "Orthothecium chryseon" OR "Orthothecium strictum" OR "Orthotrichum alpestre" OR "Orthotrichum callistomum" OR "Orthotrichum laevigatum" OR "Orthotrichum microcarpum" OR "Orthotrichum pulchellum" OR "Orthotrichum rogeri" OR "Orthotrichum scanicum" OR "Orthotrichum stellatum" OR "Orthotrichum tenellum" OR "Orthotrichum urnigerum" OR "Oxymitra incrassata" OR "Paludella squarrosa" OR "Peltolepis quadrata" OR "Phaeoceros laevis carolinianus" OR "Phascum curvicolle" OR "Phascum floerkeanum" OR "Philonotis arnellii" OR "Philonotis caespitosa" OR "Philonotis marchica" OR "Philonotis rigida" OR "Physcomitrium eurystomum" OR "Physcomitrium patens" OR "Physcomitrium sphaericum" OR "Plagiobryum demissum" OR "Plagiochasma rupestre" OR "Plagiochila britannica" OR "Plagiochila exigua" OR "Plagiothecium neckeroideum" OR "Plagiothecium piliferum" OR "Plagiothecium ruthei" OR "Pleuridium palustre" OR "Pleurochaete squarrosa" OR "Pogonatum nanum" OR "Pohlia bulbifera" OR "Pohlia camptotrachela" OR "Pohlia lescuriana" OR "Pohlia muyldermansii" OR "Pohlia sphagnicola" OR "Pohlia vexans" OR "Polytrichum formosum decipiens" OR "Porella arboris-vitae" OR "Porella cordaeana" OR "Pottia bryoides" OR "Pottia heimii" OR "Pottia lanceolata" OR "Pottia starckeana" OR "Pseudobryum cinclidioides" OR "Pseudoleskea artariae" OR "Pseudoleskeella tectorum" OR "Pterogonium gracile" OR "Pterygoneurum lamellatum" OR "Pterygoneurum ovatum" OR "Pterygoneurum subsessile" OR "Ptychomitrium polyphyllum" OR "Racomitrium fasciculare" OR "Racomitrium microcarpum" OR "Reboulia hemisphaerica" OR "Rhabdoweisia crenulata" OR "Rhabdoweisia crispata" OR "Rhynchostegiella curviseta" OR "Rhynchostegiella jacquinii" OR "Rhynchostegiella teesdalei" OR "Rhynchostegium rotundifolium" OR "Riccardia chamaedryfolia" OR "Riccardia incurvata" OR "Riccia bifurca" OR "Riccia breidleri" OR "Riccia canaliculata" OR "Riccia cavernosa" OR "Riccia ciliata" OR "Riccia ciliifera" OR "Riccia crozalsii" OR "Riccia fluitans" OR "Riccia gougetiana" OR "Riccia huebeneriana" OR "Riccia ligula" OR "Riccia michelii" OR "Riccia nigrella" OR "Riccia subbifurca" OR "Riccia trichocarpa" OR "Riccia warnstorfii" OR "Ricciocarpos natans" OR "Riella notarisii" OR "Saelania glaucescens" OR "Sauteria alpina" OR "Scapania apiculata" OR "Scapania calcicola" OR "Scapania compacta" OR "Scapania crassiretis" OR "Scapania curta" OR "Scapania gymnostomophila" OR "Scapania helvetica" OR "Scapania massalongi" OR "Scapania praetervisa" OR "Scapania scapanioides" OR "Scapania verrucosa" OR "Schistidium agassizii" OR "Schistidium flaccidum" OR "Schistostega pennata" OR "Scopelophila ligulata" OR "Scorpidium scorpioides" OR "Scorpidium turgescens" OR "Scorpiurium circinatum" OR "Seligeria austriaca" OR "Seligeria brevifolia" OR "Seligeria calcarea" OR "Seligeria carniolica" OR "Seligeria oelandica" OR "Seligeria patula" OR "Sematophyllum demissum" OR "Sphaerocarpos texanus" OR "Sphagnum affine" OR "Sphagnum fimbriatum" OR "Sphagnum fuscum" OR "Sphagnum molle" OR "Sphagnum subfulvum" OR "Targionia hypophylla" OR "Tayloria acuminata" OR "Tayloria hornschuchii" OR "Tayloria lingulata" OR "Tayloria rudolphiana" OR "Tayloria splachnoides" OR "Tetraplodon angustatus" OR "Tetraplodon mnioides" OR "Tetraplodon urceolatus" OR "Tetrodontium ovatum" OR "Tetrodontium repandum" OR "Thuidium angustifolium" OR "Thuidium blandowii" OR "Thuidium virginianum" OR "Timmia norvegica" OR "Timmiella anomala" OR "Tortella humilis" OR "Tortella nitida" OR "Tortula atrovirens" OR "Tortula brevissima" OR "Tortula canescens" OR "Tortula caninervis spuria" OR "Tortula fragilis" OR "Tortula inermis" OR "Tortula laevipila" OR "Tortula obtusifolia" OR "Tortula pagorum" OR "Tortula revolvens" OR "Tortula sinensis" OR "Trematodon ambiguus" OR "Trematodon brevicollis" OR "Ulota coarctata" OR "Ulota hutchinsiae" OR "Ulota rehmannii macrospora" OR "Voitia nivalis" OR "Weissia condensa" OR "Weissia rostellata" OR "Weissia rutilans" OR "Weissia squarrosa" OR "Weissia triumphans" OR "Zygodon conoideus" OR "Zygodon gracilis" OR "Zygodon viridissimus rupestris"))