

Light Pollution in Switzerland

An analysis of regions and natural habitats

Bachelor Thesis

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Abstract

Artificial light at night or light pollution has gained more attention from the scientific community in recent decades. Among other countries in Europe, Switzerland is presently in the phase of expanding its legislations regarding light pollution and how to mitigate excessive emissions. This thesis aims to identify what the current state of affairs Switzerland finds itself in concerning the subject. In a first step I will identify the general knowledge gathered so far on the topic of ecological light pollution and the adverse effects it has. In a second phase an analysis of how light pollution has developed in Switzerland in a twenty-year period will help identify regions of excessive light pollution. Furthermore, it will take a closer look at regions of ecological importance such as wetlands. The results show a widespread increase of light emissions in Switzerland, from which remote regions in the countryside are not excluded. This is also reflected in an increase of light pollution in protected natural reserves, which could have further severe adverse effects on natural ecosystems. In a final discourse the current legal framework regarding light pollution in Switzerland is defined. Improved knowledge about these circumstances will help distinguish which topics require further research and what can be expected in legal terms for the near future.

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Introduction

With the exponential expansion of electrification and other energy sources of mankind, the request for controlled, sustainable development with minimal side-effects becomes more of a necessity every year. A critical analysis of new technologies and engineering feats ought to be undertaken, in order to protect and maintain various aspects of our lifestyles. One such development that has been underway for millennia is the illumination of the night, in man's conquest to dominate darkness and expand its activities beyond daylight (Posch et al., 2010). The most notable growth being that of the past century with the introduction of electricity for light. With the rapid, unequivocal growth of electricity and the lighting of our cities, villages, roads and buildings alike, the question as to what possible side-effects the addition of light can possess, has only been asked in more recent decades (Rich and Longcore, 2006).

Light pollution is a largely infrequent subject, only recently starting to fall into the public eye in Europe. Several studies about the adverse effects of light pollution have been published in the past two decades (Perkin et al., 2011). The issues range from diminishing human health to damaged ecosystems and the cultural implications of losing a star-studded night sky. The research has not gone unheard of, as several states, including Switzerland, have introduced a set of rules and regulations to reduce irresponsible use of light. With the help of satellite imaging, maps can be created that accurately pinpoint regions of extreme light pollution that could facilitate necessary reduction schemes. Additionally, they can help identify dark regions, possibly worthy of protection before being further damaged by careless illumination.

Switzerland is becoming increasingly aware of light pollution. The media has gradually picked up on the subject and has begun to inform the public of the consequences of artificial light at night. One example is the discussion about excessive Christmas lighting during the winter holidays, a subject regularly discussed in newspapers (Hagedorn and Schuler, 2018; Bill, 2018). However, the ecological consequences of light pollution are often still fundamentally misunderstood or unknown altogether by the public, such as the negative effects it can have on larger ecosystems and the relationships between the species there-in (Hölker et al., 2010; Perkin et al., 2011).

A new study conducted by Kienast and Weiss (2019) has analysed the development of light emissions in Swiss forests over the past 20 years. He additionally compared them to non-forest regions and finally analysed general spaces of natural darkness (i.e. spaces unaffected by anthropogenic light, an unchanged night sky) across spatial and protected regions of Switzerland. However, the question remains how light emissions have changed in other types of habitat such as agricultural land, alpine regions or more specific habitat types such as moors and meadows in recent decades?

As a result of gaining knowledge about the subject, light pollution has been part of the political agenda throughout the last decade. Although light pollution itself is not distinctly mentioned in Swiss law, Switzerland has several forms of legislation and guidelines regarding light pollution. Recent surveys and reports organized by the Federal Office of the Environment (FOEN) suggest the administration intends to expand upon the current legal setting (FOEN, 2018).

The aims of this thesis are to reduce some of the knowledge gaps mentioned above. The intention is to broaden the general understanding of light pollution and its development in Switzerland. Regarding these aims, the following pages will summarise a few of the ecological consequences. Furthermore, to assess the development of light pollution, this thesis aims to display how light pollution has changed a 20-year period between 1992 and 2012, more specifically in various categories of natural and anthropogenic landscapes across the country. In a final discourse the legal perspective of light pollution in Switzerland is clarified.

The focus will be on the following research questions:

1. How have conservation areas been affected by light pollution since 1992?
2. What is the general legal framework in Switzerland regarding light pollution?

To address these questions, the definition, a short history and a summary of the ecological consequences will lay the foundation for a basic understanding of light pollution. The practical section of the thesis will be a processing of satellite data in order to analyse the development of light emissions in differentiated regions of Switzerland, in particular by analysing areas of high conservation concern such as dry meadows or wetlands. This will be followed by a summary of the Swiss legal setting concerning light pollution.

Light pollution - definitions

The term light pollution can often be misunderstood as the pollution of the light itself, however, as Posch et al. (2010) describe, it is the “brightening of the night sky with artificial light sources, whose light is scattered in the atmosphere. It is not about the pollution of light, but about the pollution of the natural ratio of light and dark by artificial light.” (translation from German) (Posch et al., 2010, p. 7). Kobler (2003) further details including the characteristics of light pollution, defining light pollution as:

- light that is emitted towards directions where it does not fulfil any real purpose, i.e. wasted light.
- light that is too concentrated or strong for its intended use.
- light that is emitted during times of no reasonable use.
- light that adversely affects ecosystems of insects, wildlife and humans.

Longcore and Rich (2004) divide the term “light pollution” more specifically into “astronomical light pollution” and “ecological light pollution”. The first definition, astronomical light pollution, refers to the broad-scale phenomenon of light that is either emitted directly or reflected upward, especially during the night. This results in a brightening of the night sky which results in the degradation of the view of stars and other celestial bodies. The latter definition, ecological light pollution, is derived from Verheijens’ (1985) term of “photopollution”, referring to the adverse effects artificial light has on wildlife. However, deeming the term too general, as it is just another wording for light pollution, “ecological light pollution” carries a more precise reference towards the adverse effects artificial light has on the natural lighting patterns of ecosystems.

Ecological Light Pollution

In this section we will take a closer look at the adverse ecological effects of light pollution. The focus here will be on the known effects it has on species and wildlife that can generally be found in Switzerland.

Over millions of years humans and wildlife have adapted to the rhythm of day and night, having adjusted their sleep-wake patterns accordingly in an inner biological clock (circadian rhythm) in the body of the organism. The night and day cycles help anticipate the changes in surrounding conditions, like the change from summer to winter and back (Rich and Longcore, 2006). It can be considered an evolutionary advantage if species can anticipate the changes in natural rhythms using light conditions (Held et al. 2013). This inner clock, comprising of a number of linked elements requires regular synchronization, a form of timekeeper to ensure the health of humans (Wirz-Justice and Fournier, 2010). Evidence shows that artificial light can disrupt the circadian rhythm and cause sleep deprivation in humans, resulting in mood and learning deficits. Disturbing the biological clock can severely reduce the production of melatonin, which in return can increase the risk of cancers (Reiter et al., 2007; Cho

et al., 2015). Further research concludes that irregular lighting also can affect mood and learning deficits, even without disrupting the circadian rhythm (LeGates et al., 2014).

As with humans, various species of wildlife and insects similarly follow circadian rhythms. Altercation of day and night patterns and the effects of artificial light at night (ALAN) can have dire consequences on smaller and larger species. It can distinctly alter behaviour, breeding cycles and foraging areas, further impacting several aspects of their livelihoods including orientation, reproduction, communication as well as competition and predation (Longcore and Rich, 2004; Rich and Longcore, 2006).

Birds have been recorded to alter their behaviour when confronting artificial light. Studies show that blackbirds closer to artificial light sources clearly begin to sing earlier in the day than their counterparts elsewhere (Klausnitzer in Held et al., 2013). This behaviour can also be observed in other bird species. In the same manner, blackbirds and blue tits tend to breed earlier near light sources than birds further away (Kempnaers et al., 2010; Partecke et al., 2005).

Migrating birds suffer from the impacts of ALAN, which heavily diminishes their orientation skills. Two-thirds of birds otherwise active during the daytime migrate at night (Posch et al., 2010). They commonly navigate using the magnetic field, but also with the help of the night-time sky with its stars and the moon. However, large sources of light pollution such as cities and their high-rise towers disorient these migrators as they lose vision of their guiding luminaries and because of glare. This can result in them circling these light sources for prolonged periods of time, wasting their energy needed for the long flights. It is commonly known for centuries that birds are also attracted by these lights, causing them to crash into brightly lit buildings and lighthouses (Rich and Longcore, 2006). These fatal collisions can amount to thousands of incidents on a building in a single night, sometimes even at larger distances from interfering artificial light sources on otherwise easily recognizable buildings (Posch et al., 2010; Held et al., 2013).

Bats show further side effects when exposed to ALAN. A study indicates that commuting horseshoe bats dramatically reduce their activities near street lights, often changing their flight routes to circumnavigate them (Stone et al., 2009). Another study indicates that bat colonies near well illuminated buildings delays their duration of emergence, with possible implications that juvenile bats suffer the consequences of slower growth rates due to the reduced activity of the colonies (Boldogh et al., 2007). On the other hand, studies have shown that certain bat species profit from artificial light that attracts insects, thereby favouring these illuminated locations as foraging grounds (Furlonger et al., 1987; Rydell, 1995). Often, a subtle divide can be shown between slow and fast flying bat species. As fast flying species usually profit from foraging near illuminated areas, slow flying species tend to avoid them more frequently. It has been speculated, that this is due to bird predation, causing slower flying bats to avoid streetlights to not have to engage with predators such as owls and hawks, whereas fast flying bats have better chances at outmanoeuvring them (Stone et al., 2009; Rydell, 1992).

Research on the effects artificial light has on insects has been underway for decades. Various populations are suffering significant declines on the European continent (Williams, Potts et al., Carvalhero et al. in MacGregor et al., 2015). Nocturnal insects have a seemingly strong attraction to ALAN, which can be explained through various mechanisms (Kaul and Hassel, 2001; Hoettinger and Graf, 2004; Posch et al., 2010):

- Insects navigate with luminaries, wherein artificial light can distract and drive them towards its source.

- As light sensitive species, insects are drawn towards the light. Whilst simultaneously tending to avoid close proximity to bright lights, they remain on a favoured border between light and dark, continuously circumnavigating a light source.
- Some species prefer the security of well-lit areas and are drawn into them.
- Insects may suffer the consequences of glaring light, possibly damaging their optical orientation. In addition to the glare effects, they can be accustomed to the brighter areas with pigment shifts in their eyes.

Eisenbeis and Hänel (2009) divide the fate that awaits these insects into 3 scenarios:

1. The 'fixation' effect: An insect gets distracted from its normal activity and is attracted to an artificial light source. Fixated by the light, the insect either flies directly into the hot glass of the lamp and burns or orbits the light until it is either caught by predators or falls exhausted to the ground awaiting its demise.
2. The 'crash-barrier' effect: Insects on long-distance flights, orientating themselves through several landmarks, suddenly encounter light sources. Losing their orientation, they deviate their course flying directly into the lamps vicinity, hence being unable to leave the bright zone.
3. The 'vacuum cleaner' effect: Insects living near lights are attracted to the illumination, thus 'sucking' them out of their habitats. This can result in the local depletion of populations, at times even eliminating them.

In the previous examples of the adverse effects of artificial lighting we have analysed the damages to species as individual populations. 30 % of all vertebrates and 60 % of all invertebrates today are nocturnal species (Hölker et al., 2010). It is important to express the extent changes in populations can damage the balance of communities and ecosystems. The examples above all take place in limited illuminated zones. This not only has effects on intraspecific competition, but interspecific competition as well (Rowse et al., 2015). The larger population of insects near illuminated areas can attract predators such as birds and bats alike. In this case, insect species less distracted by lights are more prone to survival than those suffering the consequences of close proximity to bright lights. Furthermore, slow flying or light sensitive bats, in an attempt to avoid predation from birds, may be naturally selected against, losing out on the opportunity of foraging near lights and suffering the declining insect populations in darker habitats (Rowse et al., 2015).

Moths are vital nocturnal pollinators for flowers. In a study conducted by MacGregor et al., (2015), the decline of moth populations, potentially driven by ALAN, show to have significant links to the provision of pollination. Additional ecosystem processes may potentially be disrupted due to the reduced nocturnal pollination.

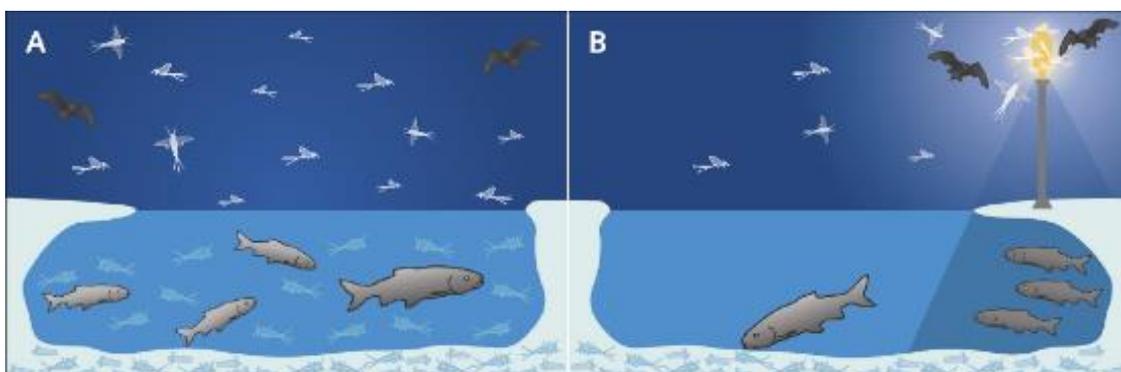


Figure 1: The schematics of a stream ecosystem under natural light conditions (A) and under the influence of artificial light (B). Notice how the insects are attracted to the light in (B), which in return attract predatory bats. Smaller fish suddenly need to seek shelter in the darker shade to avoid larger predatory fish (Perkin et al., 2011).

Another example includes the delicate ecosystems near streams and larger waterways (Fig. 1). The divide between land and water is a critical zone for sensitive communities and endangered species. Simultaneously, artificial light is generally produced in human settlements that are commonly established near water systems. The nearness of these light sources can shift the balance towards light insensitive species and predators alike, generally changing ecosystem communities (Hölker et al., 2018).

History and broaching the Issue of Light Pollution

The opening of the 20th century commenced the competition among various cities such as Paris and Berlin to become the city of lights (Schlör in Posch et al., 2010). Especially during the post-war era mid-century, following the nightly blackouts for fear of bombing raids, the electric illumination of cities became a symbol of economic improvement (Posch et al., 2010). Subsequent decades with tumbling electricity prices, rising efficiency of lighting systems and the lack of legal regulations caused exponential increases in the observed sky brightness (Posch et al., 2010). Cinzano (2000) recorded an annual 10 % increase of sky brightness in northern Italy between the 1960's and 1995 and recorded an annual growth in energy consumption of 4.6 - 5 % in external public lighting for the region. Similar observations were made in the United States (Walker and Hoag et al. in Cinzano, 2000).

Bazell and Riegel in Huber (2007) documented how astronomers in the mid-20. Century campaigned against the effects of light pollution. The aim being to establish methods of light control and receive assistance in relocating their observatories away from cities to more remote locations. This brought about the term "light pollution" and made it a public issue.

In 1988 the International Dark-Sky Association (IDA) was founded with the aim to protect the night skies, consisting of over 60 chapters worldwide, more than 20 of those being international. It takes a leading role in night sky protection by educating the public about the topic and promoting responsible outdoor lighting (IDA, 2018). The Swiss section, Dark-Sky Switzerland, was founded in 1996 and counts over 400 members today (DSS, 2018).

Critically aiding the development of the subject of light pollution Cinzano et al. (2001) published 'The first World Atlas of the artificial night sky brightness'. Based on satellite data, Cinzano et al. was able to create a global picture of how the earths night sky was illuminated with artificial light and clearly showed the brightened regions in the United States and in Europe. He concludes stating that 93 % of the United States and 90 % of the EU population live under a night sky, never darker than when naturally lit by half-moon at 15° elevation in the sky (Cinzano et al., 2001). Klett in Huber (2007) modified the images for Switzerland, showing that even in the most remote regions and natural parks, Switzerland does not have naturally dark skies anymore.

Materials and Methods

This second section of the thesis focuses on the development of light pollution in various types of regions and habitats in Switzerland throughout a 20-year period from 1992 to 2012.

For the analysis of light pollution, the term light emissions become the logical terminology, as the satellite data being used registers light emitted upwards into the sky during the night (Posch et al. 2010). The data comes in the form of satellite images, sourced and evaluated from the American Defense Meteorological Satellite Program (DMSP) using the Operational Linescan System (OLS). For Landscape Analysis Switzerland (translated from German: *Landschaftsbeobachtung Schweiz [LABES]*) the dataset is retrieved from the National Geophysical Data Center (NGDC). Before release, the NGDC prepare the data (see below).

NGDC data preparation:

- Only the center half of the 3000 km OLS-sensor width is applied, as light sources appear smaller, the brightness is more consistent, and points can be localized more easily in this section
- The effects of sunlight are excluded using calculations incorporating the zenith angle of the sun
- Glare effects are also excluded using calculations incorporating the zenith angle of the sun
- Moonlight effects are excluded by calculating the moons brightness
- Observations with cloud cover are recognized and excluded by the OLS-sensor and surface temperature raster from the National Center for Environmental Predictions (NCEP)
- Illumination from the northern lights are visually recognized and excluded

The resulting night sky brightness is the average value of one calendar year, thereby excluding one-off anomalies. From this data, a background brightness is determined and subtracted from the values. The final product is a world map with brightness values between 0 and 63 (255 = no data) and a cell-size of 30x30 arc seconds (0.0083 x 0.0083 degrees; 920 x 600 m).

For this thesis, the light emissions data was retrieved from the “Eidg. Forschungsanstalt für Wald, Schnee und Landschaft» (WSL) and prepared by M. Weiss and F. Kienast in 2012 as followed: To avoid annual peak variation, the data of 3 years is averaged, e.g. the period 1992 - 1994 includes the combined values from the years 1992, 1993 and 1994 (moving window for time). To reduce uncertainties in the georeferencing of the satellite, a smoothed average is calculated across 3x3 cells (spatial moving window). Finally, the data is projected in raster cells of 1 km² across the Swiss coordinate system and the light emission values are converted to radiance¹. These final emission values range from 0 to approximately 500.

To observe changes over the time period between 1992 and 2012, three light emission datasets are used:

1. 1992 - 1994
2. 2001 - 2003
3. 2010 - 2012

Study Area

The study area focuses on light emissions in Switzerland. For this we analyse the light emissions in reference to unique regions and categorisations in Switzerland. The next few pages will be dedicated to explaining these individual study areas both in text and graphically.

To combine and analyse the data, the software ArcGIS Desktop 10.5 is used. The habitat types are masked with the light emissions projections. To reduce uncertainties in the georeferencing, all the

¹ Radiance ($W \cdot cm^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$) * 10^{-10} in a raster of 1 km²

habitat types and the light emissions are resized and realigned to the *NOAS04* dataset (*Arealstatistik*) with a cell size of 100 m x 100 m. The light emission datasets are resampled using bilinear interpolation to smoothen out cell values. The remaining habitat types first need to be converted from polygon to raster before resampling. Within this process, the area of natural habitats such as the wetlands are given priority in the conversion process, allowing for cells with a spatial minority of wetlands (the majority being non-wetland) to still be categorised as wetland regions to include edge effects in the analysis.

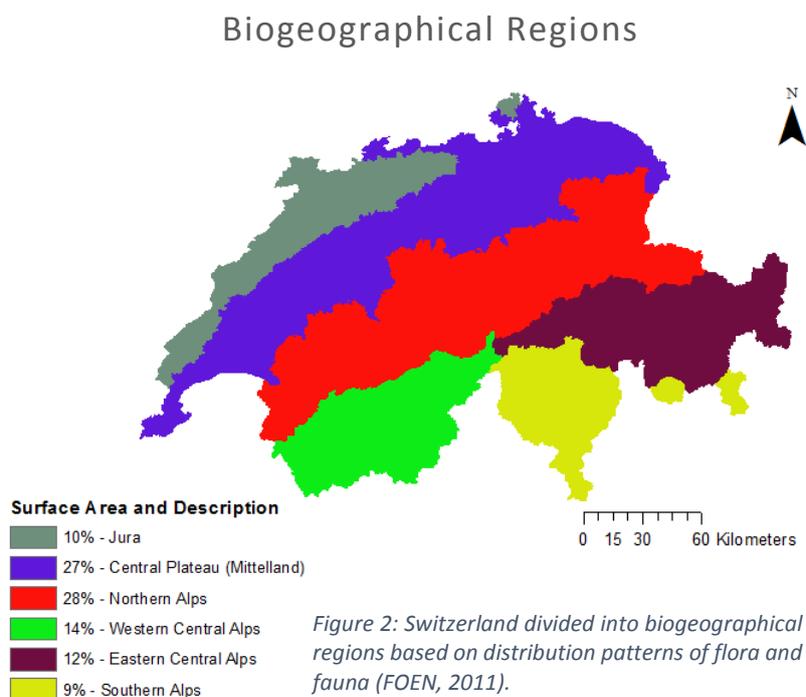
The original light emission datasets used in this thesis extend slightly beyond the study area of Switzerland. Only after the the bilinear interpolation of these light emission datasets are calculated are they then cut and combined with the individual habitat areas. This should help avoid edge effects that could occur along regions near the border of Switzerland.

It is important to note that in this analysis, only the most recent geodata of the habitat types is used, and not geodata from the periods corresponding with the light emission periods. This means that for instance wetlands documented in the 1990's might not be analysed in any of the three time periods, if they are not documented in the most recent geodata (e.g. from 2017) anymore, i.e. they have been reclassified or discarded from of the government records. The regions mapped with light emissions in this analysis are sourced from the most recent datasets provided. They do not necessarily coincide with the reality of 10 or 20 years ago. It is likely that urban landscapes were smaller in the early 90's than they were in 2011, and that in the meantime agricultural areas have either been re-designated as forests or converted urban zones after being used for buildings sites. However, the effects this would have on the results should be negligible.

For a first analysis we will take a look at Switzerland as whole and how light emissions have developed across the three time periods. The map outline of Switzerland is taken from the dataset biogeographical regions (see below).

Biogeographical Regions

The biogeographical regions of Switzerland are a statistical approach based on cartographic results of swiss flora and fauna datasets from the *Centre Suisse de cartographie de la faune* (CSCF) (Fig. 2). The division into six regions is built upon the patterns of floristic and faunistic distribution in Switzerland. This dataset is commonly applied for issues concerning widescale nature conservation in Switzerland (FOEN, 2011). For the analysis we should be able see how light emissions have developed in each of these regions and be able to compare them to one another.



The six regions are defined as follows (with German translations):

- i. Jura (Jura)
- ii. Central Plateau (Mitteland)
- iii. Northern Alps (Alpenordflanke)
- iv. Western Central Alps (Westliche Zentralalpen)
- v. Eastern Central Alps (Östliche Zentralalpen)
- vi. Southern Alps (Alpensüdflanke)

The alpine regions account for 63 % of the area of Switzerland, whereas the Jura and the Central Plateau share 37 % of the area in Switzerland (Fig. 2).

Land Use

The Swiss land use statistics shows Switzerland divided into several categories based on land use (FSO, 2017). Every cell can be designated towards a specific category of use ranging from industrial areas to orchards and glaciers. For this analysis the statistical data is from the year 2017 and is categorised according to the nomenclature of 2004 which includes 17 categories (Fig. 3). This entails four main categories as listed below:

- i. Urban (Cat. 1 - 5)
- ii. Agriculture (Cat. 6 - 9)
- iii. Forest (Cat. 10 - 12)
- iv. Unproductive (Cat. 13 - 17)

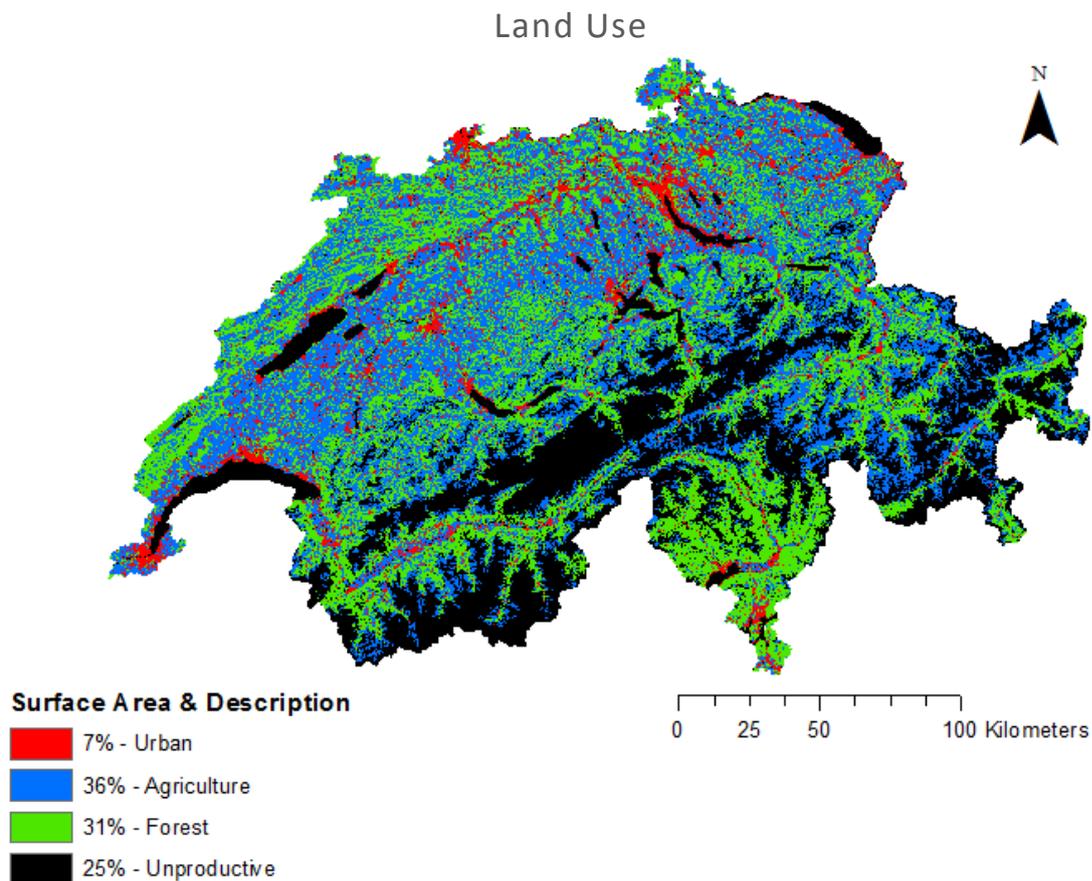


Figure 3: Swiss land use statistics from 2017 (FSO, 2017). Urban in red includes industrial, commercial, building, transportation and recreational areas and transportation. Light is commonly emitted from the urban areas. Agriculture in blue makes up the largest percentage in Switzerland (36%) and includes orchards, vineyards, horticulture areas, arable land, meadows, farm pastures and alpine agricultural areas. Forest in green includes brush forest and woods. Unproductive in black includes lakes, rivers, unproductive vegetation, bare land, glaciers and perpetual snow.

Urban includes all settlements and urban areas that are defined through workspace, living areas, recreational areas and transportation. They do not necessarily coincide with construction zones (German: *Bauzonen*), as they can be both within and outside these designated areas. Urban areas have categorical priority if other land-use types are found in the same area. *Agriculture* includes both cultivated land and alpine farming areas ranging from intensively to extensively used spaces. This does not include farmhouses, roads and brushes in fields. The category *forest* includes all types of wooded areas such as forests and shrubland. This does not include wooded areas in urban landscapes such as parks and boulevards. *Unproductive* landscapes include all non-wooded areas that do not allow agricultural use due to climatic or topographic circumstances such as lakes and high alpine regions. This is to be understood in a relative manner, as such areas can still be used for tourism, sports or fishing (FSO, 2017).

Wetlands and Dry Meadows & Pastures

The following study areas comprise more of a specific habitat analysis using datasets retrieved from the Federal Office for the Environment (FOEN).

Wetlands are landscapes that are generally inundated by water, which characterises vegetation and aquatic plants (Keddy, 2010). These landscapes can be further categorised into numerous subcategories, which may vary in definition from region to region. For this thesis the terminology for such wetland categories is translated from the swiss (German) language. Figure 4 is a combination of three wetland categories for which the light emissions will be evaluated individually.

- i. Bogs (FOEN, 2017d)
- ii. Raised bogs (FOEN, 2017e)
- iii. Flood plains (FOEN, 2017b; FOEN, 2017c)

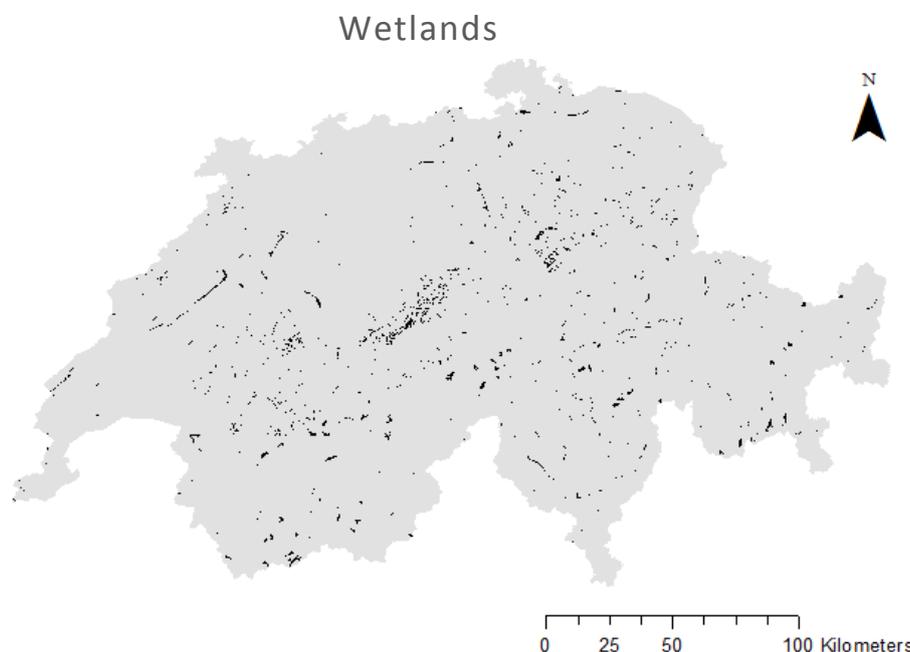


Figure 4: The wetlands of Switzerland. The map shows bogs (FOEN, 2017d), raised bogs (FOEN, 2017e) and flood plains (FOEN, 2017b; FOEN, 2017c) combined in black on the map. Raised bogs are generally a subtype of normal bogs and consequently are often found overlapping or adjacent to one another. Flood plains are regularly flooded areas in the vicinity of lakes and rivers.

The term *bog* is meant to represent the German term *Flachmoore*, which is the generic term for a moor landscape that is fed by rainwater, groundwater, slope-drainage or through temporary flooding. Due to the soil being water-saturated, it is commonly nutrient-poor favouring specialised plants that can survive in such oxygen-poor environments (Klaus et al., 2017). In Switzerland, the common counterpart

to such bogs are the “raised bogs” or *Hochmoore* in German. This type of moor landscape is typically only fed by rainwater, allowing far less minerals to enter this ecosystem. This result in an extremely oxygen-poor environment free of trees in the centre, where deceased vegetation is unable to completely decay forming comparably large peat layers, essentially raising the bog (Klaus et al., 2017; Keddy, 2010). With this in mind, raised bogs are, to a certain degree, a subtype of normal bogs. This is also reflected in the datasets used for the analysis. Patches of raised bogs commonly overlap or are found adjacent to normal bogs (FOEN, 2017d; FOEN, 2017e).

A “Flood plain” is the English term for *Auen* and encompasses areas in the vicinity of rivers or lakes that are regularly flooded (Thielen et al., 2002).

Dry meadows and pastures is the term used to define grasslands with dry, nutrient-poor soils that are extensively used for agriculture (Venn et al., 2013). The german term is *Trockenwiesen und -weiden*, and they are commonly located in the mountainous regions of Switzerland (Fig. 5)(FOEN, 2017f; FOEN, 2017g).

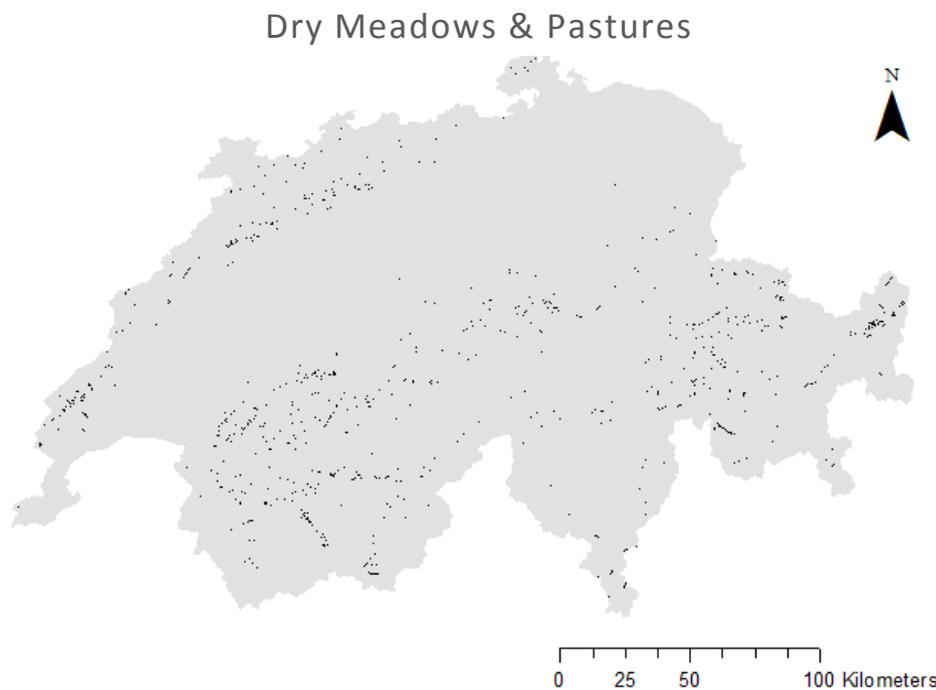


Figure 5: The dry meadows and pastures of Switzerland shown in black (FOEN, 2017f; FOEN, 2017g). Notice the lack of the habitat in the region of the central plateau (Mittelland).

The above-mentioned habitat types are classified as biotopes of national importance. They are critical in supporting natural ecosystems in Switzerland as well as the animal and plants species within. Especially the flood plains together with their fauna and flora are counted among the most endangered objects and species in Switzerland (FOEN, 2017i).

BLN Zones

BLN zones encompass the swiss federal inventory of landscapes and monuments of natural importance (Fig. 6) (FOEN, 2017g). They are considered a critical asset to maintain the natural and cultural heritage of landscapes in Switzerland. Careful maintenance of theses landscapes contributes to recreational values and aides the identification of the communities with the landscape as well as adding value for tourism (FOEN, 2019).

BLN Zones

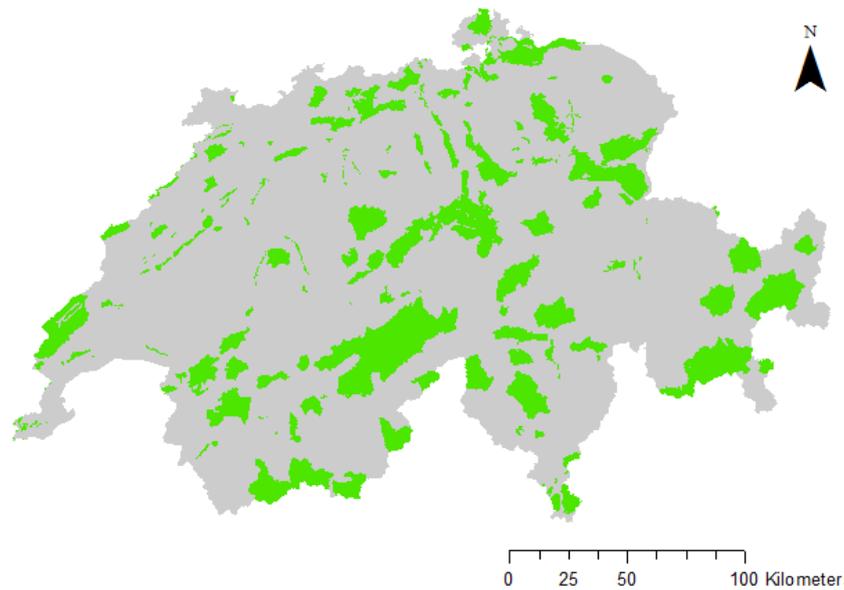


Figure 6: The BLN landscapes of Switzerland shown in green (FOEN, 2018). BLN zones entail the federal inventory of landscapes and natural monuments of national importance.

Parks of National Importance

Swiss parks of national importance are defined by visually aesthetic landscapes with a rich biodiversity and high-value national treasures and cultural assets. These regions aim to maintain these values and sustainably develop socially and economically (FOEN, 2018b). This dataset is retrieved from the FOEN in 2018 and includes the Swiss National Park in Engadin, biosphere reserves, the Nature Discovery Park Sihlwald and the park-candidate, the Nature Discovery Park Jorat (FOEN, 2018a).

Parks of National Importance

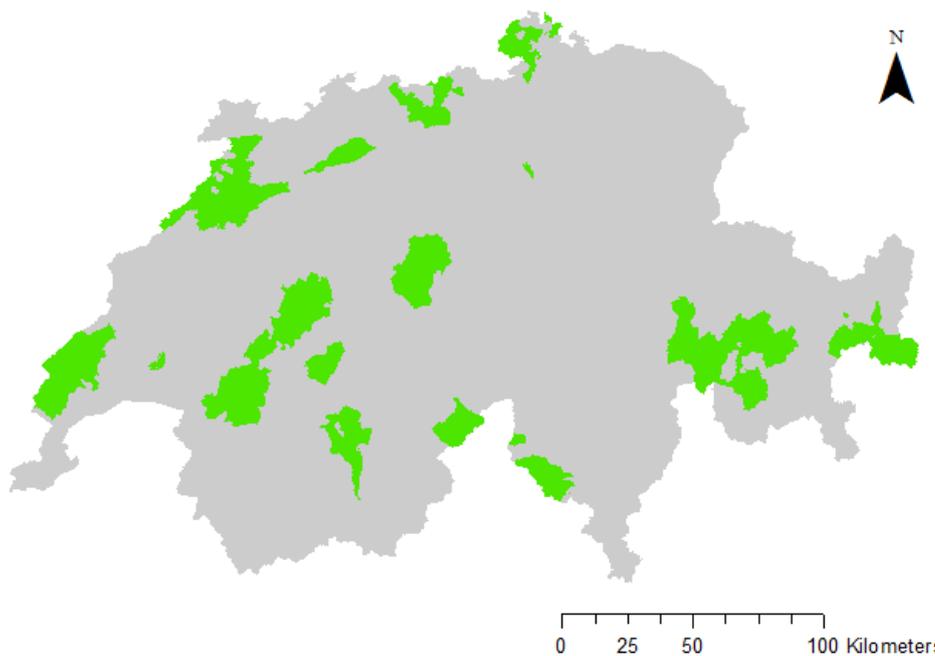


Figure 7: The parks of national importance shown in green (FOEN, 2018). This includes the Swiss National Park, biosphere reserves and natural discovery parks such as Sihlwald and the park-candidate Jorat.

Results

The boxplots in the following pages reveal the median and quartile values. Outliers in the maximum and minimum range are included. The whiskers surrounding the interquartile correspond to the 1.5 interquartile subtracted from the 1st quartile, respectively added to the 3rd quartile. For the exact numerical values see Appendix A.

Switzerland generally shows an increase across the two measured decades (Fig. 8). In the time period 1992 - 1994, intense light emissions can be shown to have been confined to small areas, marking the locations of larger cities such as Zürich, Basel and Geneva. Areas of natural darkness are found primarily in the alpine regions and somewhat in the Jura area. The Central Plateau contains a few scarce points of natural darkness and, apart from the cities, predominantly shows radiance values below 90. However, already in the second time period, 2001 - 2003, light emissions can be seen to grow, especially in the region of Zürich. Natural darkness in the alpine area has been significantly reduced. In the final period 2010 - 2012 the amount of light emission has risen in various locations across the Central Plateau with multiple larger patches of high radiance values. The regions of natural darkness are seemingly confined to predominantly uninhabited locations.

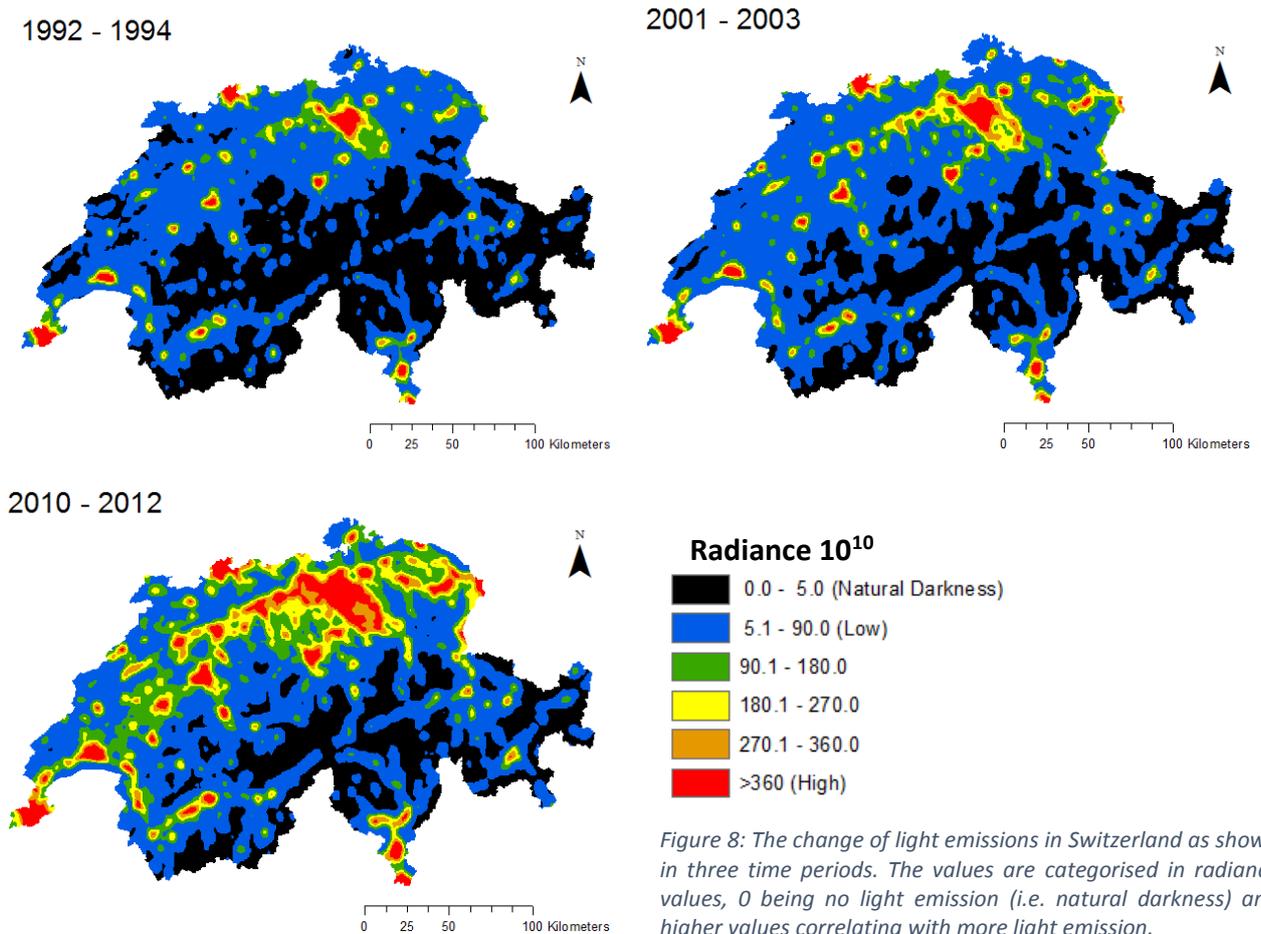
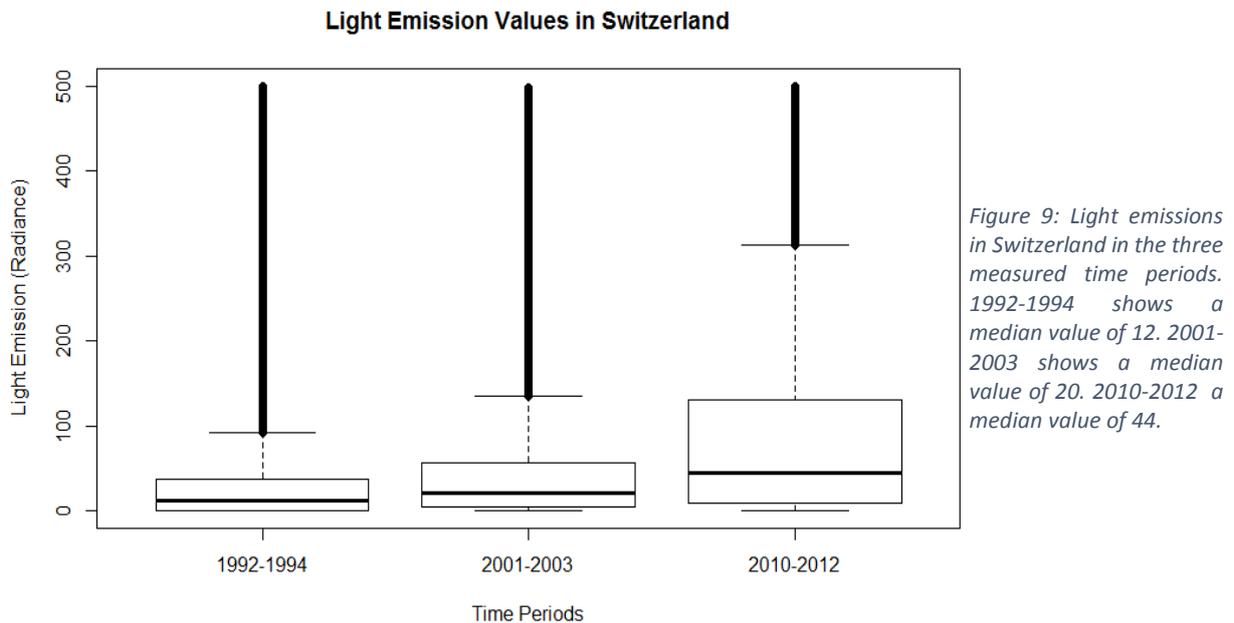


Figure 8: The change of light emissions in Switzerland as shown in three time periods. The values are categorised in radiance values, 0 being no light emission (i.e. natural darkness) and higher values correlating with more light emission.

The overall change in light emission shows a clear value increase with time (Fig. 9). The median value doubles every 9 years, starting at 12, growing to 20 and measuring 44 in the final time period of 2010 - 2012. Not only can an increase in the median and mean emissions be observed, but also a large increase in the third quartile in the time period 2010 - 2012, as it grew from 56.2 in the previous time period to a value of 130.4.



Radiance of above 100 initially covered 9.8 % of Switzerland in the early 90's (Table 1). Nearly 20 years later 31.2 % of Switzerland are above 100. At the same time 15.4 % is above 200. Areas of higher radiance grew by a factor of about 1.5 between the time periods '92 - '94 and '01 - '03. Between '01 - '03 and '10 - '12 the areas grew by a factor of about 2.5.

Table 1: The relative area of categorised light emissions in Switzerland for each time period shown in percentages. The regions are categorised by radiance values. The percentages show how much of the area of Switzerland is above the given value for each time period.

	Radiance			
	>100	>200	>300	>400
1992 - 1994	9.8%	4.0%	1.8%	0.8%
2001 - 2003	14.8%	6.7%	3.0%	1.2%
2010 - 2012	31.2%	15.4%	7.8%	3.0%

Biogeographical Regions

A similar pattern can be observed in the various biogeographical regions of Switzerland (Fig. 10). The Jura measures median radiance values of approximately 40 % higher compared to the whole of Switzerland for all time periods. The outliers of maximum light emissions grow exponentially closer towards a radiance value of 500 over time. This is also reflected in the relative areas of higher radiance values (Table 2). The Central Plateau is the clear outlier in all measurements, showing the highest radiance values for all time periods with median values of 43, 69 and 167 for the corresponding time periods as well as mean values of 102, 158 and 287. In 2010 - 2012 nearly a quarter of the Central Plateau measures light emission values above 300. It is not only the sole biogeographical region to measure maximum values of 500, but also the only region to have attained such values since the first time period (Table 2).

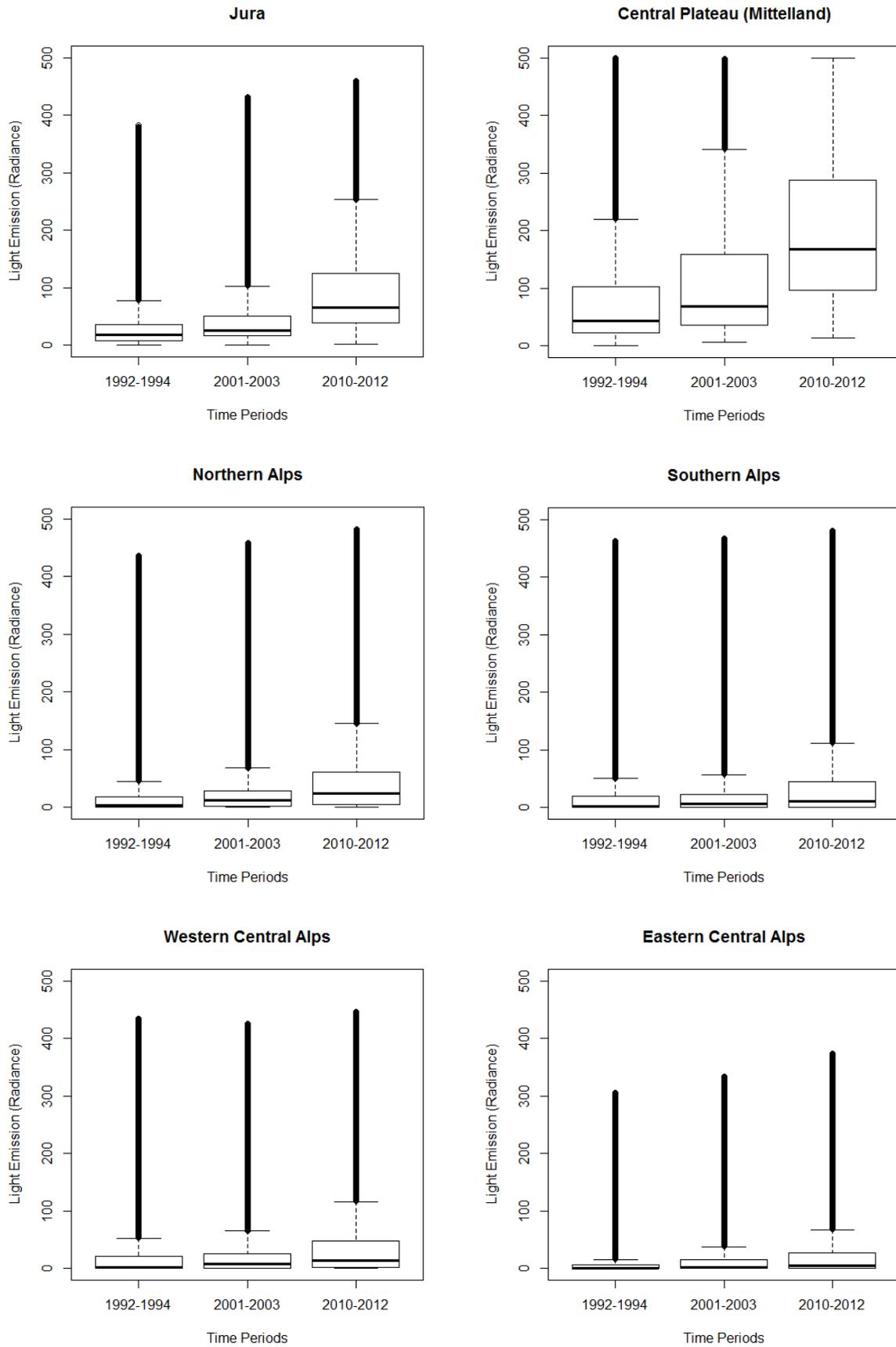


Figure 10: Light emissions of biogeographical regions in three time periods.

The alpine regions show a steady increase generally at a slower rate. Median values do not exceed 3 in the first time period and continue to grow ranging from 5 to 24 in the final period '10 - '12 (Fig. 10). The Northern Alps clearly show the highest median value for all periods, whilst the Southern Alps boast the higher mean values across all time periods. This is the result of values for the Southern Alps being skewed more towards higher values in comparison to the Northern Alps.

Table 2: The relative area of categorised light emissions in radiance values for the Swiss biogeographical regions for each time period shown in percentages.

Jura	>100	>200	>300	>400	Central Plateau	>100	>200	>300	>400
1992 - 1994	5.7%	1.4%	0.2%	0.0%	1992 - 1994	25.3%	11.0%	5.6%	2.8%
2001 - 2003	11.0%	3.2%	0.7%	0.1%	2001 - 2003	36.9%	19.0%	9.2%	3.8%
2010 - 2012	32.4%	12.1%	3.9%	0.5%	2010 - 2012	73.7%	40.9%	23.1%	9.6%
Northern Alps					Southern Alps				
1992 - 1994	2.2%	0.6%	0.1%	0.0%	1992 - 1994	2%	0%	0%	0%
2001 - 2003	5.4%	1.4%	0.3%	0.0%	2001 - 2003	2.5%	0.5%	0.1%	0.0%
2010 - 2012	14.6%	5.0%	1.4%	0.3%	2010 - 2012	5.9%	1.3%	0.3%	0.0%
W. Central Alps					E. Central Alps				
1992 - 1994	6.0%	1.9%	0.5%	0.1%	1992 - 1994	6.7%	1.6%	0.3%	0.0%
2001 - 2003	6.6%	2.4%	0.9%	0.1%	2001 - 2003	12.9%	3.8%	0.9%	0.2%
2010 - 2012	12.1%	4.8%	1.9%	0.5%	2010 - 2012	38.0%	14.2%	4.5%	0.6%

The Eastern Central Alps are the region with the lowest mean and median values in Switzerland. However, this statement of low light emissions is to enjoy with caution, as this region has proportionally the same area of higher light emissions as the Jura region (Table 2). The Southern Alps clearly lead in this statistic with a relative area of only 5.9 % of light emissions higher than 100 in the period '10 - '12, and the lowest values in both other time periods. This means that areas of higher light emissions are confined to small zones. The Central Plateau clearly falls out in this statistic having relative areas of higher light emissions exceeding the other regions by far.

Land use

The four categories of swiss land use statistics spread across the full range of values from 0 to 500 (Fig. 11). This is logical, considering that all four types can be found in both densely populated regions with high light emissions as well as is in remote locations with little to no light emissions (Fig. 3). *Agriculture* and *Forest* can both easily align with this definition, as they can both be found near large cities or be situated in remote alpine regions. *Unproductive* includes land types that are generally already found in remote locations such as glaciers. The high emission values can in return be allocated to lakes and rivers adjacent to large cities. As for *Urban*, densely populated cities are usually the source of light emissions making them prone to high light emissions. However, as mentioned previously, urban areas overlapping with other land use types are generally prioritised, meaning that even individual buildings in remote areas can be categorised as urban, allowing for low emission values as well.

Table 3: The relative area of categorised light emissions in radiance values for Swiss land use statistics for each time period shown in percentages.

Agriculture	>100	>200	>300	>400	Urban	>100	>200	>300	>400
1992 - 1994	8.7%	2.5%	0.9%	0.3%	1992 - 1994	41.8%	24.5%	13.9%	7.4%
2001 - 2003	15.4%	5.6%	1.9%	0.5%	2001 - 2003	53.9%	34.7%	20.7%	9.6%
2010 - 2012	38.8%	17.2%	7.3%	2.0%	2010 - 2012	77.3%	55.6%	38.3%	19.7%
Forest	>100	>200	>300	>400	Unproductive	>100	>200	>300	>400
1992 - 1994	7.9%	2.6%	1.0%	0.4%	1992 - 1994	4.0%	1.5%	0.5%	0.2%
2001 - 2003	12.3%	4.6%	1.8%	0.6%	2001 - 2003	5.0%	2.4%	0.9%	0.3%
2010 - 2012	28.5%	12.3%	5.4%	1.8%	2010 - 2012	9.1%	4.3%	2.2%	0.8%

Despite the same range, all four categories vary strongly in all other aspects (Fig. 11). From highest to lowest in terms of median and mean values are *Urban*, *Agriculture*, *Forest* and *Unproductive*. The median for *Urban* exceeds 100 after the 1st period, and 200 after the 2nd. Quite notable is the equal spread of the interquartile in the 3rd period. Not surprising are the relative areas of higher light emissions (Table 3). For emission values above 400, the first two time periods show relative areas of below 10 %, followed by an increase by a factor of 2 to 20 %. *Agriculture* and *Forest* both share similar values in all aspects, with *Agriculture* generally having slightly higher emission values. At this point it is noteworthy to mention that both in terms of relative area and with median values, *Agriculture* and *Forest* tend to grow by larger factors compared to *Urban* and *Unproductive*. Where between the 1st period and the 2nd the relative areas of *Urban* and *Unproductive* with higher emissions grew by a factor of generally less than 1.5, the areas of higher light emissions of *Agriculture* and *Forest* commonly grew by a factor of above 1.5 and sometimes 2. More significant is the difference between the 2nd and 3rd period, where the latter grow by factors of around 3, whereas *Urban* areas of higher emissions only grew by a factor between 1.5 and 2.

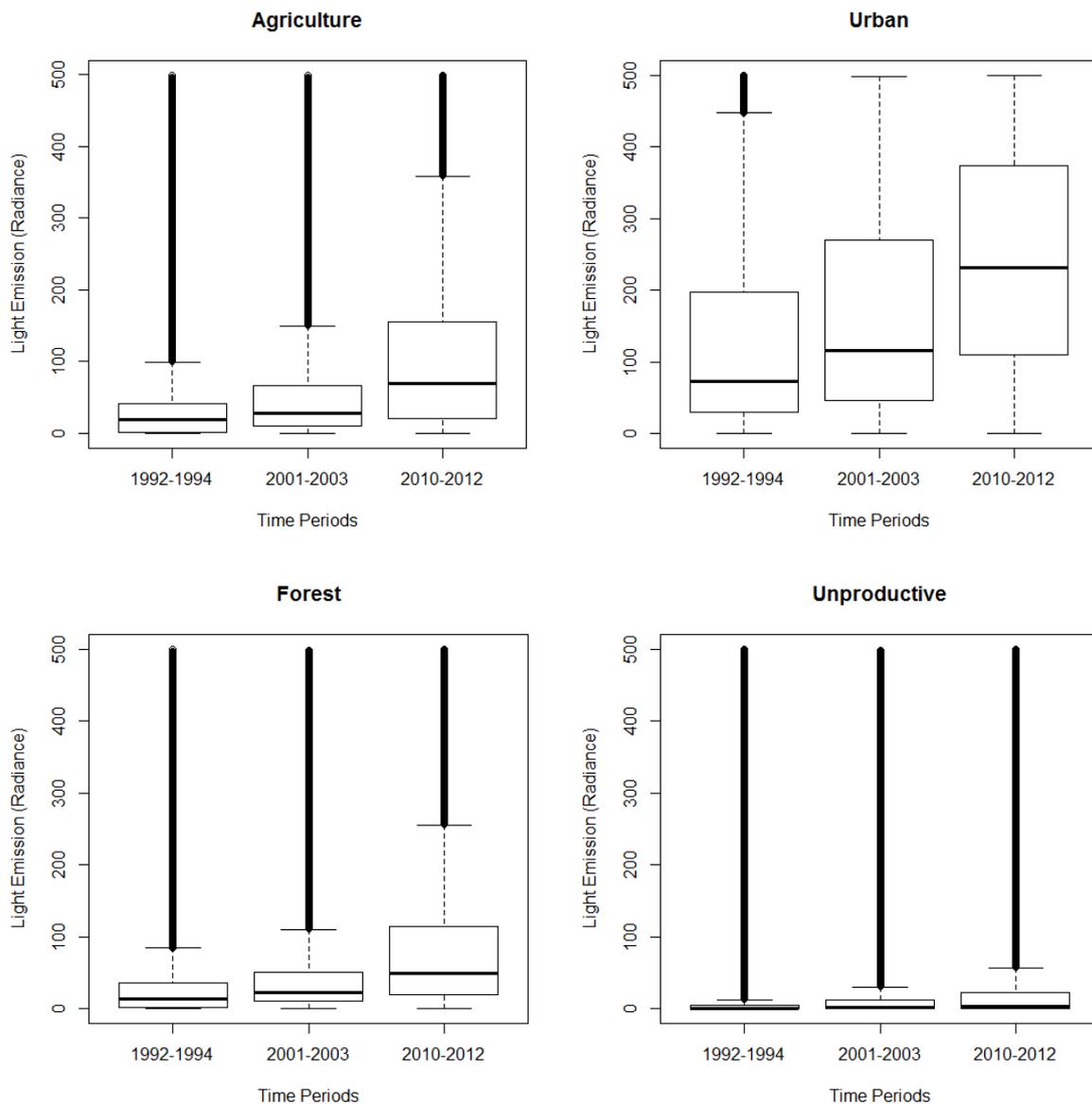


Figure 11: Light emissions of Swiss land use statistics in three time periods.

Wetlands and Dry Meadows & Pastures

The different habitat types reveal fairly similar results (Fig. 12). The median values reveal that both flood plains and bogs similarly show the lowest results, with 4, respectively 3 in the 1st period, 12 and 11 in the 2nd and 23 and 25 in the 3rd period. Raised bogs and dry meadows & pastures share values of approximately one third higher than the others. This despite the fact that flood plains have the largest 3rd quartile value in all time periods. In terms of mean values, dry meadows and pastures drop to the lowest scores whilst flood plains score significantly higher than the rest (see Appendix A).

Of particular interest are the clear outliers in bogs and raised bogs (Fig. 12 top). Further analysis using GIS revealed the outliers of the “raised bogs” dataset to be points of the “Moos Schönenhof” located in the municipality of Wallisellen, ZH. The same data points are also recognisable as the outliers for the “bogs” dataset, with the addition of “Marais des Crêts” and “Marais des Fontaines” in Meyrin, GE. These moor landscapes are clear outliers in the dataset consistently displaying exceedingly high light emission values for all time periods in comparison to the rest of the datapoints of raised bogs and bogs. The bog “Bolle di S. Martino” in Vezia, TI is also part of the clear outliers, however only for the 1st period 1992 - 1994.

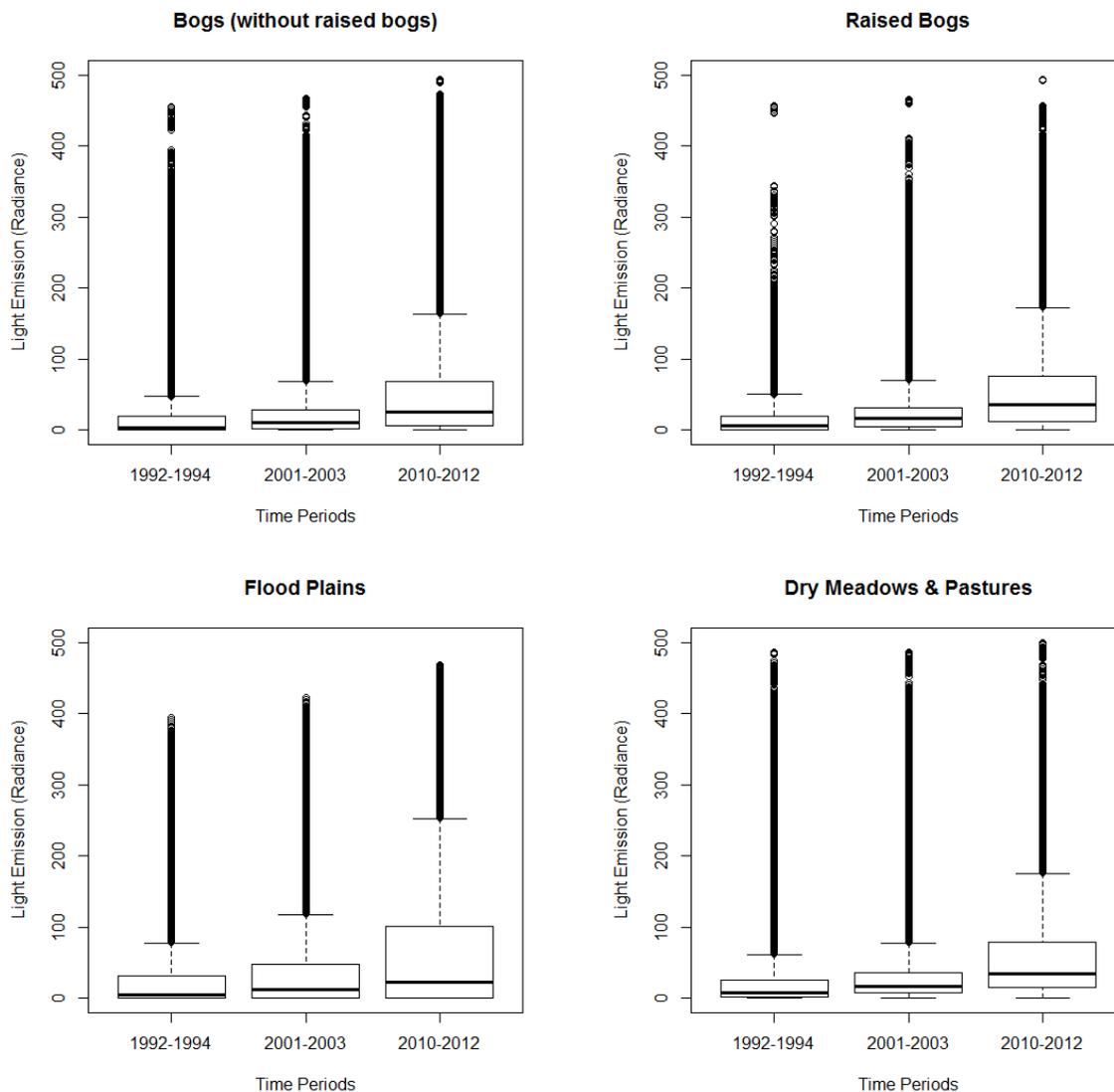


Figure 12: Light emissions of Swiss natural habitats in three time periods

The relative areas of higher light emissions show that for emissions above 100 is flood plains lead the statistics with 7 % growing to 14.3 % and 25.1 % (Table 4). For bogs, raised bogs and dry meadows & pastures the relative areas grow rather steadily despite dry meadows & pastures growing by a factor of nearly 3 between '01-'03 and '10-'12. More significant are the differences in the relative areas of light emissions above 200 and 300. Flood plains showed originally small sizes in the first 2 time periods, growing to the largest relative area of high emissions in the last period with 14.7 %, (resp. 6.2 %). This is followed by bogs at 10.5 % (resp. 5.1 %), then raised bogs at 8.5 % (resp. 4.4 %) and finally dry meadows & pastures at 5.6 % (resp. 2 %)(Table 4).

Table 4: The relative area of categorised light emissions in radiance values for Swiss natural habitats for each time period shown in percentages.

Bogs	>100	>200	>300	>400	Raised Bogs	>100	>200	>300	>400
1992 - 1994	6.8%	1.7%	0.5%	0.1%	1992 - 1994	6.0%	1.0%	0.4%	0.1%
2001 - 2003	10.4%	4.4%	2.2%	0.2%	2001 - 2003	8.8%	4.8%	1.8%	0.2%
2010 - 2012	19.2%	10.5%	5.1%	1.9%	2010 - 2012	18.4%	8.5%	4.4%	1.6%
Flood Plains	>100	>200	>300	>400	Meadows & P.	>100	>200	>300	>400
1992 - 1994	7.0%	1.7%	0.6%	0.0%	1992 - 1994	4.0%	1.1%	0.6%	0.2%
2001 - 2003	14.3%	3.8%	1.2%	0.1%	2001 - 2003	6.5%	1.8%	0.9%	0.3%
2010 - 2012	25.1%	14.7%	6.2%	1.4%	2010 - 2012	18.7%	5.6%	2.0%	0.7%

BLN zones and Parks of National Importance

Both the BLN zones as well as the parks of national importance show substantially low values. BLN zones can include national treasures and areas of cultural value, allowing certain rivers or landscapes to also be adjacent to or even within large cities if they fall under this category. This explains why the values of BLN zones can range from 0 to 500 (Fig. 13). The same cannot be said about the parks of national importance, with outlier values of below 400 in the final period. The parks do not include large cities such as Zürich or Basel but can encompass smaller cities or be located near larger cities. Despite this, the median indicates considerably lower values for BLN zones than for parks of national importance. In return, the mean values are noticeably lower for parks of national importance in comparison (Appendix A) and the 3rd quartile is generally larger for BLN zones, especially in 2010 - 2012 (Fig. 13).

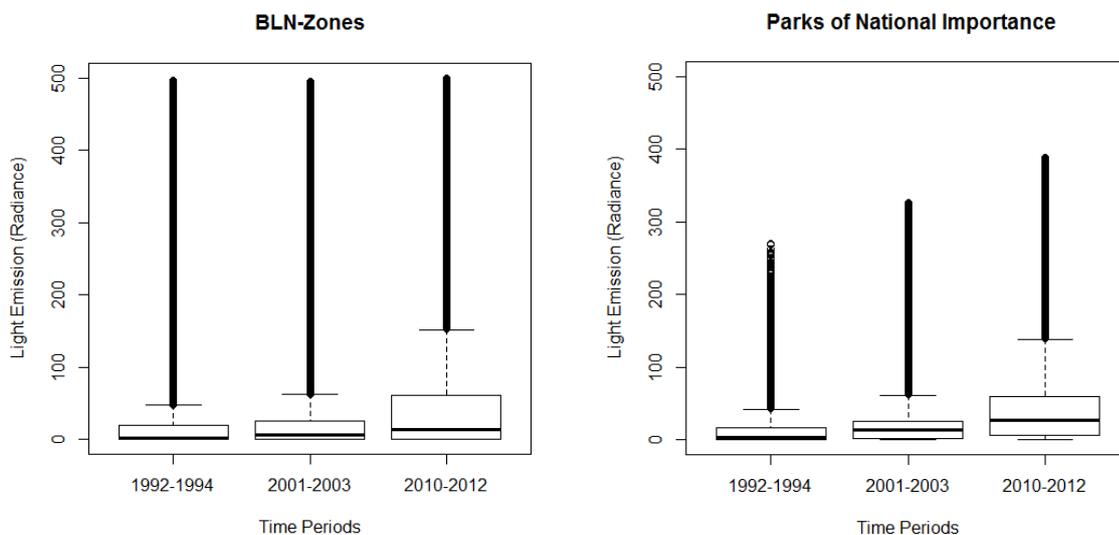


Figure 13: Light emissions of Swiss BLN zones and parks of national importance in three time periods.

The large 3rd quartile of the BLN zones is reflected in the relative areas of higher emissions, probably indicating values less skewed toward the higher end (Table 5). The area of values above 100 starts at 3.4 %, grows to 6.1 % and continues to 16 % for the last period. A similar pattern of growth can be observed for the areas with values above 200. With parks of national importance all of these relative areas are exceptionally low small. A surprising growth can be noted for the relative area with emissions above 100, increasing from 2.2 % in 2001 - 2003 by a factor of nearly 5 to 10.6 % in 2010 - 2012.

Table 5: The relative area of categorised light emissions in radiance values for Swiss BLN zones and parks of national importance for each time period shown in percentages.

BLN	>100	>200	>300	>400	Parks of N. I.	>100	>200	>300	>400
1992 - 1994	3.4%	0.9%	0.4%	0.1%	1992 - 1994	0.8%	0.1%	0.0%	0.0%
2001 - 2003	6.1%	2.0%	0.6%	0.2%	2001 - 2003	2.2%	0.2%	0.0%	0.0%
2010 - 2012	16.0%	6.0%	2.1%	0.5%	2010 - 2012	10.6%	2.7%	0.4%	0.0%

Discussion

The results suggest that light pollution in various regions and habitats in Switzerland are growing exponentially. In general, the largest amounts of light pollution can be found in the densely populated areas of Switzerland such as the Central Plateau (Fig. 10 and Fig. 11). Even though the sizeable emissions are found here, the regions of significant exponential growth, often larger than can be observed in the Central Plateau, are generally in areas currently with lower emissions values (Appendix A). This could be the result of light pollution growing stronger and spreading from areas of already high light pollution to nearby areas that possibly do not emit light at all. This effect is often described as a dome or a bell of light above cities, that can even brighten up the night sky of natural landscapes hundreds of kilometres away (Posch et al. 2010). Another reason could be the urbanisation and creation of suburbs, as people begin to populate more remote locations away from cities, resulting in a general increase of light pollution all over Switzerland (FSO, 2018).

Natural habitats such as wetlands and dry meadows are not the exception. As critical environments for various endangered species, the effects light pollution can be detrimental to their ecosystems (FOEN, 2017i; Hölker et al., 2018). As biotopes of national importance (FOEN, 2017i), further empirical studies should be conducted in these areas to aid policy makers in the process of mitigating light emissions in adjacent areas. The results show certain biotopes to already be affected by extreme intensities of light emissions, especially those near larger cities (Fig. 12).

In terms of accuracy regarding the satellite data and the analysed landscapes, the results should be examined with caution for a variety of reasons. The light emissions observed with the satellite data retrieved from the DMSP are thoroughly well averaged considering the long time periods. The first and second time periods, 1992-1994 and 2001-2003, are well calibrated in comparison to one another: using overlapping time-frames of service between older and newer satellite generations, the development of recent light emissions captured should be consistent with those measured in previous years from previous satellite generations. However, the measurements of the final time period, 2010-2012, lacks an overlapping time-frame of service, suggesting that the next generation satellite of those years was unable to calibrate with measurements from its predecessors. Therefore, the stronger increase in light emissions leading up to the last time period must be ratified using datasets from other satellite platforms, e.g. by using VIIRS-DNB data (Kienast and Weiss, 2019).

In addition, utilising the method of light emissions captured by satellite data may underestimate or overestimate certain landscapes. This can depend on factors such as absorption of light emissions by the landscape, decreasing measured light emissions. In a scenario where a forest is adjacent or near a well-lit urban settlement, one should consider the light emissions directed towards the forest as well as reflected emissions, for example from aerosols in the atmosphere back down towards the forest canopy. It is conceivable that a significant portion of these light emissions are absorbed by the dense leaf canopy. The remaining light is reflected in several directions, some towards the ground where more absorption and reflection occur, directly impacting nocturnal species. Other emissions are reflected into the atmosphere and measured by satellite, whereas atmospheric characteristics further influence and reduce these emissions. Not only can this lead to an underestimation of light emissions, but also to an abstraction of the results depending on the characteristics of the diverse landscape categories. The same real light emissions in an extensive meadow, in a forest and on an unproductive landscape can be misinterpreted by the satellite measurements, each showing different values due to the reasons mentioned above. Overestimations are a further issue that can be caused by poor resolution of the light emissions data and by smoothed out cell values. Prior to this thesis a first spatial moving window averaged the cell values in a 3x3 section of cells, maintaining the original cell size of 1 km². The data was further developed in this thesis, reducing the cell size to 100 m x 100 m and

realigning it to the *NOAS04* dataset followed by a resampling using bilinear interpolation to further smoothen out the cell values within the now dissected 1 km² cells. The necessity for more consistent data and to reduce statistical outliers instigated these procedures to smoothen out cell values. Consequently, the smoothed dataset can blur the results to a point where emissions sources may be spread across surrounding regions and habitats that have close to no light emissions. This effect can be distorted by the further reduction of cell size and realignment performed in the data preparation for this thesis.

Regarding the numerous habitat types analysed in this thesis, resolution has a severe impact on the results. The wetlands, dry meadows and pastures, BLN zones and parks of national importance were all originally retrieved as polygon datasets. As such, they needed to be transformed into raster datasets, thereby losing their original borders conforming to the 100 m x 100 m scale. Apart from the parks of national importance, the polygons of patches and shapes with protrusions in the original datasets are often miniscule in size, heavily segregated and not rarely only a fraction of the size of a 100 m x 100 m cell. The light emission datasets originally had a 1 km² cell size, whereas the results try to interpret this data for countless small patch habitats after cell dissection, resampling and realignment. The light emissions for an individual patch can and should not be interpreted separately, but as a general measure for the area in and surrounding the patch in combination with other light emissions nearby.

The question arises as to why such an increase in light pollution pursues despite the consequences and what Switzerland is doing to prevent it? The following text discusses the legal aspect of light pollution and how it is regulated in Switzerland.

One of the pioneering legislations to be passed concerning light pollution was the “Sky Law” (Act 31/1988) which was passed in 1988 on the Canary island of La Palma, Spain. The primary goal was to protect the astronomical observatories from astronomical light pollution caused by nearby settlements (Fayos-Sola et al., 2017; Carlos, 1988). Hence, this legislation provided the precedent for various other regulations regarding light pollution around the globe (Starlight Foundation, 2017). The first national law regarding light pollution was imposed in the Czech Republic in 2001 (Clarke, 2002; NZZ, 2002), within which astronomical light pollution was also the focus of its implementation as well as energy efficiency.

As the topic of light pollution and its effects started reaching the public eye in Switzerland at the turn of the millennium, the absence of nationwide regulations caused individual villages and cities to create their own legislations. In 2003 Hinwil ZH was the first swiss municipality to ban skybeams, a form of bright headlights directed towards the sky and often used near discotheques or other large events to attract visitors (DSS, 2003). In 2004, the city of Burgdorf BE followed the example, shortly preceding the canton of Lucerne (DSS, 2004; Baumeler, 2004). Although these bans help reduce excessive light pollution, they were not essentially addressing the issue of light pollution. In this manner, Coldrerio TI were the first municipality to pass an ordinance in 2007 to protect the night sky, natural ecosystems and increase energy efficiency (Lenzin, 2007). In the same year the canton of Ticino approved of guidelines to avoid light pollution (Canton Ticino, 2007). Cantons such as Zürich and Bern followed the example providing brochures and similar guidelines informing the public about light pollution and how to avoid it (Klaus et al., 2005; Beco). These guidelines are built primarily upon the Federal Act on the Protection of the Environment (EPA, 2018), which will be discussed more thoroughly in the following section.

The protection of nature and the environment is controlled by several federal acts. To avoid impairment and damage caused by light pollution, the following enactments have authority:

- The Federal Constitution (FC; SR 101): Art. 74 § 1 and 2 designate the overall protection of the environment and art. 78 § 4 defines the protection of animal and plant life, their habitat and diversity.
- The Federal Act on the Protection of Nature and Cultural Heritage (NCHA; SR 451): Art. 1 - 3, 5 and 6, define the need to protect objects of national importance in the federal inventory. In our case, these objects need to be protected from excessive light pollution. Section 3 of the SPA further defines the protection of indigenous flora and fauna. Both the FC and NCHA mention the precautionary principle (German: *Vorsorgeprinzip*) to avoid damages from pollution before they can occur.
- The Spatial Planning Act (SPA; SR 700): Art. 1, and 3 define the aims and planning principles of spatial planning to include the protection and preservation of the landscape. Art. 17 further defines the parameters of protected zones.
- The Hunting Act (translated from German: “Jagdgesetz”) (JSH; SR 922.0): Art. 1 § 1 defines the preservation of wildlife, wherein art. 7 § 4 states the protection of wildlife from disturbances.
- The Federal Act of Fisheries (translated from German: “Bundesgesetz über die Fischerei”) (BGF; 923.0): Art. 5 defines the protection of endangered species.
- The Federal Act on the Protection of the Environment (EPA; SR 741.01): Art. 1, 7 § 1 and 2 as well as art. 11 - 14 (*see below for details*)
- Further acts and regulations that can have authority regarding light pollution include the Traffic Act (translated from German: “Strassenverkehrsgesetz”) (SVG; SR 741.01): Art. 26, 31 - 33, expressly art. 32 which defines the cautionary obligations concerning visibility. The Signal Regulation (translation from German: “Signalisationverordnung”) (SSV; SR 741.21): Art. 100 provides additional instructions about street-advertising to protect landscapes.

Apart from these national sets of legislation, multiple cantons and municipalities have incorporated light pollution regulations into cantonal and municipal legislations. These legislations are found in sectors such as environmental protection, energy and building (FOEN, 2017a).

In this section we will take a closer look at the EPA, the reason being that it is the only act that mentions light pollution and explicitly aims to control it. In the context of the EPA, light pollution is referred to as ‘radiation’. In a message concerning the draft of the EPA in 1979, the term radiation includes the “effects of non-ionizing radiation such as bright light, light, light flashes, ultraviolet-, infrared- or laser radiation and microwaves.” (translated from German; Swiss Federal Council, 1979, p. 783). Radioactive substances are covered by the legislation on protection against radiation and on atomic energy (art. 3 § 2 EPA).

The EPA urges to protect humans, animals and plants, their communities and habitats against harmful or tiresome effects such as radiation (art. 1 § 1 and art. 7 § 1 EPA). In a first phase to protect against these effects, art. 11 § 2 of the EPA expects to limit these emissions as far as the technology and operating conditions allow. In a second phase, the emissions are to be limited even further if the effects are considered to be harmful for the surrounding environment (art. 11 § 3 EPA). Art. 13 § 1 of the EPA assesses when the levels of emissions are considered harmful, whilst a legislation on emission-limits is taken into account with art. 13 § 1. The emissions, such as light pollution, are supposed to be limited by implementing measures at the source of the emissions (art. 11 § 1 EPA).

However, to date the government has not set any quantitative values for limitations against harmful light emissions. In reference to non-ionizing radiation, the Legislation of the Protection from non-ionizing Radiation (translated from German; NISV; SR 814.710) is active, but strictly refers to the so-called “Elektrosmog”. This entails radiation from signalling stations and electric or magnetic fields and does not include light pollution. Currently, the administrations are left to interpret when measures are

to be undertaken based on their individual assessment of the EPA for separate cases of harmful light pollution (Deublein, 2016).

A major guideline on light pollution for administrations is the Recommendation to Avoid Light Pollution published by the FOEN (then BUWAL) in 2005. It includes general planning and technical principles on how to avoid or reduce light pollution (Klaus et al., 2005). Although this guideline is still actively used by cantonal administrations, it does not set light pollution limits. Furthermore, the development of lighting since 2005, especially with the introduction of LED's, has significantly changed the use of lighting (Deublein, 2016). In 2013 the swiss government has ordered the FOEN to update and revise this guideline and address all of the above-mentioned issues (Deublein, 2016). As result, a new guideline (in German: Vollzugshilfe) is currently under revision and should be published in 2019 (FOEN, 2018).

Another legal possibility to tackle light emissions are Norms. Norms are documents used to define the characteristics and properties of a product, process or service. As they can be easily revised and kept up to date with technology by national or international private-law organisations, they are often efficient in determining testing procedures and safety requirements. However, norms only become legally binding if they are referred to in legislative documents such as in laws, decrees or contracts between individuals. In that sense, guidelines and norms are not necessarily legally binding (Led-know-how, 2018; FOEN, 2017).

The norm SN EN 13201 was the first norm to regulate road lighting in Switzerland and has been in place since 2004. Originally, it solely regulated minimum lighting values, generally to enhance road safety. It entirely neglected setting a maximum limit of light emission (CEN/TC, 2004; Posch et al., 2010). In the updated version from 2016, the issue of tangible maximum values remains, but SN EN 13201 - 2 includes qualitative suggestions as to how disturbance of nearby residents from light pollution can be reduced (FOEN, 2017a, Topstreetlight, 2017).

The same can be said for the norm SN EN 1293 regarding sports venues and SN EN 12464 - 2 regarding the lighting of workspaces outside. They include lighting requirements to ensure visibility and safety but lack in setting maximum limits. SN EN 1293 offers standards to limit disturbance from light emissions, based on the international norm CIE 150, but only from individual facilities instead of collective emissions. SN EN 12464 - 2 includes standard values for outdoor lighting to reduce disturbing nearby residential buildings (FOEN, 2017a).

Explicitly regarding light pollution is the norm SIA 491 (SN 586 491). It was put into effect on the 1st May 2013 and serves to regulate the use of light in the outdoors (Deublein, 2016). It seemingly remains the only swiss norm actively aimed towards protecting the environment from excessive illumination. It acts as a guideline to support proprietors, architects, planners, builders, operators and institutions during planning, building, operation and inspection of outdoor lighting. Building upon the previously mentioned norms, the aim is to create optimal lighting to suffice the requirements of people using it, whilst simultaneously reducing disturbance and damages to nearby landscapes and animals (SIA, 2013). It differs from the previous norms in reference to light emissions values, where-in it does not set any standard values at all. According to the authors, this has two reasons:

- a. To avoid discrepancies with other norms
- b. The belief that not all environmental issues can be solved with repressive regulations

The Swiss Society of Engineers and Architects (SIA) prefer to gather practical experience as to whether the addition of standard values to the norm are necessary before considering implementation at a later stage (Kobler, 2013).

Conclusion

The findings of this study are alarming. The ecological consequences of light pollution can affect not only individual species, but also a broader range of ecosystems. The effects can change behavioural patterns influencing the orientation, reproduction, competition and predation habits, often linking multiple species to the issue. With a general exponential increase of light pollution over the past decades, these effects may become more apparent. Regions of high population density such as the Central Plateau show close to no natural darkness of the night sky. Natural habitats such as wetlands and dry meadows found in these locations are already exposed to extreme values of light emission. Flood plains are, amongst others, areas with some of the most endangered objects and species in Switzerland. These habitats need to be protected from external adverse effects to safeguard the biodiversity of Swiss fauna and flora. Understanding the real consequences light pollution has on these regions could be a topic for further empirical research. A more distinguished analysis of the habitat types is advised, to identify the development of light pollution in individual areas.

In legal terms, the current legislations in place lack the specific inclusion of light pollution. Individual municipalities have taken the matter into their own hands, setting up legal frameworks tackling the issue light pollution as a product of excessive energy use. On the federal and cantonal level, a multitude of legislations set the baseline for an overall protection of natural habitats to avoid further impairments and damage to natural ecosystems. However, the final instance regarding light pollution for many cantons is a federal guideline on light pollution that is more than a decade old. Despite its good intentions, the legal application of the guideline is negligible. Nonetheless, the Swiss Federal Office for the Environment is presently in the process of revisioning its documents on light pollution. In addition, a slowly growing variety of legal norms are becoming available. These can include lighting requirements to support proprietors, architects, planners, builders, operators and institutions during planning, building, operation and inspection of outdoor lighting. With these concepts, Switzerland has the opportunity to essentially incorporate light pollution into a legal setting, with the aspirations of slowing down or even mitigating emissions in critically affected regions.

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Appendix A

Table 6: Basic radiance values of various regions and habitat types of Switzerland. The statistical values are calculated from R Studio and correspond with the boxplots from the main text. This includes the minimum and maximum values, the 1st and 3rd quartile as well as the median and mean values. The "Switzerland" results are calculated directly after the process of bilinear interpolation with GIS. All the other datasets needed to be further combined and cut into their subsequent regions and habitat types before analysis. Within this process, GIS rounded the numeric values of the light emission datasets to full numbers.

Switzerland	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	0.33	12.04	36.59	37.13	500.05
2001 - 2003	0	3.92	20.26	51.52	56.21	498.64
2010 - 2012	0	8.56	44.12	90.77	130.38	500.05
Jura	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	7	18	30.65	35	383
2001 - 2003	0	16	26	46.03	51	432
2010 - 2012	1.00	38	66	95.81	124	459
Central Plateau	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	23	43	83.52	102	500
2001 - 2003	6.0	36	69	115.40	158	498
2010 - 2012	13.0	97	167	199.70	287	500
Northern Alps	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	0	3	14.83	18	436
2001 - 2003	0	1	12	25.58	28	458
2010 - 2012	0	5	24	48.83	61	482
Southern Alps	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	0	1	28.57	20	462
2001 - 2003	0	0	6	33.74	23	467
2010 - 2012	0	0	11	51.48	45	481
W. Central Alps	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	0	1.0	21.63	21	435
2001 - 2003	0	0	7	25.89	26	425
2010 - 2012	0	1	13	41.38	47	446
E. Central Alps	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	0	0	8.69	6	305
2001 - 2003	0	0	2	13.69	15	333
2010 - 2012	0	0	5	23.54	27	373
Agriculture	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	2	19	35.56	41	499
2001 - 2003	0	10	28	53.93	66	498
2010 - 2012	0	21	70	104.40	156	499
Urban	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	30	73	130.30	197	500
2001 - 2003	0	46	116	166.40	270	498
2010 - 2012	0	110	231	243.00	374	500
Forest	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	2	14	32.63	35	499
2001 - 2003	0	10	22	46.42	50	498
2010 - 2012	0	20	49	85.71	114	500
Unproductive	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	0	0	13.77	5	500
2001 - 2003	0	0	1	18.84	12	498
2010 - 2012	0	0	3	31.04	23	500

Bogs	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	0	3	22.41	19	455
2001 - 2003	0	2	11	36.16	29	467
2010 - 2012	0	6	25	64.92	69	493
Raised Bogs	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	0	6	22.35	20	456
2001 - 2003	0	5	17	36.80	31	466
2010 - 2012	0	12	35	66.9	79	493
Flood Plains	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	0	4	26.45	31	395
2001 - 2003	0	0	12	39.68	47	422
2010 - 2012	0	0	23	75.08	101	469
Meadows & P.	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	1	8	21.62	25	486
2001 - 2003	0	7	16	31.8	35	486
2010 - 2012	0	15	34	60.38	78.75	499
BLN	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	0	1	16.91	19	496
2001 - 2003	0	0	6	24.74	25	495
2010 - 2012	0	0	13	47.55	61	500
Parks of N. I.	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
1992 - 1994	0	0	3	11.79	17	270
2001 - 2003	0	1	13	19.13	25	326
2010 - 2012	0	6	27	43.01	49	389

Eigenständigkeitserklärung

Die unterzeichnete Eigenständigkeitserklärung ist Bestandteil jeder während des Studiums verfassten Semester-, Bachelor- und Master-Arbeit oder anderen Abschlussarbeit (auch der jeweils elektronischen Version).

Die Dozentinnen und Dozenten können auch für andere bei ihnen verfasste schriftliche Arbeiten eine Eigenständigkeitserklärung verlangen.

Ich bestätige, die vorliegende Arbeit selbständig und in eigenen Worten verfasst zu haben. Davon ausgenommen sind sprachliche und inhaltliche Korrekturvorschläge durch die Betreuer und Betreuerinnen der Arbeit.

Titel der Arbeit (in Druckschrift):

Light Pollution in Switzerland: An analysis of regions and natural habitats

Verfasst von (in Druckschrift):

Bei Gruppenarbeiten sind die Namen aller Verfasserinnen und Verfasser erforderlich.

Name(n):

Kyek

Vorname(n):

Stephan

Ich bestätige mit meiner Unterschrift:

- Ich habe keine im Merkblatt [„Zitier-Knigoe“](#) beschriebene Form des Plagiats begangen.
- Ich habe alle Methoden, Daten und Arbeitsabläufe wahrheitsgetreu dokumentiert.
- Ich habe keine Daten manipuliert.
- Ich habe alle Personen erwähnt, welche die Arbeit wesentlich unterstützt haben.

Ich nehme zur Kenntnis, dass die Arbeit mit elektronischen Hilfsmitteln auf Plagiate überprüft werden kann.

Ort, Datum

Zürich, 25.02.2019

Unterschrift(en)



Bei Gruppenarbeiten sind die Namen aller Verfasserinnen und Verfasser erforderlich. Durch die Unterschriften bürgen sie gemeinsam für den gesamten Inhalt dieser schriftlichen Arbeit.