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Abstract:

In the human quest for light, there is a negative side of our well-lit cities; light pollution. Light pollution still increases and there is a discrepancy between legislation and science. Where research can show solutions which are not adopted into legislation, however, many guidelines only consider the astronomical impact and leave out the ecological aspect and the impact on humans. Considering how dependent humans are of light, it might demand a further movement in the way of addressing possible solutions. It might need a perspective leading away from a human-above-all approach and instead considering a view that puts people in connect with nature. This thesis was made with an ecocentric approach, a more-than human approach, looking at all aspects of light pollution and creating a plan for a city to come to terms with light pollution in the aspect of ecology,

In pursuit of dark skies. An ecocentric lighting design strategy for a city without light pollution

Miranda Ivarsson

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1 INTRODUCTION

When you think of a city at night, it is almost unimaginable to not think of an illuminated city; streetlights that guide cars and dwellers to their destination, lights that highlights architectural masterpieces and accentuating bridges from afar. Lights in cities are there to guide, showcase, and captivate. Cities have become the epicentres of light.

In Nordic countries like Sweden, light in cities is essential to provide a life for the inhabitants during the darker half of the year. Light prolongs the days in the Swedish cities, it can stimulate economy, support a social life and enable outdoor life in the afternoons (Garnert, 2016).

The negative side of our well-lit cities is light pollution. Light pollution is defined as the "total sum of adverse effects of light" (Science Communication Unit, UWE Bristol, 2023). The most noticeable and visible adverse effect of light pollution is skyglow, the diffuse dome of light that can be seen over cities during the night. Skyglow brighten the sky, interferes with astronomical observations and has become so common that natural darkness nowadays is a rare phenomenon (Bogard, 2013).

In addition to producing skyglow, ALAN (artificial light at night) has been shown to have harmful effects on both humans and nature. Which are more affected by obtrusive and direct illumination. (Svechkina, et al., 2020)

Skyglow is a measurable phenomenon that has been extensively studied, and research has led to prevention guidelines in some countries and local areas. However, recent research indicate that these guidelines primarily take skyglow into account and might not solve the impact on ecosystem, despite their environmental intention (Bará & Falchi, 2023). This may stem from the challenge of quantifying aspects related to the ecological and human effects of light pollution, which have consequently received less attention until more recent research.

Light pollution has increased worldwide since it was discovered (Kyba, et al., 2023). One possible cause may be the deficiency of knowledge and (appropriate) legislation. Another cause appears to be linked to the phenomenon known as 'shifting baseline syndrome'. This syndrome denotes a gradual shift in the perception of normalcy over time because people forget or do not know about past conditions. Consequently, this can result in challenges such as acceptance of environmental degradation and different views on what is worth to protect in nature. (Soga, et al., 2018) Continuous exposure to ALAN and a lack of exposure to natural darkness can lead people to perceive a polluted sky as natural. This can result in a greater aversion to unlit areas and increased indoor time. Ultimately, natural darkness may be viewed as unfamiliar, uncomfortable, and potentially unsafe (Lyytimäki, 2012). In contrast there is a knowledge that darkness plays a pivotal role in the well-being of both the environment and its inhabitants including humans.

Research argues that light pollution should be considered a pollutant among other airborne or waterborne pollutants, in addition there is a shift in considering light pollution as an effect solely of excessive lighting, towards a way of seeing all light as potential contributors to light pollution (Bará & Falchi, 2023),

Considering how dependent humans are of light, this shift might demand a further movement in the way of addressing possible solutions. It might need a perspective leading away from a human-above-all approach and instead considering a view that puts people in connect with nature and as equally important. There seem to be a dissonance between what would be of best interest for nature and what would be of best interest for humankind, however, it is crucial to understand that humans not only contribute to light pollution but are also part of the system affected by its impact on ecosystems (Hirt, et al., 2023).

1.1 Motivation

Growing up in Sweden on the 58th parallel north, winter meant playing outside in the dark, on cloudless nights there was a clear, starry sky forming the backdrop to many memories. In contrast, moving to larger cities changed this experience, the nights became obscured by skyglow, and the dark nights became rare. Returning to my childhood place now, the sky is polluted with light and has lost a part of its starry backdrop. While there are undeniable benefits to artificial lighting for humans, it raises questions about what we may be sacrificing in exchange. When I researched about light pollution last semesters at Aalborg university, I learned that there are profound adverse effects on artificial light at night for both nature and humans. I also realised there is more to it; it is a significant loss experienced by humanity, the loss of natural darkness, which holds a deep cultural significance. In our quest for illumination, we might risk losing a vital aspect of our heritage and connection to nature. Lighting designers that advocate for natural darkness and less light might seem like a paradox, yet being a lighting designer is also about controlling the light, dictate where light is used and deciding the quantity of light. While lighting designers at present may contribute to the issue of light pollution, lighting designers also have the potential to contribute to its resolution. Light pollution is one of the few human-caused problems that are in fact solvable, what stands in the way are we humans.

1.2 Initial research question

Based on background knowledge and personal interest an initial research question was formed:

Can a new approach to urban lighting balance the human desire for light with natures need for darkness?

This initial research question will guide the theory and the analysis. This thesis will investigate whether it is possible to combine the human desire for light, and natures need for variation in light and darkness cycle, knowing the importance of darkness for both human and nature. The thesis will adopt a Nordic perspective, with a particular focus on Sweden, to address the unique conditions of darkness experienced in the northern regions.

2 METHODOLOGY

2.1 Framework - Ecocentric design

The overall framework for this project will be guided *by Ecocentric design* a more-than-human approach which has its foundation in *Ecocentrism*, a view that encourages a reconsideration of the rights and demands humans have in relation to ecological systems. Ecocentrism is rooted in the factuality that all life relies on interdependency and that ecological systems that nature offers are essential for all form of life. (Washington, et al., 2017)

In contrary to an anthropocentric or human-centred view which puts the individual human needs at first, ecocentrism has the overall goal of a symbiosis between human and nature, and to place human in relation to nature. Ecocentrism acknowledges that humans are an equal part of nature and that it is humans' duty to respect and protect the ecosystems and repair the damages caused by humans. (Kopnina, et al., 2018)

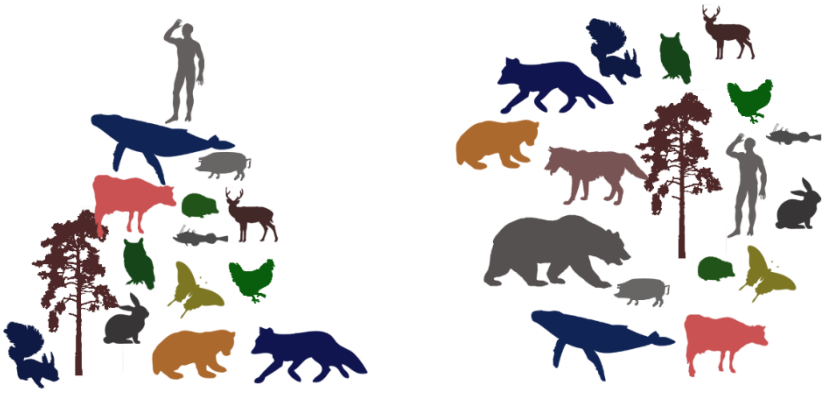

Figure 1 Anthropocentrism vs. Ecocentrism, Self-produced, 2024

Yeang (2020) introduced "Ecomimesis principles" to support and guide an Ecocentric design process. The core idea is 'repurposing' meaning that the thinking our natural environment and human role within nature needs to change. Instead of viewing nature as something to endlessly retrieve from, the approach should be to see it as something to protect and work alongside. This means changing the mindset from exploiting nature to being its caretaker and ally. In an ecocentric design this is done by focusing on nature and letting every step in the design being guided by the "science of ecology".

In many traditional design methods, the usual approach is to focus on the internal aspects first, then consider how it affects the environment afterward. This means that the impact on ecosystems and natural cycles is often evaluated after the design is already finished or

partly done. In an ecocentric design, the natural environment surrounding the system being designed should be the main influence right from the start of the design process, an "outside-in" approach can be adopted to start by looking at the large-scale system and cycles first and going inwards to the actual place where the design is placed. (Yeang, 2020)

An Ecocentric design relies on three principles that should be considered in the design process.

Purpose: The design should have a purpose aimed at solving the major problems humanity faces today and achieving sustainability. This involves addressing current environmental or social issues, preventing further harm, maximizing ecological effectiveness, and contributing positively to human civilization.

Context: The design must be put in context "with the systems nearby and in the wider region", it should be analysed how the design interacts with the surrounding environment in smaller scale and in larger scale.

Balanced: The design should be optimised and balanced for both human and nature. The goal is not to minimise either human or nature, instead find an optimised and balanced symbiosis. (Yeang, 2020)

2.1.1 Theory - methods

The theory researched whether light pollution is an environmental problem to see if a design can be properly purposed. In search for and optimised design the Zotero collection "ALAN_DB" with articles concerning ALAN was used. Google scholar was used with search terms: ecological light pollution, ALAN, astronomical light pollution, light pollution, human health.

2.1.2 Analysis - methods

To put the design in a context a case study was developed, A case study can be an effective tool to give contextual Insight and to study factors within a real-life setting. It was also used in search for practical application, where a case study can have direct implications for practice (Priya, A, 2022)

Due to the fact the nights are diminishing, and fewer people experience natural darkness today, an autoethnographical part was used to get a subjective understanding and deeper insight of the studied area**.** An autoetnographic method can be used to gain knowledge through a lived experience and to make sense of the world. (Schouwenberg & Kaethler, 2021)

3 THEORY

The theory section will give a foundation for the analysis and the design, research why we have light in cities. Seek out what research says about the human needs and the environmental needs in regard to light pollution.

3.1 Light in the city

"It is only with the benefit of light, after all, that urban spaces become accessible at night." Brandi 2006

Why do we have light in cities? A simplified answer can be that vision is humans' primary sense and in the absence of light, vision is lost, with the presence of some light, the ability to see is present (Boyce, 2019). A more in-depth answer can be that natural selection and evolutionary forces have contributed to the development of genetic systems that can sense time and adjust performance and behaviour according to the daily variations in temperature and light (Bhadra, et al., 2017). Since this have made humans diurnal, day living creature, the eyes have evolved to have optimal function in daylight (Liljefors, 1999).

Due to the limited vision during darkness human activities have historically been located when there is daylight or when there are cloud free nights with a full moon present. Garnet (2016) describes nights in Sweden before the invention of light as "wrong hours for humans", a time to sleep or rest but not to handle any duties, things had to wait for daylight.

In the long dark ours in the north, other senses played a more pivot role, listening, talking and touching. The darkness could hide things, and darkness was a backdrop for the evil forces in many myths and legends. On the other hand, the long winter darkness was associated with times of rest and socialisation. (Garnert, 2016)

In Sweden, public lighting was invented in the year 1700, when the government legislated that every house in the city should put up a torch on the outdoor in the evenings, for the sake of people not trembling in the streets (Witasp, 2005). The first electric public lighting in cities was said to "freeing people from the dark" (Garnert, 2016). Lighting since then have evolved and the electric lighting has certainly allowed humans to prolong activities into the night. (Jägerbrand & Spoelstra, 2023)

Today there are several reasons why the society have and keep the light in cities.

Safety: The most basic purpose of lighting at night is to illuminate the paths so people can avoid obstacles on the way and not risk stumbling or falling. Lighting is there to guide the way through town. For bikes and cars, the light is fundamentally there to avoid collisions and accidents by illuminating the roads. The widespread use of road lighting originates from the conclusion that the illumination can mitigate the accidents between cars and pedestrians and objects without their own lighting. (Boyce, 2019)

Security: Public lighting was originally introduced as a mean to reduce crime and vandalism against both persons and property (Casciani, 2020). Public lighting in cities now have the purpose of decreasing acts of crime and *fear of crime* by increasing human visibility. Lighting for reducing of crimes in cities often outlines as more lighting will have fever placer to hide and more visibility for face recognition (Boyce, 2019). Fear of crime or our perception of security is linked to well-lit, uniform streets, and the perception of darkness or shadows is related to fear of crime. In cities it is common to adopt increased illuminance to reduce fear of crime. The increased illuminance is said to improve people's

peripheral vision and the contrast between pedestrians and their surroundings. (Casciani, 2020)

Extending the day: Light in cities have prolonged the ability to activities beyond sunset. Today the light during night is there to support a 24-hour economy, in cities this can mean to ensure access to activities such as entertainment, restaurants and shops in the evening. In the later hours light can support night workers and companies that rely on night shifts. (ARUP, 2015)

Aesthetics: A significant portion of artificial nighttime illumination has been implemented for aesthetic purposes. Aesthetic lighting has the benefits that it can enhance the impression and the sense of a place (Gaston, et al., 2014). This reason applies to the emotional side of human, where cities illuminate for the reason of beatification. Examples can be light installations, bridge lighting, light festivals. This is in many cases a commercial act, where companies can attract visitor or costumers. (Boyce, 2019)

Light in cities have become so common and it has seamlessly integrated into what is perceived as 'invisible infrastructure', a term that describes a phenomena where human only notice the absence or when something is broken or missing. This leads to a state where light, a part of the invisible infrastructure, is never questioned in any terms as long as it is there. (Schulte-Römer, 2023)

Picture 1, Aesthetic lighting, kai3952, 2020, CC BY-SA 2.0

Picture 2, Lighting in the night, Pixabay, CC0 1.0, 2016

3.2 Light pollution

While ALAN have provided many benefits to humans, the introduction of ALAN made scientist start to discover how the sky at night became obscured. In the 70's the term light pollution was used to describe the airglow polluting the night sky, reducing the number of visible stars and celestial objects. (Riegel, 1973)

At first, *pollution* in this context meant it was a bothersome issue for astronomy rather than something that could have consequences for the environment. This misunderstanding influenced many definitions of light pollution that made wrong distinctions between useful

and polluting light. For example, that light pollution occurs when artificial light is used in places where it's not wanted or needed, or when it's used too much (Bará & Falchi, 2023), however, nowadays there is a knowledge that all ALAN can contribute to light pollution (Zielinska-Dabkowska, et al., 2023).

Jägerbrand, et al., (2022) argues that the most correct definition of light pollution would be the "sum total of all adverse effects of artificial light" as stated in the (International Comission on Illumination, 2020)

The consequences of light pollution are being researched in three main areas: environmental and ecological impact, atmospheric and sky pollution affecting astronomical research, and the effects of ALAN on human health (Jägerbrand et al., 2022). Each of these areas employs different methods, scales and perspectives in their research (Rodrigo-Comino et al., 2021). Therefore, each area will be presented separately encompassing consequences, causes and possible solutions.

Consequences This section will explore why we should care about light pollution and what its consequences are. To adopt an ecocentric approach, it is essential to consider all three areas of impact—environmental and ecological effects, astronomical light pollution, and human health—to gain a holistic perspective.

Causes Light pollution originates from ALAN. If all ALAN were turned off, light pollution would be eliminated. However, various factors contribute differently to light pollution. Certain qualities of light, such as its intensity, colour and duration, significantly influence the extent of light pollution. Identifying and understanding these factors is crucial to addressing the root causes effectively.

Solutions This section will review scientific research findings on potential solutions to light pollution. It will examine strategies to avoid light pollution in the three different areas. By exploring all solutions to the different type of light pollutions a combination of solutions can be appropriate for an ecocentric design

3.3 Astronomical light pollution

The sign of astronomical light pollution is the phenomenon known as skyglow. Skyglow can be seen as a bright dome of light on the sky over cities, this pollution obscures the sky and decreases the contrast between the sky, stars and celestial objects which as a result makes them less visible. (Barentine, 2022)

3.3.1 Consequences

Skyglow has an immediate impact on the ability to perform astronomical research. For most of the 20th century, the brightness of the sky has increased rapidly due to the introduction of new lighting technologies, the construction of cities, and population

growth. Around 80% of the world is currently affected by light pollution, and between 2011 and 2022, the night sky has brightened by 9.6% annually. (Kyba, et al., 2023) As a result, the most remote professional observatory locations can detect impact from artificial skyglow. (Green, et al., 2022)

3.3.1.1 A lost cultural heritage

Throughout history, humanity has studied the night sky to answer fundamental questions about our origins and the universe (Tomanik & Bastos, 2012). However, the nature of the night sky has changed significantly since the introduction of ALAN. Due to skyglow caused by ALAN, the night sky that most people see today is not the same as the one our ancestors observed (Kyba et al., 2023).

3.3.2 Causes

Skyglow occurs when light emits from the source and photons travel in the air. If a light source can emit light in various directions some photons will move uninterrupted through the atmosphere and continue in space. Other photons will scatter in the lower atmosphere when they collide with droplets of water, molecules, particles of dust, and other pollutants, when reflected back to the ground it causes the sky to brighten. Further photons reflect on the ground or on objects before travelling upwards. Other photons travel long distances on earth before scattering occurs. (Barentine, 2022)

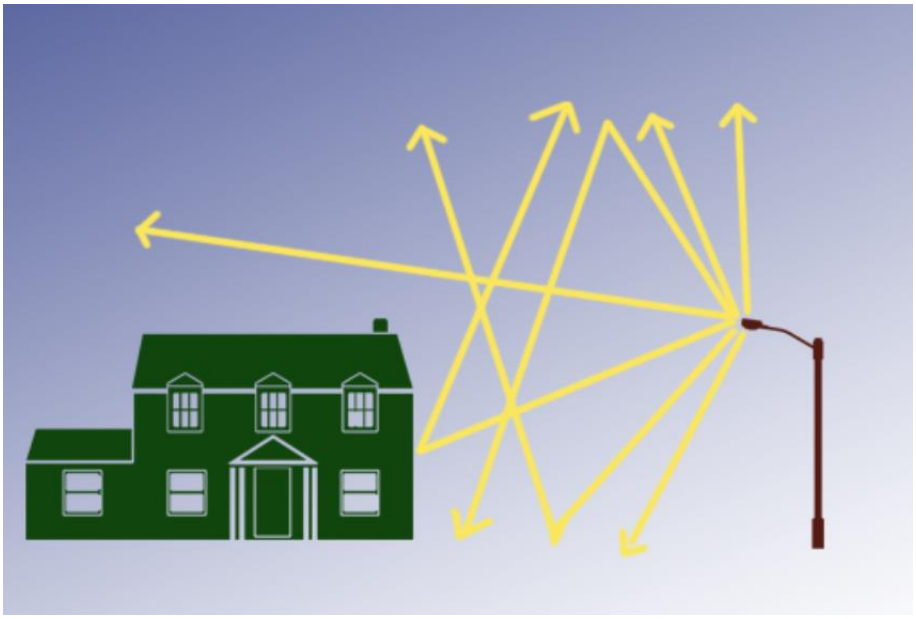

Figure 2, Lighting bounces, Self-produced, 2024

In 2014 the Nobel prize in Physics was given for creating efficient blue LED (light emitting diodes), which produce bright white light while saving energy compared to earlier technology. This led to a common believe that this technology would make cities more sustainable. As cities worldwide rapidly switch their outdoor lighting to LED to save energy and money, other factors were overlooked. (Zielinska-Dabkowska & Bobkowska, 2022)

The spectral power distribution of ALAN plays a crucial role in influencing the extent to which light pollution negatively affects the night sky. (Tabaka & Kolomanski, 2023) The

white light in LED has a richer content of blue light with shorter wavelengths in the spectral power distribution. Shorter wavelengths scatters more in the atmosphere compared to more orange-red light that contain longer wavelengths, resulting in a higher increase in sky brightness, particularly at longer distances from artificial light sources. (Kocifaj & Barentine, 2021)

A study indicates that testing different wavelengths contribution to light pollution showing those emitting a broader range of wavelengths in the blue spectrum contributed 15-20% more to light pollution in terms of sky glow compared to sources with higher levels of yellow content, such as high- and low-pressure sodium lamps. (Luginbuhl, et al., 2014)

When we look at the sky in a city, around half of the glow we see comes from light that travels straight up, while the other half comes from light that bounces off surfaces. However, this ratio can change depending on things like the type of lights being used and how far away we are from them. In many places, the amount of light going straight up into the sky usually makes up about 10 to 15% of the total light emitted from light sources. (Luginbuhl, et al., 2009) How much the ground or object reflection contribute to sky glow depends on the material. In cities the most common materials are, pavement, asphalt, soil and grass, which reflect around 15%. In countries where the ground can be covered in snow during the winters, studies show that the reflection can increase by times 10 compared to less reflective material like asphalt. (Tabaka & Kolomanski, 2023)

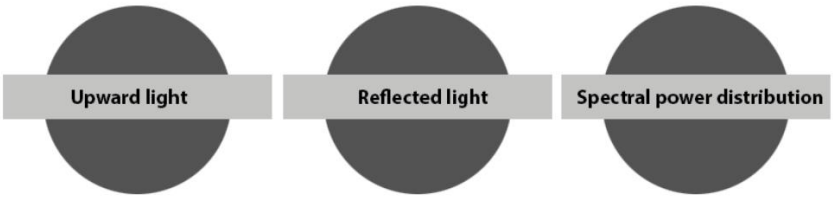

Figure 3, Causes of astronomical light pollution, Self-produced, 2024

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3.3.3 Solutions

A measurable mitigation of sky brightness can be found in the city Flagstaff in Arizona, where the inner city is located 1.5km from Lowell Observatory. Flagstaff is a city with around 76000 inhabitants and has a history of regulating light according to keep a low sky brightness since 1989. The main act from the city was to divide the city into three different lighting zones and to put up a limit of lumens per acre in the different lighting zones. This was to ensure to "balance the need to preserve Flagstaff's dark sky resource with the need for safe lighting practices" (Flagstaff municipality, 2016). The lighting zones were adopted according to their relative position to the observatory sites that should be kept dark.

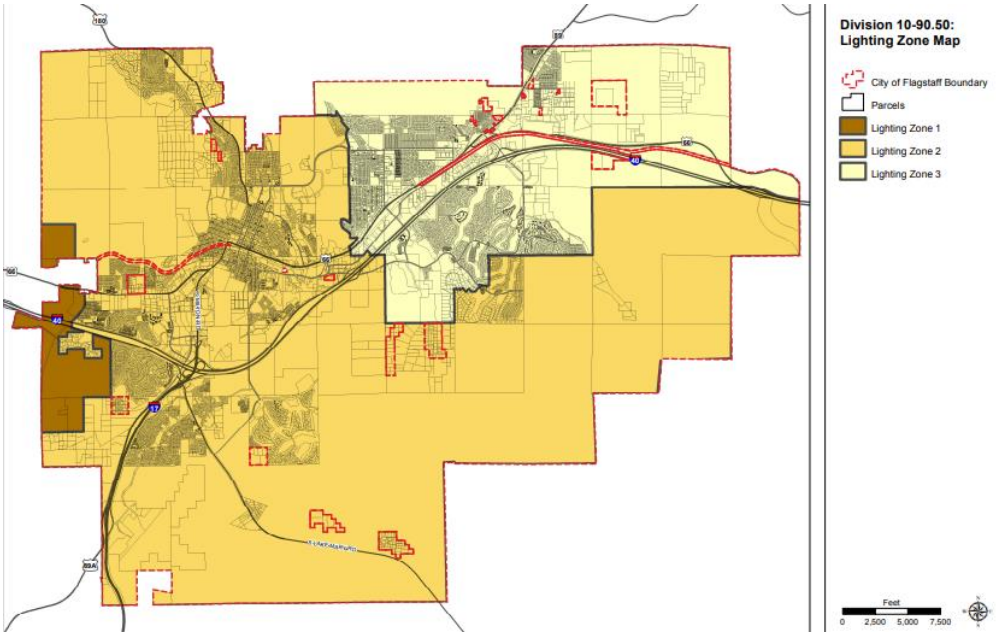


Figure 4, Flagstaff lighting zones, Flagstaff Municipality, 2011

There are three requirements that apply for all three zones.

- Use PCA (Phosphor-Converted Amber LED) or NBA (Narrow-Band Amber LED)
- All lighting should be shielded so the light only illuminates within the boundaries of the property.
- Lighting curfew applies to all lighting zones, except for business that are open during the night.

The three zones have different requirement of lumens per acre, where lighting zone 1 situated in the outskirts closest to the observations require less lumens per acre then in the middle of the city in zone 3.

Table 10-50.70.050.A: Maximum Total Outdoor Light Output Standards			
Land Use	**Zone 1**	**Zone 2**	**Zone 3**
Commercial, Industrial, and Multi-family Residential (lumens per net acre)			
Total (Fully Shielded and Partially Shielded)	25,000	50,000	100,000
Partially Shielded only	0	5,500	5,500
Non-LPS	2,500	5,000	10,000
Single-family Residential (lumens per parcel inclusive of accessory structures)			
Total (Fully Shielded and Partially Shielded)	10,000	10,000	10,000
Partially Shielded only	0	4,000	4,000

Figure 5, Max total lumen output, Flagstaff municipality, 2016

Within the lighting zones there are light classes to apply to different stakeholders in the zones. (Flagstaff municipality, 2016)

Class 1	Class 2	Class 3
All outdoor lighting used in	Outdoor lighting used in	Outdoor lighting used with

situations where maintaining accurate colour representation is essential for the activity's effectiveness. • "Sales areas outdoor, • Service stations • Primary customer building entry/exit areas • Seating areas outdoors at restaurants. • Recreational field/track/arena areas. • External and internal lighting for signs."	applications where providing general illumination for safety or security is the main priority. • "Pedestrian walkways • Driveways • Parking lots"	decorative means. • "Architectural illumination • Flag and monument lighting • Landscape lighting • The illumination of trees, shrubs, or other vegetation."

Table 1, Light classes, Flagstaff municipality, 2016

The three lighting classes have different guidelines for shielding within the lighting zones, the default stated is fully shielded luminaires with full cut-off above horizontal plane, 90 degrees from zenith.

Lamp Type and Lighting Class	Zone 1	Zone 2	Zone 3
Non-Residential[2] Outdoor Lighting			
Class 1 Lighting (Color Rendition):			
All lamp types and outputs	FS	FS	FS
Class 2 Lighting (General Illumination):			
All lamp types and outputs	FS	FS	FS
Class 3 Lighting (Decorative):			
All lamp types 2,500 lumens[1] or above per Fixture	X	A	FS
All lamp types below 2,500 lumens[1] per Fixture	FS	A[3]	A[3]
Residential[2] Outdoor Lighting			
Class 1-3 Lighting			
Lighting (Color Rendition):			
All lamp types 1,000 lumens[1] or above per Fixture	FS	FS	FS
All lamp types below 1,000 lumens[1] per Fixture	FS	A[3]	A[3]

Table 2, Fully shelded, Flagstaff municipality, 2016

The lighting in Flagstaff used to consist of low-pressure sodium lamps with a narrow band peaking at a wavelength at 589nm NBA (Flagstaff municipality, 2016) a lighting technique known for having a low impact on sky brightness due to the phenomenon known as the *Purkinje effect,* explained as "when light intensity decreases, red objects are perceived to fade faster than blue objects of the same brightness" (Luginbuhl, 2009). In 2012 Flagstaff retrofitted their street light fixtures into PCA and NBA Several measurements and comparisons shows that there was no increased sky brightness after the change to PCA and NBA (Flagstaff municipality, 2016) The sky brightness of Flagstaff has been extensively measured throughout the years. Every year there is an annual report produced that includes the sky brightness measurements. Flagstaff has kept low sky brightness, since the start of protecting the dark night sky (International Dark Sky, 2024)

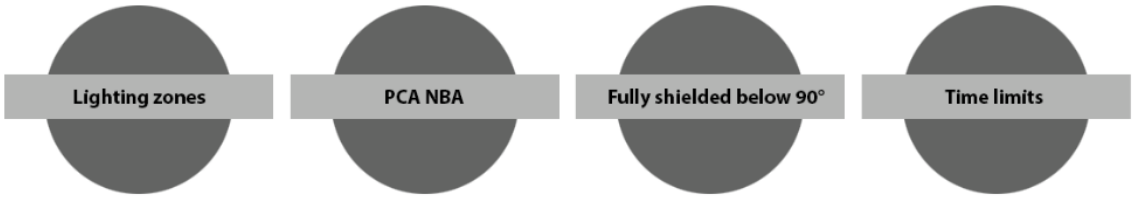


Figure 6, Solutions to astronomical light pollution, Self-produced, 2024

3.4 Ecological light pollution

Most of species on earth uses light as an energy provider or uses light as source of receiving information. Primary producers like plants and micro-organisms uses light to store energy and grow. The variability in light patterns acts as a regulatory mechanism for many organisms, influencing the timing and duration of various natural cycles such as days, months and seasons. Nocturnal living species is triggered to start their nightly activities with the change in the solar pattern. For some animals light serves as a navigational tool and some animals rely on starlight for navigation. (Hirt, et al., 2023)

In the two last decades there has been a rapid increase in research regarding the effects light pollution have on species on earth. In these days it has been know that ALAN affects biodiversity to a larger extent than previously known. (Svechkina, et al., 2020)

3.4.1 Consequenses

There are four main aspects of how light pollution affects living creatures,

1.
The first aspect is that ALAN suppresses the melatonin production, where even low levels seem to be disruptive. In many animals, melatonin helps control sleep, manage the internal circadian clock, lower stress, regulate the immune system, and prevent cancer. (Grubisic, et al., 2019)

2.
Another important aspect is that it is evident that animals exposed to ALAN can change patterns of how they eat, grow, reproduce, and survive. (Gaston & Alejandro Sánchez, 2022).

3.
The third is that ALAN can obstruct navigation and orientation by attract or repel or interfere with the internal orientation system. Consequences are collisions, disruptions in migratory patterns and rising risk of exposure predators, which subsequently can cause decline of populations in certain species. (Jägerbrand & Spoelstra, 2023)

4
The fourth is that ALAN disrupt the natural variations in length of daylight and darkness, the variations are important cues for timing seasonal events like when buds start growing, when animals reproduce, and when they should migrate. (Gaston & Alejandro Sánchez, 2022)

While the focus in research mostly has concerned how individual species are affected by ALAN, the most devastating effect comes from the potential disruption of whole

ecosystems. create a chain reaction of effects with wider consequences for human welfare. By disturbing natural processes in plants and animals, ALAN disrupts entire ecosystems and the benefits they offer, like pollination, controlling pests, and recycling nutrients. (Hirt, et al., 2023)

ALAN interferes with the interactions and relationships between different species in an ecosystem. It affects when and where species are active, as well as how well they can see and hide from predators. This can cause ripple effects in the relationships between different species, even affecting those not directly affected by artificial light (Briolat, et al., 2021).

The patterns of natural light have remained relatively constant throughout Earth's history. Consequently, organisms have not had to adapt to significant changes in light conditions. Therefore, when humans introduce light pollution, a novel and distinct type of disturbance, organisms and ecosystems may be ill-equipped to manage the change, as they have not evolved to cope with such changes (Hirt, et al., 2023).

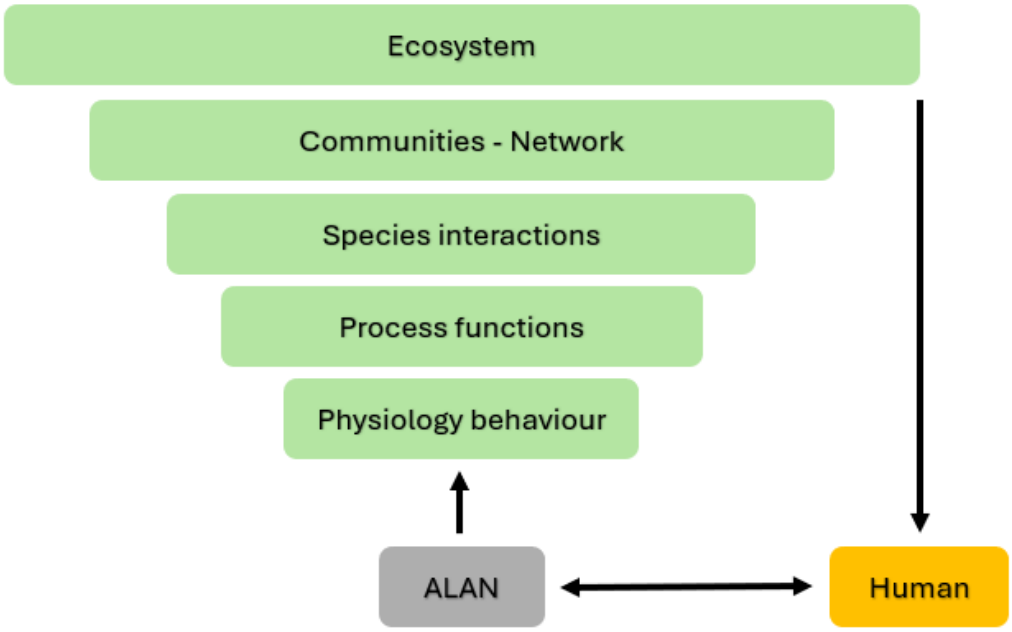


Figure 7, Consequenses of Ecological light pollution and relation to humans, Self-produced, 2024

3.4.2 Causes

The type of ALAN that causes ecological light pollution is a complex topic considering animals and plants react to different amount of light and different wavelengths in light. Skyglow are considered a cause of ecological light pollution, since skyglow extend beyond cities it can obscure or change the "natural nocturnal light sources" such as moon phases, starlight and polarized moonlight used by many species on land and on waters for visual cues and navigation (Owens, et al., 2020)

Much as the environment is affected by skyglow animals typically look towards the horizon or ground rather than the sky. Many species are directly exposed to light emitted, scattered and reflected below the horizontal plane. As a result of inverse square law light below horizontal plane can exceed the intensity of upward-emitted light. (Jägerbrand & Brutemark, 2022)

Direct illumination is the cause of *light traps*, where insects are drawn to the light and are not able to escape. Studies have shown that streetlights can act as light traps, the most dramatic effect showed from light with blue-rich content (Boyes, et al., 2021). Flight to light behaviour has a direct corelation with the wavelengths of the of the light with the total attractiveness by the light, where light with longer more red wavelengths attracted fewer insects (Donners, et al., 2018). However, this only applies to flight to light and may not apply to other species that being repelled by light, or for other species which uses different wavelengths. Highly specialized light spectra can be the cause of ecological traps for species incapable of perceiving the light, mistakenly assuming they are in a safe habitat. (Jägerbrand & Spoelstra, 2023)

Most birds migrate during night and uses light to navigate. ALAN can cause disruption in the navigation path; this applies specifically to a high contrast area where there is light in otherwise dark surrounding. Examples can be illuminated high buildings, light from lighthouses, ships and oil rigs out on the ocean. (Jägerbrand & Spoelstra, 2023)

For the marine life light pollution is caused by light that spills into the water from illuminated bridges, harbours and lights near the costal line. Those lights act as permanent increaser of the light at night for the marine life, shipping and light fisheries act as temporary increaser of the light at night for marine life. In the ocean, blue artificial light can penetrate deeper because red light gets absorbed more rapid due to the physical matter of water. This means that blue light has a greater potential to influence processes occurring at greater depths (Davies, et al., 2014) Research has shown that even low levels of illumination can have adverse effect on the marine environment (Jägerbrand & Spoelstra, 2023).

For those animals that act upon avoidance or *fear of light,* direct road light can act as a barrier that isolate populations and cut off their natural passageways (Bliss-Ketchum, et al., 2016). The indicators for trees and shrubs to prepare for seasonal changes are temperature and light, the immediate cause of light pollution for trees and shrubs are direct unshielded light that emit lights on the stem and leaves. Trees and shrubs are specifically vulnerable for light during the winter due to lighting can start processes that are dedicated to spring season (Czaja & Kołton, 2022). Many species have evolved to react upon polarized light, which naturally can be seen as light over water, man-made materials can together with artificial light act as polarized light, which also cause the attract-repel effect in some species. (Horváth, et al., 2009)

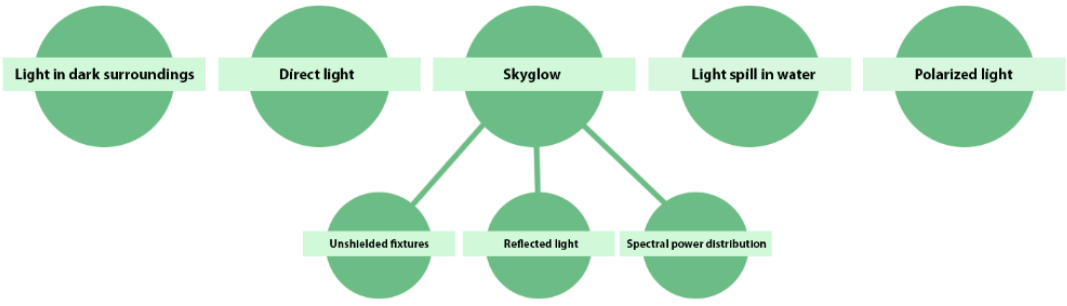


Figure 8, Causes of Ecological light pollution, Self-produced, 2024

3.4.3 Solutions

Where solutions to astronomical light pollution can be observed, measured and compared, solving how to reduce the ecological impact is a more intricate problem. It is a fact that ALAN has adverse effects on wildlife and whole ecosystems, however, there is not a scientific consensus about the long-term impact nor mitigation threshold measurements. (Jägerbrand & Spoelstra, 2023)

In Sweden it is regulated in the "The precautionary principle" that precautionary measures should be taken if there is a question if an action is potentially harmful to human health or the environment (Klimat- och näringslivsdepartementet, 1998). The precautionary measures should be taken despite absence of scientific consensus. The measures should prevent, restrict and counteract through protective measures and adaptations. (Naturvårdsverket, u.d.)

Since ecological light pollution do not have a research consensus nor consensus about mitigation thresholds it is advised to use precautionary measures (Science Communication Unit, UWE Bristol, 2023) (Hölker, et al., 2023) (Jägerbrand & Spoelstra, 2023).

Best practice guidelines can be implemented to follow precautionary measures, best practice can be described as the strategy that according to research most effectively approaches the problems that ALAN causes in a ecosystems, a given area or for specific species (Science Communication Unit, UWE Bristol, 2023).

Lighting zones can be used to categorise land areas into different zones, providing an overview of areas that need strategic natural environment protection. Zoning simplifies nature conservation efforts in landscape-level planning and assists in identifying lighting requirements for diverse urban development areas and functions. Zones can be categorized based on desired lighting levels, and corresponding limits on light emissions can established for each zone type. (Jägerbrand & Bouroussis, 2021)

One important solutions for ecological light pollution is to restrict where the used light is falling. For astronomical light pollution is restricted to avoid upward light, while ecological light pollution also benefits from darker skies the light on the ground is of more concern. (Jägerbrand & Spoelstra, 2023) Using the BUG-rating system (backlight, uplight and glare) allows for a stricter control of where lighting falls. Strictly shielded light can be prevented from falling on areas intended to be dark. This can specifically be implemented in marine areas, to avoid light spill in water. (Bureau of Land Management, 2023)

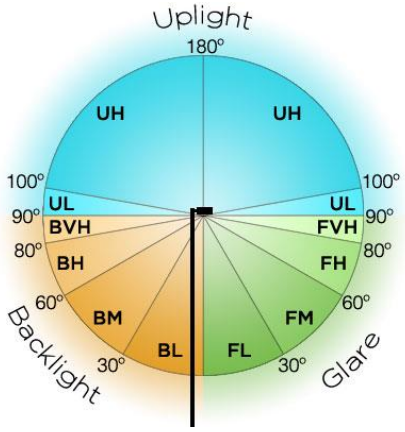


Figure 9, BUG-rating system, Take three inc, 2024

- Backlight – This is the light that is spilled from behind the fixture into areas where it is unwanted.
- Uplight – This is the resulting light spill above the top of the fixture
- Glare – Glare is the amount of front light in the forward zones and happens when the light is too strong or concentrated.

(Illuminating Engineering Society, 2017)

Applying a curfew and use adaptive lighting and dimming the light during the night has shown to lower the effect of ecological light pollution, it can still affecting certain species, and is not a solution per se, however, this can be a precautionary measure to have overall lower lights (Science Communication Unit, UWE Bristol, 2023). Switching off light during the night have the best practice, however it is notable that some species are more active during dawn than during night (Jägerbrand & Bouroussis, 2021).

Due to difficulties in accurately determining specific light intensity thresholds, A precautionary method can be to adopt a strategy for protected areas to maintain light levels below those typically experienced under moonlight. Moonlight illumination levels typically fall within the range of 0.05 to 0.1 lux. (Jägerbrand & Spoelstra, 2023)

There is no consensus about which colour of light to use, as animals see in different spectra. It is advised to avoid monochromatic light, except in situations where only marine life is affected (Science Communication Unit, UWE Bristol, 2023). However, as a best practice and precautionary measure, it is recommended to use ambient light with no blue content, since this appears to affect the fewest species (Jägerbrand & Bouroussis, 2021).

Another aspect is to implement and keep strict ALAN-free zones, this has shown to be of best practice to avoid the ecological damage that light pollution can have. The ALAN-free zones can apply to environmentally sensitive areas or ecosystems, intrinsically dark areas, nature reserves and habitats with endangered species in need of protection. Careful attention needs to be taken on where these zones applies and to offer buffer zones in the edges. (Science Communication Unit, UWE Bristol, 2023) Based on the precautionary principle, it appears wise to preserve ALAN-free zones of various sizes within urban landscapes for supporting organisms in urban environments (Gaston, et al., 2012).

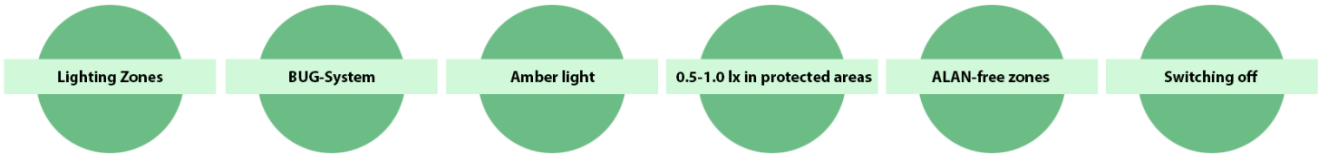


Figure 10, Solutions to Ecological light pollution, Self-produced, 2024

3.5 Impact on human health

While the cities are illuminated for humans and has in many aspect been illuminated to increase the standard for humans there are aspects of light pollution that concerns human health.

3.5.1 Consequenses

ALAN has been indicated to be linked with various human health problems such as cancer, obesity, sleep disorder, mental and neurological disorders and cardiovascular diseases (Cao, et al., 2023). While there is still a need for more research in the field to put a stronger link between ALAN and human health problems. Most of the researched symptoms connected with ALAN are all stemmed from the disruptive affect ALAN has on the bodily circadian rhythm. The human body has been evolved to be regulated by the complex mechanism that enables the functions and behaviour to be aligned with the regular day and night-cycle, known as the circadian rhythm. (Hicks, et al., 2020)

The circadian rhythm is mostly regulated by the change of light and darkness and controls the release of hormones, the temperature, the pattern of sleep, hunger and the process of digesting food (National Institute of General Medical Sciences, 2023). Disruption in the circadian rhythm and excessive exposure to light during the evening and nighttime can disturb the body's natural rhythm, hinder the release of melatonin, disrupt sleep, and strain the visual system. (Zielinska-Dabkowska, et al., 2023). Even though humans tend to benefit in other ways from light and seem more prawn to adjust to immediate short-term consequences in the disruption of circadian rhythm, the effects are similar to other living creatures.

3.5.1.1 Connectedness with nature

One under looked aspect of ALAN polluting the sky is when it takes away the ability to see the dark sky it is also a loss of experiencing nature. People are recognizing that fostering a connectedness with nature improves overall wellbeing. This connection with nature is considered a crucial aspect of wellbeing, akin to well-established factors such as income

and education. Nature connectedness can also be valuable to larger extent, since it is expected to lead to attitudes that support the environment and following positive actions by being open to sacrifice. (Lumber, et al., 2017)

In regard to the night sky, natural connectedness is fostered by devoting time to see and appreciate the wonders of the celestial universe, and by looking at the cultural and personal significance of the stars and night sky (Barnes & Passmore, 2024). Gallaway (2010) argues that the loss of night sky beauty needs to be considered since it has been essential for the development of human life, the reinvention of society, and gaining and using of knowledge. The author concludes that the most significant cost of light pollution may be the "aesthetic damages" because beauty is an essential component of the wholeness of human life.

Taking these into consideration a loss of the natural dark sky might also result in less connectedness to nature with side effects such as losing a source to human well-being and a willingness to preserve nature (Lumber, et al., 2017).

3.5.2 Causes

For humans who together with other species regulate the rhythm accordingly to light and darkness the immediate cause is that ALAN introduce more light at night which return more impulses and stimulation through the retina. That overall extra light comes from all the imposed ALAN. Skyglow plays a role in the overall extra light and so does obtrusive light that spill into homes, and exposure to direct light in cities and urban areas. (Liu, et al., 2023)

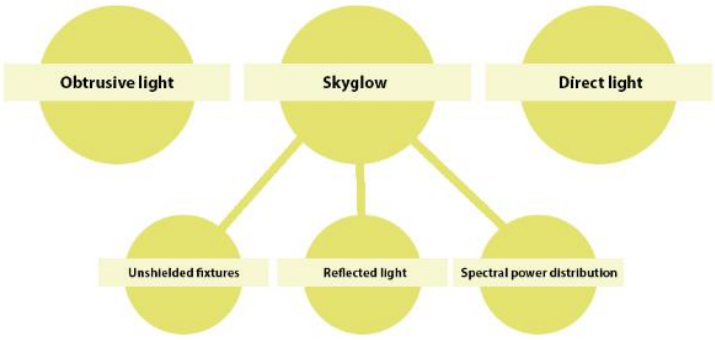


Figure 11, Causes of the human impact of light pollution, Self-produced, 2024

3.5.3 Solutions

To address solutions to the adverse impact ALAN can have on humans there is first a need to address misconceptions about safety that does not relate to science (Zielinska-Dabkowska, et al., 2023). There is limited support that brighter light supports safety and security. instead, a study found that reducing and balancing brightness can create a more relaxed atmosphere with enhanced visibility, fostering a stronger visual connection with others. This increased the feeling of safety and established both spatial and social connectedness between the space, its surroundings, and the people present (Hvass & Hansen, 2022). Another study concludes that there is no evidence of a link between higher rate of crimes while shutting off, dimming or using part night lighting (Steinbach, et al., 2015). Human benefit from glare free low lighting that make it easier to navigate,

detect objects and potentially dangerous situations (Zielinska-Dabkowska, et al., 2023). Intrusive light into homes can be regulated with BUG-rating system (See figure 9). An overall lower light level support the human natural circadian rhythm and humans are specifically sensitive to blue wavelength lights during the night (Bhadra, et al., 2017).

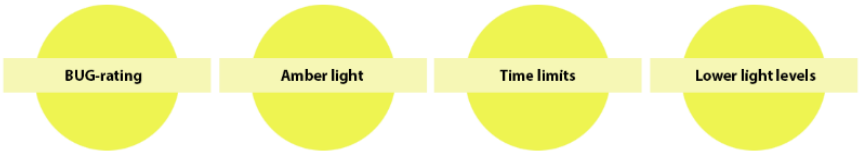


Figure 12, Solutions to the human impact of light pollution, Self-produced, 2024

3.6 An Ecocentric balanced design

To get an ecocentric balanced lighting design all of three aspects needs to be taken into consideration. Despite the absence of consensus regarding solutions to the ecological light pollution and the effect on human health there is still a lot of solutions with precautionary measures that can mitigate light pollution in general. Solutions should be designed to be versatile and flexible to be open for coming research consensus. (Jägerbrand & Spoelstra, 2023)

The starting point in most lighting design is human, to put both humans and nature as equals, the starting point of all lighting design should be darkness. Light pollution guidelines established by the Australian government recommend that lighting designs should prioritize natural darkness as the foundation. Artificial light should be used sparingly and only for well-defined purposes, in designated areas, and for the duration necessary for human activities, according to the Commonwealth of Australia (2020).

Gaston (2012) examined options for solutions to light pollution for ecological impact and astronomical impact in relation to "human security and amenity". in the table no change equals "0", a positive change equals "+" and "–" equals negative impact.

Option	Biodiversity impact	Cost and carbon saving impact	Human security and amenity	Dark skies impact
Maintain natural unlit areas	0	0	0	0
Remove lighting to extend natural unlit areas	+	+	0/-	+
Reduce duration of lighting	0/+	+	0/-	+
Reduce trespass of light	+	+	+/0	+
Reduce intensity of light	+	+	+/0/-	+
Broaden spectrum of light	-	+	+	-

Table 3, Solutions to light pollution and their impact, Gaston K, 2012

According to the table humans might not have an immediately win on possible solutions for light pollution , however there is also not something that is lost. And it might be the point in an ecocentric design where humans need to compromise.

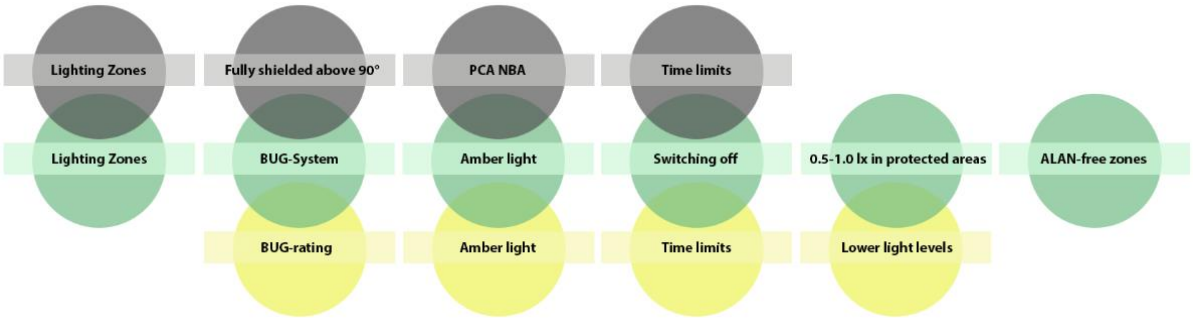


Figure 13, Considering solutions on all aspects, Self-produced, 2024

3.7 Legislation

Despite scientific knowledge of ALAN having adverse effect on astronomy, ecology and human health, European Union lacks a unified legislation on supranational level for regulating light pollution. ALAN is not yet recognized as a significant pollutant, so policies to reduce its negative effects are often not prioritized. (Widmer, et al., 2022)

In Sweden, it is divided who is responsible for the public lighting. The Swedish Transport Administration is responsible for some parts and the municipalities are responsible for some parts. Around 430000 km of the roads in Sweden are private, 100000 km are state roads and 40000 km are municipal roads. of the state roads around 9% have lighting, where The Swedish Transport Administration is responsible for 3% of the lighting and municipalities are responsible for the rest. (Trafikverket, 2023)

In Sweden the municipalities are obliged to follow the regulations in TSFS 2021:122 (Transportstyrelsens föreskrifter och allmänna råd) (The Swedish Transport Agency's regulations and general advice), this is a general regulation and for more detailed and specific advice municipalities are guided to VGU (Väg & Gators utforming) (Design of roads and streets) and the standard SS-EN 13201:2 (Vägbelysning) (Road lighting). In TSFS 2021:122 there is a part that says that light pollution should be limited to reduce the adverse effect on animal life and light pollution that impacts light-sensitive and endangered species should be specifically restricted. Lighting should be designed to minimize barrier effects that disrupt the natural movement patterns of animals. It is advised to reduce the spatial dispersion from light sources or by lowering the intensity of lighting during periods of low traffic (Transportstyrelsen, 2021).

For The Swedish Transport Administration, it is mandatory to follow their own guidelines in VGU, for municipalities it is not imperative to use VGU and may only function as a guide (Sveriges Kommuner och Regioner, 2021).

In VGU 2022 there are guidelines directed towards light pollution.

- Ground rule: No lighting outside urban areas. In Sweden an urban area (tätort) is defined by a contiguous settlement with at least 200 inhabitants (Statistiska Centrabyrån, 2022).
- Lighting fixtures should not spread lighting in the wrong direction and should therefore have flat glass.
- The colour temperature should be 3000K and with less part of blue light.
- All lighting fixtures should be dimmed during the night down to 40% compared to evening light.
- Adaptive lighting according to lighting in the area.

(VGU, 2022)

In November 2024 new rules and guidelines regarding light pollution will be implemented in VGU. There is a demand for upward light ratio and all lighting fixtures should only emit light downwards.

- There is a demand to mitigate excessive lighting, there should be maximum 20% over regulation demand.
- In the new regulation there is a demand for attendance-controlled lighting for GCM (gång, cykel och moped)(pedestrian, bicycle and moped).
- The lighting planning tool from The Swedish administration of transport should be used to control sensitive areas.

(Trafikverket, 2023)

These new rules do not apply for existing lighting only for prospective (Trafikverket, 2023), however, The Swedish Transport Administration strategy focuses on placing lighting where it is most beneficial. For state-owned lighting, the Swedish Transport Administration assesses its necessity. If the lighting does not meet the required criteria, an investigation can be initiated to consider its removal, primarily to reduce energy consumption and minimize disturbances to wildlife and nature (Trafikverket, 2022).

4 ANALYSIS

This section will start with an experience of darkness and analysing a city in terms of light pollution through zones, to provide information for how and where a new lighting plan should be outlined.

4.1 Darkness

"To know the dark, go dark"
Wendel Barry, 1970

With the diminishing nights and shifting baseline syndrome, there was a need to experience the darkness on first hand, to experience why it was swept away and how it actually is to experience darkness.

Two sites were visited, one site in a rural area with cloudy condition to see if it could be complete darkness, and another site with the chance of a true starry sky.

4.1.1 Experience

March 2nd. Cloudy night: Hälleskogsbrännans nature reserve, Västerås municipality

There was a knowing that if the site was not far away enough from settlements the cloudy sky would instead be lit up by light pollution from nearby villages and the cloud coverage would help the sky to exceed sky brightness of a starry sky, and the snow coverage would contribute even more. If the site would be far away enough the clouds would instead make it pitch black.

It took around three hours to walk to the centre of the nature reserve. Put up the tent in the middle of the burnt down forest and waited for the astronomical twilight. There is a tower in the middle where there is possible to view the area.

Picture 3, Hälleskogsbrännan Nature reserve, Self-produced, 2024

When the darkness hit the area the SQM-L meter could not pick up any light to be able to give measurements. The camera could not pick up any light to take pictures, and the eyes could not pick up any light to even see the hands. The compact darkness made the eyes lose all its purpose, there was not even light engage a scotopic vision. The ears started to listen in a new way. Listening to every sound that could be in the area, the ears even started to listen to sound it could not even hear. The brain tried to explain every sound; It must have been the wind. Knowing that there are animals which can pick up every movement that are made in the forest. There was a wonder if our ancestor before the invention of light also felt watched. And there was a sense of losing all human purpose, could not move, could not flee, just be. It was not a time for human.

March 8th . Starry sky: Färnebofjärden national park. Sandviken municipality.

There was a knowing that this might be one of the darkest spot in the lower part of Sweden, which have very few spots left. However, it was not expected to be truly dark, instead a Class 3 on the Borle scale, a rural sky.

The site resides along Dalälven, a river in the middle of the park. Since arriving after astronomical twilight, it was decided to walk the 5km in dark to the decided stargazing spot. It took around 20 minutes for the eyes to adapt to be able to see a little bit in front of the feet. The eyes started to look for movements, reacting to branches waving in the wind. The walk was slow and cautious, one small step ahead of the other. The starry sky glimpsed above head through the high-top trees. Another round of thinking about the ancestors, how appreciated a cloudless night in the North must have been. The stargazing spot was striking, the sky was flooded with stars, and there was a wonder when

this was experienced last time, many years ago. There is a time for humans under the stars.

Picture 4, Färnebofjärden, Self-produced, 2024

4.2 Gävle – A case study

Gävle is a city situated in the central part of Sweden and have a population of around 77000 in Gävle city and around 103000 in the municipality (Statistiska Centralbyrån, 2023). Gävle has a population growth of approximately 1000 people per year (Gävle Municipality, 2024). Gävle is considered a larger city by Swedish standards (Sveriges Kommuner och Regioner, 2022).

Figure 14, Gävle, Edited from Free Maps, 2024

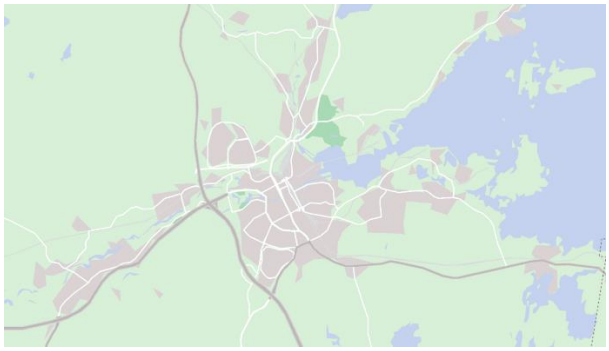
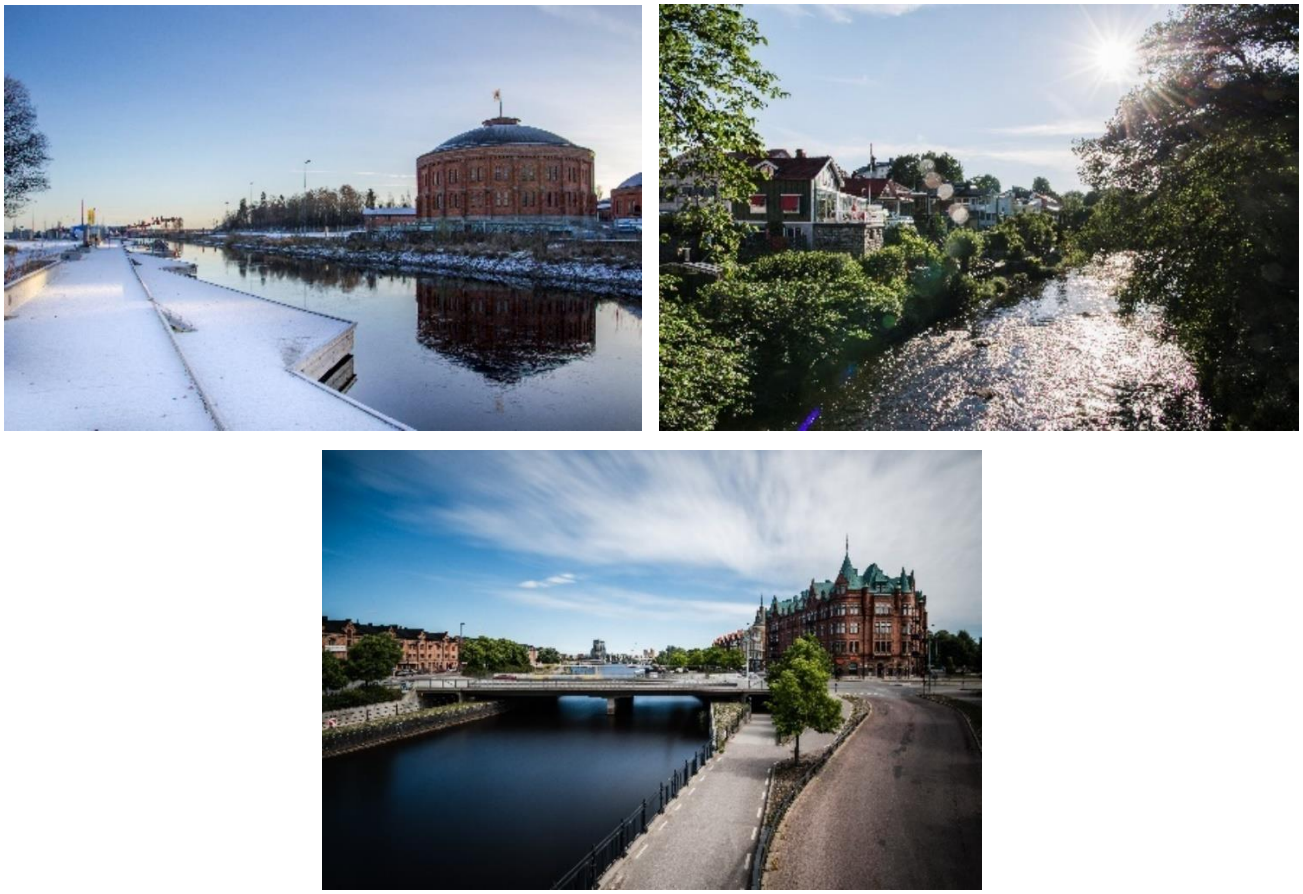


Figure 15, Gävle City, From Free Maps, 2024

The costal location of Gävle in the Bothnian Sea, have historically made it a principal import and export city. Today it is the third largest container port in Sweden, an important logistic point for exporting paper, wood and steel from the central region of Sweden (Port of Gävle, 2024).

Located on the 60th parallel north Gävle is characterized by dark winters and bright summers. During the winter solstice, there are 5 hours and 40 minutes of daylight (Franke, 2022), while during the summer solstice, there are 19 hours of daylight. However, since the sun does not go below 6 degrees, it is bright all hours of the day (Franke, 2019).

Gävle was chosen for having all the attributes of a city where there is a need for light to function for its citizen and business industries while also having a lot of preserved areas to protect.



Picture 5-7, Gävle City, Copyright Gävle municipality, Used with permission, 2024

4.2.1 Nature

In Sweden nature reserves are the primary method for long-term conservation of valuable natural areas. Nature reserves typically encompass extensive areas of valuable nature, including waterways, marine environments, forests, open cultural landscapes, and boglands. Nature reserves are safeguarded under The Swedish Environmental Code, which is the legal framework for creating nature reserves. Both municipalities and county administrations can form a nature reserve. Nature reserves in Sweden are typically created to safeguard valuable ecosystems and endangered species to maintain biodiversity. However, creating nature reserves also aim to ensure that people have access to nature areas for recreation and outdoor activities. (Naturvårdsverket, 2024)

Gävle municipality constitutes of 52 nature reserves, ranging from forest to boglands.

Some areas in Gävle are protected by Natura 2000. Natura 2000 forms a network of protected areas in European union., The Natura 2000 is designated to preserve valuable areas which constitute habitats or species deemed especially worthy of protection (European environment agency, 2023). The EU's species and habitats directive serves as the main tool for fulfilling the Convention on Biological Diversity goals to promote biodiversity and protect endangered species and habitats. To achieve this, all countries in EU designate specific areas, known as Natura 2000 sites, to create a coherent network. These sites constitute of species or habitats of high conservation value. Each designated area must implement necessary measures to achieve the biodiversity goal. (Naturvårdsverket, 2023)

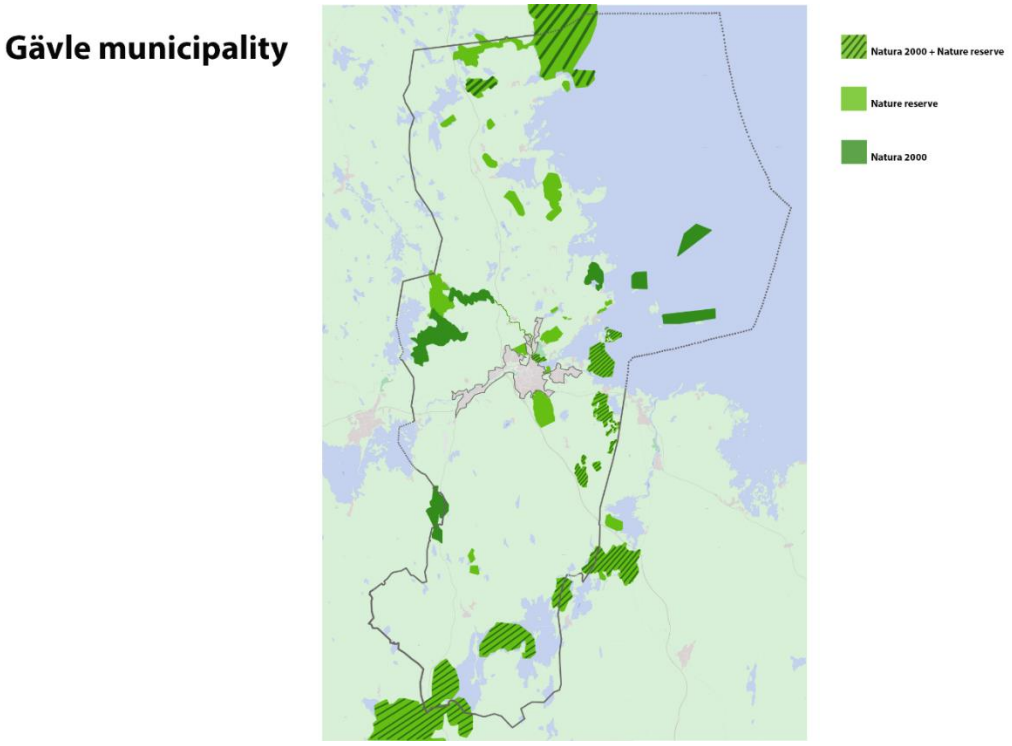


Figure 16, Natue reserve and Natura 2000, Edited on Google maps, 2024

4.2.2 Lighting

Gävle municipality does not have a designated lighting master plan, a part of Gävle technical handbook contain some remarks about lighting. The lighting of the city has two aims, one is the functional lighting, and the other part is the decorative lighting. The purpose of the functional lighting is to ensure safety in the traffic and to illuminate interchanges and passages. Lighting is described as the core of the city and should help to create a comprehensible urban environment that feels safe at night. The lighting should also help to create a comprehensible urban environment that feels safe at night. The decorative lighting should enhance the functional lighting, adding an aesthetic and stimulating dimension to the spaces. Gävle municipality acknowledges that lighting can create opportunities for the city, and it is important to Gävle municipality to use lighting to create an impression, coherence and identity for the city (Gävle municipality, 2022).

In the Architectural strategy for Gävle municipality, the vision about lighting is expressed as something that should have high quality in the infrastructure, parks and squares. The urban planning principles highlights that main entrances facing the street should have ample lighting to ensure residents' safety at night. The goal of this is also enhances the lighting of the street and overall atmosphere. (Gävle municipality, 2020)

Gävle municipality is responsible for the lighting in the inner city and on the municipally owned roads and areas. is responsible for the lighting on the government owed roads. The private land and roads might have community owned roads. (Trafikverket, 2021)

Figure 17, Who owns the lighting?, Lantmäteriet, 2024

4.2.3 Light pollution in Gävle

Gävle municipality works environmentally by following the municipality's environmental plan, Environmental Strategic Program 2.0, the goal is to create a green and sustainable Gävle. The program highlights points about clean water, clean air, natural spaces rich in biodiversity and that Gävle municipality will enable residents and businesses to adopt environmentally sustainable practices. They do not include anything about lighting or light pollution. (Gävle municipality, 2020)

Light pollution maps from VIIRS 2022 showing Flagstaff showing sky brightness, Flagstaff to the left and Gävle to the right as comparison below. The cities have approximately the same size and population. Measurements in mag/arcsec^2. 22,00 mag/arcsec^2 on the scale is a sky without any added sky brightness, below 18,38 mag/arcsec^2 is a heavily polluted inner city sky.

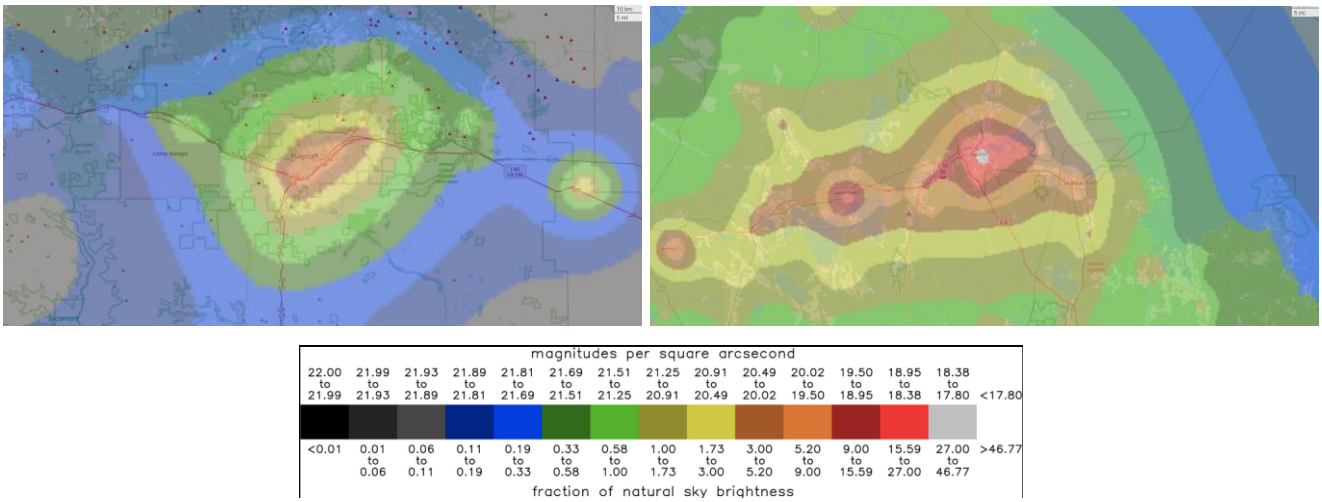


Figure 18, Gävle compared to Flagstaff, Light pollution map, 2022

4.3 Outside-in

This section will look at the impact the lighting in a city will have on the environment. This will include looking at the astronomical, ecological and human impact in the surrounding. And will set the foundation for where the new design concept should be made.

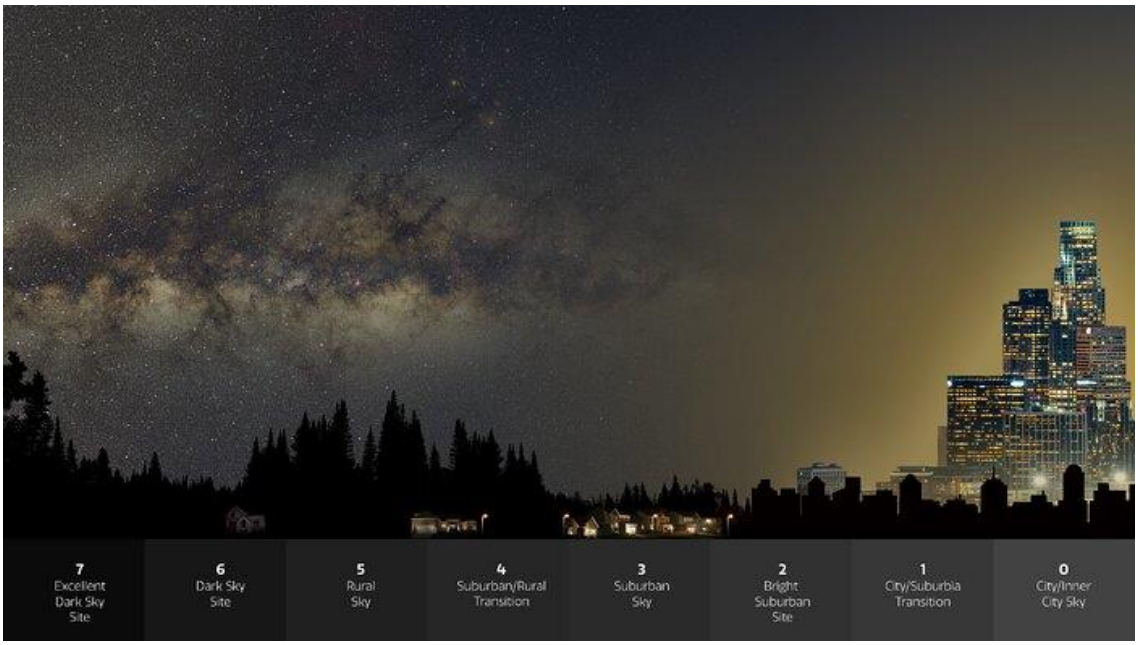
To examine how a city like Gävle affects its surrounding with light the analysis uses the ecocentric 'outside-in' approach. Starting from the outskirts and going inwards. A medium-sized city is estimated to affect an area of 100km from away from the city. Looking at where Gävle is located there are several other villages and cities in the larger area which will contribute to light pollution and their contribution blends in the area and there is no way to absolutely distinguish one areas pollution from the other, looking at the contribution of light pollution from Gävle will be a sum from surrounding areas.

4.3.1 Existing Lighting zones

The area where Gävle is located will be divided into zones according to the CIE (International Comission on Illumination, 2020), this will be done to see how different areas contribute to light pollution. This helps identify which areas need special attention for preserving nature and protecting them from future light pollution. These zones also provide a framework for controlling light pollution in cities or regions. Dividing areas into zones makes it easier to plan for nature conservation and urban development, ensuring that lighting is appropriate for different areas and purposes (Jägerbrand & Spoelstra, 2023). The estimations of the zones is guided by the light pollution maps (Light pollution map, 2022) and finetuned with observations.

The existing lighting zones in Gävle are in zone 2-4, zone 0-1 doesn't exist within Gävle municipality (See picture 8 and table 4).

Bortle scale (visual scale)



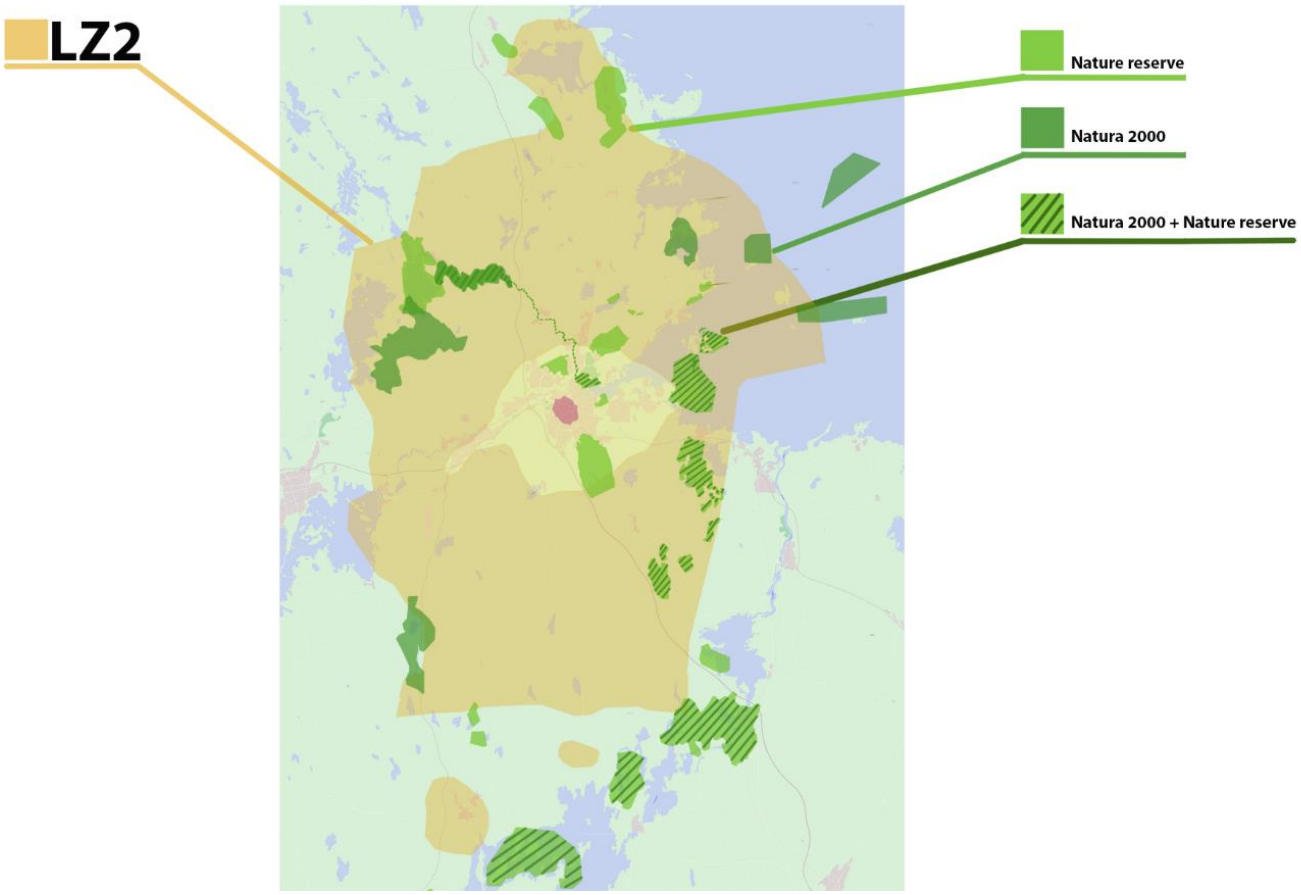
Picture 8, Bortle Scale, P. Marenfeld, 2022, CC BY 4.0

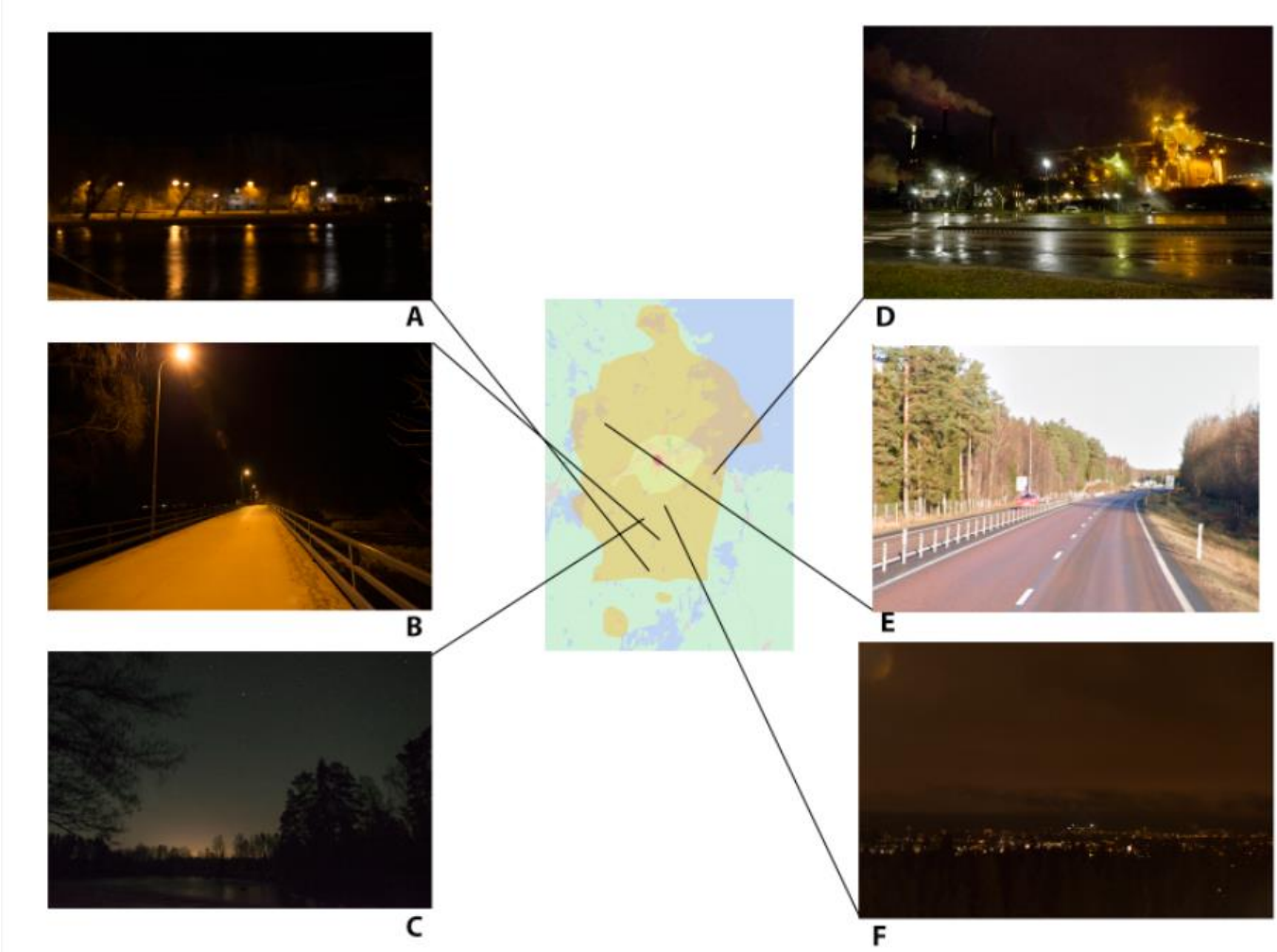
Lighting Zone	SQM (mag/arcsec²)	Bortle Scale (visual scale)	Description
4	<18.38	8-9	Places with human activity where people are accustomed to "high levels of light". Lighting is typically deemed essential for safety, security, and convenience, and is often consistent and continuous.
3	18.38-19.50	6-7	Placed of human activity where people are used to "moderately high light levels". Lighting is usually preferred for safety, security, and convenience, and is often consistent and continuous.
2	19.50-21.69	4-5	Places of human activity where people are accustomed to "moderate light levels". Lighting is often used for safety and convenience, but it does not need to be uniform or continuous
1	21.69-21.99	2-3	Areas where lighting could negatively impact flora and fauna or disrupt the area's character. Human residents and users are accustomed to low light levels. Lighting might be used for safety and convenience, but it is not necessarily consistent or continuous.
0	21.99-22.00	1	Areas where lighting would significantly and negatively impact the natural environment, disturbing the biological cycles of plants and animals and/or diminishing human enjoyment and appreciation of nature. In these areas, human activity is considered less important than preserving the natural environment.

Table 4, Lighting zones description, International Dark sky, 2015

4.3.2 Lighting Zone 2:

In the outskirts of the Gävle about 50km from the centre the direct light from the city is not visible, however the sky is brighter than a pristine starry sky. This area is more affected by the light from LZ4 and LZ3 than it is from light within this area, The roads only have lighting at the exits and limited lighting in the inhabited areas. The concerns in this area are the industrial sites, which have massive lighting close nature areas.





Picture 9-14, Linging zone 2, Self-produced, 2024

A: Lights in water next to a nature preserve area

B: Light spill in water, light that are on in low inhabited area

C: Skyglow from Gävle city, in nature reserve

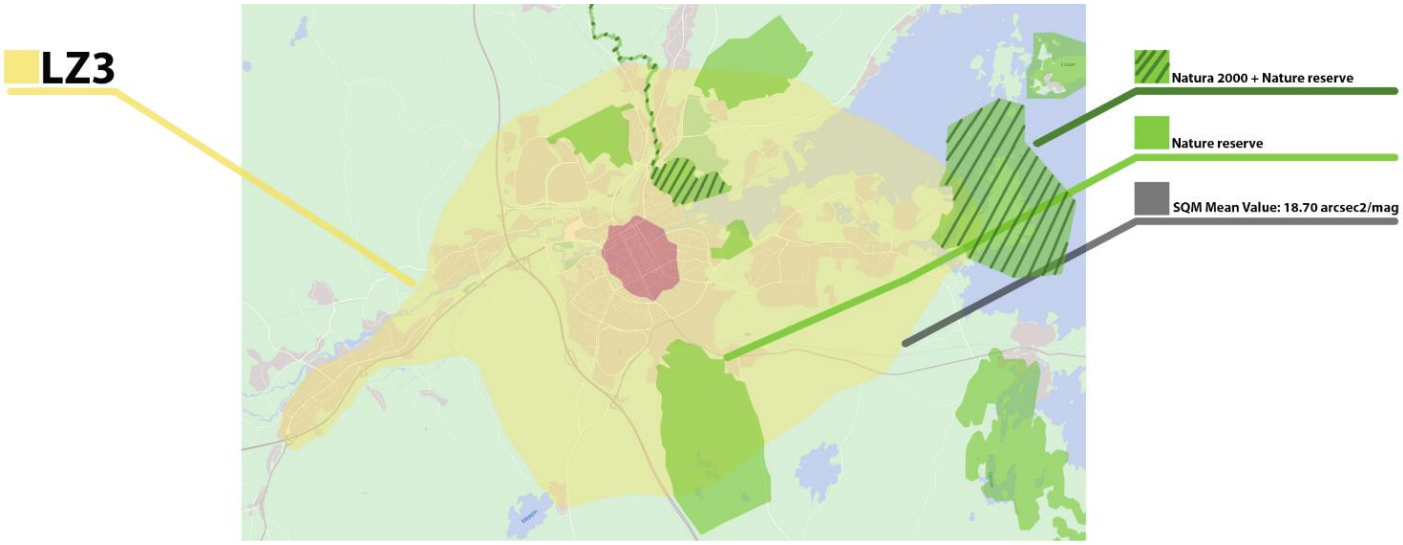
D: Industrial area

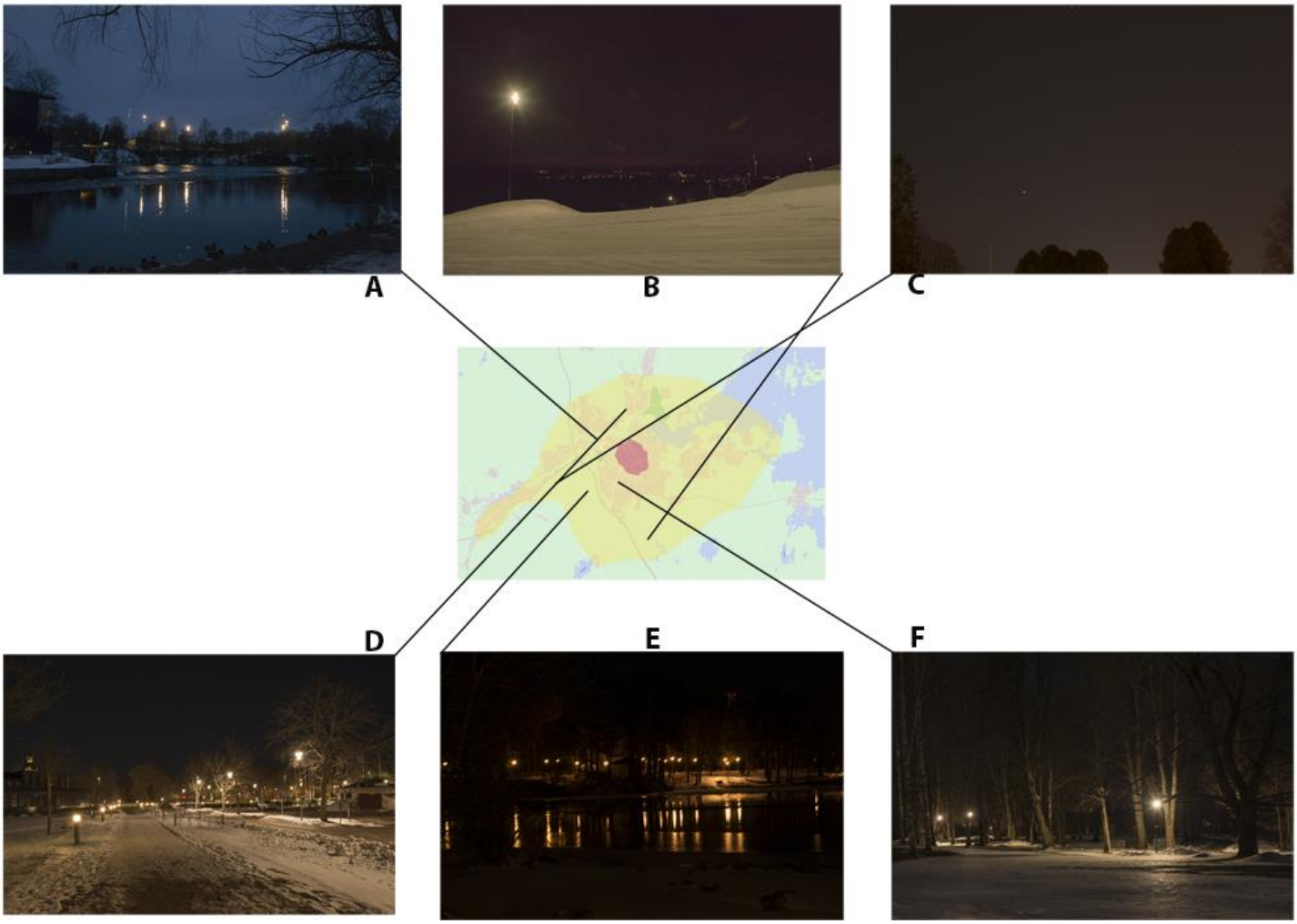
E: No lights on highway

F: Skyglow from Gävle city

4.3.3 Lighting Zone 3:

This zone is mostly residential homes, a few industrial areas, apartments mixed with houses. This zone have a high light pollution indicator. The main concern in this area is that the zone contain nature reserves and Natura 2000 areas or border.





Picture 15-20, Linging zone 1, Self-produced, 2024

A: Sports lighting visible from afar.

B: Unshielded sports lighting

C: Starry sky photographed from open area

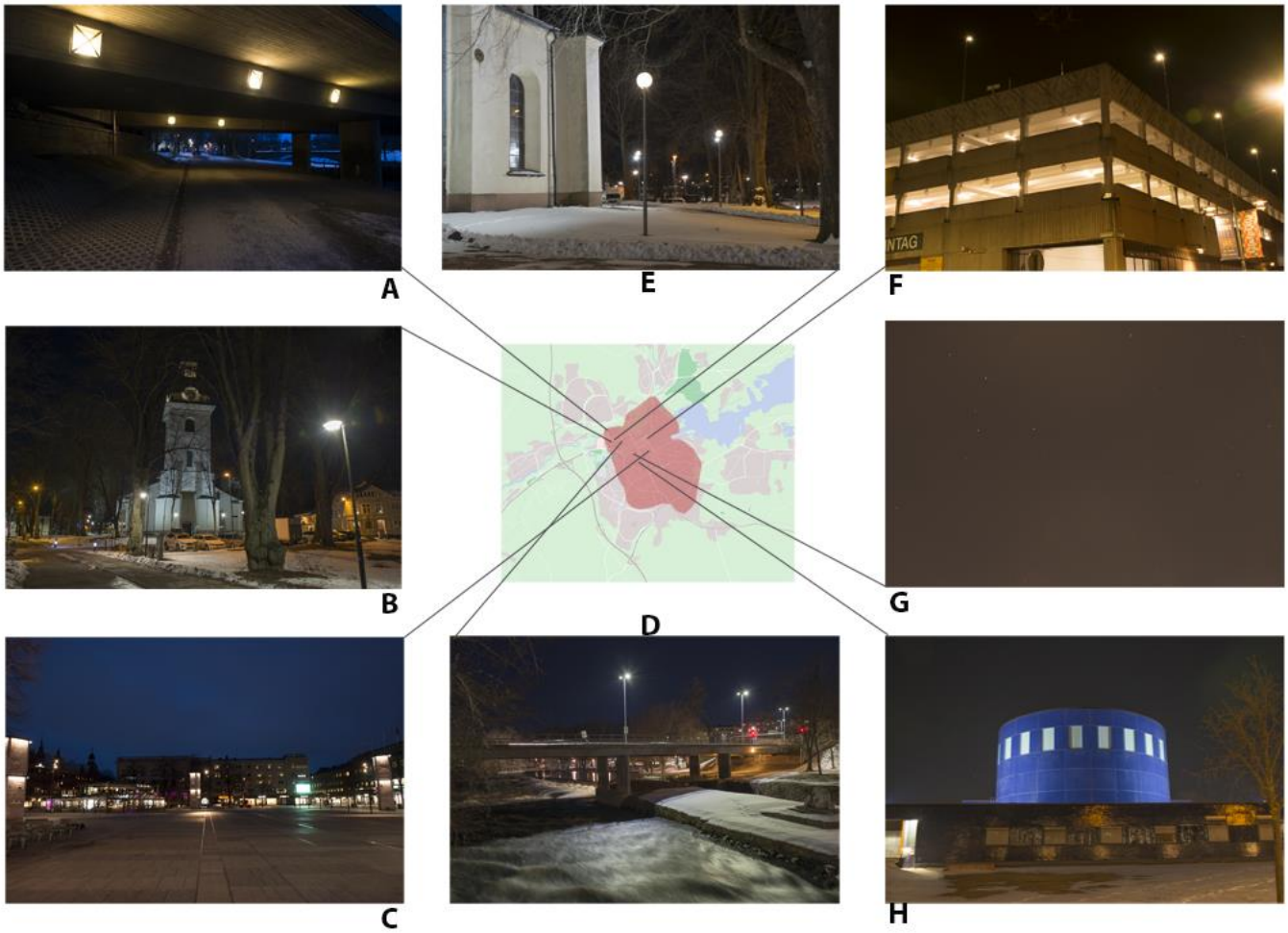
D: Parking lot with no cars

E: Light in water

F: Strong unshielded light in park

4.3.4 Lighting Zone 4:

According to light pollution map this is the zone that contribute most to light pollution in terms of skyglow. In Gävle this zone is residential houses mixed with offices and shops. These is where the main square is located and all the important services. This is the most busy part of Gävle.



Picture 20-28, Linging zone 4, Self-produced, 2024

A: Light pointing straight out

B: Upward light and a lot of spill light from from fixtures, overall overly lite area

C: Main square, Dark spots in the middle, many bilboards

D: Glary light from road on bridge. Light spills into water from bridge

E: Fixtures with light in all directions.

F: Light from parking house/shopping centre goes to residential home across the street.

G: Night sky photographed from main square

H: Cold light, upward light

4.4 Research question

From the theory and the analysis, a research question was formed to give a foundation for the design.

How can an ecocentric lighting design concept in a city be composed to avoid all aspects of light pollution; ecological, astronomical and human health.

5 DESIGN

This section will propose a lighting ordinance for Gävle municipality based on found research regarding astronomical, ecological and impact on humans. This section will also highlight main principles with illustrated lighting design suggestions according to the proposed lighting ordinance.

5.1 Proposed lighting ordinance

The main objective of the proposed lighting ordinance is to think of all aspects of light pollution, but also finding the balance to be a place for humans.

5.1.1 Shielding

All lighting should use lighting with a BUG-rate of upward light to zero, named as U0 in the BUG-rating system. Ideally, the beam angle cut-off should not exceed 60° for directional luminaires with symmetrical distribution. Uplight can only be considered when the upward spill is contained.

5.1.2 Colour temperature.

Best practice to avoid light pollution is to use warm light, CCT (colour corrected temperature) is insufficient as a marker for light pollution, the recommendation is instead to use light with maximum 5% of the spectrum in 490nm. At times this can correlate with warmer colours in the CCT-scale, however, it is advised to decide luminaires based on Spectral power distribution.

5.1.3 Light levels

There are two way of keeping the light levels low, the first is to count lumens per acre, a recommendation is to have maximum 25000 lumens per acre in inner cities and, the second is to keep average of 10 lux across the site irrespective of the area size, shielding and type of area. This should be used as maximum and not design goals.

5.1.4 Curfew

It is advice to have a general recommendation that lighting should be off or dimmed after 10 p.m and 6 a.m. This curfew applies different to different lighting zones; however this should be the default state.

5.1.5 Street lighting

The street lighting follows The Swedish Transport Administration upcoming regulation for 2024, where street lighting is not used outside urban areas and attendance-controlled lighting on walking and bicycle ways. In addition, the BUG-rating system can be used to not cause back light into protected areas.

5.1.6 Signs

It is advised that all signs that are permanently installed should be illuminated with downlight or background light. All illuminated signs could be included in the curfew be shut off at 10:00 p.m. or within one hour of the end of normal business hours, whichever occurs later. It is also advised that all sign illumination comply with the overall

recommended spectral power distribution where the blue-white content is kept below 490nm must be <5%.

5.1.7 Proposed Lighting zones

A proposition for new lighting zones uses Model Lighting Ordinance (IDA & IES, 2011) was The proposed new lighting zones are outlined according to IES zoning system (IES RP-33) and European union recommendations for new legislation (Science Communication Unit, UWE Bristol, 2023). The zones are based on population density in the area, use of the area and if the area is protected.

There are five lighting zones (See Table 4). Foremost it is advised that no zone will be a Lighting zone 4 because of the high effect on other areas (IDA & IES, 2011).

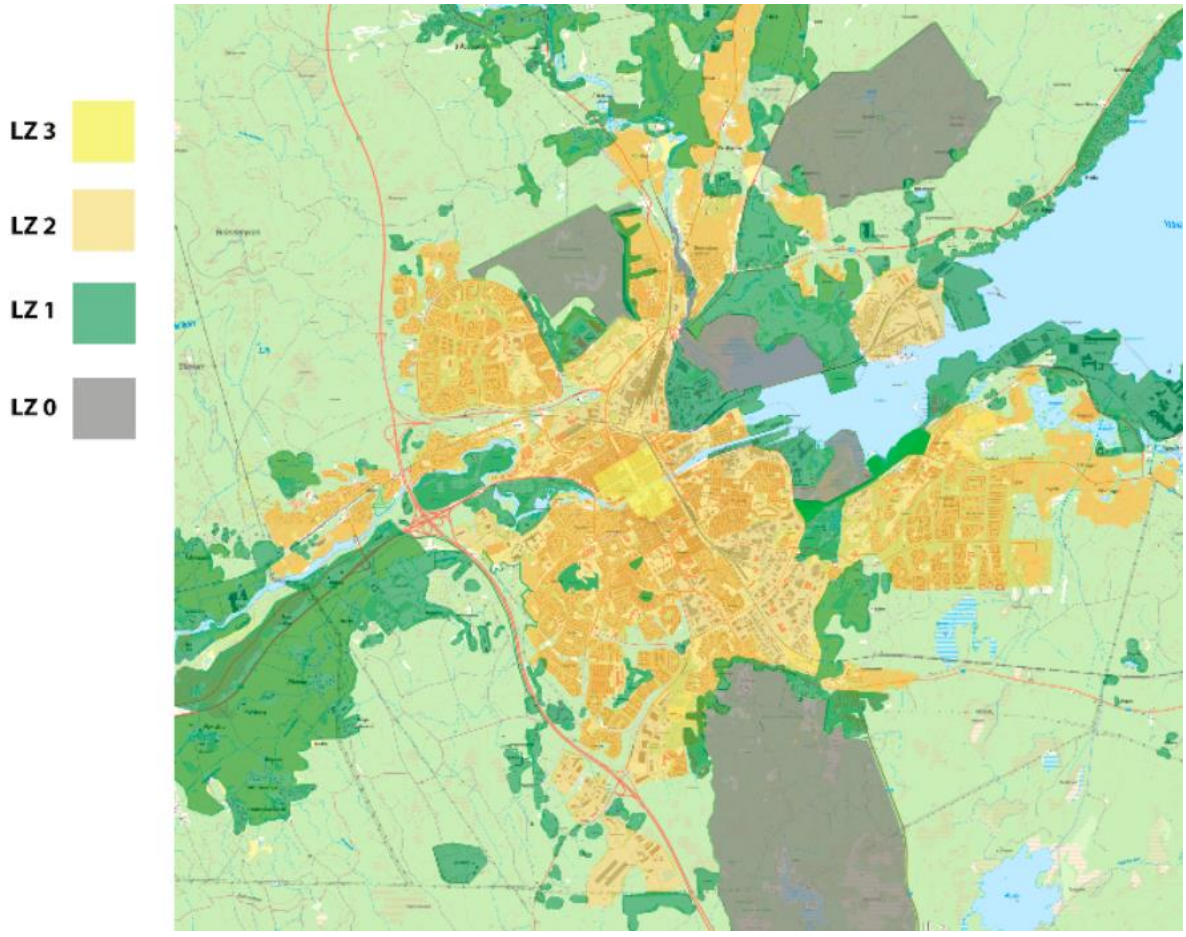


Figure 19, Preferred lighting zones, Self-produced, 2024

5.1.7.1 Lighting zone 3

The inner city is from where existing lighting zones have the most contribution to light pollution in terms of sky brightness. This is the area with most people and most light, in Gävle there are many places in the inner city where there are only pedestrian streets. The lighting is there for security and not for safety in regard to possible accidents. This area has the least effect on ecological light pollution in terms of obtrusive light, simple because this is a place for humans. However, humans are also the most affected of this area. What is needed in this epicentre of illumination is to make sure that lighting only light up where it's needed and not contribute to skyglow. The pedestrian streets in the inner city does not

have any lighting class legislation instead it is advised to have lower lighting for comfort and glare and to not produce intrusive light into residential homes.

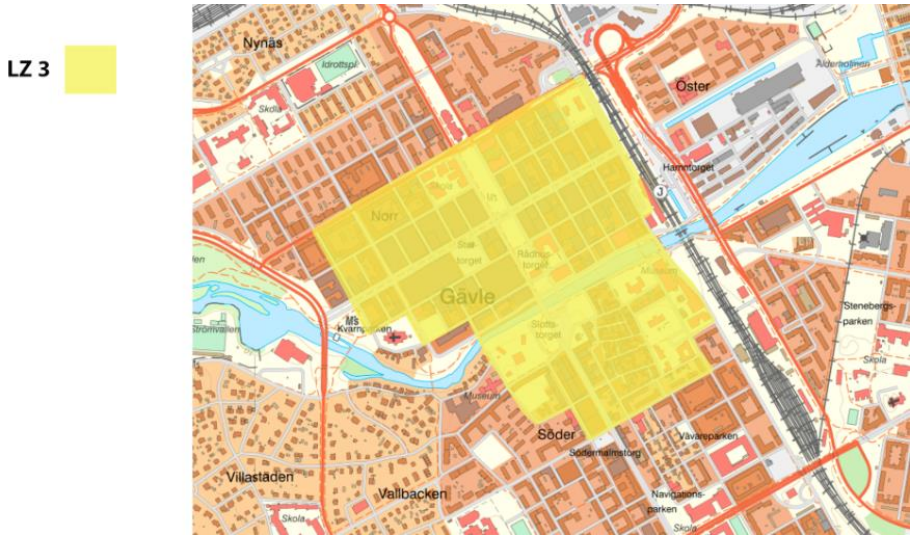


Figure 20, Preferred lighting zone 3, Edited on Lantmäteriets maps, 2024

Lighting zone 3 should follow the general rules and is advised to not shut off light but to dim the light during the night. Much of the light pollution that comes from inner city also comes from light that goes slightly over 90 degrees, which are coming from advertising billboards, illuminated signs, decorative lighting in the city.

5.1.7.1.1 The square - Stora Torget

Suggestion for the inner-city square – Stora torget, keeping lighting poles low, BUG-rating is set to U0 and light angel kept under 70 degrees to not cause obstrusive light. The granite ground is around 10% more reflective than asphalt and will make it brighter which should be regulated with light levels. The existing lighting on the statues can be filtered or retrofitted to monocromatic red light to set charactere to the square and also give orientations clues. The lighting on the square is worked with the principle that not all need to illuminated, instead the lighting can create paths where people can walk.

Picture 21-22, **The inner square now, Self-produced, 2024**

Suggested lighting for the square.

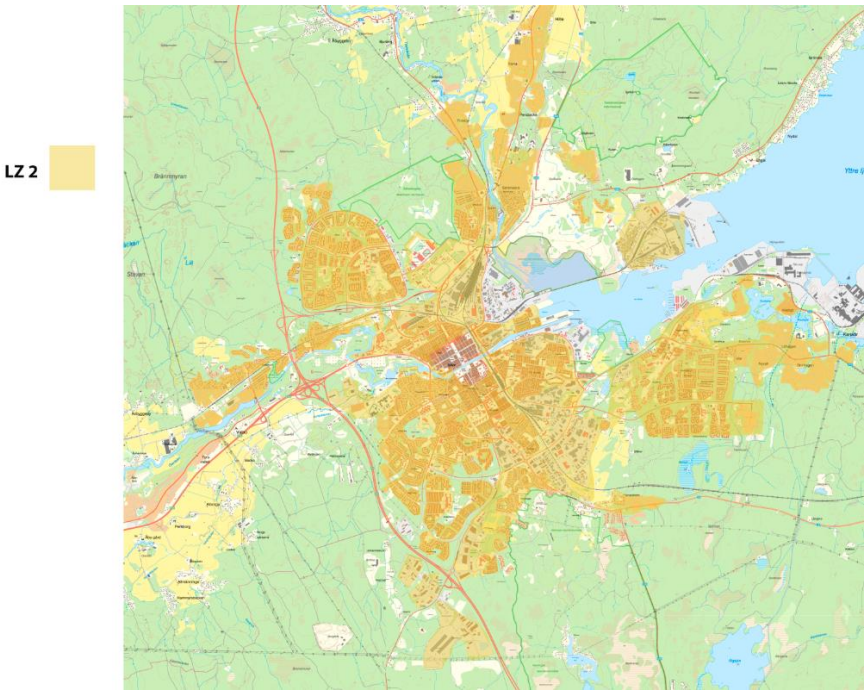
Decorative downlight, fully cut off above, that also can give visual cues.

Shielded functional lighting with a cut-off of to not fall into peoples homes, nor contribute to sky brightess.

5.1.7.2 Lighting zone 2

This zone is considered the default zone in built environment, the existing area here in Gävle is considered the second biggest contributor to sky brightness. Some places in this area act as buffer-zone

The biggest general issue in this zone is that it might border to nature reserves, and in borders to protected areas the light needs to be shut off during the night. This area is highly populated and contains mostly of residential homes and businesses. The areas close to water should be fully cut of in the back to not spill any light in the water.



5.1.7.2.1 The church

The church is a place

Picture 21-22, **The church now, Self-produced, 2024**

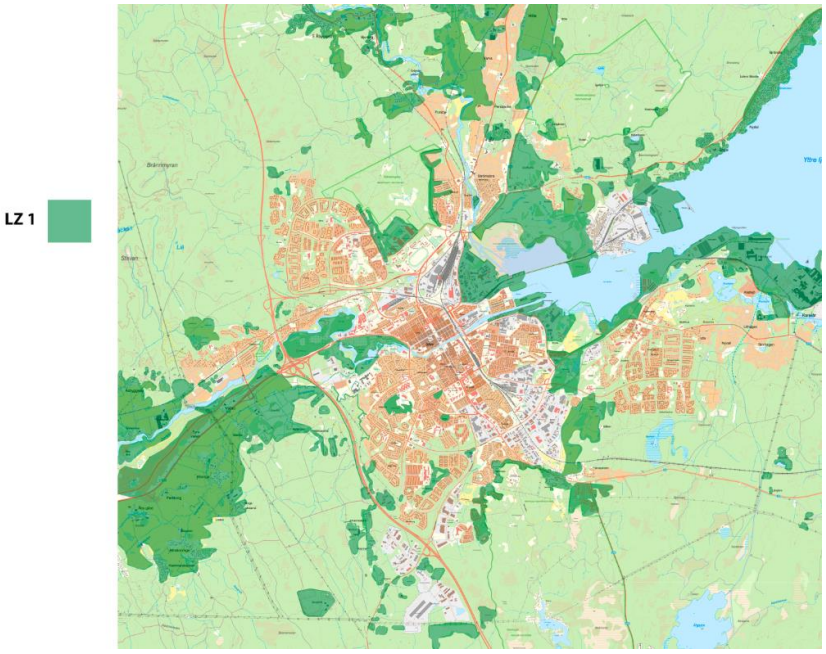
Suggested lighting for the church.

Low shielded wayfinding lighting, that has motion sensors

Using the openings to cut off light,

5.1.7.3 Lighting zone 1

This is the zone that borders to protected areas, lighting should be used with caution, and the light is shut off during the night, there is low population in these areas. Instead there are recreational areas and some businesses. One of the main concerns are the roads near protected areas in water.

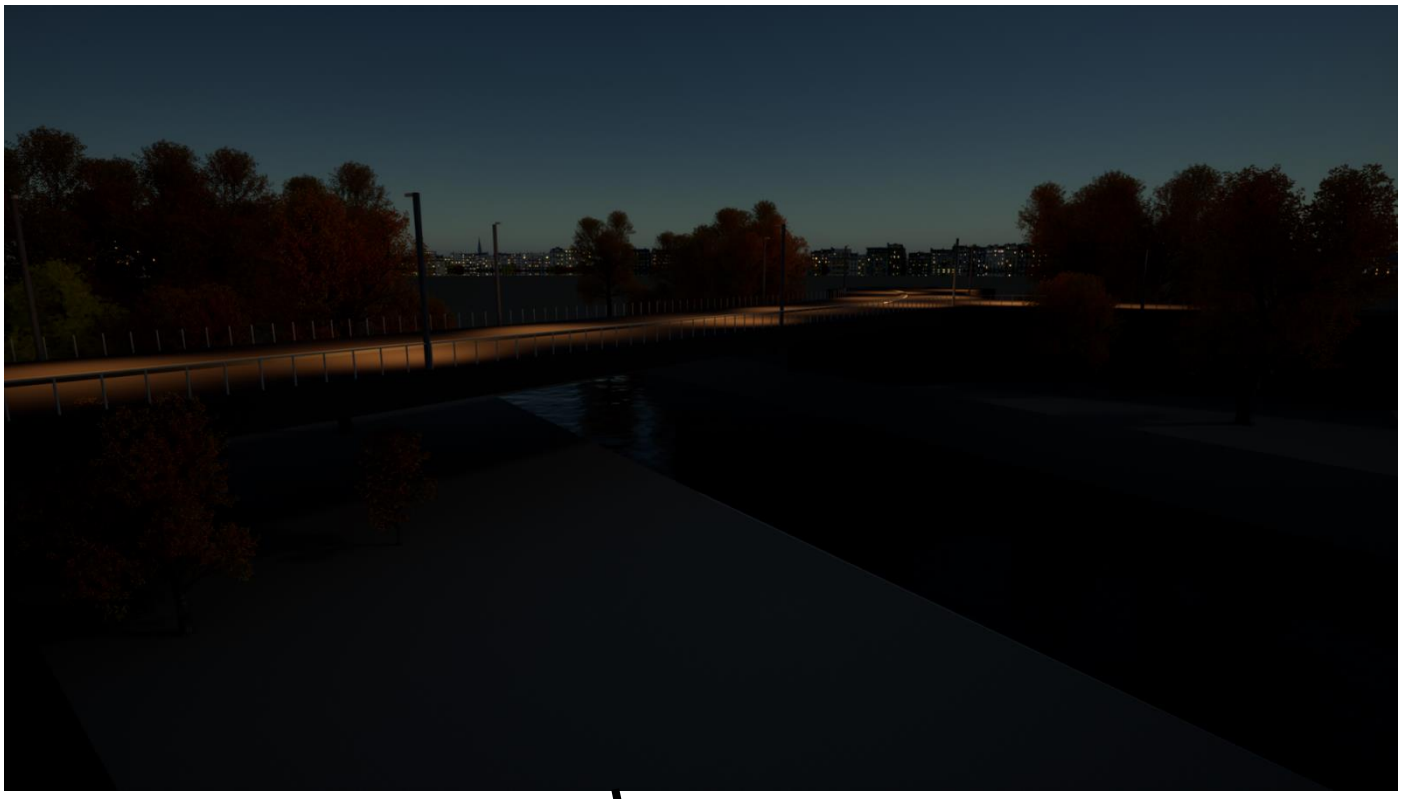


5.1.7.3.1 The bridge

It is suggested that to have lighting on the bridges that has full cutoff in the back, to not spill any light into the water and disturb the life in water. The existing lighting is fairly cold which penetrates deeper into the water compared to light with more red. The bridge has lighting legislation that needs to be followed.

Picture 1, Existing lighting on the bridge, Self-produced, 2024

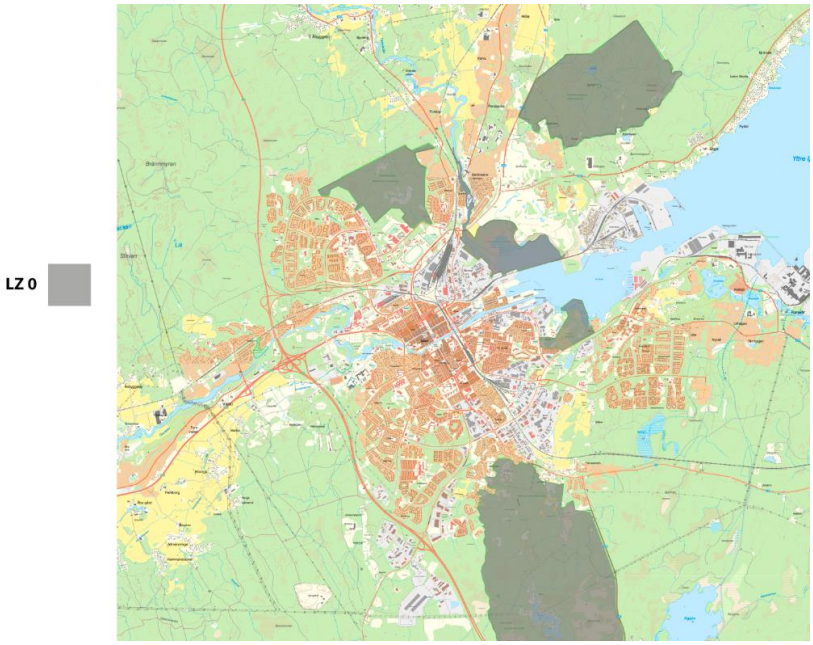
Suggested lighting for the bridge.



Lighting is fully shielded
in the back to not spill
any light into the water.

5.1.7.4 Lighting zone 0

These are the protected areas, which protect endangered species, and sensitive environment. In zone 0 there should be no lighting. And zone 1 could act as a buffer zone to the protected areas.



6 DISCUSSION

This thesis has explored the possibility of finding optimized or balanced lighting solutions to address light pollution.

The most significant finding is the substantial gap between legislation and scientific research. While some new and upcoming legislation represents progress, it often lacks a crucial element: nature's need for darkness. Research highlights the necessity for curfews, ALAN-free zone, and the extension of already dark areas. Sweden has legislation advocating for precautionary methods when there is uncertainty, but this principle is clearly not applied when it comes to lighting and light pollution.

There is a common misconception that Sweden's new upcoming legislation is effective (Science Communication Unit, UWE Bristol, 2023). However, it is not mandatory for municipalities to adopt these regulations, and municipalities contribute more significantly to light pollution than the fewer government-owned state roads. Another issue identified in this thesis is that most legislation and guidelines overlook the ecological and human impact perspectives. Although these guidelines claim to address ecological issues, they primarily aim to mitigate astronomical light pollution. It is easy to jump to quick-fixes and not think of the long run, the human and ecological perspective still need more research, however there are still a lot that can be done to mitigate the impact of light pollution.

It is crucial to understand that all light, not just misdirected light or light with high intensity, has the potential to contribute to light pollution. Recognizing this is essential for developing effective strategies to mitigate the adverse effects of artificial lighting on both the environment and human well-being.

It seems that a balanced and optimized lighting solution is achievable if we, as humans, are willing to make some compromises to address light pollution. We might need to accept living with less light out of necessity, as the adverse effects of excessive lighting can be severe for both humans and the environment.

7 CONCLUSION

All the different aspects of light pollutions need to be addressed if we should come terms with light pollution and not create further problems in the future. There is a discrepancy about what science say are best practice and what legislation and guidelines say and often the ecological and human impact are missing. Coming to terms with light pollution might seem like a utopia, but if we humans are willing to have a more ecocentric approach and are willing to compromise then a city that exchanges light pollution for a starry sky is no longer a utopia.

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