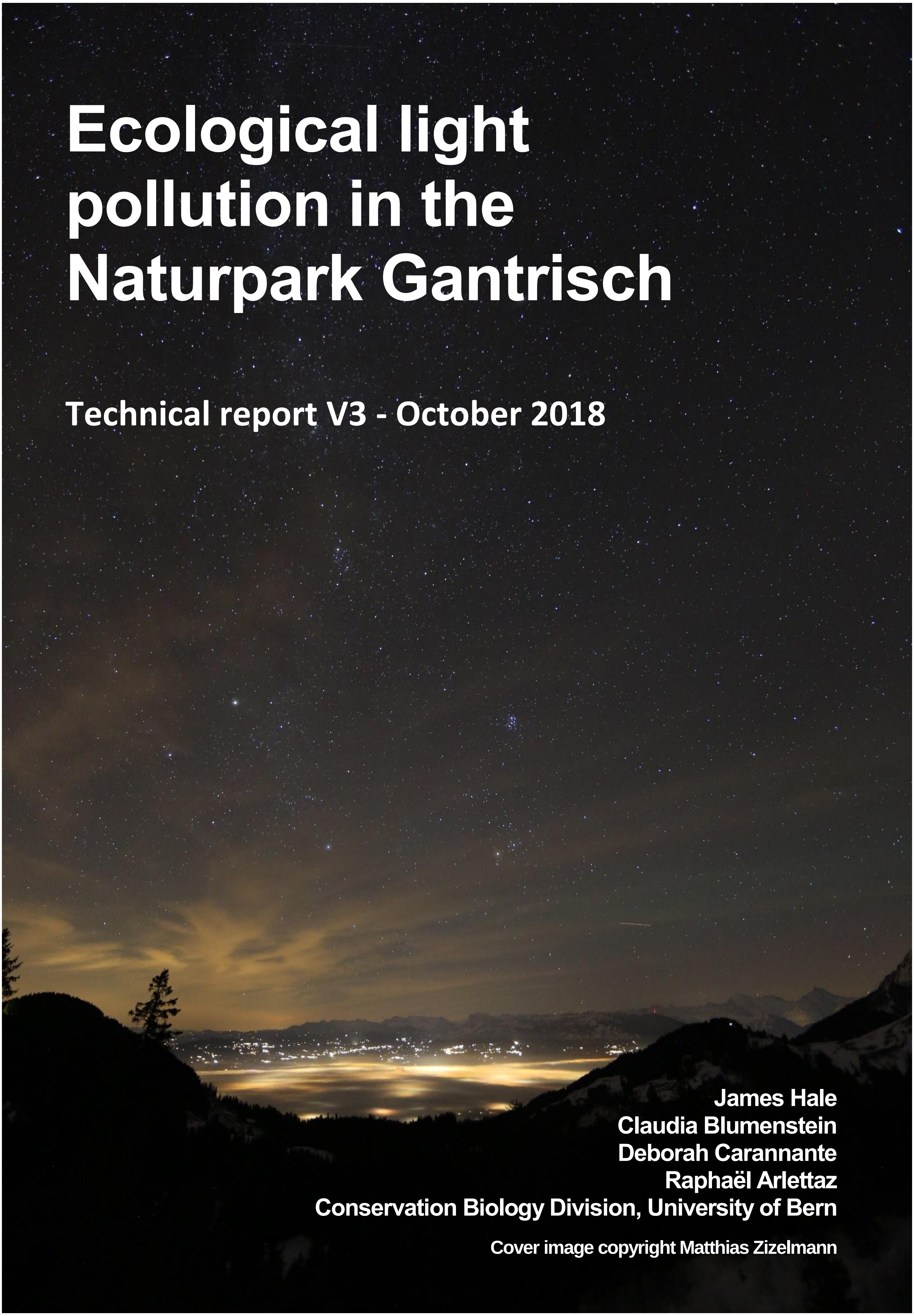


Ecological light pollution in the Naturpark Gantrisch

Technical report V3 - October 2018

James Hale
Claudia Blumenstein
Deborah Carannante
Raphaël Arlettaz
Conservation Biology Division, University of Bern

Contents

1 Background

This report was prepared by Dr. James Hale from the University of Bern, Division of Conservation Biology, at the request of the Naturpark Gantrisch. The two broad aims were 1) to gain a greater understanding of the nighttime landscape within the park and 2) the testing and identification of locations where rare and priority species may be impacted by lighting within the park. This document and associated analysis was created to support the development of a variety of dark-sky and ecological infrastructure projects.

2 Summary

- Outdoor artificial lighting is known to disrupt many ecological communities.
- Globally, lighting emissions are getting stronger, expanding and becoming dominated by white LEDs
- Switzerland has some of the darkest skies in Europe, and areas such as the Naturpark Gantrisch potentially hold rare and valuable examples of dark habitats.
- There are many ways to measure lighting emissions within the park. The most useful measures from an ecology perspective are VIIRS satellite images, ISS photography and lamp inventories.
- VIIRS data for the past 3 years show seasonal variation, but no obvious trend between years.
- One ISS image was useful for identifying sources of emissions in the north of the park.
- It was possible to secure street lamp inventories for the majority of the park.
- Additional lamp surveys were undertaken in areas of high lighting emissions, and near to sensitive habitats – many sources of problem lighting are not from street lamps.
- The worst lighting is from poorly shielded floodlights, advertising signs and globe/sphere type lamps associated with railways, outdoor sports areas, banks and other businesses, schools, hospitals and retirement homes, churches, garages and gas-stations.
- A more complete inventory could be created and maintained with a citizen science approach
- Through a literature review we identified evidence for light-sensitive species and habitats; artificial lighting can have impacts though direct illumination, by magnifying horizontally polarized light signals, and by obscuring monthly lunar lighting cycles.
- The most directly relevant research papers related to bats and aquatic insects.
- The lack of research on other mammals is particularly concerning, given their strong tendency towards nocturnal activity.
- For other taxa, a lack of research evidence does not imply that no impacts exist. In most cases there is sufficient justification for a precautionary approach involving restricting lighting near to key habitats.
- There is good evidence to suspect impacts on aquatic habitats and grasslands.
- A spatial indicator of ecologically relevant light pollution was developed based on a visibility analysis of VIIRS bright lighting locations. This was further refined to identify core dark zones that could be the focus of additional protection, enhancement and darkening projects.
- Most of the Swiss biotopes of national importance that are found within the park are already located within dark viewshed areas. However, high percentages of amphibian spawning areas and fens are subjected to lit viewsheds caused by lighting from Plaffeien and Belp.
- Experimental research in summer 2017 revealed that LED lighting within 80 m of river edges can impact adult Ephemeroptera, Trichoptera and Diptera.
- Surveys of main river sections identified numerous lighting sources needing mitigation.
- Passerine bird migration is known to be impacted by artificial lighting and we identified a zone within the park which would benefit from lighting restrictions in this context.

- A series of recommendations are outlined, including the application of a broad precautionary approach to lighting near to priority species and habitats, and public engagement to raise awareness of the unique nature of the dark habitats and best lighting practice.
- A particularly clear opportunity for addressing ecological light pollution is to reduce lighting adjacent to streams, rivers and ponds and to focus habitat improvements on the existing dark network of aquatic habitats.

3 Recommendations

The results of this analysis have revealed a variety of impacts, potential impacts and knowledge/data gaps relating to ecological light pollution within the Gantrisch Naturepark. In many cases, there is still sufficient evidence to justify a precautionary approach – limiting all lighting near to sensitive habitats. Particular problems are: a lack of data on the effectiveness of mitigation - particularly the use of amber LED lights, an incomplete lamp inventory, and the impact of lighting from Bern and other settlements outside the park boundaries on sky quality and landscape view from within the park. The following actions are recommended:

- Develop citizen science surveys to maintain and fill gaps in lighting inventories.
- Engage with managers of lighting associated with railway stations, outdoor sports areas, banks, shops, schools, hospitals, retirement homes and garages. Specifically, provide information on best practice and offer support for shielding, removal or replacement with reactive lights. Offer to publicise any improvements as good-news stories.
- Develop support for a dimming and switch-off curfew e.g. between 00:00 and 04:00, for all public and private lighting in the park, particularly for emission hotspots.
- Collaborate with surrounding settlements such as Bern city to implement street light dimming and to reduce other large emission sources that impact on the parks sky quality.
- Collaborate with researchers to improve knowledge of impacts on mammals, and to clarify the effectiveness of mitigation, particularly for amber LED lights
- Focus on efforts to remove, replace, dim and shield lamps that are adjacent to aquatic and grassland habitats.
- Focus additional lighting mitigation near to known bat roosts.
- The dark river corridors should be publicized as a special feature of the park.
- Focus broader ecological enhancement and darkening projects within the core dark zone – the Schwarzwasser river and valley, Sense main river corridor and upper Sense valley.
- This zone provides an important reference/baseline for light naive habitats. Also these are unusual areas to visit and might be a suitable focus for the promotion of “dark tourism”.
- Undertake a public consultation with residents and businesses owners within the core dark zone, explaining how special this area is, what species are impacted by light pollution, what they can do to help and asking what ideas they have. This serves to raise awareness and to prevent new problem lights being installed in the future.

4 Introduction

Switzerland currently has some of the darkest skies in Europe (Fig 1A). The Naturpark Gantrisch is at the interface between highly populated urban areas (such as Bern) and the Western edge of the alpine dark corridor that extends to Eastern Austria. The Naturpark Gantrisch therefore provides visitors access to habitats which are rare within Europe - ones that experience relatively natural cycles of night sky brightness.

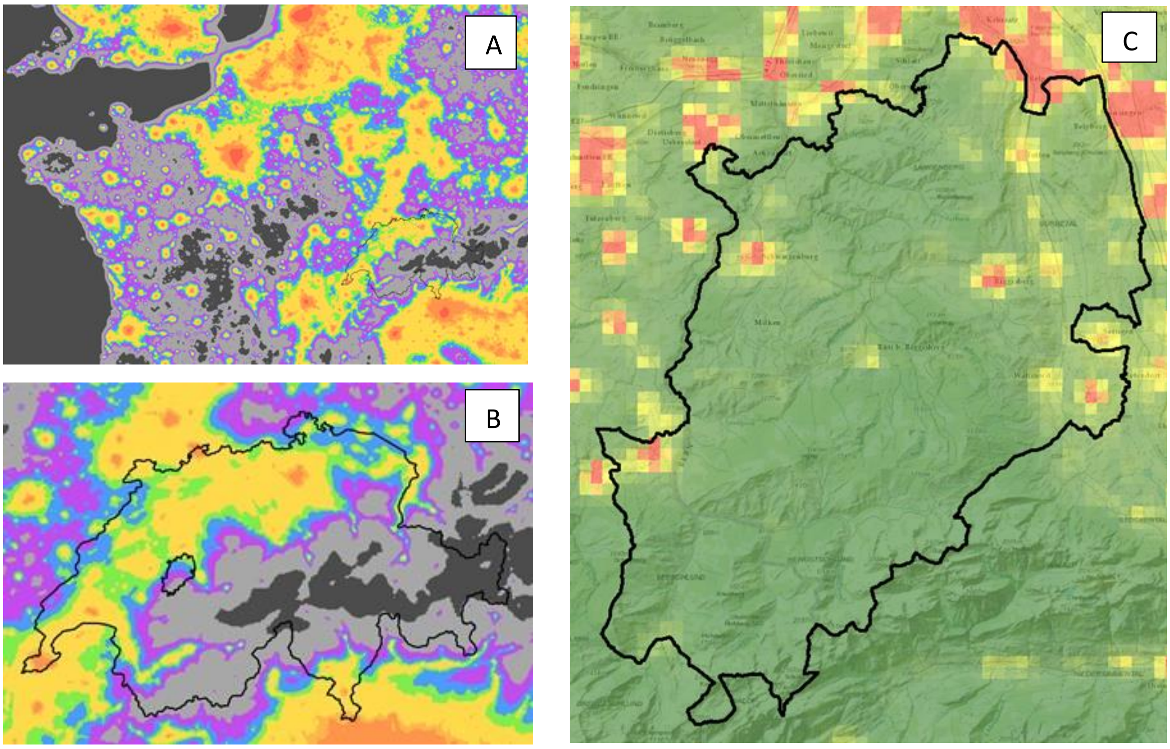


Fig.1 Artificial night sky brightness for A) part of Europe and B) Switzerland, (Falchi, Cinzano et al. 2016, Falchi, Cinzano et al. 2016). C) Artificial lighting emissions for Gantrisch from VIIRS satellite data (Aug 2016). World Topographic Map (basemap) for panel C and other figures supplied by Esri, 1st December 2017 (http://www.arcgis.com/home/item.html?id=30e5fe3149c34df1ba922e6f5bbf808f).

Unfortunately there has been a long-term trend for increasing light emissions within Switzerland over the past decade, which may threaten the integrity of sensitive wildlife populations. In addition, a broad switch to powerful white LED street lighting is already underway within the park and its surrounding communes, whose consequences for wildlife are largely unknown. The park contains a range of rare or priority species groups which are known to be sensitive to artificial lighting. These include bats, amphibians and aquatic insects. Until now, there has been no strategic management of darkness as a valuable habitat. This is due to poor mapping of the different types of light pollution, and a general lack of research on its ecological impacts. In the sections below, we outline:

- The key sources of lighting data available for the park
- Surveys of street lighting and other major emission sources
- A review of known ecological impacts for rare and priority species
- Exposure modelling for key ecological habitats
- Recommendations for action

5 Key sources of lighting data available for the park

5.1 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 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. Importantly, the DMSP OLS data is no longer being collected, so VIIRS is the primary way to track changes in emissions over time within and adjacent to the park. VIIRS 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 and made available to the public via the NOAA website.

Important caveats to the use of this data to track emissions are:

- The VIIRS sensor records emissions between 0.5 and 0.9 um. In effect, it is blind to blue parts of the visible light spectrum. This means that increases in blue light emissions (e.g. from new white LED lights) will not be detected.
- Data collection is at ~01:30, so unfortunately this misses the expected evening peak in urban emissions, but it might be a better indicator of lights that are present throughout the night.
- The pixel resolution is insufficient to identify the exact source of emissions. It is possible that a strong signal is the result of a single bright lamp or lots of dull lamps. Clarifying this may be important ecologically and require ground surveys.

Monthly averaged mosaics have been available for download at no cost since Jan 2014 from here http://ngdc.noaa.gov/eog/viirs/download_monthly.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. To support this analysis 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. They were then clipped in ArcGIS 10.3, using a polygon derived from the boundaries of Naturpark Gantrisch, buffered by 1km. Each image was then re-projected to the Swiss Grid CH1903 and resampled to a consistent pixel size of 500m (see example for Naturpark Gantrisch in Fig.1). 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.

A summary of the VIIRS emissions for Naturpark Gantrisch can be seen below in Fig. 2A. Note the peaks around January each year, due to increased surface reflectance due to snow and also possibly due to extra seasonal lighting. Data taken from the month of August may be more of a reliable indicator of typical lighting emissions – there is no obvious trend yet, but this is just three data points.

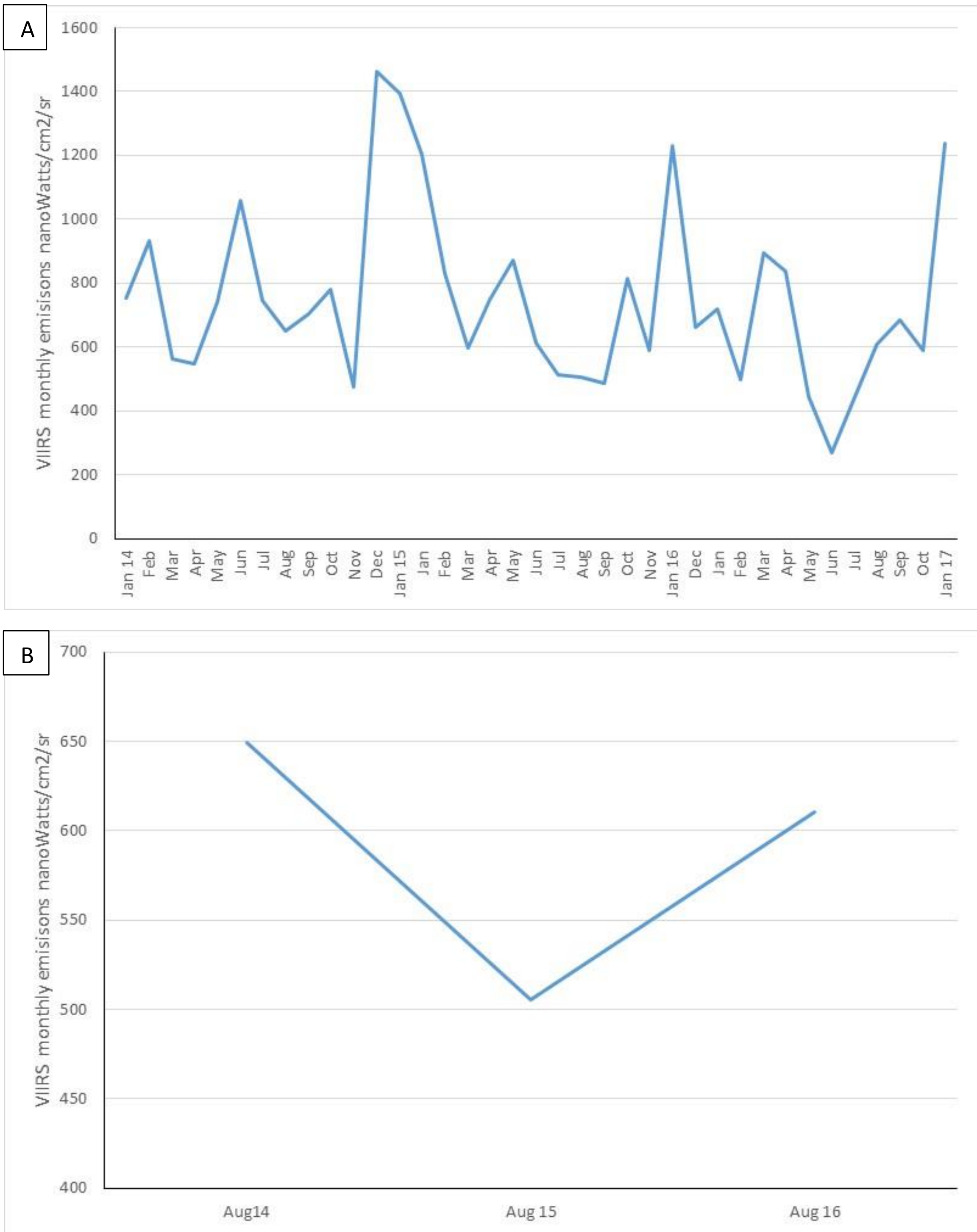


Fig.2 VIIRS lighting emissions for the Naturpark Gantrisch at A) monthly intervals between Jan 2014 and Jan 2017 and B) three emission values for Aug 2014, Aug 2015 and Aug 2016.

5.2 Photography from the International Space Station

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. 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 radiance calibrating and processing of ISS data for Switzerland. Only 1 of the 7 calibrated images available for Switzerland intersects the boundary of the Naturpark - ISS038-E-16196. It was captured on the 7th December 2013 at 22:32:14 (Swiss Time).

As can be seen from Fig. 3, it covers the northern half of the park. It was downloaded from here: http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS038&roll=E&frame=16196 This image proved useful when identifying the exact sources of emissions within brightly lit parts of the park (see section below on surveys of street lighting and other major emission sources)

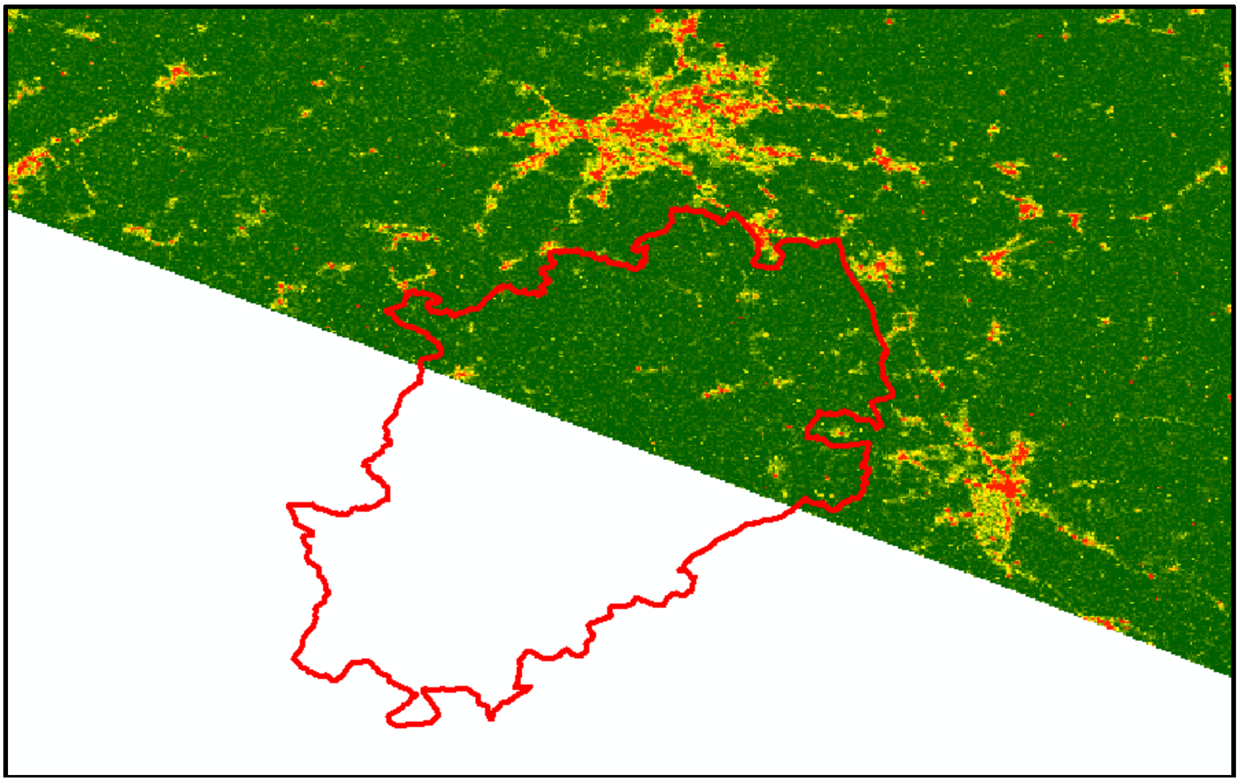


Fig.3 A radiance calibrated photograph (ISS038-E-16196) of the Naturpark Gantrish.

5.3 Lamp inventories

Databases (lighting inventories) held by street lighting managers are the primary tool used for the management of street lighting. However, it is common for these inventories to be incomplete or unavailable. In some cases, the owner of a particular street lamp may be unknown, often if the lamps is 15-20 years. 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). Whilst such inventories can be highly useful for identifying lamps that may be too close to sensitive habitats, it is important to recognise that street lighting inventories only provide a partial record of the lighting present in a particular area. Seasonal (temporary) lighting, private lighting (e.g. of churches, factories, shops or car parks) and public amenity lighting (e.g. path lighting within parks) will all be missing. In some locations the contribution of street lamps to the total emissions and to the total number of lamps can actually be quite small.

The aim was therefore to generate a comprehensive inventory of all lighting within the park. This was an ambitious target, which relied upon rapid access to the existing databases of street lamps and also depended upon the majority of street lamps already being mapped. Staff at the Naturpark Gantrisch took responsibility for contacting the various managers of lamp inventories for each of the communes that fall within (and adjacent to) the park boundaries. Whilst the quality of the inventories appears to be high, it proved difficult to access all the existing inventory data quickly. Inventory data for three communes are still missing: Riggisberg, Burgistein, Plaffeien, Oberschrot. This presented a dilemma – whether to undertake the survey work early and risk duplicating existing inventories, or delay the survey and risk running out of time to complete the inventory. The decision was taken to delay the survey - starting in autumn 2017. This had practical benefits, as the longer nights permitted longer survey sessions. In addition, a decision was taken to focus lamp surveys on two types of locations: 1) where VIIRS emissions where particularly high and 2) within and around known sensitive habitats.

A total of 1348 street lamp records were supplied as the basis of the Naturpark Gantrisch inventory. These were supplied as two databases (1327 + 21 lamp entries), which were not combined as the field names were not identical. Access to this data is restricted to Gantrisch staff, and these two files are provided in the digital appendix within a folder (GNP_Inventory_Data_Supplied) as GNP_Inventory1_Data_Supplied_March17.shp and GNP_Inventory2_Data_Supplied_Aug17.shp

6 Surveys of street lighting and other major emission sources

6.1 Survey methodology

In the absence of any published VIIRS lighting thresholds for ecological impacts, we chose to undertake ground surveys at locations with an emission class of >=2nW/cm^2/sr in the composite image captured in August 2016. The justification for this threshold is that 2nW is a typical emission for part of a small village or low-density residential area, and that the lighting from such areas would be expected to have at least low levels of ecological impact. For reference, the brightest location in the Naturpark Gantrisch in August 2016 was on the boundary of Belp, with a value of 15nw. The brightest location in the whole of Switzerland was Zurich Airport, with a value of 110nW. Examples of the land-covers associated with these emissions are given in Fig. 4. The locations of emissions >=2nW/cm^2/sr within the Naturpark Gantrisch are shown in Fig. 5. These high-emission locations were visited at night and in inventory of obvious bright sources of lighting was created using the software package Fulcrum. This allowed the location of a specific lamp or group of lamps to be recorded as a point feature, which was then attributed with information (latitude, longitude, lamp type, spectrum, mitigation, notes, photograph ID). Where there was a need for remediation works or the lamp was an example of best practice, photographs were taken and their unique ID was stored as an attribute within the lamp point inventory.

During this survey it became clear that certain land-uses were typically responsible for high emissions: garages, railway stations, banks, sports, hospitals and nursing homes. These were then identified using the google map search function and visited. Finally, the main river corridors were surveyed for all sources of lighting (within 100m of river edge), in response to the identification of this as a sensitive habitat type (see later section on *Exposure modelling for key ecological habitats).*

Fig.4 Locations containing 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 C and D have a VIIRS pixel value of $10nW/cm^2/sr$), E) 84 street lamps in an area of mixed medium-high density development + additional mixed lamps associated with the colleague in the centre of the image, and 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. World Imagery basemap supplied by Swisstopo, 1st December 2017 (http://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9).

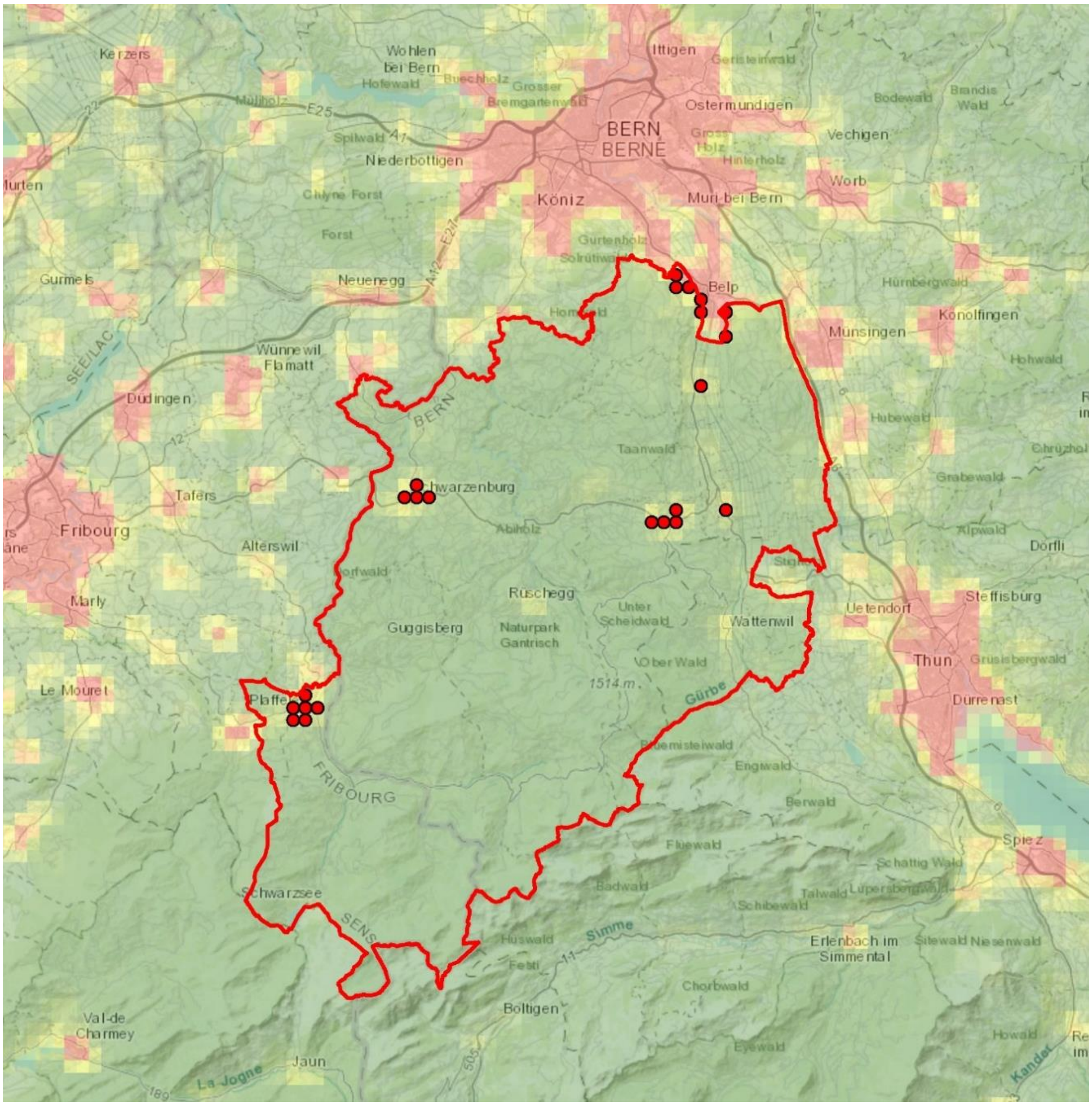


Fig.5 The locations of emissions >=2nW/cm^2/sr within the Naturpark Gantrisch in August 2016.

These surveys resulted in 107 lamps or groups of lamps being recorded in the inventory. Of these 69 are considered to need mitigation, with 23 a priority. This inventory was saved as a shapefile - Additional_GNP_inventory_lamps_2017_.shp

In addition, 9 locations were identified as dark – mostly dark bridges which should be protected from lighting where possible (e.g. communicate this to Geminde). These are saved as the shapefile Additional_GNP_inventory_Dark_2017_.shp

See Fig.6 for an overview of these new inventories.

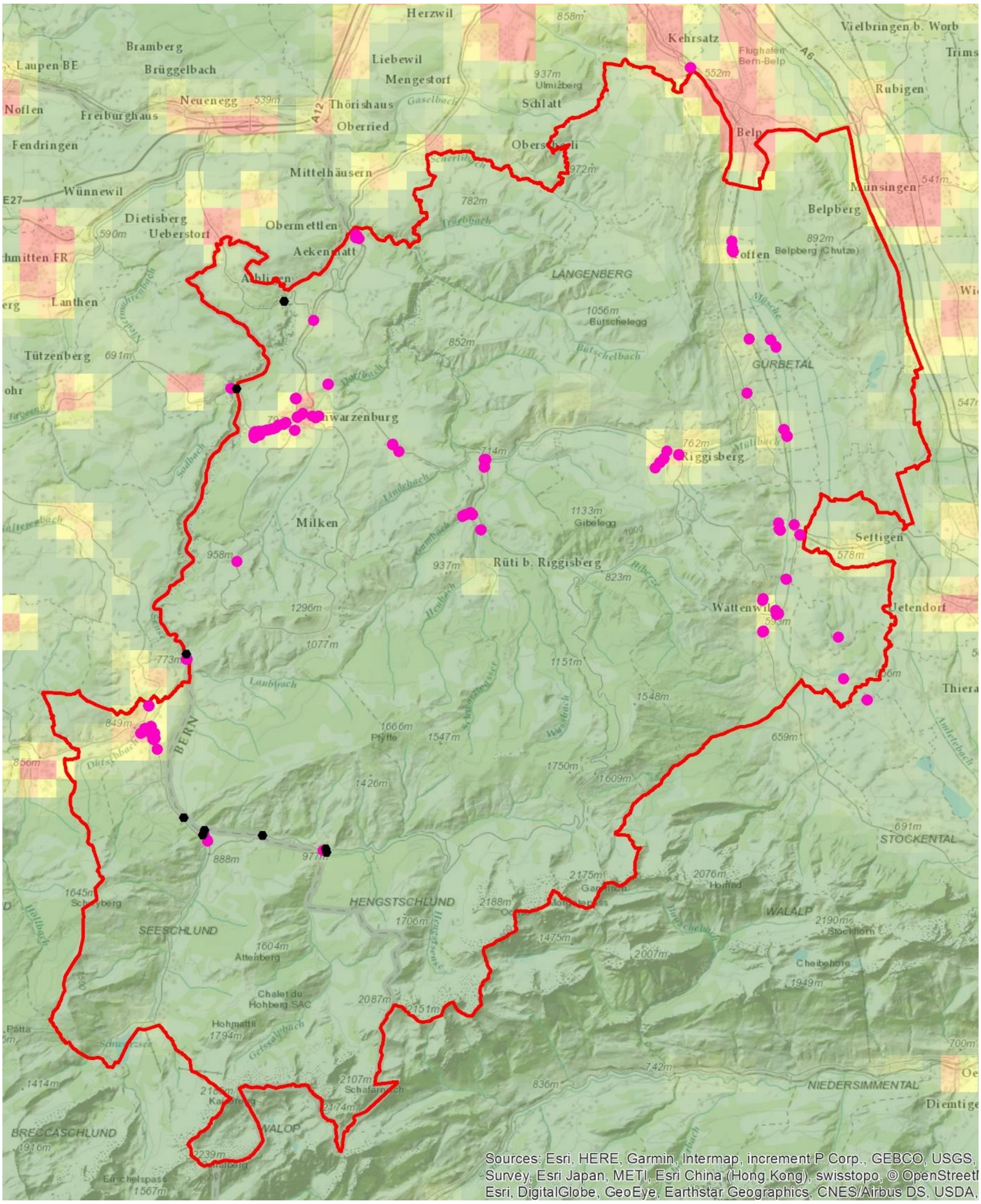


Fig.6 The location of new inventory data collected in 2017. Purple spots represent lamps and black spots represent important dark locations.

6.2 Typical problems and solutions

In general, the public street lights that were encountered during the surveys were reasonably well shielded. LED lamps were very common, typically with full cut-off flat glass. However, it was notable that most seemed to be high colour temperature (cold white) and very bright. In general, it would be worth discussing the potential for dimming these street lamps (e.g. after 00:00). Also, switch off between 00:00 and 04:00 should be considered to improve sky quality for astronomy. In comparison, the quality of private or non-street lighting was typically much worse.

6.3 Non-standard LED lights

Whilst LED street are often fitted to full-cut-off lamps, this is not always the case. The examples below are both for LED lamps that have upward lighting emissions.

Fig.7 Non-standard LED fittings

Railways clearly need to be lit for safety, but in some cases there is excessive lighting. Much of the lighting in railway stations within the park uses 360 degrees LED lighhting with a cone shaped lantern. This allows light to escape above the horizon, as seen in stations such as Toffen, Burgistein, Lanzenhäusern, Schwarzenburg or Schwarzwasserbrücke. Typical lamps are seen in the example below from Toffen station.

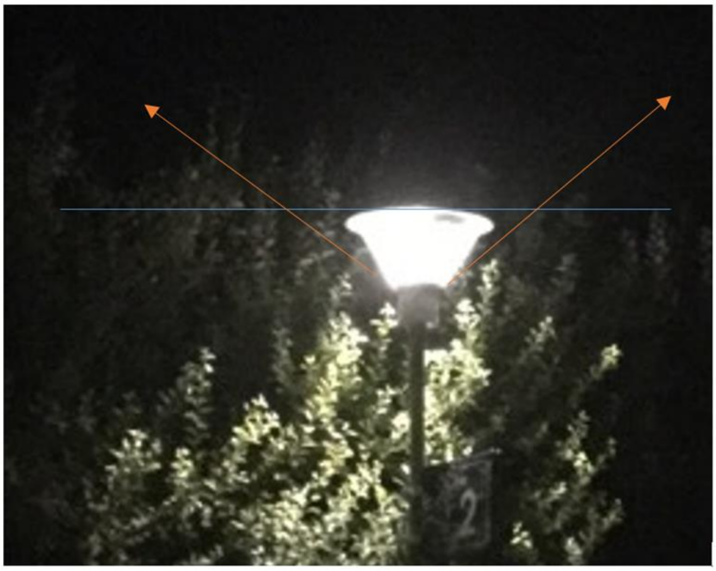


Fig.8 Poor shielding of railway station lighting. Light needlessly falls on vegetation and upwards.

- These lamps should be replaced, or potentially retrofitted with shields to reduce upward emissions and lighting trespass onto habitats.
- Similarly, future lighting plans should explicitly require better lamp designs.

Sports stadiums and outdoor sports areas appear to generally be well shielded, although it is difficult to know whether the lighting levels are excessive (more than needed for the activity taking place). There is probably a tendancy to over-light. A major difficulty in assessing the potential impacts of these lights is trying to find out *when* the lamps are operated. Football fields may be operated during spring and autumn, when temperatures are suitable but dusk comes early. These may have greater ecological impacts than icehockey pitches which are limited to the winter. In addition, pitches linked to schools might have a very restricted number of operating days, but this needs to be clarified. As a result, many lamps were not operating during the survey. It is difficult to know how lighting can be reduced without restricting the sport activity, although better shielding is possible in some cases. It may be worth contacting these groups directly to ask that they:

- Ensure lights are switched off quickly after the event
- Add extra shields to ensure no lighting trespass to buildings or habitats
- Make use of best practice lighting information

Fig.9 Flood-lighting at ice hockey pitch. Note the tree cover that is also lit.

Fig.10 Football pitch lighting trespass onto tree cover adjacent to a river – important habitats for bat feeding and reproduction displays of mayfly (ephemeroptera).

Lighting of **banks and other businesses** can be highly variable. Raiffeissen banks seem to have the best lighting – often limited to a small red lit sign. The worst lighting examples of businesses within the Naturpark Gantrisch included uplights aimed at white painted walls. Other banks also have “globe lamps” as architectural/path lights. The centre of most villages have shops which appear to leave window display lights on for the whole night for advertising. Industrial areas also often have permanent lighting in delivery areas.

Solutions include:

- Agree or enforce a 00:00 - 04:00am curfew. This might be the most practical and low-cost solution in urban centres with lots of small businesses.
- Retrofitting shields/hats to globe lamps
- Replace ground-based architectural floodlights with on-roof downlights
- Provide best practice lighting information to businesses so that future lighting is dark-sky friendly.
- Offer to publish any changes they make to their lighting – providing free a advert!
- Promote reactive lighting when lamps are needed for occasional delivery, or for security.

Fig.11 Architechtural lighting with upwards emissions contributing to skyglow.

Fig.12 Globe style lights by a bank. 50% of this light is wasted and can cause glare to the viewer.

Fig.13 Heavily lit shop window and signage operating late into the night.

Fig.14 Lighting in delivery area – potential to fit reactive lighting.

Schools, hospitals and retirement homes

Schools and residential institutions often have a wide diversity of lights intended for security and safety. Many are not well shielded – globe-style lights are common. Suggested solutions include:

- Provide best practice information for dark-sky friendly lighting
- Provide them with shields/covers that are easy to retrofit
- Suggest reactive security lighting, which is more effective than fixed lights which attract attention.
- Promote this as a good learning opportunity for the children and parents.

Fig.15 Globe lights in a Wohnheim/Pflegeheim – 50% of lighting is of no use, being emitted upwards to cause skyglow. Possibility to retrofit „hats“ to block upward emissions.


Fig.16 Globe lights in a housing development. Needs shielding to prevent upward emissions.

Churches and chapels in the park were often badly lit, using ground-based floodlights for architectural lighting, and poorly shielded lights for pathways. Yet some such as the church in Kirchenthurnen are not lit at all. See image number 13 for an example of a heavily lit church at night http://www.fotogalerien.ch/thumbnails.php?par_tour=650&par_lang=1&par_grossefotos=1

Suggested solutions:

- Provide best practice architectural lighting information so that future lighting is dark-sky friendly.
- Extra shields could be added to path lights ensure no upward lighting emission
- Ensure churches use full cut-off path lamps in the future
- Remove ground based flood lighting, replacing with on-roof downlights
- Alter ground based lighting with bespoke shields
- Push for a 00:00 to 04:00 curfew

Fig.17 A church with ground-based architectural lighting - much light misses the church or reflects upwards, causing skyglow.

Fig.18 Ground based floodlight – should be replaced with structural down-lighting.

Garages and other car-related businesses

As with schools and banks, there was huge variation in the quality of lighting of car-related businesses. This may reflect the differing reasons lighting has been installed e.g. safety, security or advertising. Several garages had lights in areas to draw attention to cars fo sale, and possibly as security. Other garages had lighting for 24h self service petrol pumps or car washes. However, even for petrol/gasoline stations there was lots of variation – some were very heavily lit. Even if there was little direct upward lighting due to a roof, nuisance light is still emitted horizontally, and some astronomical light pollution will result from ground reflectance.

- The main solution is to agree a lighting curfew on all garages from a 00:00 - 04:00am. This might be the most practical and low-cost solution, and reduces the impacts on competition between businesses.
- Ensure reactive work and security lights that can be triggered for the entire night.
- Provide best practice lighting information so that future lighting is dark-sky friendly.
- Offer to publish any changes they make to their lighting – providing a free advert!

Fig.19 A 24 Hour gas station, with bright and apparently permanent lighting.

Fig.20 Typical gas station lighting


Fig.21 Unusual garage lighting!


Fig.22 Carwash with striplights

7 Review of known ecological impacts for rare/priority species

7.1 Methodology

A literature analysis was undertaken to determine which priority species and habitats within the park are particularly sensitive to light emissions, in additional to other species and habitats considered important to the Naturpark Gantrisch (attractive species, those related to the ecological infrastructure work and other monitoring projects). These species and habitats come from the UNA 2010 report (Arten und Lebensraumförderung im regionalen Naturpark Gantrisch), and from discussions with staff at the Naturpark Gantrisch (Table 1).

Table 1 Species included in the literature review on the ecological impacts of artificial lighting

Bats (Fledermäuse)	Kleine Hufeisennase, Lesser Horseshoe Bat, *Rhinolophus hipposideros*
	Grosses Mausohr, Greater Mouse-eared Bat, Large Mouse-eared Bat, Mouse-eared Bat, Mouse-eared Myotis, *Myotis myotis*
	Mopsfledermaus, Western Barbastelle, Barbastelle *Barbastella barbastellus*
Other mammals	Luchs, Lynx, Eurasian Lynx, Carpathian Lynx, *Lynx lynx*
	Wolf, Gray Wolf, *Canis lupus*
	Fuchs, Red fox, *Vulpes vulpes*
	Dachs, Badger, *Meles meles*
	Hermelin, Stoat, Ermine, Short-tailed Weasel, *Mustela erminea*
	Igel, Hedgehog, *Erinaceus europaeus*
	Gartenschläfer, Garden Dormouse, *Eliomys quercinus*
	Rothirsch, Red Deer, *Cervus elaphus*
	Reh, Roe Deer, *Capreolus caproeolus*
Birds (Vögel)	Auerhuhn, Western Capercaillie, Capercaillie, *Tetrao urogallus*
	Birkhuhn, Black Grouse, *Tetrao tetrix*
	Eisvogel, Common Kingfisher, European Kingfisher, Kingfisher, *Alcedo atthis*
	Wachtelkönig, Corncrake, Corn Crake, *Crex crex*
	Flussuferläufer, Common Sandpiper, *Actitis hypoleucos*
	Zitronengirlitz, Citril Finch, Alpine Citril Finch, *Serinus citrinella*
Butterflies (Tagfalter)	Kleiner Schillerfalter, Lesser Purple Emperor, *Apatura ilia*
	Hochmoorperlmutterfalter, Cranberry fritillary, *Boloria aquilonaris*
	Blauschillernder Feuerfalter, violet copper, *Lycaena helle*
	Skabiosenscheckenfalter, marsh fritillary, Euphydryas *aurinia aurinia*
	Kleiner Alpenbläuling, Osiris blue, *Cupido Osiris*
	Schwarzgefleckter Bläuling, *Phengaris arion*, Large Blue, *Maculinea arion*
Grasshoppers (Heuschrecken)	Kiesbank-Grashüpfer, Gravel Grasshopper, *Chorthippus pullus*
	Türks Dornschrecke, Alpine Groundhopper, *Tetrix tuerki*
	Alpenschrecke, Small Alpine Bush-cricket, *Anonconotus alpinus*
	Sumpfschrecke, Large Marsh Grasshopper, *Stethophyma grossum*
	Sumpfgrashüpfer, *Chorthippus montanus*
Snails (Landschnecken)	Glänzende Glattschnecke, *Cochlicopa nitens*
	Feingerippte Grasschnecke, *Vallonia enniensis*
	Bauchige Windelschnecke, Desmoulin's Whorl Snail, *Vertigo moulinsiana*
Red List Aquatic insects	Eintagsfliegen/Mayflies/Ephemeroptera,Steinfliegen/Stoneflies/Plecoptera,Köcherfliegen/Caddis/Trichoptera
Vascular plants	Kopf-Kreuzkraut, *Tephroseris capitata*

(Gefässpflanzen)	
	Pyrenäen-Löffelkraut, Pyrenean scurvygrass, *Cochlearia pyrenaica*
	Schweizer Alant, Schweizer Alant, *Inula helvetica*
	Schlangen-Lauch, Sand Leek, *Allium scordoprasum*
	Zimt-Rose, Double cinnamon rose, *Rosa majalis*
	Berner Sandkraut, Fringed sandwort, Arenaria *ciliata (var. bernensis)*
Fungi (Pilze)	Riesenritterling, *Tricholoma colossus*
	Stachelschuppiger Wulstlig, *Amanita strobiliformis, Amanita solitaria*
	Favres Schwärzling, *Lyophyllum favrei*
Lichens (Flechten)	Schwarzfrüchtiger Kugelträger, *Spherophorus melanocarpus*
	Korallenkugelträger, Clustered coral lichen, *Spherophorus globosus*
	Parmelia laevigata
	Lecanatis abietina

For each of these broad taxonomic groups, we undertook a literature search within the Web Of Science (WoS) database, which combined the key lighting search terms with a list of Latin, German and English species names sourced from the Swiss *Liste der National Prioritären Arten* (2011), www.catalogueoflife.org, www.iucnredlist.org and taxon-specific guides.

The following artificial lighting search string was used (with bats as an example):

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 polariz* NOT electrons NOT dually OR polaris* OR unpolariz* OR unpolaris* OR “light-trap*“ OR “light trap*“ OR illumin* NOT Illumina NOT *RNA-Seq NOT nano* NOT virus* NOT *satellite NOT transcriptome) AND ("kleine Hufeisennase" OR "Lesser Horseshoe Bat" OR "Rhinolophus hipposideros" OR "Grosses Mausohr" OR "Greater Mouse-eared Bat" OR "Large Mouse-eared Bat" OR "Mouse-eared Bat" OR "Mouse-eared Myotis" OR "Myotis myotis" OR "Mopsfledermaus" OR "Western Barbastelle" OR "Barbastelle" OR "Barbastella barbastellus"))

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. The following natural lighting search string was used:

“lunar OR moon OR "stellar orientation" OR "star* navigation".

7.2 Details of review results

Bats

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, Jones et al. 2009). Similarly, cool white LED lighting was found to reduce commuting behaviour (Stone, Jones 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 typically 20-60 lux.

In addition, there are two papers with consider the impact of natural lighting on the **Greater Mouse-eared Bat** *Myotis myotis*. Holland, Borissov et al. (2010) and Greif, Borissov et al. (2014) demonstrate that this species uses the sunset to calibrate a magnetic compass, although they disagree about whether polarization cues at sunset are relevant. This is potentially relevant to the skyglow produced by large cities at sunset, which conceivably could be mistaken for a setting sun. Incidentally, there are several other relevant papers that deal with the impacts of lighting on sister species. In particular, many studies simply report impacts for Myotis, as species identification based upon calls for this group is considered unreliable. One interesting paper by Cichocki, Lupicki et al. (2015) describes the apparent relationship between moon phase and changes in activity of **Noctule** bats within a winter hibernacula. 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, Halliday et al. 2012). There is some evidence for lunar-phobia in *Myotis daubentonii* (**Daubenton's bat**) (Ciach and Frohlich 2017), a phenomenon that might be more common within bats than generally perceived (Saldaña-Vázquez and Munguía-Rosas 2013). Recent work points to the risks of lighting bat roosts, specifically roosts within churches (Rydell, Eklöf et al. 2017). More research on the impact of roost lighting would be beneficial, as this is one of the few situations where bats are grouped into a small space and therefore vulnerable to point sources of pollution or disturbance.

Other mammals

No papers on priority mammal species (except bats) and lighting were identified. 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, Kuparinen 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/m2). This represents a major research gap, and precautionary approach is needed, particularly as most of the mammal species listed as priorities have high levels of nocturnal activity.

Birds

We found no papers detailing impacts of artificial lighting on the bird species listed as priorities for the park. However, there are several papers or chapters that address this broader subject, all of which focus upon bird migration and orientation (Gauthreaux Jr, Belser et al. 2006, Muheim, Moore et al. 2006, Wiltschko, Stapput et al. 2010, McLaren, Buler et al. 2018). 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, Belser et al. (2006) of papers which demonstrate that caged migratory birds (particularly immature ones) orient towards horizon glows from cities. Given the variety of papers that provide evidence for impacts of lighting on raptors and passerines, and the use of artificial lighting to improve trap efficiency during bird surveys, it is still plausible that the bird species listed as priorities within the Naturpark Gantrisch are sensitive to artificial lighting. A precautionary approach is therefore advisable for lighting in associated habitats.

Butterflies

No directly relevant research was identified. This is probably because the lepidoptera searched for are predominantly diurnal. However, it is still plausible that lighting could encourage crepuscular behavior. In addition, relevant papers may have been missed because 1) research on lepidoptera 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. Certainly there is good evidence for other lepidopteran species to be impacted by artificial light. Macgregor, Pocock 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, Zoller 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 of van Langevelde, Braamburg-Annegarn et al. (2017), who show that populations of nocturnal or light attracted moths are declining much faster than diurnal populations. In summary, there is little evidence for lighting impacts on day-flying Lepidoptera. However, broad impacts are known for night-flying lepidoptera and it makes sense to restrict lighting in park habitats where diversity or abundance of these insects is greatest.

Grasshoppers

No directly relevant papers were found. However, we identified several papers listing impacts of lighting on Orthopteran species that are not on the list of Naturpark Gantrisch priorites, e.g. papers on the cricket *Teleogryllus commodus* have shown artificial lighting impacts on mating behaviour, melatonin production and immune function (Durrant, Michaelides et al. 2015, Botha, Jones et al. 2017). There are also examples of Orthoptera catches in light traps, but it is not clear how reliable these are as indications of sensitivity to lighting – 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, Haslem et al. 2012) and activity levels in katydids (Lang, Kalko et al. 2006), implying that avoidance responses to artificial light might also be expected (and should be tested for in future research).

Snails

No directly relevant papers were found. However, we found several papers on impacts of lighting for Gastropod species that are not on the list of Naturpark Gantrisch priorities. However, there is plenty of evidence of crepuscular, diurnal and nocturnal behaviour in these groups (Pimentel-Souza, Schall et al. 1984, Hickman and Porter 2007). This represents a major research gap, which in some cases would be relatively easy to address.

Red List aquatic insects – Ephemeroptera, Trichoptera and Plecoptera (ETP)

Many species of aquatic insects in Switzerland are of conservation concern; 43% of Swiss Ephemeroptera, 40% of Plecoptera and 51% of Trichoptera are included in national Red Lists. Given the abundance of streams and rivers in GNP, and their inclusion as a habitat of interest within the new Ecological Infrastructure project, it was decided to include these three Orders in the review.

Broadly, lighting adjacent to aquatic habitats appears attract disproportionately more aquatic than terrestrial species on insects (Perkin, Hölker et al. 2014). A recent large controlled study by Manfrin, Singer et al. (2017) in Germany demonstrates the magnitude of this attraction effect. There are numerous records of adult Trichoptera and Ephemeroptera being recorded in light traps, although the lamps typically used in these traps (e.g. UV blacklight) are different in spectrum to most outdoor artificial lighting. Ephemeroptera species within the Caenidae, Baetidae and Polymitarcyidae families are attracted to Compact Floursecent Lamps (CFL) (Turcsanyi, Szentkiralyi et al. 2009), and experimental evidence indicates an Ephemeroptera species in the Polymitarcyidae is attracted to LED light (Szaz, Horvath et al. 2015). 3 papers considered the impacts of artificial lighting on just 1 species of Ephemeroptera listed as a Swiss priority - the night-swarming mayfly *Ephoron virgo*. Szaz, Horvath et al. (2015) and Egri, Szaz et al. (2017) demonstrate that huge numbers of this species can be attracted to 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. As discussed in the butterfly section, it is possible that the impacts of artificial lighting on many of the ETP species found in the park have been researched, but that the individual species are not visible due to the use of community level analyses. A precautionary approach is therefore advised, particularly for lighting immediately adjacent to streams or on bridges.

There is little evidence for the attraction of adult Plecoptera to artificial lighting. However, it is plausible that there is a repulsion effect. This is an areas that requires research.

An issue that is also much discussed is the impact of horizontally polarized light on the attraction of aquatic insects. Under natural lighting conditions (from the sun, moon and stars), light reflecting from the water's surface is highly horizontally polarized. This is detectable by many aquatic insects, which can help them orient and navigate (e.g. when returning to the water to lay eggs). Artificially polarized light has been found to attract more Ephemeroptera individuals than standard CF light (Turcsanyi, Szentkiralyi et al. 2009) and more Ephemeroptera individuals compared to standard LED light (Szaz, Horvath et al. 2015). The concern regarding artificial lighting is that it is often associated with other infrastructure such as asphalt roads and car roofs, and that light reflection from these smooth, dark surfaces can also be horizontally polarised (Horváth and Varjú 1997). Therefore, the presence of artificial lighting may result in additional ecological impacts, if lamps are also adjacent to plastic sheeting or glass associated with agriculture, or near to built-infrastructure such as bridges or roads or PV panels. The presence of smooth dark surfaces near to streams should therefore be recorded as an additional risk-factor during lighting surveys.

Regarding juvenile aquatic insects, there is some evidence that artificial lighting disrupts larval drift – a key process in streams that allows insects to re-locate to better habitats downstream. Importantly, insect drift is highest just after dusk… when lights are typically turned on. Henn, Nichols et al. (2014) found negative impacts of bright (1400 lux) incandescent light on two Ephemeroptera families (Baetidae and Leptohyphidae). Similarly, Perkin, Hölker et al. (2014) found strong reductions in the drift density of Ephemeroptera (Baetidae family) under experimental HPS lamps. Interestingly, underwater lights may also attract a broad range of aquatic insects (Gyekis, Cooper et al.), including Ephemeroptera (Ephemerellidae, Heptageniidae and Leptophlebiidae) and Trichoptera (Hydroptilidae) (Weber 1987). Again, a precautionary approach is advised, particularly for lighting immediately adjacent to streams or on bridges.

Fig. 23 A female mayfly (Ephemeroptera) attracted to a lit bridge and laying its eggs on the bridge surface (rather than the water) (Photo J Hale)

Vascular plants

Plants use light as an energy source and information, yet no directly relevant papers were found for impacts of artificial lighting on the parks priority plant species. However, impacts on these species are still plausible, either due to direct changes to physiology, or indirectly via impacts on pollinators or grazers. As with the literature review for insect species, it is possible that relevant studies do exist, but that they included the species of interest within a community analysis, making the paper difficult to find. Whilst there is very limited information on the impact of artificial lighting on natural plant communities, an open access online paper by Bennie, Davies et al. (2016) "Ecological effects of artificial light at night on wild plants." provides an excellent overview. Another recent paper by Flowers and Gibson (2018) demonstrates impacts on grass species, and impacts of artificial lighting on invertebrate communities in grasslands are starting to be documented. Notable recent papers include Knop, Zoller et al. (2017) who demonstrated impacts on nocturnal plant pollinator networks, and Davies, Bennie et al. (2017) who identify impacts on ground beetles and spiders. A precautionary approach therefore makes sense, limiting lighting close to vegetated habitats, particularly grasslands and areas containing park priority plant species.

Fungi and Lichens

No papers were found that directly related to artificial or natural sources of light and the Gantrisch priority species. However, there is clear evidence for photoperiodism in these groups and some species release spores during the night (Bell-Pedersen, Garceau et al. 1996). This represents a research gap, which should be addressed, and again there is a need for a precautionary approach, limiting lighting close to habitats containing park priority species.

Other species groups

Impacts on fish migration and breeding behaviour of amphibians are also documented, although they did not fall within the remit of this study. In any case, this further indicates the need to focus on keeping aquatic habitats dark.

8 Lighting exposure modeling for key species and 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 the priority species that are found within the park.
- 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, yet we have no lamp inventory or surface illuminance data/models for the park. The next question is therefore what can be done to identify *potential* ecological impacts, given the data available?

The VIIRS data is likely to be the most useful source of an indicator of broad lighting exposure, given its complete coverage for the park and regular updates. However, simply extracting areas of high emissions from the VIIRS map is unlikely to provide an indicator of locations where ecological impacts would be expected. This is because these emissions are usually from locations with low ecological potential i.e. urban areas. However, species occupying apparently dark habitats nearby have a high potential to encounter these lit areas during migration, foraging or dispersal. In addition, 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, Holland, Borissov et al. (2010) and Greif, Borissov et al. (2014) demonstrate that the bat *Myotis myotis* uses the post-sunset glow on the horizon to calibrate a magnetic compass. It is possible that the lighting emissions from settlements at sunset, could potentially be mistaken for a perpetually setting sun, with impacts on bat 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 both proximity and topography on the visibility of lighting emissions. The output is a map showing parts of the Naturpark Gantrisch where lighting emissions can/cannot be seen.

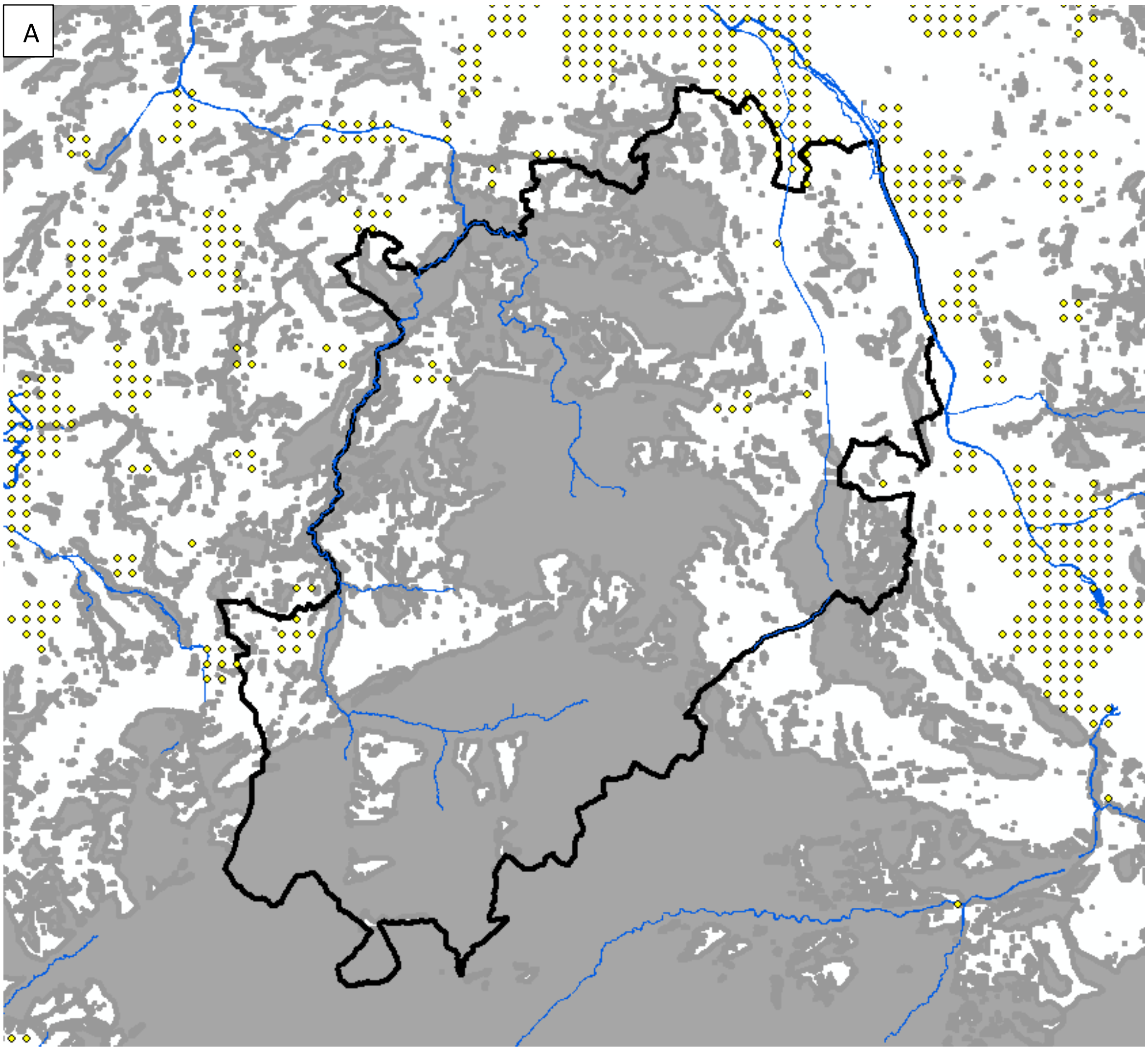
8.1 Direct visibility of bright lighting emission locations (viewshed mapping)

Two datasets were uploaded to a map document in ArcGIS: 1) The Swiss 25m DEM raster height dataset 2) VIIRS lighting data for Aug 2016. Both were clipped to a version of the park 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 low-medium brightness 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 >=2nW/cm^2/sr, which we consider to be a level of lighting emission likely to have *some* 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 2nW points were treated as *observer locations*, although we interpreted the resulting map as area where these 2nW 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 park boundary and converted to a binary (lighting visible/invisible) raster.

We used a 2NW threshold from the Summer VIIRS satellite data as that is a typical level for the lighting from the centre of a village. The assumption is that species which use the setting sun to calibrate an internal compass, or which are attracted/repelled by lighting might be impacted by these locations.

The resulting visibility model (Fig. 24) represent a worst case scenario, where light levels typically found in small villages (2NW) impact species within a 10km radius, as long as the light is visible (based upon topography). This results in a connected dark viewshed zone that covers the Schwarzwasser river and valley, the Sense main river corridor and the upper Sense valley. Other smaller areas with dark viewsheds include the upper Gurbe valley. This dark viewshed map is stored in the digital appendix under the name *Gan_vis2nw_10k.shp*


A

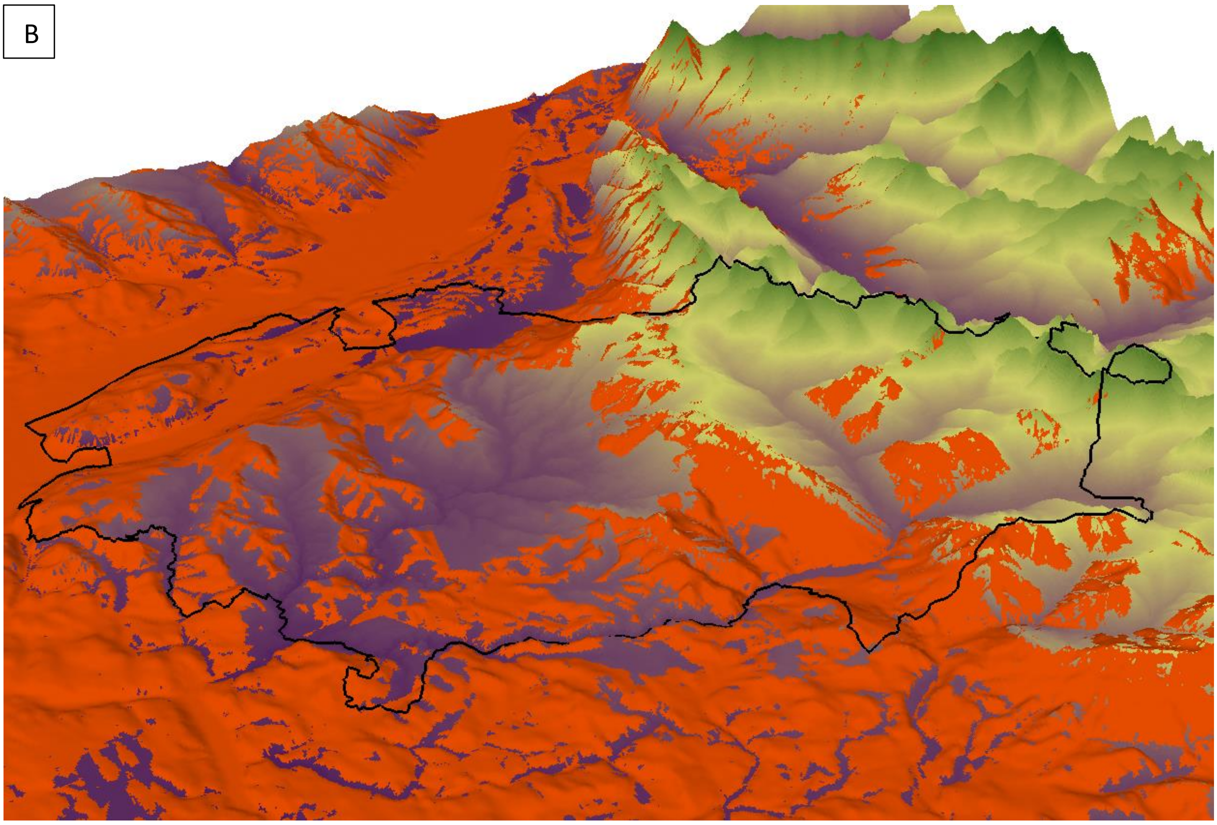


Fig. 24 A) Dark viewsheds (grey) based upon visibility analysis of >2nW lighting emission sources (yellow dots) within 10km distance. B) Lit (orange) viewsheds displayed in 3D (viewed from NW direction). The shielding effect of the topography can be clearly seen in B.

8.2 Sky brightness

A key finding from the literature review was that species from several of the taxonomic groups 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, Cinzano et al. 2016). The raster dataset represents a model of zenith sky radiance (mcd/m2) Fig. 25. 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, Falchi et al. (2001) which suggests locations with artificial sky brightness of <0.09 are darker than a quarter moon.

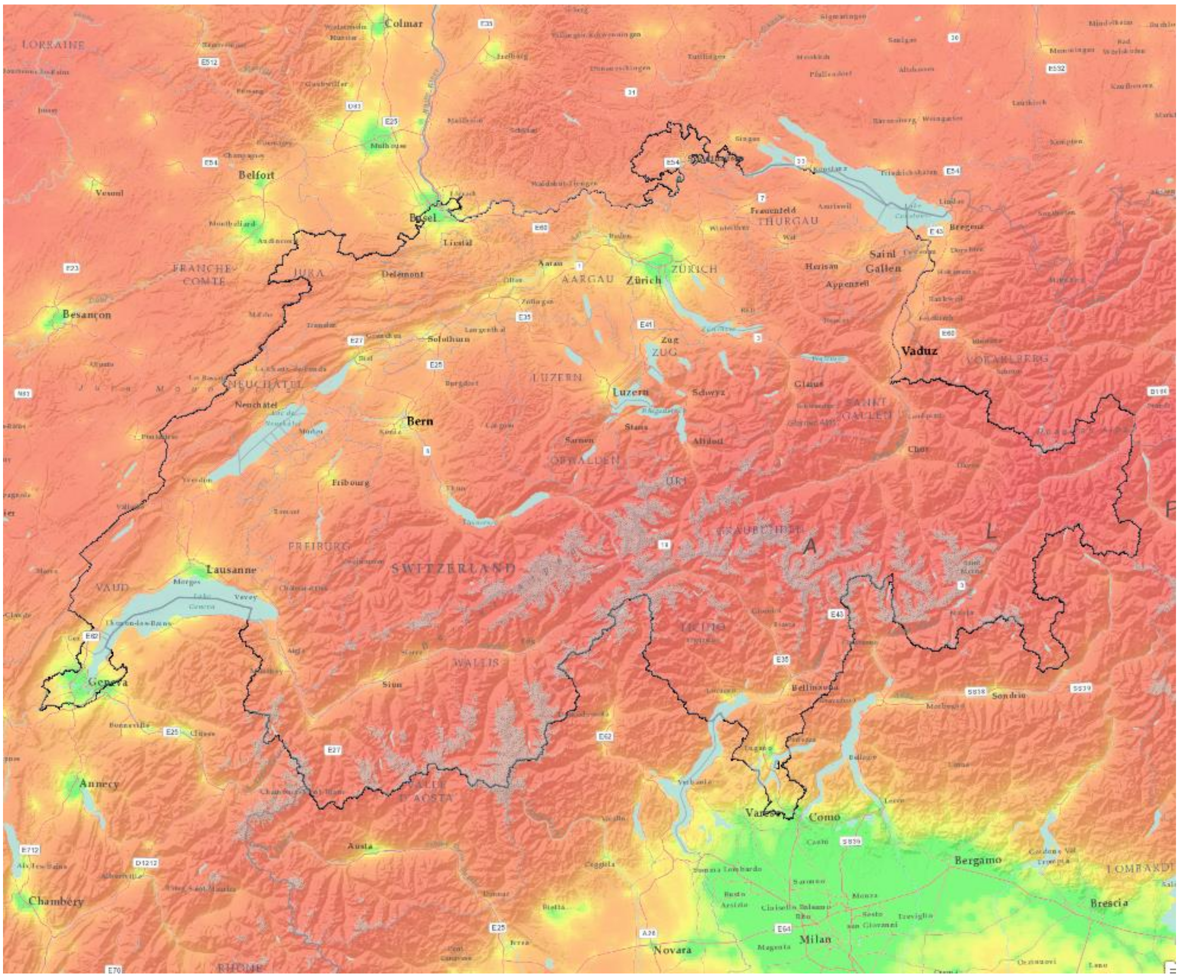


Fig. 25 Simulated zenith radiance data (mcd/m^2) by Falchi et al 2016. Radiance values in this image range from 0.02 (red) to 9.91 (green).

8.3 Core ecological dark zones

We propose that the main area of dark viewsheds (Fig. 26) should be treated as the core ecological dark zone for management purposes. This dark viewshed map is stored in the digital appendix under the name Gan_Vis2NW_10K_clippedGan1km_core___.shp

An important caveat is that these zones may still suffer from skyglow and from isolated light sources (e.g. lamps) which could also have ecological impacts. One way to identify the *darkest* locations is to intersect this main core zone with the most recent sky brightness model. This shows that the parts of the main dark viewshed zone that are furthest to the south are most likely to experience a natural lunar cycle (Fig 27). The further north, the greater the skyglow (closer to Bern)… with habitats in the yellow band experiencing near constant full moon type conditions. Therefore, habitat work for mammals and amphibians that respond to lunar cycles could be prioritised for habitats towards the south of this core dark viewshed zone. Similarly, work to remove, replace, dim and shield lamps should be focused on these core areas of dark viewsheds, particularly those which also have low skyglow.

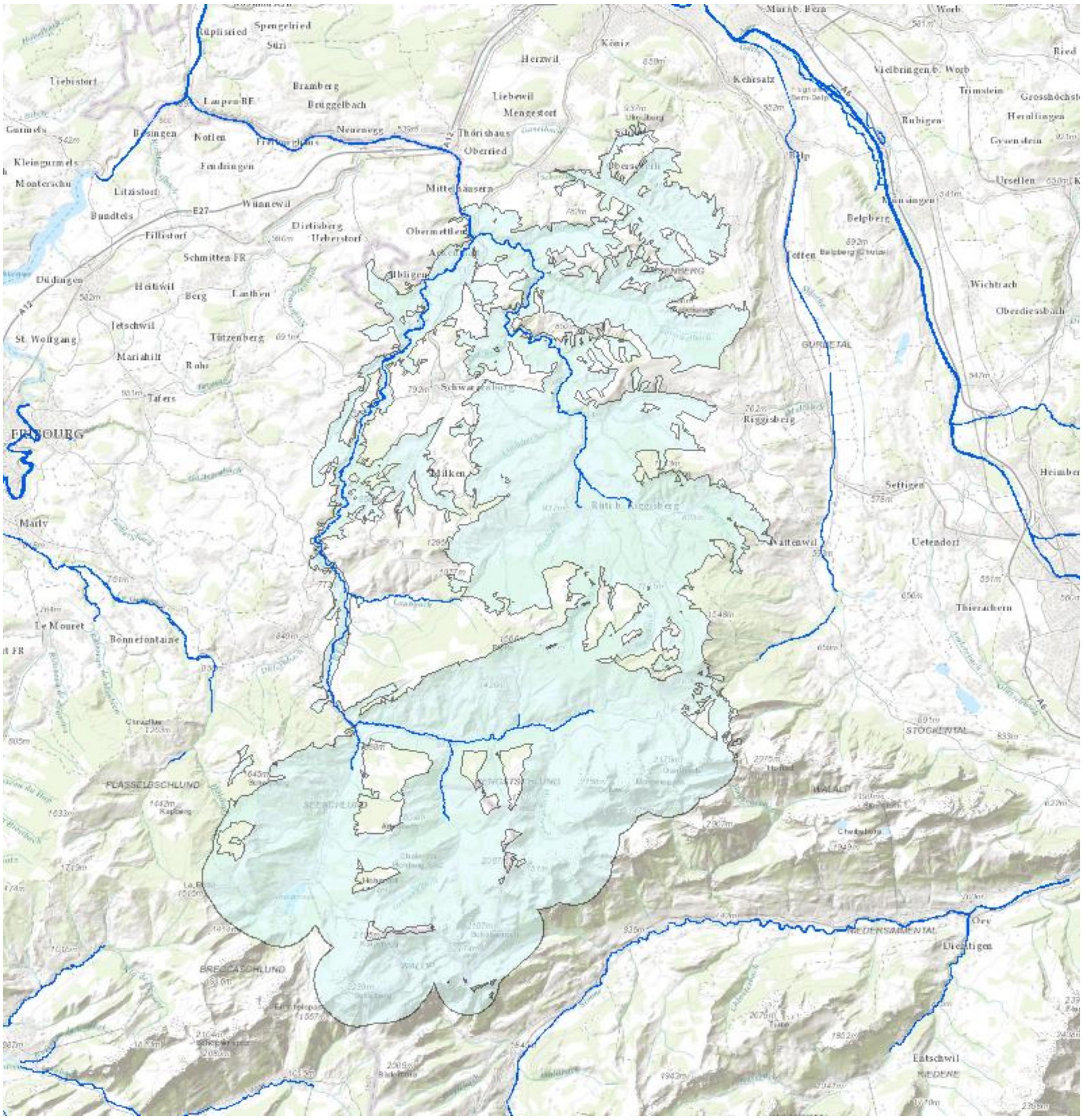


Fig. 26 Proposed core ecological dark zones (based on visibility models), encompassing the Sense and Schwarzwasser rivers and valley sections. Note how the topography protects the upper Sense and Schwarzwasser watersheds from receiving any light directly from nearby settlements.

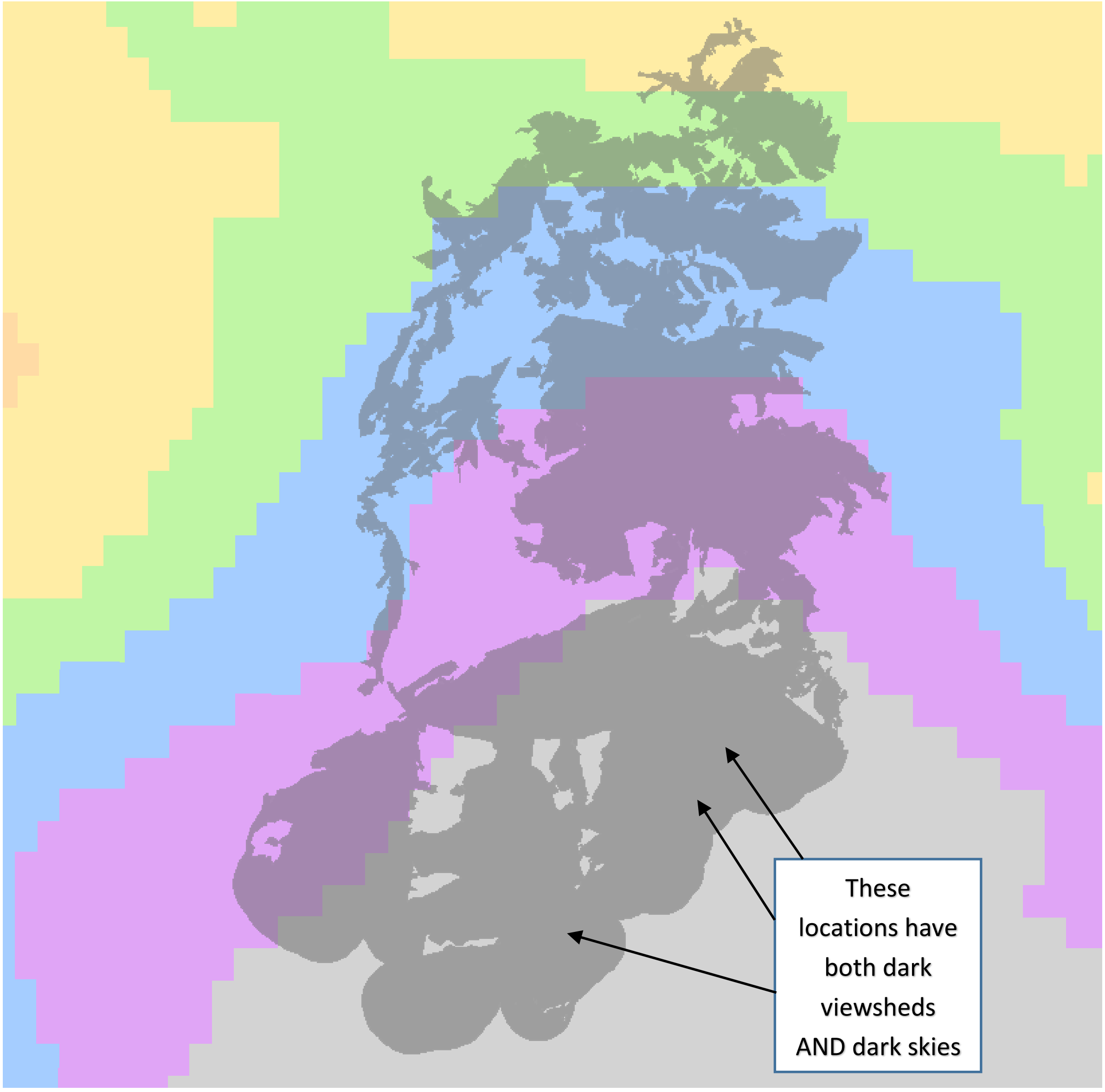


Fig. 27 Core dark viewshed zones, intersected with the 2015 sky quality model. Habitats within the light grey and purple bands have values <0.09 mcd/m^2, which indicate locations with a natural lunar sky brightness cycle.

8.4 Habitat exposure to artificial lighting

It was decided to focus on national priority habitats, although this analysis could be completed easily for any habitat map. Maps of biotopes of national importance (as identified in the Swiss Biodiversity Strategy (2011)) were downloaded, combined, converted to a 100m grid point layer, clipped to the park boundaries and saved in the digital appendix as Swiss_priority_biotopes_Gant_100m_grid.shp (Fig.28). These biotope types are as follows:

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

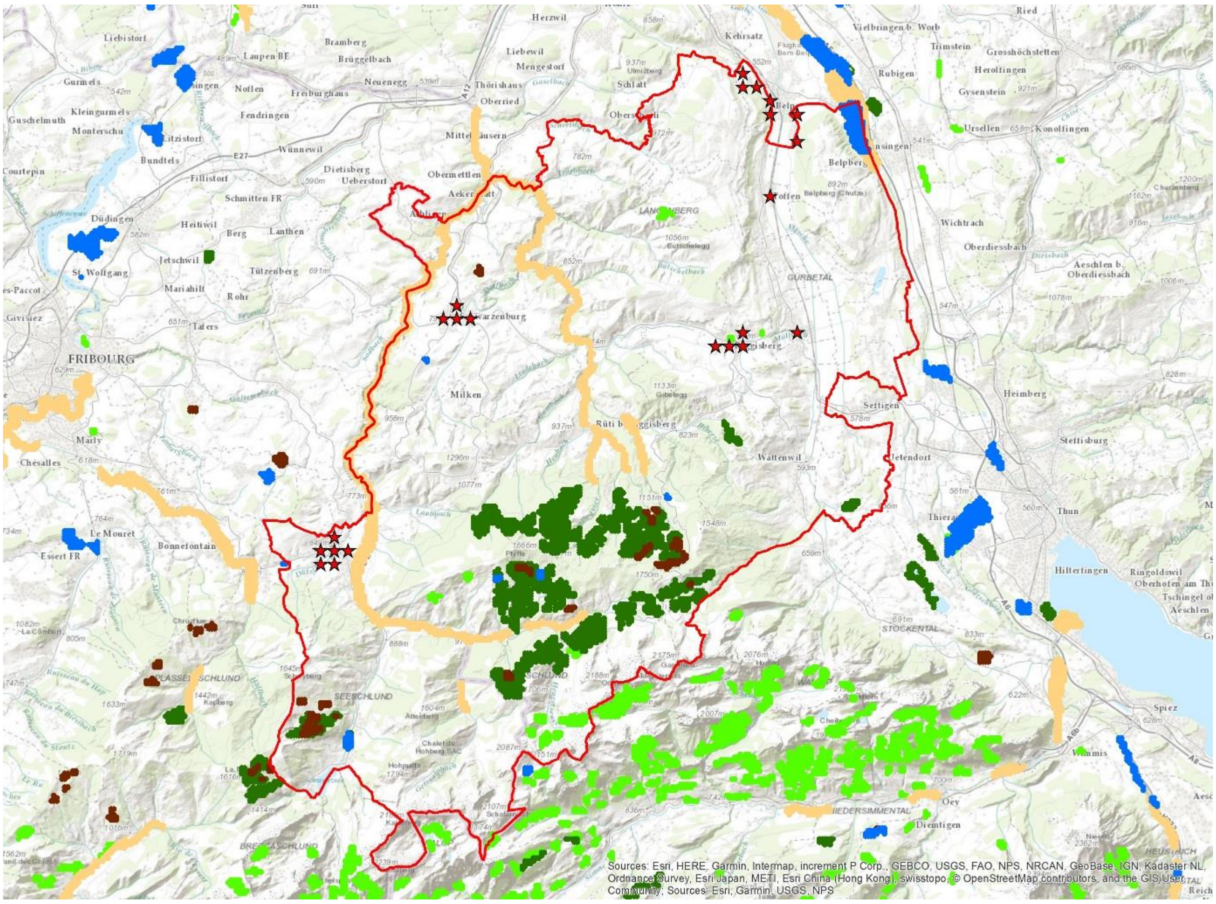


Fig.28 Biotopes of national importance found within the Naturpark Gantrisch, along with VIIRS emissions >2nW in August 2016. Amphibian Spawning areas are represented by blue points, Dry Meadows and Pasture by light-green, Alluvial by yellow/cream, Fens by dark-green and Raised Bogs by brown. Red stars indicate strong light emission locations.

To explore their level of exposure, these points were intersected with the full dark viewshed map and their frequency of exposure was calculated (Table 2). As can be seen in Fig 29, most of the biotopes are in locations which have dark viewsheds. When broken down by biotope type, 76% of all amphibian spawning areas appear to be exposed to bright viewsheds, mostly due to emissions from Belp. 15% of alluvial habitats are also exposed to bright viewsheds, due to their proximity to Belp and Plaffeien. 25% of fens have bright viewsheds, mostly due to lighting from Plaffeien. <u>We therefore recommend that efforts are made to reduce the strength of lighting emissions in Plaffeien and Belp to expand the area of biotopes with dark viewsheds.</u>

Table 2 summary of biotope locations exposed to lit or dark viewsheds.

	Dark viewshed	**Lit viewshed**	**% lit viewshed**
Amphibian spawning areas	32	103	76
Alluvial	877	155	15
Fens	1325	450	25
Raised bogs	152	5	3
Dry meadows and pasture	108	15	12

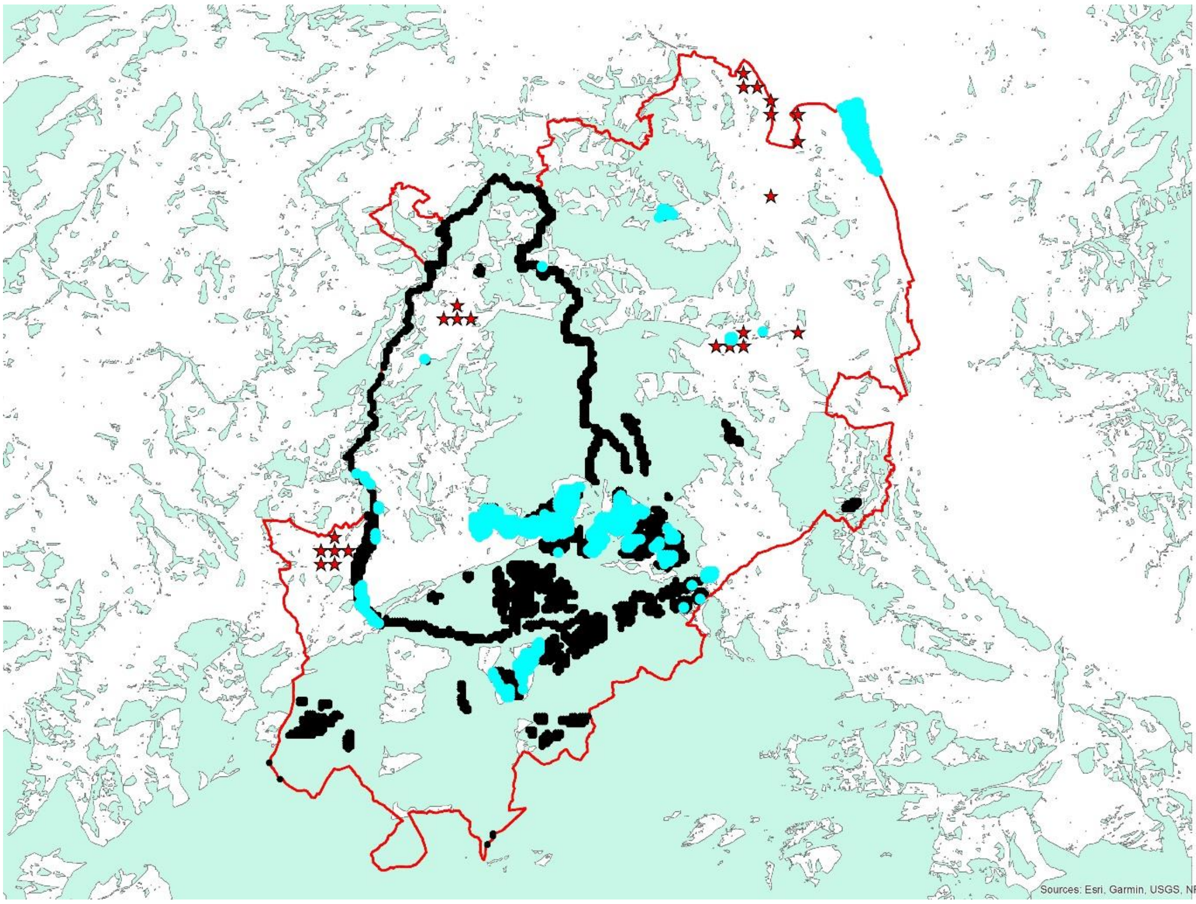


Fig. 29 Biotopes of national importance found within the Naturpark Gantrisch, overlaying the dark viewshed map created using VIIRS emissions >2nW in August 2016. Biotopes that have a lit viewshed are highlighted in light blue. Due to the topography, lighting biotopes in the center of the park are potentially exposed to lighting from Plaffeien.

8.5 Models for lighting impacts on rivers and streams

Given the abundance of streams within the Naturpark Gantrisch and the reasonable research evidence that many aquatic species are impacted by artificial lighting, we decided to focus on this habitat in more detail. Whilst very recently there has been a study published looking at the impacts of lighting on aquatic species (Manfrin, Singer et al. 2017), we felt that applying the results to practical nature conservation in the park was not possible. This is because nothing is known about the distance thresholds for impacts, i.e. how close a lamp needs to be to the river before it starts attracting (and potentially killing) insects. Also, there were no suitable studies that used white LED lights, which we know are becoming very common. We therefore undertook a study to estimate the attraction effect of LED lighting on adult aquatic insects, and to identify lamp proximity thresholds. Following this we undertook ground surveys of lamps along the main rivers in the park, to identify those which need to be modified to reduce their impacts on this habitat.

8.5.1 Masters student research project – lighting impacts on adult aquatic insects

This study was undertaken by Deborah Carannante and Claudia Blumenstein as part of their master's degree within the Conservation Biology Division at the University of Bern. They were supervised by Dr James Hale and Prof. Raphaël Arlettaz, although at the time of writing their research has not yet been published in a peer reviewed journal. Artificial lights are often installed in close proximity to water bodies, as is the case in the Gantrisch Naturepark. Despite evidence that they are attracted by lights, adult aquatic insects are a relatively poorly studied group in the field of ecological light pollution. This knowledge gap is even more of concern, as little is known about the consequences of switching from traditional to LED lamps. This study focuses on exploring the difference in the density of adult aquatic insects around LED lamps compared to dark control sites, and how those densities change depending on lamp proximity to aquatic habitats.

The study was undertaken in the summer of 2017 along the Gürbe river within the Gantrisch Naturepark. It involved repeated sampling at multiple locations along the river, using White LED lamps (1500 lumen), switched-on (treatment) or off (control). Various insect traps were installed adjacent to each lamp to provide an indication of the local density of insects attracted to the light. Lights were installed at different distances from the stream edge, ranging from 0 to 80m. We focused our analysis on mayflies (Ephemeroptera - Fig. 30) and caddisflies (Trichoptera) as many species are both severely threatened and phototactic. In addition, Diptera are an important food source for protected insectivorous species, e.g.common pipistrelle (*Pipistrellus pipistrellus*). It is therefore crucial to identify the impacts of white LED lamps on these taxa and to test mitigation measures.

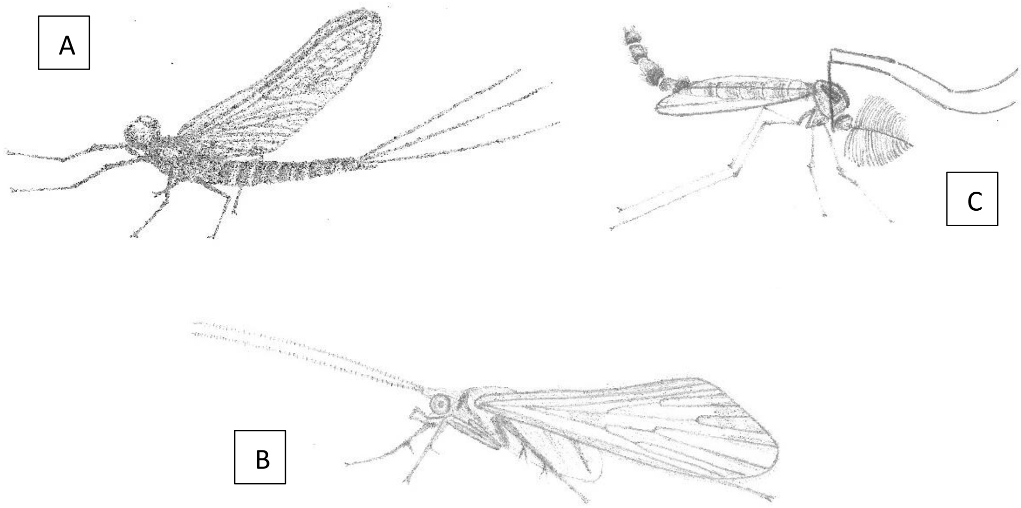


Fig. 30 Examples of insects from the three study Orders: A) Ephemeroptera, B) Trichoptera, C) Diptera. Images copyright C. Bluemenstein.

We found that LED lighting massively increases the local densities of Ephemeroptera, Trichoptera and Diptera. Compared to the control, we recorded an increased in catches under lit conditions of approximately 18’000%, 8’000% and 9’000% respectively.

We also identified distinct lamp-proximity thresholds for impacts on two of the three studied taxa. The abundance of mayflies (Ephemeroptera) decreases significantly from 20 to 40 meters from the river edge. In contrast, the abundance of caddisflies (Trichoptera) drops rapidly between 0 and 10 meters from the river. For Diptera, no clear distance threshold can be detected, but catches broadly reduce as lamps are moved further from the river edge. See Fig. 31 for examples of survey.

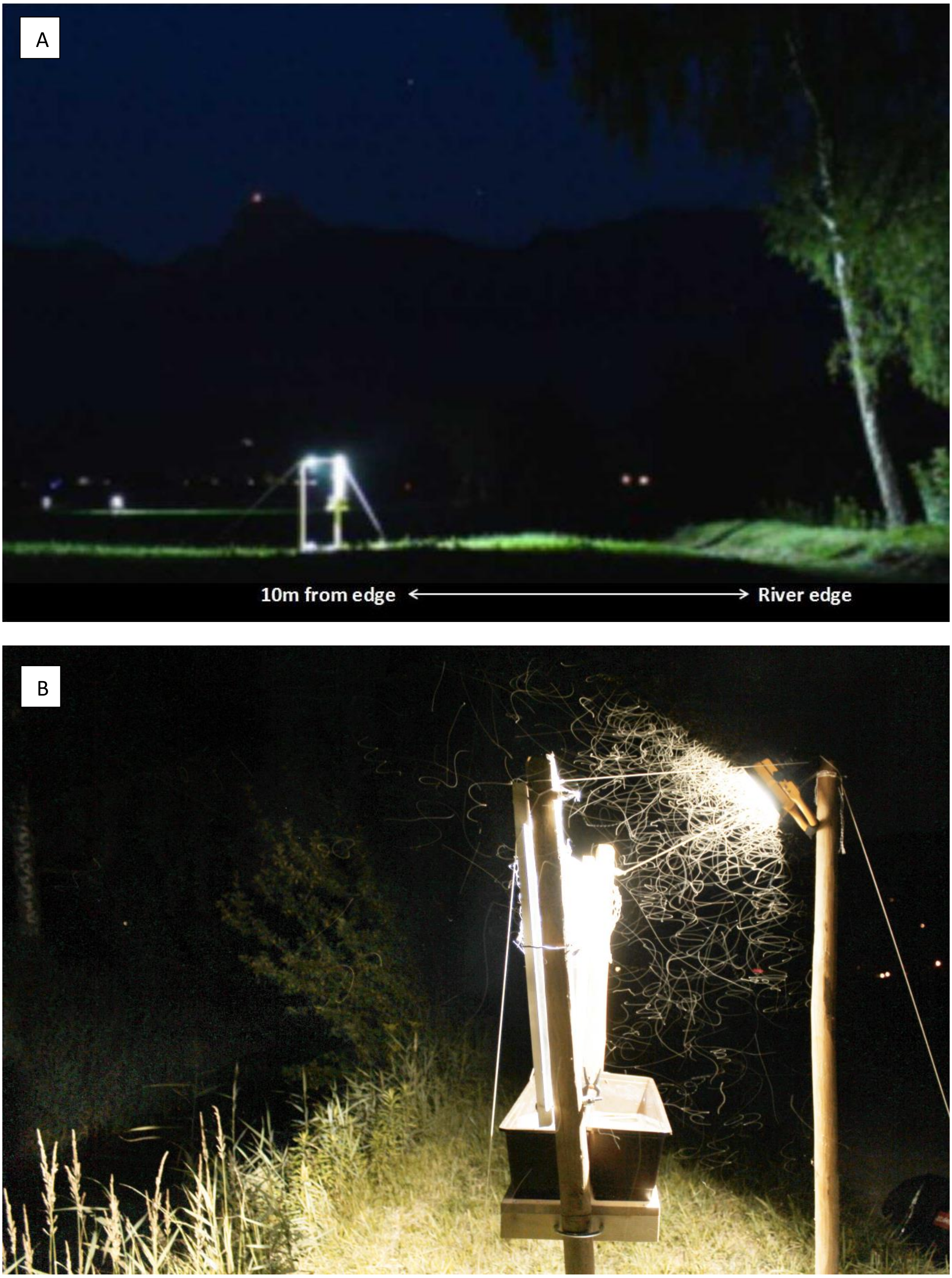


Fig.31 A) Insect surveyed adjacent to lamps at different distances from the river. B) example of insect aggregation at the light (Images copyright D. Carannante).

8.5.2 River lamp surveys

As a result of the thresholds identified above, we chose to survey all lighting within 100m of the river's edge for all main rivers in the park. In general, the Sense and Schwarzwasser rivers have few lamps within the 100m buffer zone. Even the Gürbe has large sections that are unlit. This is something which should be publicized as a special feature of the park, and they should be conserved as dark habitats. These locations could also be useful ecological references points, for drawing comparisons with heavily light-polluted streams elsewhere. With relatively little effort it would be possible to connect existing dark sections to form a larger dark river network, but strategically removing a few lamps that appear of little value.

- There are clear benefits from removing such lamps completely, but it is also likely that dimming, shielding or converting these lamps to amber LED would be beneficial.
- Possibly even more important is to prevent the installation of any new lighting in this dark river network.

24 problem locations have been identified within 100m of the main rivers. These are flagged in the new inventory under the field "River_corr". The problem locations are located in the upper Sense, upper Schwarzwasser and throughout the lower section of the Gürbe. In general it was difficult to know how far up each river to survey. For example, at Rüschegg-Heubach the Sense is little more than a stream with lots of dry streambed. From google maps, it can be seen that both bridges in this village are lit, but these are not included in the inventory. It is unclear whether the ecological impacts of lighting in such a small stream are equivalent to lighting in the main river stem.

In the Sense there are very few problem lamps, most of which could easily be dealt with (Fig. 32).

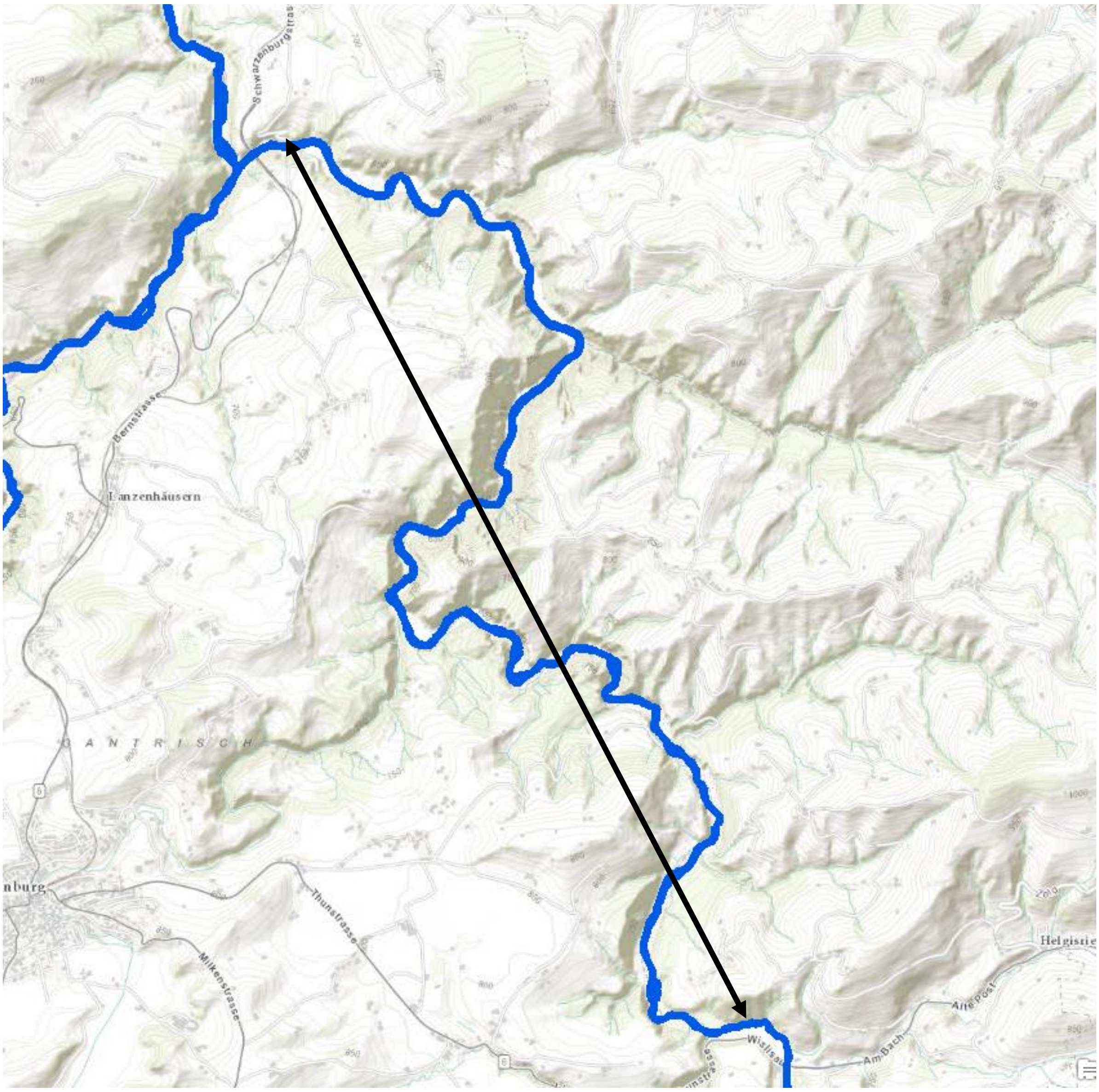
(Fig. 32) Lighting locations (light blue points) within 100m of the upper Sense river.


Fig. 33 New LED lighting within 100m of the Warme Sense (Zollhause)

In the Schwarzwasser, there are very few problem lamps, most of which could easily be dealt with. In particular, the 11km long section of river between the Schwarzwasserbrücke and Wislisau (Fig. 34) is almost completely dark – just a few small farmhouses with minimal lighting. This section could therefore be considered a rare example of a dark lowland stream. Lots of aquatic insect activity and bat activity was observed during the surveys. One option would be for the Naturpark Gantrisch to collaborate with local farmers in this section to create a habitat enhancement project specifically for light-sensitive species. This might then serve as a national example of best practice.

At Wislisau there is LED lighting associated with the bridge which should be better shielded, dimmed and ideally replaced with amber LED lighting. This might be challenging to achieve, but it would connect several more km of dark river habitat.

As mentioned above, there is also some lighting on the bridges in Rüschegg-Heubach which was not included in the inventory, but which may still benefit from similar mitigation.



(Fig.34) 11km of high-quality dark river habitat on the lower Schwarzwasser.

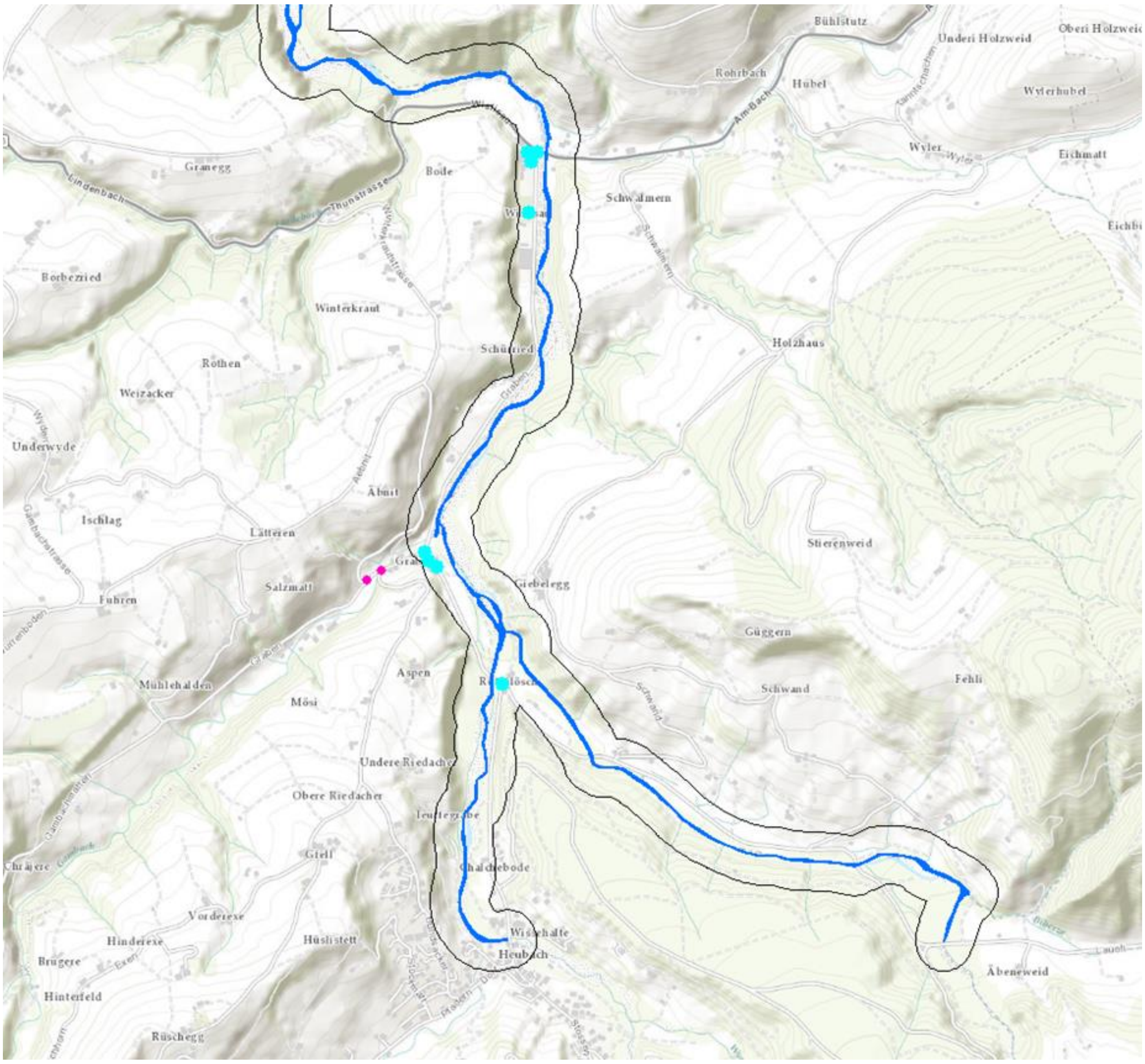


Fig. 35 Lighting locations (light blue points) adjacent to the upper Schwarzwasser.

The lighting adjacent to the **Gürbe river** (Fig. 36) is more difficult to address in some cases. The small amount of lighting adjacent to bridges in Kaufdorf and Wattenwil could be easily solved with removal, shielding, dimming etc. However, there are many lamps within 100m of the river edge at Toffen. Most of these would be difficult to remove, but it would be possible to address the powerful LED lights on the bridge and to shield many of the lamps associated with the train station. Much of the lighting from the bridge is trespassing onto the water surface and riparian area. This could be solved with the careful addition of shields, but dimming and converting to amber LED would probably be beneficial.

The typical lights used in most stations emit light in all horizontal directions. However, in some cases this is not needed. Light from lamps on the Toffen East platform (Fig. 37), as well as from the strip-lights within the seating area are currently illuminating the river, potentially attracting nationally rare adult aquatic insects away from the river, and restricting the movements of fish and birds along the river corridor. Bats were observed feeding on insects attracted to the bridge light, whilst a heron fed in the stream below by the light of the lamps! It is recommended that in the short term, shields are added to these lights to prevent light emissions to the East (towards the river). For the strip-lights it might be easier to install a physical visual barrier along the fence boundary.

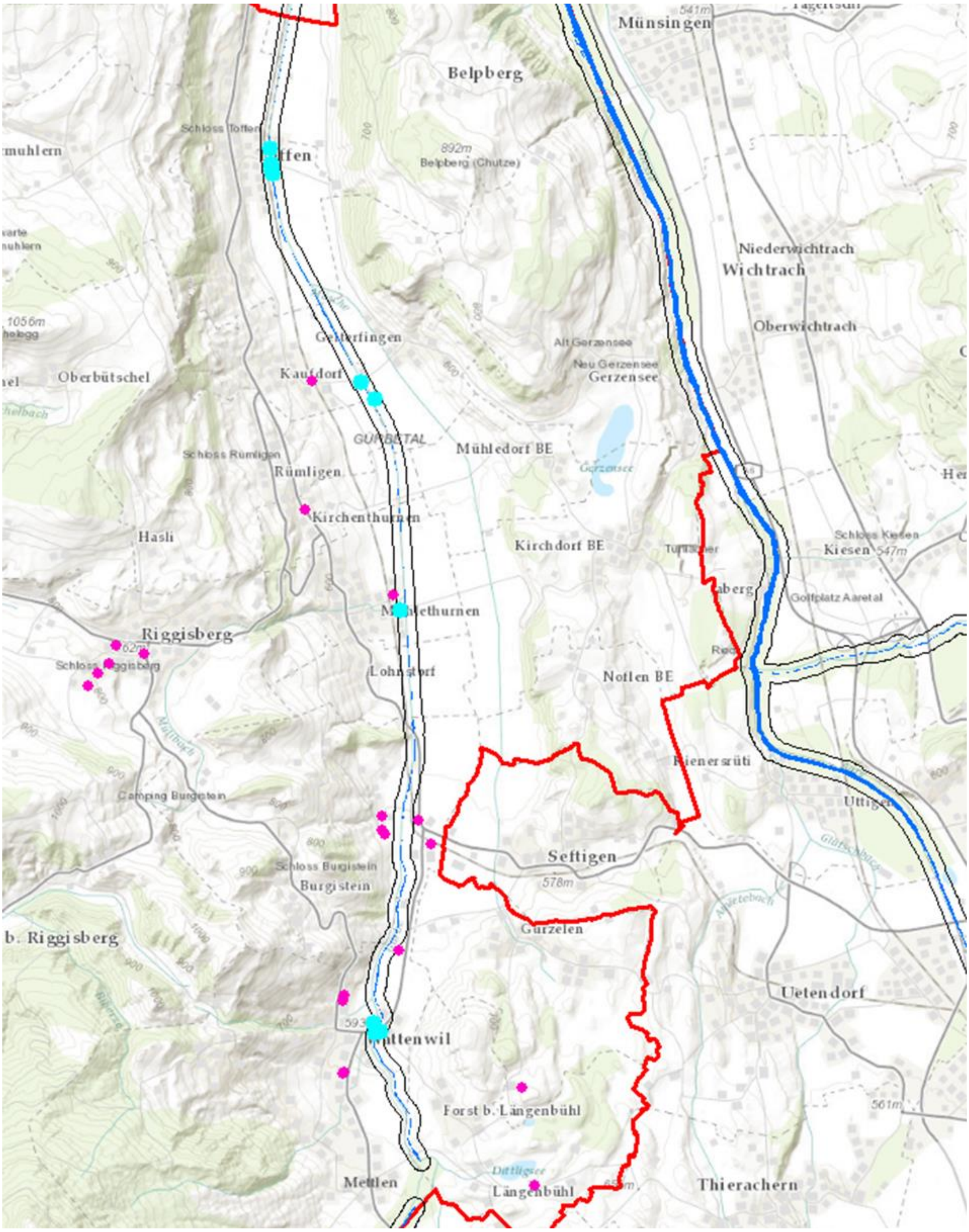


Fig.36 Problem lighting locations (light blue points) on the Gurbe river.

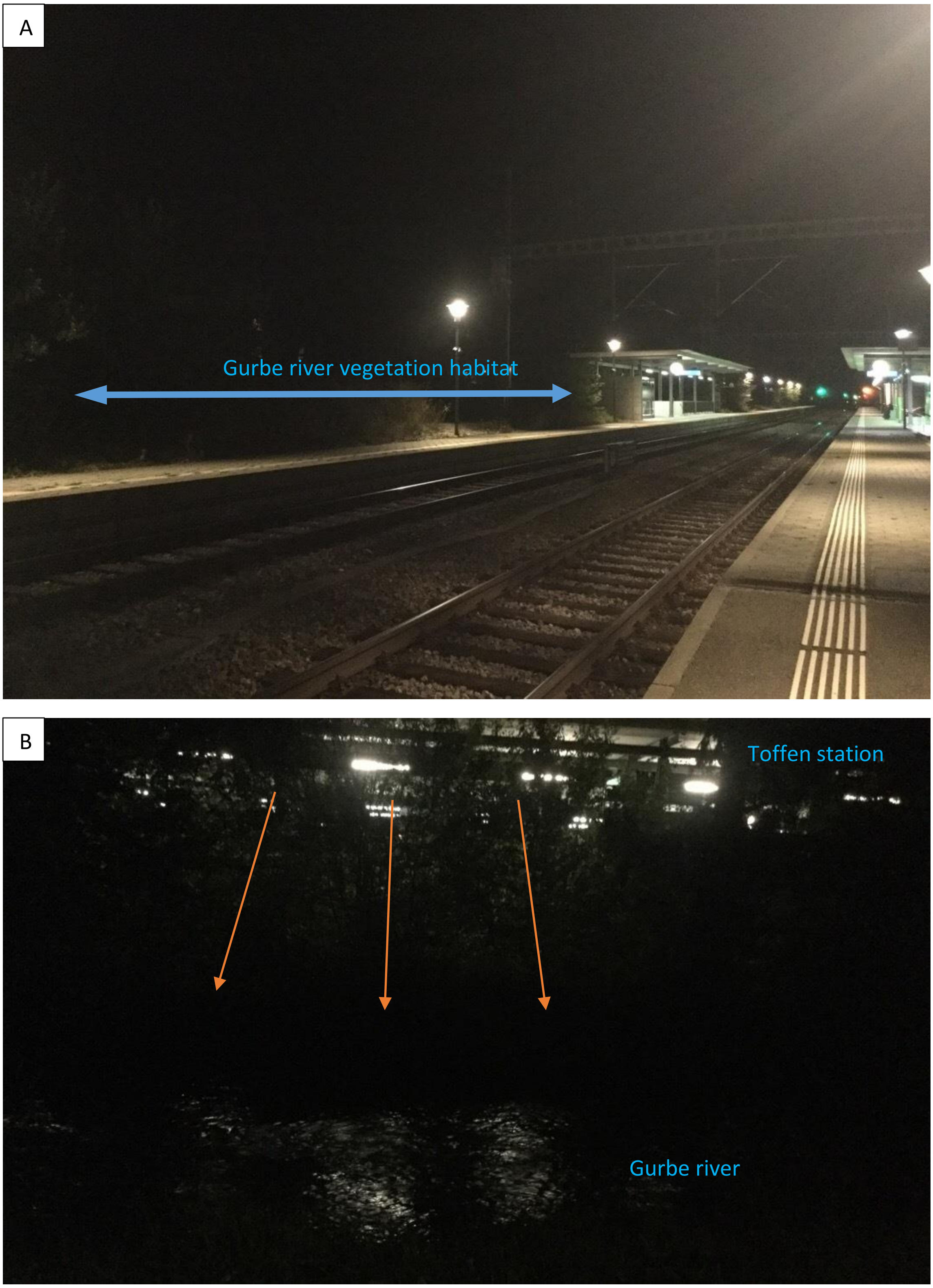


Fig. 37 East platform seating area lighting, when viewed from the railway (A) and stream (B). Note the light from the waiting area on the East platform can be seen reflecting in the water surface.

8.6 Bird migration

Whilst there are currently no lighting thresholds that can be used for identifying where migrating birds might be impacted, there are existing models for bird migration routes available for Switzerland (Fig. 38) (Liechti, Guélat et al. 2013). These indicate a general migration pathway through the Gantrisch. A hotspot for migration at the Gurnigel wasserscheide is well known by local naturalists, and we therefore suggest a lighting exclusion zone in this area. The exact location of the watershed was identified using an analysis of the DEM and then buffered by 200m. This buffer size could be adjusted as more empirical data becomes available.

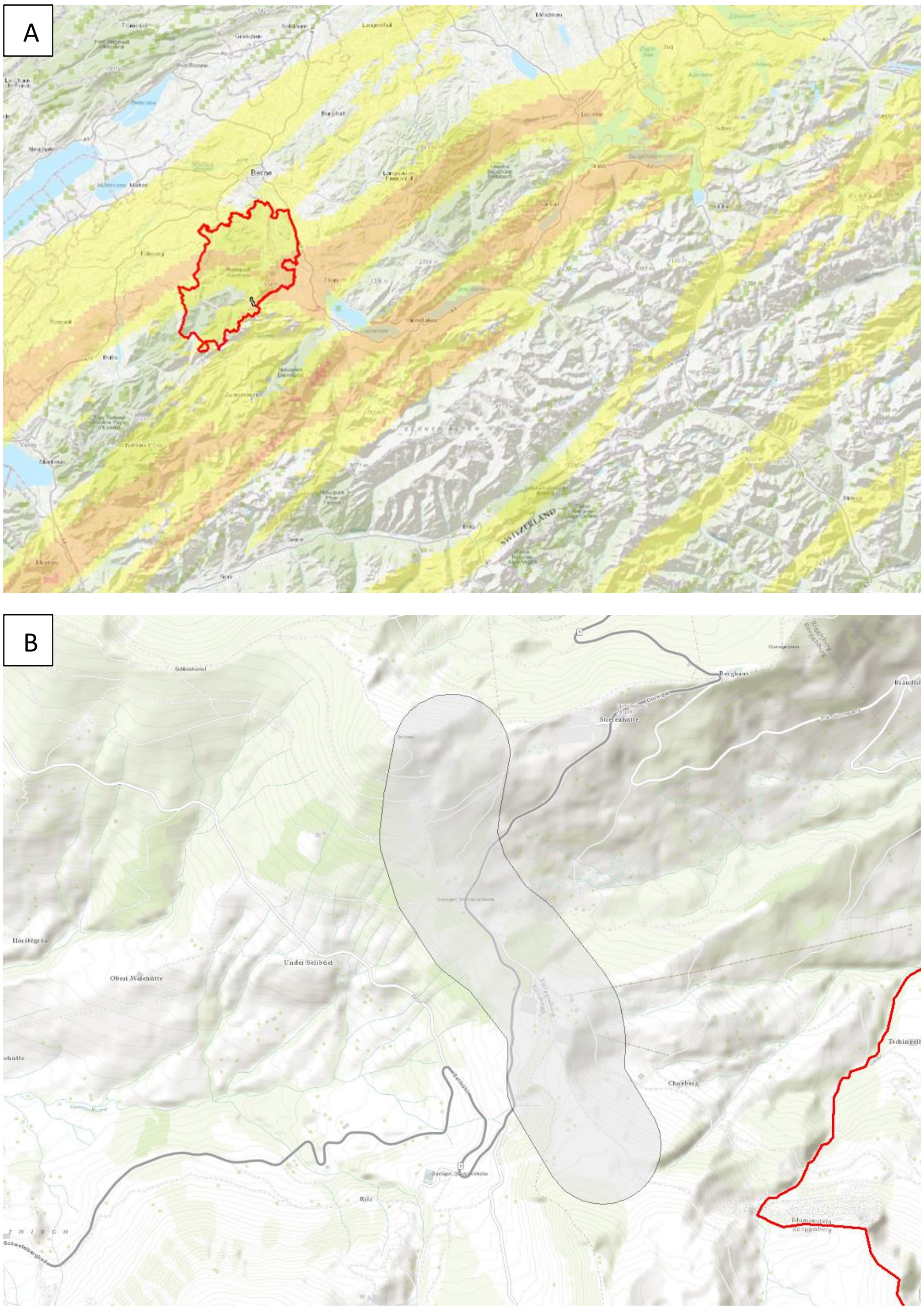


Fig. 38 A) Autumn model for passerine migration routes in Switzerland (Liechti, Guélat et al. 2013), and B) proposed lighting exclusion buffer zone following the Gurnigel watershed in Naturpark Gantrisch.

9 Digital appendix – zipped files

- VIIRS data for Gantrisch (raw) - *Viirs correct gantrisch clip*
- VIIRS data for Gantrisch (resampled to 500m, Swiss Grid) - *Viirs correct gantrisch clip reproject*
- Existing lamp inventories supplied as a baseline - *GNP_Inventory_Data_Supplied*
- New inventory of additional lamps or groups of lamps that may need mitigation - *Additional_GNP_inventory_lamps_2017_.shp*
- New inventory of important dark locations (mostly dark bridges) - *Additional_GNP_inventory_Dark_2017_.shp*

10 References

Bell-Pedersen, D., N. Garceau and J. J. Loros (1996). "Circadian rhythms in fungi." Journal of Genetics **75**(3): 387-401.

Bennie, J., T. W. Davies, D. Cruse and K. J. Gaston (2016). "Ecological effects of artificial light at night on wild plants." Journal of Ecology **104**(3): 611-620.

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

Ciach, M. and A. Frohlich (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**(3): 547-559.

Cichocki, J., D. Lupicki, J. Bojarski and A. Wazna (2015). "The impact of the moon phases on winter activity of the noctule bats Nyctalus noctula." Polish Journal of Ecology **63**(4): 616-622.

Cinzano, P., F. Falchi and C. D. Elvidge (2001). "The first World Atlas of the artificial night sky brightness." Monthly Notices of the Royal Astronomical Society **328**(3): 689-707.

Davies, T. W., J. Bennie, D. Cruse, D. Blumgart, R. Inger and K. J. Gaston (2017). "Multiple night-time light-emitting diode lighting strategies impact grassland invertebrate assemblages." Global Change Biology **23**(7): 2641-2648.

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

Egri, A., D. Szaz, A. Farkas, A. Pereszlenyi, G. Horvath and G. Kriska (2017). "Method to improve the survival of night-swarming mayflies near bridges in areas of distracting light pollution." Royal Society Open Science **4**(11).

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

Falchi, F., P. Cinzano, D. Duriscoe, C. C. Kyba, C. D. Elvidge, K. Baugh, B. A. Portnov, N. A. Rybnikova and R. Furgoni (2016). "The new world atlas of artificial night sky brightness." Science Advances **2**(6): e1600377.

Flowers, N. D. and D. J. Gibson (2018). "Quantified effects of artificial versus natural nighttime lighting on the Eurasian grasses Bothriochloa bladhii (Poaceae) and Bothriochloa ischaemum (Poaceae) and the North American grasses Panicum virgatum (Poaceae) and Sorghastrum nutans (Poaceae)." The Journal of the Torrey Botanical Society **145**(2): 147-155.

Fox, R. (2013). "The decline of moths in Great Britain: a review of possible causes." Insect Conservation and Diversity **6**(1): 5-19.

Gauthreaux Jr, S. A., C. G. Belser, C. Rich and T. Longcore (2006). "Effects of artificial night lighting on migrating birds." Ecological consequences of artificial night lighting: 67-93.
Grant, R., T. Halliday and E. Chadwick (2012). "Amphibians' response to the lunar synodic cycle—a review of current knowledge, recommendations, and implications for conservation." Behavioral Ecology **24**(1): 53-62.
Greif, S., I. Borissov, Y. Yovel and R. A. Holland (2014). "A functional role of the sky's polarization pattern for orientation in the greater mouse-eared bat." Nature Communications **5**.
Gyekis, K. F., M. J. Cooper and D. G. Uzarski "A high-intensity LED light source for larval fish and aquatic invertebrate floating quatrefoil light traps."
Henn, M., H. Nichols, Y. Zhang and T. H. Bonner (2014). "Effect of artificial light on the drift of aquatic insects in urban central Texas streams." Journal of freshwater ecology **29**(3): 307-318.
Hickman, C. S. and S. S. Porter (2007). "Nocturnal swimming, aggregation at light traps, and mass spawning of scissurellid gastropods (Mollusca: Vetigastropoda)." Invertebrate Biology **126**(1): 10-17.
Holland, R. A., I. Borissov and B. M. Siemers (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**(15): 6941-6945.
Horváth, G. and D. Varjú (1997). "Polarization pattern of freshwater habitats recorded by video polarimetry in red, green and blue spectral ranges and its relevance for water detection by aquatic insects." Journal of Experimental Biology **200**(7): 1155-1163.
Kachamakova, M. and D. Zlatanova (2014). "Behaviour of Eurasian Lynx, Lynx lynx (L.), in Captivity during the Breeding Season." Acta Zoologica Bulgarica **66**(3): 365-371.
Knop, E., L. Zoller, R. Ryser, C. Gerpe, M. Hörler and C. Fontaine (2017). "Artificial light at night as a new threat to pollination." Nature **548**(7666): 206.
Lang, A. B., E. K. V. Kalko, H. Romer, C. Bockholdt and D. K. N. Dechmann (2006). "Activity levels of bats and katydids in relation to the lunar cycle." Oecologia **146**(4): 659-666.
Liechti, F., J. Guélat and S. Komenda-Zehnder (2013). "Modelling the spatial concentrations of bird migration to assess conflicts with wind turbines." Biological conservation **162**: 24-32.
Macgregor, C. J., M. J. O. Pocock, R. Fox and D. M. Evans (2015). "Pollination by nocturnal Lepidoptera, and the effects of light pollution: a review." Ecological Entomology **40**(3): 187-198.
Manfrin, A., G. Singer, S. Larsen, N. Weiss, R. H. van Grunsven, N.-S. Weiss, S. Wohlfahrt, M. T. Monaghan and F. Hölker (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.
McLaren, J. D., J. J. Buler, T. Schreckengost, J. A. Smolinsky, M. Boone, E. Emiel van Loon, D. K. Dawson and E. L. Walters (2018). "Artificial light at night confounds broad-scale habitat use by migrating birds." Ecology letters.
Muheim, R., F. R. Moore and J. B. Phillips (2006). "Calibration of magnetic and celestial compass cues in migratory birds - a review of cue-conflict experiments." Journal of Experimental Biology **209**(1): 2-17.
Penteriani, V., A. Kuparinen, M. D. Delgado, F. Palomares, J. V. Lopez-Bao, J. M. Fedriani, J. Calzada, S. Moreno, R. Villafuerte, L. Campioni and R. Lourenco (2013). "Responses of a top and a meso predator and their prey to moon phases." Oecologia **173**(3): 753-766.
Perkin, E. K., F. Hölker and K. Tockner (2014). "The effects of artificial lighting on adult aquatic and terrestrial insects." Freshwater Biology **59**(2): 368-377.
Pimentel-Souza, F., V. T. Schall, R. Lautner Jr, N. D. Campos Barbosa, M. Schettino and N. Fernandes (1984). "Behavior of Biomphalaria glabrata (Gastropoda: Pulmonata) under different lighting conditions." Canadian journal of zoology **62**(11): 2328-2334.
Rydell, J., J. Eklöf and S. Sánchez-Navarro (2017). "Age of enlightenment: long-term effects of outdoor aesthetic lights on bats in churches." Open Science **4**(8): 161077.
Saldaña-Vázquez, R. A. and M. A. Munguía-Rosas (2013). "Lunar phobia in bats and its ecological correlates: a meta-analysis." Mammalian Biology-Zeitschrift für Säugetierkunde **78**(3): 216-219.

Steinbauer, M. J., A. Haslem and E. D. Edwards (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**(5): 367-380.
Stone, E. L., G. Jones and S. Harris (2009). "Street Lighting Disturbs Commuting Bats." Current Biology **19**(13): 1123-1127.
Stone, E. L., G. Jones and S. Harris (2012). "Conserving energy at a cost to biodiversity? Impacts of LED lighting on bats." Global Change Biology **18**(8): 2458-2465.
Szaz, D., G. Horvath, A. Barta, B. A. Robertson, A. Farkas, A. Egri, N. Tarjanyi, G. Racz and G. Kriska (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**(3).
Turcsanyi, I., F. Szentkiralyi, B. Bernath and F. Kadar (2009). "Flight of mayflies towards horizontally polarised and unpolarised light." Aquatic Insects **31**: 301-310.
van Langevelde, F., M. Braamburg-Annegarn, M. E. Huigens, R. Groendijk, O. Poitevin, J. R. van Deijk, W. N. Ellis, R. H. van Grunsven, R. de Vos and R. A. Vos (2017). "Declines in moth populations stress the need for conserving dark nights." Global change biology.
Weber, R. G. (1987). "An underwater light trap for collecting bottom-dwelling aquatic insects." Entomological news (USA).
Wiltschko, R., K. Stapput, P. Thalau and W. Wiltschko (2010). "Directional orientation of birds by the magnetic field under different light conditions." Journal of the Royal Society Interface **7**: S163-S177.