

DARKERSKY4CE

Ecosystem Services Report

The Role of Dark Skies for Ecosystem Services



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Purpose and Scope of the Report

This *Report on Dark Sky and Ecosystem Services* (A.1.2, D1.2.2) is an overall work of three working groups composed of partners, associated partners and relevant stakeholders on the role of the dark sky for ecosystem services, the negative impact that light pollution can have on the functioning of ecosystem services, and the importance of engaging stakeholders to achieve the goal of enhancing the role of the dark sky and reducing light pollution.

The working groups focused on three categories of ecosystem services (provisioning, regulating and cultural), analysing which stakeholders benefit from the dark sky and which stakeholders may be impacted or affected by its function.

Although the report is designed to be useful for anyone wishing to utilise the topic of the value of the dark sky for ecosystem services, the common thread throughout the report is the connection with the project's pilot demo sites to connect the findings to realities known to the project partners and to be useful for the development of the pilot actions themselves.

The following lists the four Pilot Actions across five demonstration sites:

D.3.2.1 Public lighting systems - Leipzig surroundings (Germany)

D.3.2.2 Astrotourism educational offer - Kujawsko-Pomorskie Voivodeship (Poland)

D.3.2.3 Stakeholders dialogue - Pinerolese Area (Italy)

D.3.2.4 Demonstration of monitoring methods - Somogy County (Hungary) and Carinthia region (Austria)

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1. Ecosystem Services and Dark Sky

1.1. What is the relationship between dark sky and Ecosystem Services?

The valorisation of the dark sky and, consequently, the reduction of light pollution caused by the incorrect management of artificial light at night (ALAN), is an issue of increasing relevance, but it is still a niche topic and little understood by policy makers, economic operators and citizens. Among the possible tools designed by the DARKERSKY4CE project to raise general awareness of the impact that light pollution can have on our lives, ecosystem services have been chosen to be a good instrument.

Briefly, an ecosystem is a community of living organisms (like plants, animals, and microbes) that interact with each other and with their non-living environment (such as air, water, and soil) in a specific area. These interactions create a system where energy flows and nutrients are cycled. Ecosystems can be as small as a pond or as large as a rainforest or ocean. Everything in an ecosystem is connected, and changes to one part can affect the whole system.

Ecosystem services (ES) are natural benefits that ecosystems have always provided. The concept of ecosystem services was developed by scientists and environmentalists to help people understand how much we depend on nature for our well-being and survival and to give them a value well understood by people. Basically, the idea of ecosystem services was created to make the value of nature more visible, especially in economic and policy decisions—because people often take nature for granted until it is damaged or lost.

Over the years, various classifications of ecosystem services have been proposed. In this document, the CICES system (Common International Classification of Ecosystem Services) of the European Environment Agency will be used, both because it was recently updated, and because of the scientific rigour and clarity of application for the purposes of this document (European Environment Agency, 2024).

The need to divide ES into groups has led to the creation of four categories. At the base there are the supporting ES which are essential for all other ES and contribute to the in situ conservation of biological and genetic diversity as well as evolutionary processes. As they are more general, they will not be investigated in this report. Below, three primary macro-categories of ES are identified: provisioning, regulating and cultural.

Provisioning ES guarantees the supply of food, water, and raw materials. Regulating ES involves the abilities of environmental components to regulate air, water, and soil quality, protect against natural hazards, and mitigate biotic adversities. Cultural ES stem from human interactions with living systems, including landscapes and for recreational enjoyment (Murgese et al., 2024).

What is the connection between a dark sky and ecosystem services?

Dark sky can be considered a component of natural capital. Natural capital encompasses the totality of natural resources and ecological processes that sustain life on earth and enhance human well-being. It refers to the world's stocks of natural resources that provide essential goods and services to people. Natural capital serves as the foundation for ES; without robust and functional natural capital, the



delivery of these services would be significantly impaired. In this report we will try to analyse the connection between each type of ES and dark sky (when present and verifiable).

As the alternation of day and night, often endangered by light pollution, is very important for the functioning of many ecosystems, the lack of a sufficiently dark night can have consequential effects on the functioning of an ecosystem. Classic examples are those related to nocturnal pollinators disturbed by ALAN or the ease with which some predators are able to hunt their prey (creating an imbalance between species).

In this report we first analyse in chapter 1 the ES on which there are studies or evidence on the influence of the dark sky and light pollution. The various services of similar function have been grouped together in order to carry out a comprehensive analysis. In some cases, scientific research is still underdeveloped, requiring assumptions to be made about indirect relationships between the various services.

Subsequently, in chapter 2 we analyse the stakeholders that can be impacted by or can have an impact on ES. This exercise allows us to know who to talk to in order to improve the situation regarding light pollution that impacts the functioning of an ES.

Finally, in chapter 3 we look at concrete examples of how we can develop actions to reduce light pollution in a specific context and what communication strategies can be used to achieve ES.

1.2. Provisioning ES affected by light pollution

Provisioning Services: These ES are products that can be harvested, consumed, or traded. Examples include:

- **Food provision;**
- **Provision of raw materials** as wood, water, mineral resources etc.;
- **Provision of active agents** such as chemical compounds used for pharmaceutical applications, or microorganisms used for medical purposes (e.g. antibiotics).

In this section, the provisioning services that may be significantly impacted by light pollution are analysed. Selected effects will be explained.

Table 1.2.1 - FOOD

CICES Code	ES category	Group	Simple descriptor
1.1.1.1 1.1.2.1 1.1.3.1 1.1.4.1	Provisioning (Biotic/Biophysical)	Cultivated terrestrial plants for nutrition, materials or energy;	Any crops and fruits grown by humans for food, e.g. food crops;
		Cultivated aquatic plants for nutrition, materials or energy;	Plants that are cultivated in fresh or salt water that we eat;
		Reared animals for nutrition, materials or energy;	Livestock raised in housing and/or grazed outdoors;



		Reared aquatic animals for nutrition, materials or energy.	Animals that are cultivated in fresh or salt water that we eat.
1.1.5.1 1.1.6.1	Provisioning (Biotic/Biophysical)	Wild plants (terrestrial and aquatic) for nutrition, materials or energy; Wild animals (terrestrial and aquatic) for nutrition, materials or energy.	Food from wild plants; Food from wild animals.
4.2.1.1 4.2.2.1	Provisioning (Abiotic/geophysical)	Mineral substances used for nutrition, materials or energy; Non-mineral substances or ecosystem properties used for nutrition, materials or energy.	Minerals in our food; The ways that the physical environment contributes to our nutritional health.

An important aspect of provisioning ES is that related to the production of human food. We can consider different aspects of this process.

Regarding the production of plants for human consumption, light has a fundamental role in the growth of a healthy plant, influencing a number of its physiological responses. In recent decades, considerable efforts have been made to mimic the effects of natural sunlight, increasing production and strength of cultivated species (Neo et al. 2022) and contributing to so-called “Controlled Environment Agriculture”. The introduction of LED lighting allowed the tuning of the light spectrum to adapt to different phases of plant development at a decreasing energy cost. Artificial lighting has been shown to influence “the performance of enzyme, gene expression, cell wall formation, plant defense and postharvest quality”, further enhancing the production of nutrients (Sena et al. 2024; Zhang et al. 2020). The contribution of artificial lighting applies not only to terrestrial plants, but also to aquatic plants, including algae (Yago et al. 2017).

In the context of livestock or poultry production, controlled lighting can improve animal well-being, thus promoting social activities between mates, and increasing productivity: stability of egg production or milk yield across seasons, prolongation or anticipation of reproductive periods. This can be dangerous for semi-wild farming, since more lighting can induce a thinner coat (Penev et al. 2014).

However, in a non-controlled environment, artificial light can cause distress to animal and plant species. On one hand, humans tend to eat fewer and fewer wild terrestrial animals or vegetables, so the effects of ALAN on these services is quite indirect, although light pollution has a non-negligible effect on these species. On the other hand, aquatic species are at even greater risk. Coastal waters are usually light-polluted, since humans tend to settle near them, and water has specific interacting optical characteristics (Hölker et al. 2023). Light is attenuated in water by absorption and scattering. Absorption is stronger at long wavelengths whereby redder light is more readily absorbed, while scattering is stronger at short wavelengths whereby bluer light is more readily scattered. Moreover, particles contained in water have specific optical features that contribute to the overall spreading of light in water. Other sources of light pollution are far from the coast, ranging from offshore fishing, shipping and mining.

The abundance of artificial light relative to historical natural light levels poses a significant threat to the whole marine ecosystem, with different effects depending on species (vertebrates or invertebrates, plants or plankton, and so on), on their typical size and their preferred environment.

A set of studies performed on cyanobacteria, which are organisms capable of photosynthesis and that serve as the basis of the aquatic food web, shows that the luminosity generated by light pollution, especially at night, is not sufficiently high to boost the photosynthetic process, but it is perceived by the organisms and can modify their behaviour at cellular level. Moreover, light pollution influences the composition of microbial communities.



Fish have evolved based on the quantity and type of light they were subjected to. Some species are known to be sensitive to changes in melatonin. On a diurnal basis, fish can naturally move to deeper water to avoid predators that rely on vision, only emerging at night. ALAN helps predators, with the overall effect to reduce the fish population. The cycle of night/day, possibly altered by artificial light, controls sleep cycles, with consequences on feeding habits, metabolism and growth. Daylight length is also linked to seasonal rhythms that are particularly important for sexual maturation, reproduction and, for some species, for spawning migration. The adaptation of species affected by light and the search for an equilibrium between predator and prey can have long term evolutionary effects, such as introduction of new species or migration of others into less polluted areas.

Table 1.2.2 - NON-FOOD

CICES Code	ES category	Group	Simple descriptor
1.1.1.2 1.1.2.2 1.1.3.2 1.1.4.2	Provisioning (Biotic/Biophysical)	Cultivated terrestrial plants for nutrition, materials or energy; Cultivated aquatic plants for nutrition, materials or energy; Reared animals for nutrition, materials or energy; Reared aquatic animals for nutrition, materials or energy.	Material from plants, fungi, algae or bacterial that we can use; Plants that are cultivated in fresh or salt water that we can use as material; Material from animals that we can use; Animals that are cultivated in fresh or salt water that we can use as material.
1.1.5.2 1.1.6.2	Provisioning (Biotic/Biophysical)	Wild plants (terrestrial and aquatic) for nutrition, materials or energy; Wild animals (terrestrial and aquatic) for nutrition, materials or energy.	Wild plants (terrestrial and aquatic) for nutrition, materials or energy; Materials from wild animals.
4.2.1.2 4.2.2.2	Provisioning (Abiotic/geophysical)	Mineral substances used for nutrition, materials or energy; Non-mineral substances or ecosystem properties used for nutrition, materials or energy.	Natural inorganic materials from nature that we can use; Gaseous, fluid or non-mineral solid inorganic materials from nature that we can use (excludes water vapour).

Literature research and discussions led to the conclusion that light pollution has a mostly indirect impact or no influence on either the production of materials of plant or animal origin or energy production. However, there are several cases when excessive lighting might influence material production. This is the situation for production of material derived from plants, fungi, algae, or bacteria. The most visible example is production of processed timber (terrestrial ecosystems) or seaweed as insulating material (aquatic ecosystems). The time and intensity of flowering, germination, and seedling growth depend on light signals received by plants. The photoperiod that is disrupted by excessive or misdirected artificial light in the environment may cause plants to flower too early or too late, with impacts on pollination and



seed dispersal. Moreover, extended light exposure at night influences plant growth rates. Some plants might grow too tall or unnaturally toward the light source. There are additional indirect factors that mitigate the plant's reproduction and growth. Many plants depend on nocturnal pollinators like bats, moths, and other insects, whose natural behaviour patterns are disrupted by light pollution.

Due to alteration of the natural day-night cycle, artificial light disrupts aquatic environments too, especially in coastal or freshwater areas. The mechanisms regulating the processes of photosynthesis and respiration of algae and aquatic plants may be disrupted.

It is worth mentioning that some artificial lights, especially in shallow water environments, can increase water temperatures, affecting plant and algal growth. This might result in alteration of the local aquatic ecosystem by encouraging non-native species that prefer the altered conditions. The indirect impact on the aquatic flora affects fish and invertebrates. When subjected to unnatural light availability, the patterns of their behaviour may have an indirect impact on the health of aquatic plants. In the case of fish species avoiding light, the introduction of artificial light changes their feeding and breeding patterns, affecting plant life.

In the case of material production from animals cultivated in fresh and salty waters, the impact of light pollution is doubtful or indirect. In the case of cattle, light alters melatonin production of animals, with influence on reproduction patterns, growth and rearing. In this example, the effect may include an increase in hide production. In case of hunting animals for fur, feathers or bones, bright spotlights stimulate the freeze response of many species and change the bird migration patterns. Therefore, the number of kills might increase (Bowler et al. 2020).

There is no clear evidence that the production of material harvested and used as raw material for non-nutritional purposes decreases or increases with artificial light exposure. Such materials include, e.g. pearls, reeds, agar and superconductor electrodes. The lack of evidence may be an artefact of the fact that there is little research on this topic, as one study indeed shows the reduction in survival of specific types of mussels due to their exposure to ALAN (Tidau et al. 2023).

Apart from production, plant and animal material (both aquatic and terrestrial), as well as wind, solar power and hot springs, are renewable energy sources. Artificial light can be beneficial for energy production in the case of plant material as it may help protect plants by controlling pest and predator activity (McQuate and Jameson 2011).

Artificial light also impacts the volume of harvested wood (Bennie et al. 2016). However, the effects are not obvious in the case of energy produced from animal waste (i.e. dung or biogas from aquaculture waste). In the case of wind and solar energy, there are not enough sources to prove the impact of ALAN on its production. However, wind energy production increases artificial light pollution (Yakushina 2022).

Table 1.2.3 - ENERGY

CICES Code	ES category	Group	Simple descriptor
1.1.1.3 1.1.2.3 1.1.3.3	Provisioning (Biotic/Biophysical)	Cultivated terrestrial plants for nutrition, materials or energy; Cultivated aquatic plants for	Plant materials used as a source of energy; Plants that are cultivated in fresh or salt water that we can use as an



		nutrition, materials or energy; Reared animals for nutrition, materials or energy.	energy source; Animal materials used as a source of energy or for traction.
1.1.5.3 1.1.6.3	Provisioning (Biotic/Biophysical)	Wild plants (terrestrial and aquatic) for nutrition, materials or energy.	Wild animals (terrestrial and aquatic) for nutrition, materials or energy.
4.1.1.3 4.1.1.4 4.1.2.3 4.2.1.3 4.2.2.3 4.2.2.4 4.2.2.5	Provisioning (Abiotic/geophysical)	Mineral substances used for nutrition, materials or energy; Non-mineral substances or ecosystem properties used for nutrition, materials or energy.	Natural inorganic materials from nature that we can use as an energy source; Hydropower; Wind power; Solar power; Geothermal power.

Effects of ALAN on the production of energy can be distinguished in two dimensions: biotic/biophysical and abiotic/geophysical. The former refers mainly to alterations caused by light pollution in biomass of wild and cultivated species. One of the most prominent use cases is wood burning and tree material used in biogas production coming from cultivated and wild trees. Depending on species and wavelengths of light, studies have shown positive effects in the form of earlier and longer growing seasons (Fig. 1.2.1, Fig. 1.2.2), leading to greater yield (Bennie et al. 2016, Chaney n.d., Czaja & Kolton 2022, French-Constant et al. 2016, Wei et al. 2023, Zheng, Teo & Koh 2021). But as ALAN poses a stressor itself, the resistance of trees to climatic changes, droughts, pests and diseases can be impaired, especially outside of controlled artificial conditions like greenhouses. Furthermore, certain crops like maize or soybeans are cultivated as resources for biofuel and biogas production. Here, similar effects can be observed as with trees. Depending on the species and the light spectrum, ALAN can positively influence growth rates and yield, but also increases stress on the plants (Neo et al. 2022, Palmer et al. 2017, Sena et al. 2024). Wild plants are of lesser relevance in this context due to the smaller efficiency compared to industrialised farming, even if wild tree usage can be of significance for energy production.

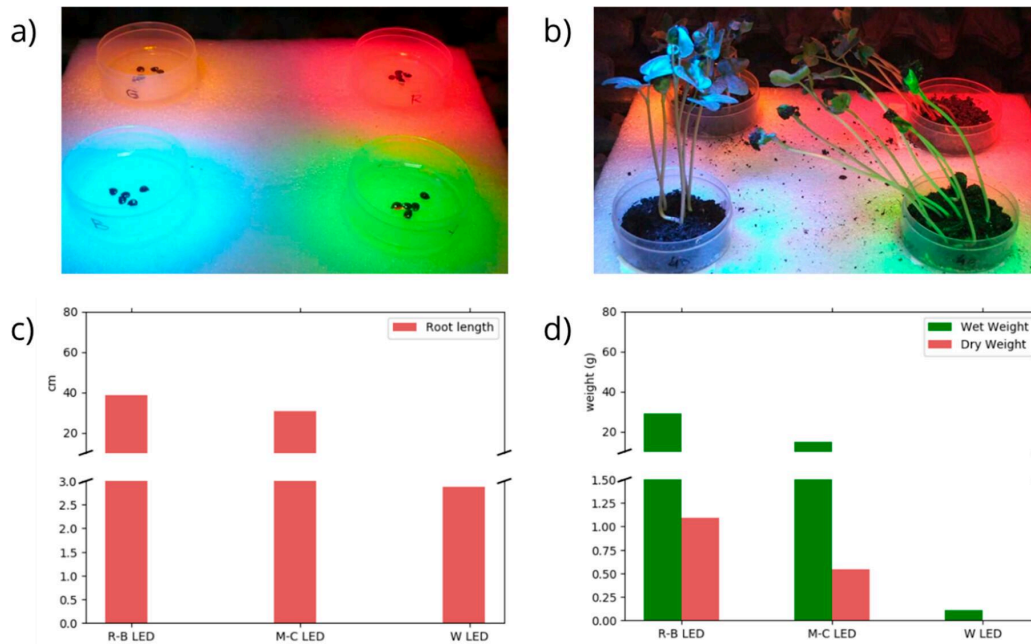


Figure 1.2.1 (a), (b) Sprouts of *Ipomoea purpurea* (common morning-glory) before and after germination under exposure to monochromatic LED light sources. (c), (d) Root length, wet and dry weight of red spinach grown under different light spectra: red/blue, multi-colored and white LED. Source: Neo et al. 2022



Figure 1.2.2 London plane (*Platanus × acerifolia*) tree in Liverpool city centre on three dates in 2014. The right hand side receives direct illumination from street lighting, thus autumn coloration was delayed and the illuminated portion of the crown retained leaves well into December. Source: Bennie et al. 2016.



An aspect worth mentioning is the use of artificial light in pest and predator control, thus indirectly securing the yield of tree and crop biomass (Adams, Mwezi & Jordan 2021, McQuate & Jameson 2011, Ogino et al. 2016, Shimoda & Honda 2013). It should not be forgotten that those measures pose harm to the ecosystems in which the grown plants exist and it is unclear to what extent the short-term increase in yield causes long-term harm. Because it is unlikely that ‘unwanted’ species can be targeted independently, crop protection based on artificial light could ultimately threaten the use of plant materials as an energy source in general. A relevant example is pollination, on which both trees and fuel crops depend and which is negatively affected by ALAN (Bennie et al. 2016, Guenat & Dallimer 2023, Knop et al. 2017). ALAN leads to alterations in the flowering period, disturbances to insect behavior and population decline, as well as less successful pollinations.

A more recent application is the use of cultivated algae and phytoplankton for biofuel production. As the quantities generated still lack relevance in the overall energy mix, effects of ALAN have to be deduced by existing studies on marine life forms. In general, artificial light can greatly increase the yield and quality of biomass and is used strategically in aquaculture farming (Yago et al. 2017, Bará et al. 2018, Grubisic 2018, Marques et al. 2022). But the positive effects depend on the individual species (Fig. 1.2.3), different beneficial wavelengths of light (Diamantopoulou et al. 2021), and co-factors like temperature (Caley et al. 2024). Also, aquatic resources like seaweed and algae used in biofuel and biogas production are part of vulnerable marine ecosystems, in which ALAN acts as an additional stressor (Fig. 1.2.4), thus threatening the yield (Bará et al. 2018, Diamantopoulou et al. 2021, Hölker et al. 2023, Miller & Rice 2023). In this context, the positive effects of ALAN mainly apply under strictly controlled artificial conditions.

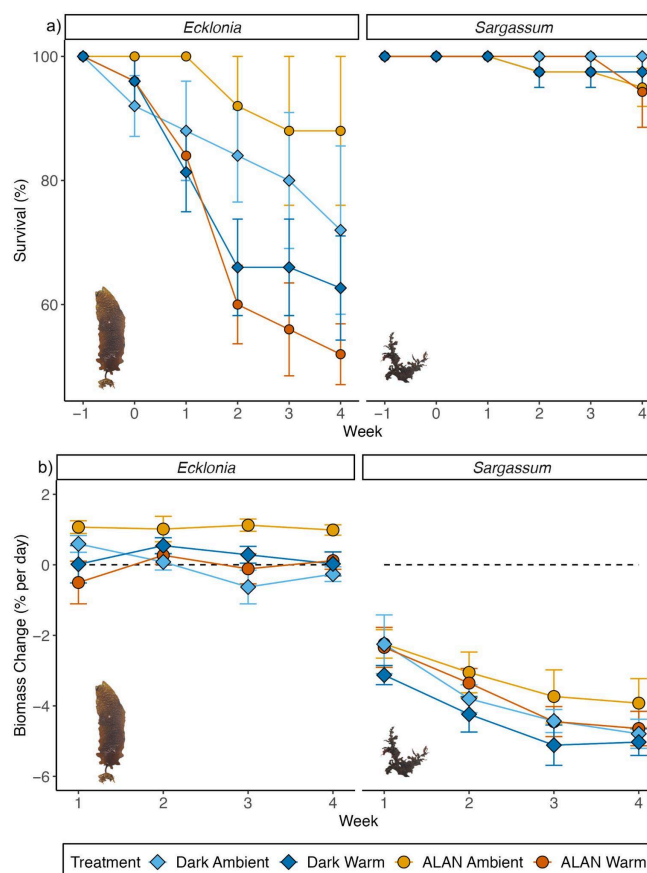


Figure 1.2.3 (a) survival (%) and (b) biomass change (% day⁻¹) of *Ecklonia* and *Sargassum* for light and warming treatments. Points above the dotted line indicate an increase in biomass per week, while points below the line indicate a decrease. Source: Caley et al. 2024.

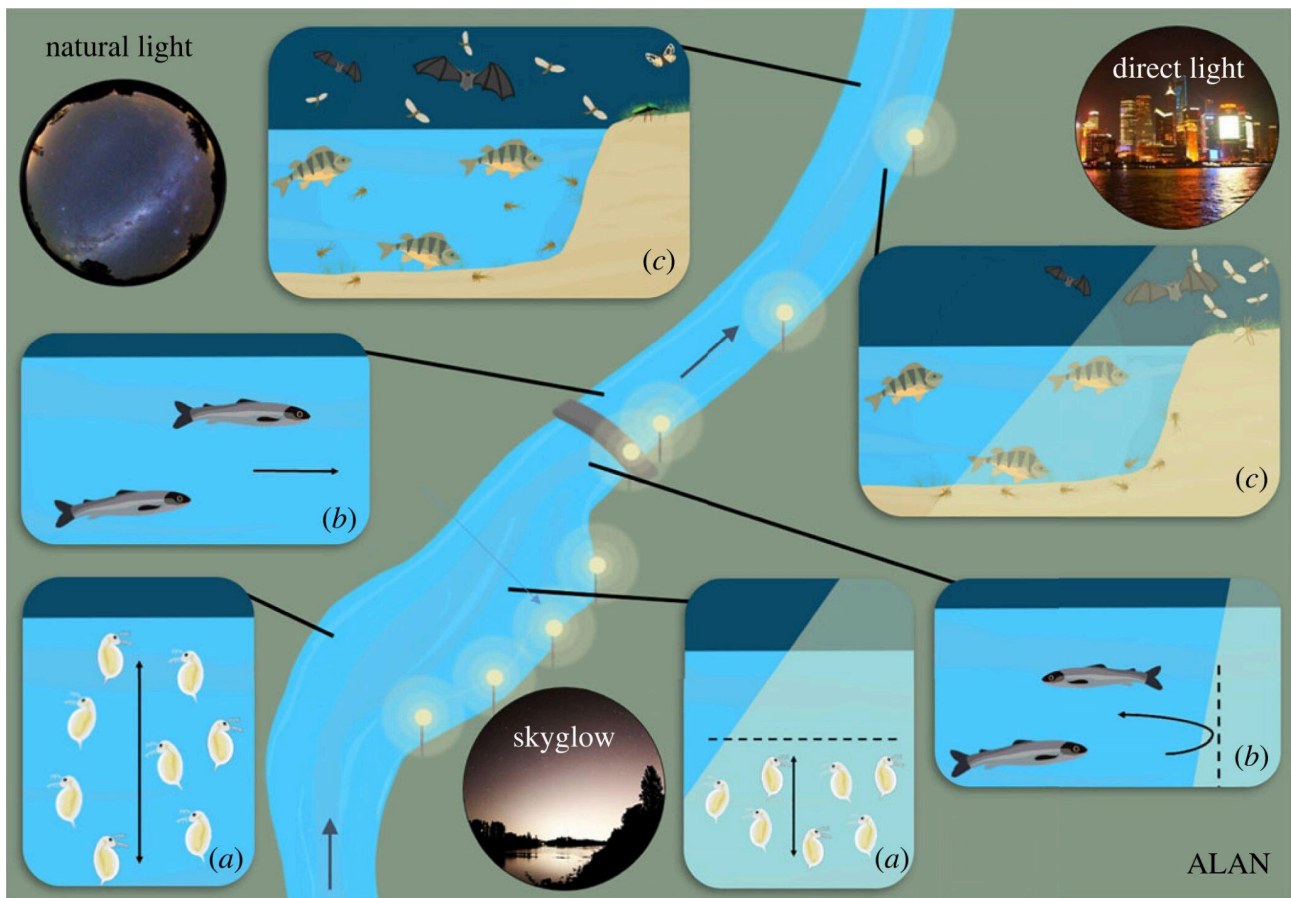


Figure 1.2.4 Ecological consequences of ALAN along a river-lake ecosystem including changed behaviour and predator-prey relationships. Source:Source: Hölker et al. 2023.

Looking at wild as well as cultivated animals, their significance for energy production is less pronounced. Especially as animal products like whale blubber are nowadays no longer used to any significant extent, effects of ALAN on animals as a source of energy cease to be relevant. The most obvious application is the use of manure from cultivated animals in biogas production. Even if ALAN has significant effects on livestock's health, reproduction and behaviour due to stress caused by disturbing the sleep cycle (see the previous sections on food and non-food ecosystem services), correlations regarding the yield of manure cannot be found in today's body of research.

Energy production further includes natural inorganic materials as well as geophysical properties like wind, sun, water and geothermal heat as energy sources. In general, effects of ALAN or light pollution are difficult to detect due to their abiotic nature. For instance, it can be regarded as doubtful that inorganic chemicals like uranium are negatively affected by light pollution and relevant research could not be found. The same can be said for the energy yield from sunlight via photovoltaic systems, geothermal energy or hydropower. At most, indirect effects could be deduced if the energy source is connected to biological life. In that sense it could be argued that the impacts of ALAN on aquatic life forms (e.g. overgrowth of algae, see Grubisic, 2018) indirectly influence the utilisation of hydropower (e.g. possible blocking of turbines or weirs through ALAN-induced overgrowth), but this would have no direct relation to the potential energy of the water actually used by hydroelectric power stations.

The relevance in the context of ecosystem services mainly comes from man-made infrastructure being a significant cause of ALAN and light pollution in the process of capturing energy. This includes, among other



things, lighting for workers on paths and worksites, street lamps on connected roads, vehicles in use, or safety and emergency lighting. Particularly damaging is the fact that these sites are usually in remote areas that were previously less affected by artificial light pollution. Wind turbines provide a better researched example of infrastructure that demonstrably contributes to ALAN, thus negatively impacting ecosystems despite their important role in the decarbonization of the economy (Yakushina, 2022). It is plausible to think that those effects also apply to the other abiotic means of energy utilization described previously, thus emphasising the need for better consideration of light pollution mitigation through specific research efforts, as well as developing updated legal requirements.

Table 1.2.4 - INDIRECT

CICES Code	ES category	Group	Simple descriptor
1.2.1.1 1.2.1.2	Provisioning (Biotic/Biophysical)	Genetic material from plants, algae or fungi.	Seed collection; Plants, fungi or algae that we can use for breeding.
1.2.2.2	Provisioning (Biotic/Biophysical)	Genetic material from animals.	Wild animals that we can use for breeding.
1.2.1.3 1.2.2.3	Provisioning (Abiotic/geophysical)	Genetic material from plants, algae or fungi; Genetic material from organisms.	Genetic material from wild plants, fungi or algae that we can use; The genetic information that is stored in wild animals that we can use.

Seed production and seed collection need particular ecological mechanisms that are directly affected by ALAN. Certain plants need nocturnal pollinators for reproduction but ALAN drives these pollinators away, consequently reducing pollination success and seed production. Lewanzik and Voigt (2014) found that artificial night lighting reduces the pollinating and seed dispersing activities of frugivorous bats in specific ecosystems.

ALAN produces multiple effects on organisms across the plant kingdom including fungi and algae. The changes result in important plant reproductive function modifications as well as alterations to essential plant growth patterns and natural ecological connections. Natural light functions as an essential component for plants to regulate their growth patterns as well as their flowering cycles and seed production processes. The plant procedures that occur naturally experience disruptions because of ALAN. The research indicates artificial illumination generates contradictory effects on flowering patterns because it simultaneously suppresses and induces floral development depending on the plant species. Plant organisms demonstrate heightened light sensitivity particularly toward red wavelength light sources (see Fig. 1.2.1). Incorrect flower timing prevents plants from completing their reproductive cycle (Bennie et al. 2016).

The scientific literature lacks comprehensive understanding about the effects of fungal light pollution. The reactions to ALAN show that algae living in water exhibit extreme sensitivity. The exposure to ALAN results in reduced algal biomass levels (Grubisic et al., 2017). The study conducted by Grubisic (2018) evaluated how periphyton communities made up of algae together with cyanobacteria and



microbial organisms in water would react to ALAN exposure. White LED lights generated major changes that affected both biomass measurements and structural diversity levels. The effects of ALAN extend to areas with no pre-existing artificial lighting while also affecting regions that previously had artificial lighting until they adopted LED technology. The decline in periphyton biomass under artificial lighting shows that additional delicate biological processes besides photosynthesis are affected by ALAN, yet scientists have not fully understood them.

Academic research has given minimal attention to studying the effects of ALAN on the genetic material of wild plants, fungi and algae while devoting more attention to its impact on wildlife. The available research shows that plants constantly exposed to ALAN face disruptions to their circadian rhythms, leading to changes in gene expression patterns. Gene oscillations that manage photoprotection and photosynthesis underwent modifications in *Posidonia oceanica* seagrass after exposure to ALAN, according to Dalle Carbonare et al. (2023).

Table 1.2.5 - WATER

CICES Code	ES category	Group	Simple descriptor
4.1.1.2 4.1.2.2	Provisioning (Abiotic/geophysical)	Surface water used for nutrition, materials or energy; Groundwater used for nutrition, materials or energy.	Surface water that we can use for things other than drinking; Sub-surface water that we can use for things other than drinking.
4.1.1.3	Provisioning (Abiotic/geophysical)	Surface water used for nutrition, materials or energy.	Hydropower.

ALAN constitutes light pollution and is increasingly recognized as an important factor in global environmental change (Hölker et al. 2023). It is also increasingly threatening human health and well-being, wildlife, and many es and functions (Anderson et al. 2024). Light pollution emissions are increasing rapidly, especially in a more urbanized world.

Surface waters have been a source of food since prehistoric times and are an important source of freshwater that can be used for drinking and irrigation. They are recreational areas offering opportunities for tourism development and are used for bathing. They play an important role in generating electricity, retaining water in the landscape, recharging groundwater and intercepting storm water. It is a fact that half of the human population lives near freshwater coasts, and surface inland waters around the world are increasingly exposed to light pollution (Hölker et al. 2023). These emissions are degrading the ES provided by these functioning ecosystems. This is classified as ecological light pollution, which refers to the penetration of light through point sources into local aquatic environments (Anderson et al. 2024). According to Hölker et al. (2023), the ecological impacts of light pollution remain largely unexplored in inland waters (Figure 1.2.5).

Light conditions are crucial for aquatic organisms in freshwater ecosystems. At the same time, freshwater ecosystems are a biodiversity hotspot and the wide-ranging effects of light pollution affect all levels of biodiversity (Hölker et al. 2023). Inland waters are known to cover a very small proportion of the Earth's surface (less than 1%) and are home to about 10% of all known species and as many as a



third of all vertebrates, totaling more than 125,000 species (Dudgeon et al. 2006). However, transferring knowledge from terrestrial to freshwater ecosystems is not straightforward, as waters have specific optical properties that cause important differences in illumination, spectral composition, and polarisation patterns. To adapt to these conditions, freshwater organisms have evolved specific physiological and behavioral responses, which in turn affect population, community, and ecosystem levels (Hölker et al. 2023).

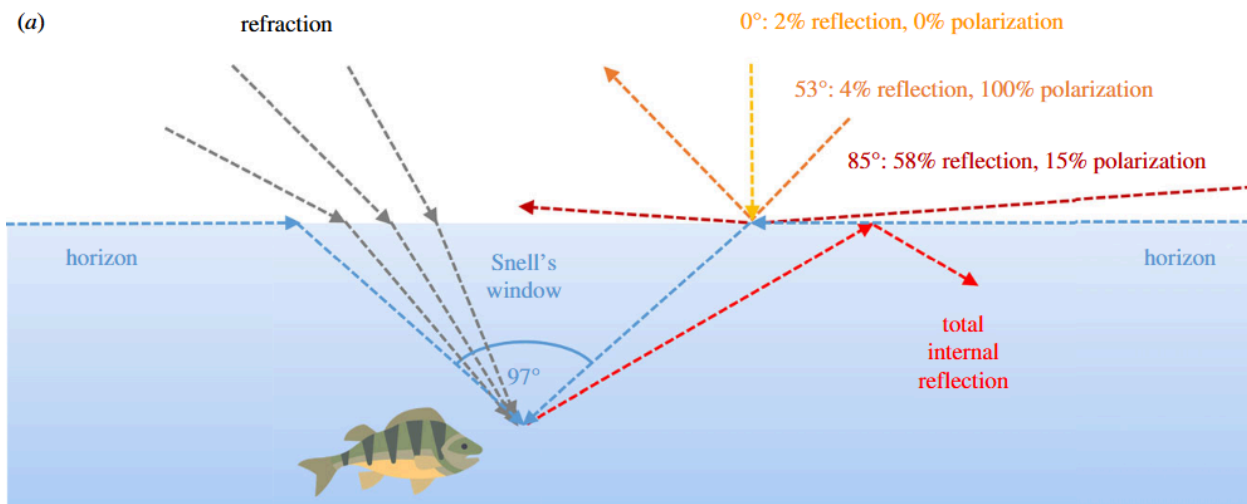


Figure 1.2.5: Light refraction, reflection and polarization at the air-water interface (Source: Hölker et al. 2023).

Artificial light is a challenge for aquatic life. Unnatural light intensity results in the disruption of biological processes, which can lead to the desynchronization of biological rhythms in individuals and entire ecosystems. These effects result in changes in physiological processes, bodily functions, and behavior. They are propagated through various interactions and affect population dynamics, adaptive capacity, evolutionary pathways, food chain relationships, ecosystem processes, and biodiversity. Stressors such as global warming and water pollution are more sensitive to organisms exposed to artificial light at night. Artificial light at night causes an inhibition of melatonin production in vertebrates, especially in fish, triggering a cascade of physiological responses. The seasonal variation in day length (photoperiod) is impaired by exposure to ALAN, which affects the control of sexual maturation. Artificial light sources in the vicinity of freshwater ecosystems, such as illuminated bridges, overpasses, dams, and other infrastructure elements, can significantly hinder the movement and migration routes of many species of animals, including fish, bats, monotremes, and toads. Such effects of light on the migratory behavior of freshwater animals are common, as animals can either be attracted to light or avoid it. As a consequence, the time and energy input for movement is increased, which can disrupt the synchronization of reproduction and reduce its success (Hölker et al. 2023).

ALAN attracts nocturnally active aquatic flying insects, which often become easy prey for terrestrial predators or die of exhaustion, making them particularly vulnerable. It is important to note that freshwater insects account for 60% of all known freshwater animal species (Dijkstra et al. 2014), and their exposure to artificial light at night also affects natural orientation signals (Hölker et al. 2023).

The presence of ALAN in the vicinity of freshwater environments can act as an energy source for microbial phototrophs such as cyanobacteria, diatoms, and green algae, which can thrive even at minimum light levels. Such conditions can lead to changes in the structure of microbial communities, with species that use night-time light to their advantage taking over (Hölker et al. 2015). One of the



most pronounced effects is seen in the impact of night skyglow on the day-night vertical migration of zooplankton, indicating the wider ecological reach of light pollution (Hölker et al. 2023).

Groundwater is not directly exposed to artificial light but can be affected by the indirect effects of light pollution on surface ecosystems. The quality of infiltrated groundwater can be affected by changes in soil biodiversity and the activity of microorganisms that naturally filter precipitation. One example is the presence of active watercourses in karst cave systems. Artificial lighting in tourist caves promotes the formation of lampenflora (Mulec & Kosi, 2009). The term lampenflora refers to the phenomenon of the proliferation of mainly phototrophic organisms in the vicinity of artificial light sources in caves. Lampenflora is a major challenge in terms of cave conservation, cave inventory, and underground biota, as well as a challenge for cave managers. Lampenflora can alter the chemical composition of water (pH and oxygen dynamics) and affect the microclimate of the cave environment. Increased biological activity can cause changes in groundwater quality in environments where rivers flow through caves.

Although hydropower is considered a renewable energy source, light pollution around dams, reservoirs and hydropower plants can affect fish migration, especially at night. Artificial light confuses and alters the behaviour of many fish species, which rely on natural light signals to navigate. Nelson et al. (2021) state that ALAN increases predator densities near fish barriers and passages. This makes fish pathways less efficient, with long-term effects on the health of rivers and the structure of populations (Brüning et al. 2018).

1.3. Regulating ES affected by light pollution

Regulating Services: These services help regulate environmental conditions and processes that affect human well-being offering many basic services that make life possible for people, such as:

- **Climate regulation:** Forests and oceans absorb carbon dioxide, helping to mitigate climate change.
- **Water purification:** Wetlands and forests filter pollutants from water, improving water quality.
- **Pest control:** Predators like birds or insects control pest populations, reducing the need for chemical pesticides.

In this section, the regulating ES that may be significantly impacted by light pollution will be analysed. They will be selected and the effects will be explained.

Table 1.3.1 - WASTE PROCESSING

CICES Code	ES category	Group	Simple descriptor
2.1.1.1 2.1.1.2	Regulation & Maintenance (Biotic/Biophysical)	Reduction of nutrient loads and mediation of wastes or toxic substances of anthropogenic origin by living processes.	Decomposing wastes or polluting substances; Filtering wastes or sequestering pollutants.



5.1.1.1 5.1.1.2 5.1.1.3 5.1.1.4	Regulation & Maintenance (Abiotic/geophysical)	Mediation of waste, toxins and other nuisances by non-living processes.	Diluting or removing waste; Natural processing of waste; Underground storage of waste.
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The increasing environmental issue of light pollution consists of improper and surplus artificial illumination, which produces multiple ecological problems. Research about how artificial lighting and astronomical observation affects both human wellness and wildlife conduct exists extensively but scientific knowledge about its influence on waste decomposition and bacterial processes remains relatively new. This section evaluates how ALAN affects microbial decomposition processes along with bacteria involved in organic and inorganic matter breakdown throughout ecosystems and natural waste handling systems. Organic materials require bacteria to decompose which results in the cycle of nutrients. These processes are controlled by environmental factors including temperature and light exposure. The decomposition processes of organic and inorganic waste, together with bacterial activity, undergo changes because of ALAN through multiple mechanisms. Research about decomposing waste materials along with biological substance transformation of organic and inorganic matter by different species has not yet received sufficient scientific attention.

The artificial lighting system creates temperature alterations and accelerates excessive algal growth throughout aquatic ecosystems. Research has demonstrated that exposure to artificial illumination alters bacterial gene expression which produces less efficient decomposition rates (Bennie et al. 2018). Soil ecosystems experience disturbances from ALAN because the bacterial communities in urban soils show decreased network stability. Main biogeochemical processes performed by these communities become affected when interspecies interactions change due to this destabilization. Soil bacterial behavior stands as one of the major ecological effects of the rising ALAN incidence according to Li et al. (2024). ALAN exposure has been shown to decrease the bioremediation capacity of the bacterial pathogen *Pseudomonas aeruginosa*. The regulatory process known as quorum sensing becomes impacted when bacteria are exposed to ALAN because it reduces their ability to produce virulence factors and form biofilms (Mukherjee et al. 2019).

Soil bacteria, along with fungi, serve as vital decomposers of organic matter while recycling nutrients. The presence of artificial light alters microbial populations by allowing less efficient decomposing bacteria to dominate, thus decreasing natural waste breakdown efficiency (Hölker et al. 2010a). Changes due to ALAN slow down the decomposition of plant materials and organic waste which results in greater accumulation of undecomposed materials.

The natural removal of waste through hydrological and biological processes becomes disrupted by ALAN in multiple ways, affecting waste dilution and removal in ecosystems. The efficiency of natural water systems to dilute and remove waste decreases with increased light exposure (Hölker et al. 2010a). The decomposing organisms including fungi and bacteria function better in dark environments, which is why ALAN affects their activities. According to some studies, ALAN exposure appears to decrease fungal sporulation and enzymatic activity, resulting in decreased decomposition rates (Gaston et al. 2015). The behavior of decomposers and scavengers that contribute to underground waste ecosystems is modified by light pollution. Research indicates that night-time illumination attracts disruptive species which disturb soil layers to expose buried waste to surface contamination (Grubisic et al. 2019).

Light pollution emerges as a vital factor that impacts bacterial decomposition processes while affecting waste dilution, removal and its underground storage. Natural waste management processes together with



pollutant degradation efficiency become impaired by ALAN through its disruption of microbial rhythms. The current field requires additional research to understand how responsible lighting practices with motion-activated lights and bacteria-friendly wavelengths can help minimize these effects.

Table 1.3.2 - MEDIATION OF NUISANCES OF ANTHROPOGENIC ORIGIN

CICES Code	ES category	Group	Simple descriptor
2.1.2.1 2.1.2.2 2.1.2.3	Regulation & Maintenance (Biotic/Biophysical)	Mediation of nuisances of anthropogenic origin.	Reducing smells; Reducing noise; Screening unsightly things.
5.1.2.1	Regulation & Maintenance (Abiotic/geophysical)	Mediation of nuisances of anthropogenic origin (e.g. screening effect of topography).	Natural protection.

In this section, it is worth examining, in relation to waste processing, whether ALAN has a direct or indirect impact on the level of human-induced odours or noise, whether it can neutralize these nuisances in whole or in part, or whether it explicitly worsens the current situation.

First, it is important to clarify what this study considers anthropogenic odours. These are scents that are wholly or partly attributable to human activity. Anthropogenic odour is unquestionable in the case of industrial activities and transportation; however, the categorization of agricultural activities is ambiguous because certain processes (e.g. the decomposition of organic matter) occur naturally and without human intervention, but may be augmented through agricultural activities. To ensure clarity within the scope of this report, all odours attributable to human activity - including those arising from agricultural practices - are considered anthropogenic, i.e. non-natural. Regarding the interrelationships between these odours and ALAN, it can be stated that this is a sparsely researched area, and no studies or investigations specifically addressing this topic were found during the research. Nevertheless, it can be argued that, while not directly, ALAN demonstrably disrupts the circadian rhythms of insects and microbes involved in organic matter decomposition. This may affect their feeding habits and potentially slow down decomposition processes, leading to the accumulation of unpleasant odours. Given that no credible, peer-reviewed studies were found on this matter in the most common, online accessible scientific databases, there is currently no reliable evidence of how and in what form ALAN influences the level and perception of human-induced odours.

Anthropogenic odours are almost inseparably linked to the emissions of human-induced noise, as their sources typically originate from identical or highly similar activities (Ren et al. 2024). Some examples include transportation, the operational noise of agricultural machinery, or the general ambient noise of urban environments. It is therefore reasonable to assert that locations with artificial light are highly likely to experience human-induced noise, given that human activities, in the vast majority of cases, necessitate the presence of at least a minimal level of (artificial) illumination. The absence of such illumination either renders the activity entirely unfeasible or significantly impedes its execution. An interesting development in this regard may be the future emergence and widespread adoption of so-called "dark factories", wherein fully automated machinery operates entirely without human intervention, thereby eliminating the need for artificial light; however, it must be acknowledged that



production processes within these facilities may still generate auditory and/or olfactory emissions (Texspace Today 2025; Blair 2025). The combined exposure to anthropogenic light and sound, both of which represent significant sensory stressors, indisputably exerts deleterious effects upon wildlife. This combined exposure adversely affects approximately 30% of invertebrate species and roughly 60% of vertebrate species (Wilson et al. 2021). The persistent and simultaneous presence of artificial light and noise—particularly in environments where endocrine-disrupting chemical compounds are also prevalent—creates a profoundly negative environmental milieu. This milieu detrimentally influences the hormonal systems (Seebacher 2022; Gabinet 2024) and, consequently, the entire life cycle of living organisms, with particular emphasis on the growth and reproductive patterns of individuals. Such environmental alterations may precipitate changes in the territorial distribution of organisms, for instance, a reduction or complete elimination of avian populations in urban-proximal habitats. This detrimental impact extends beyond the realm of animal ecology, as the experimentally validated and demonstrably negative effects of artificial noise and light on human health are well-established. These effects particularly include sleep disturbances attributable to the disruption of melatonin and cortisol production (Gabinet 2024), which can, in the long term, predispose individuals to develop mental health disorders such as depression and anxiety (Hu et al. 2025). Based upon these considerations, the preservation of dark skies is not only of critical importance from the standpoint of animal and plant conservation, but is also fundamentally crucial for the protection of human health. Consequently, further investigation into this domain is both indispensable and of inestimable value.



Figure 1.3.1 - Escalating visual environmental pollution resulting from human activities

The natural environment's positive impact on human mental and physical health is not solely attributable to the human organism's limited capacity to adapt to the modern era's light and noise burdens. An integral component of human well-being is also the intrinsic "healing" effect of pristine nature's visual experience. The modern era developments have occurred rapidly within a few decades, and the escalating visual environmental pollution resulting from human activities, the adverse sensory changes in the environment of natural parks and presence of human-constructed artificial landmarks (such as transmission towers, multi-story buildings, and aerial power lines) collectively diminish the ecosystem service functions provided by untouched nature (Fig. 1.3.1). The recreational and therapeutic benefits afforded by such environments are correspondingly reduced, which can be



quantified as long-term economic losses in addition to the aforementioned detrimental effects on flora, fauna and human health.

Following the examination of biotic and biophysical conditions, a brief analysis of ALAN's potential abiotic and geophysical effects is warranted, particularly regarding its influence on the topographic screening effect. Among these effects, the most conspicuous is skyglow, which denotes the reduction in contrast between the observed natural landscape and the celestial sphere due to the diffused light emanating from artificial light sources. This diffusion impedes the effective light-shadowing function of topography, thus compromising the appreciation of the pristine night sky and the associated observational activities. Moreover, light spilling over from its intended area can illuminate previously shadowed areas, diminishing the screening effect of landforms, while excessive brightness and glare can impede the ability to discern details within the landscape, thereby degrading the visual quality of the screened areas. In summary, the preservation of dark skies is not only essential from an ecological perspective but also from a public health standpoint, making further research in this area vital.

Table 1.3.3 - EROSION CONTROL AND WATER FLOW REGULATION

CICES Code	ES category	Group	Simple descriptor
2.2.1.1 2.2.1.2	Regulation & Maintenance (Biotic/Biophysical)	Erosion control.	Controlling or preventing soil or sediment loss by running water; Controlling or preventing soil or sediment loss by wind.
2.2.2.1 2.2.2.2	Regulation & Maintenance (Biotic/Biophysical)	Hydrological cycle and water flow regulation.	Ecosystems controlling river and lake levels during normal conditions; Controlling the peaks in river levels; Mitigating flood waves.

The impact of ALAN on erosion control and water flow regulation represents a critical yet underexplored area of ecological research. ALAN disrupts natural cycles and biological processes that directly and indirectly influence vital ES, such as soil stability and hydrological regulation.

Erosion Control

a. Vegetation Growth and Soil Stability

Artificial light at night can interfere with plant growth by altering photoperiodic cues, thereby weakening root development and the structural integrity of plants that are crucial for stabilising soil. Vegetation plays a vital role in erosion prevention by anchoring soil with its root systems. Disruptions in natural growth patterns, particularly in grassland and edge habitats, may result in increased soil vulnerability to erosion processes. Bennie et al. (2016), in one of the most accessible and widely cited studies on the subject, demonstrated that ALAN significantly alters phenology and growth patterns in several grassland plant species, potentially influencing soil retention capacity and altering ecosystem structure.

b. Disruption of Soil Microbial Communities



Soil microorganisms, including fungi and bacteria, are essential in soil aggregation and nutrient cycling. Studies While the ecological functions of these communities are widely recognised, their specific responses to artificial light at night (ALAN) are only beginning to be understood. Research on this subject remains limited, with only a few experimental studies providing direct evidence. However, recent findings suggest that ALAN can indeed impair microbial-mediated ecosystem functions.

In a controlled long-term experiment conducted in an Ecotron facility, it was demonstrated that exposure to high levels of ALAN significantly altered the composition and function of soil microbial communities. Specifically, the study observed reduced soil respiration rates and shifts in microbial carbon-use efficiency during periods of peak plant biomass, particularly under conditions of elevated artificial light (Cesarz et al. 2023). These functional changes were closely associated with decreased soil moisture content, a factor known to influence microbial activity and aggregation processes.

Although the mechanistic pathways remain partly unresolved, these results strongly suggest that ALAN may reduce the soil's capacity to retain structure and organic matter, thereby increasing its susceptibility to erosion and degradation. The implications are particularly relevant in semi-natural or edge habitats where soil stability is already vulnerable. Given the ecological significance of microbial processes in sustaining soil quality and resilience, further empirical research in this area is urgently needed. Nonetheless, current evidence supports the hypothesis that artificial lighting at night can interfere with microbial dynamics in ways that undermine key erosion control functions.

Hydrological cycle and water flow regulation

a. Disruption of aquatic and riparian vegetation

Riparian and aquatic plants, especially those sensitive to light levels, rely on natural light cues for regulating growth and dormancy cycles. Artificial lighting in riparian zones interferes with these processes, reducing plant cover and diminishing water retention capacity in these areas. This disruption results in increased surface runoff, decreased groundwater recharge, and reduced effectiveness in flood mitigation.

b. Altered nocturnal animal behaviour

Many nocturnal species, such as amphibians and invertebrates, play a critical role in maintaining hydrological balance, particularly in wetland ecosystems. ALAN can alter their activity patterns, causing them to migrate from their natural habitats or decrease their activity levels. These behavioural changes lead to imbalances in plant growth and water cycle dynamics, ultimately disrupting the ecological functions that these species support.

c. Increased urban runoff and reduced infiltration

In urbanized areas, where artificial lighting is prevalent, impervious surfaces often dominate, exacerbating surface runoff and reducing natural groundwater infiltration. The presence of ALAN in such areas further disrupts natural hydrological processes, contributing to more frequent and severe flood events and diminishing water retention during dry periods.

Conclusion

Mitigating the effects of light pollution through dark sky initiatives presents a viable strategy for reinforcing erosion control and sustaining water flow regulation. Such interventions are especially valuable in peri-urban and rural contexts where natural systems are still partially intact. By restoring natural light-dark cycles, these initiatives help maintain vegetation growth, support microbial and faunal activity, and uphold the hydrological functions essential to ecosystem resilience. Consequently,



integrating dark sky principles into environmental policy and land-use planning represents a low-cost, high-benefit approach to conserving ecosystem services in both developed and developing regions.

Table 1.3.4 - LIFECYCLE MAINTENANCE, PEST AND DISEASE CONTROL

CICES Code	ES category	Group	Simple descriptor
2.3.2.1 2.3.2.2 2.3.2.3 2.3.2.4 2.3.2.5	Regulation & Maintenance (Biotic/Biophysical)	Lifecycle maintenance (pollination, seed dispersal), habitat and gene pool protection.	Pollinating our fruit trees and other plants; Spreading the seeds of wild plants; Providing habitats for wild plants and animals that can be useful to us.
2.3.3.1 2.3.3.2	Regulation & Maintenance (Biotic/Biophysical)	Pest and disease control.	Controlling pests and invasive species; Controlling disease.

Light pollution can have serious direct or indirect impacts on life cycle maintenance and on protection of habitats and gene pools. These are fundamental regulating ES, crucial for maintaining the balance and health of ecosystems. As artificial light sources proliferate, they disrupt natural light cycles or manipulate the presence and activity of species that are important ES providers, thus leading to profound ecological consequences. For example, pollination is one of these vital services that has long been considered to be restricted to diurnal species. But in fact, the fertilisation of crops by pollinators does not stop at sunset. On the contrary, it has been confirmed recently that (1) more than 60% of invertebrates are nocturnal (Hölker et al. 2010b) and that (2) insect activity is on average 31.4% higher at night than during the day (Wong and Didham 2024). Several studies have demonstrated how the contribution of nocturnal pollination substantially outweighs the contribution of diurnal pollination and it shows to be highly complementary, improving fruit quality (e.g. Fijen et al. 2023; Robertson et al. 2021) and adding complexity to the structure of pollination networks (García et al. 2024; Alison et al. 2022). Findings indicated that few plants showed a significant mismatch between expected and actual pollinators. For example, plant species with expected nocturnal pollination were visited by diurnal and nocturnal insects, but also vice versa, as some plant species apparently adapted to diurnal pollinators were also visited by nocturnal moths (García et al. 2024). These recent findings make it even more vital to further investigate the contribution of nocturnal pollination in the overall network. Vertebrate pollinators such as bats can also have a special role, particularly in tropical regions, with bat-pollinated plants being far more dependent on their respective vertebrate pollinators than bird-pollinated plants (Ratto et al. 2018). ALAN has been shown to disrupt nocturnal pollination networks (Knop et al. 2017), thus having negative consequences for plant reproductive success and affecting pollinator behaviour, movement, foraging and reproduction, leading to a significant decline in their abundance and functionality (Shivanna 2022). In artificially illuminated communities, nocturnal visits to plants were significantly reduced compared to dark areas (Knop et al. 2017; Bittel 2017). The effect of ALAN on plant-pollinator interactions is not limited to the night: Giavi et al. (2021) showed that artificial light at night can alter diurnal plant-pollinator interactions. Plant species-dependent changes can have unknown consequences for the pollinator community and the services they provide.



Frugivorous tropical bats have a fundamental role in maintaining neotropical biodiversity, as they support habitat regeneration and propagation of various plant species through seed dispersal (Bautista Plazas and Stevenson Diaz 2023; Da Silva et al. 2024; Aguilar-Garavito et al. 2014). Bats play a key role in response to the ongoing forest fragmentation at tropical latitudes (Abedi-Lartey et al. 2016). Other small nocturnal mammals such as lemurs (Ramananjato et al. 2020; Ramananjato 2025) and rodents (Weighill et al. 2017) are important contributors to seed dispersal at night.

If we consider darkness as a habitat for nocturnal species, then of course we can consider artificial light as a threat and as one of the most drastic changes to the night-time environment: light pollution is basically turning night into day (DarkSky International 2014). As research scientist Christopher Kyba explains, predators use light to hunt, and prey species use darkness as cover. Cloudy skies near cities are now hundreds or thousands of times brighter than they were 200 years ago, and we have only recently begun to learn the drastic effect this can have on nocturnal ecology (DarkSky International 2014). Bats, moths, owls, and many other animals rely on the dark to hunt, mate, and conduct their nocturnal lives (Clavier 2024). In this perspective, light pollution can constitute an obstacle to all of these activities. If we consider breeding grounds as crucial habitats for the preservation of wild populations, artificial light poses a relevant threat for some species. It has been observed, for instance, that corals synchronise their reproduction based on lunar cycles, and - more importantly - periods of darkness post-sunset can act as an inducer for spawning (La Torre Cerro et al. 2025). For sessile broadcast spawning marine invertebrates such as corals, successful sexual reproduction strictly depends on conspecifics spawning synchronously, and ALAN could potentially threaten the health of coral reefs - already affected by climate change - by masking natural light-dark cycles that synchronize broadcast spawning (Davies et al. 2023). Another study found that ALAN is able to disrupt the natural diel tentacle expansion and contraction behaviour, a key mechanism for prey capture and nutrient acquisition in corals (Mardones et al. 2023). Amphibians - having the largest proportion of nocturnal species among vertebrates after chiropterans - have a preference for darkness during the breeding season, as well (Vignoli and Luiselli 2013), and several studies demonstrated how ALAN can potentially affect their breeding behaviour and reduce their fitness (Touzot et al. 2019; Touzot et al. 2020). While some species may be disadvantaged by light pollution, others could experience positive effects on breeding (Thawley and Kolbe 2020), and this will create further imbalance in the ecosystem.

In terms of feeding grounds, artificial light has been shown to disrupt guild assemblages, especially in insectivorous bats. Haddock et al. (2019) found that slower-flying bats adapted to cluttered vegetation or with a high-frequency echolocation call were negatively affected by light sources at the forest edge; on the other hand, faster-flying generalist bat species were unaffected by artificial light at the edge of urban forest and used light and dark forest edges in a similar way. Even in tropical forests it has been observed that bats explored and consumed food less often in dimly illuminated areas compared to naturally dark areas, indicating that artificial light alters the foraging behaviour of fruit-eating bats (Lewanzik and Voigt 2014). A similar effect was also observed on nocturnal and crepuscular bees, where foraging activity was limited in response to light (Kelber et al. 2006). For these reasons, ALAN should be considered an anthropogenic edge effect that can reduce available feeding habitat and decrease connectivity for light-sensitive species (Haddock et al. 2019).

Great dispersers such as wolves can perceive illuminated areas as a greater factor of fragmentation when compared to road densities (Kudrenko et al. 2023), and other small nocturnal mammals tend to avoid lit underpasses, as well (Sordello et al. 2025). This suggests that ALAN can act as an agent of nightscape fragmentation for different species.



Plants can also be severely impaired by artificial lights, affecting traits important to fitness and also altering the habitat. Murphy et al. (2022) found that aboveground production of invasive cheatgrass was more than 5 times greater under ALAN than any other species in their treatments. This suggests that ALAN may influence the outcomes of interspecific interactions and thus modify the environment (Murphy et al. 2022). As urbanization increases, its role in invasion biology becomes more important, especially when an urban disturbance such as ALAN benefits the growth of invasive species (Murphy et al. 2022; Liu and Heinen 2024). More interestingly, it has been shown that under constant environmental conditions, continuous artificial lighting causes damage to leaves due to oxidative stress, the main cause of which is circadian asynchrony, i.e. a mismatch between the internal rhythms of the organism and external light-dark cycles (Shibaeva et al. 2024).

Moving back to fauna, an indirect impact of light pollution is observed on trophic interactions, thus also influencing the relationship between pests and their prey. Miller et al. (2022) experimentally investigated impacts of cool- and warm-temperature artificial lights at night on a population of pea aphids and their predator, ladybird beetles. They observed evidence of aphid-driven dynamics in the cool, light conditions where aphids thrive and exhibited strong anti-predator behaviour. In contrast, they found stronger predator-driven dynamics in warm conditions where ladybird beetle predatory success was higher, thus displaying that light temperature can influence not only pests but also their natural predators' behaviour, limiting their role in controlling population growth. Bats are also well known to be efficient at controlling pests, as several studies in agricultural ecosystems have shown: for instance, Ancillotto et al. (2024) conducted an exclusion experiment and an economic evaluation to estimate the impact of bat insectivory on crop damage and economic savings. Their results demonstrated that the presence of bats in apple orchards can significantly reduce the damage caused by pests, resulting in a 32.1% reduction in affected apple trees and a 50% reduction in the total weight of damaged apples per tree. This translates to estimated economic savings of 551 €/ha/y, because it permits the reduction of insecticide and, consequently, it minimizes the negative impacts of such chemicals on the environment and human health (Ancillotto et al. 2024).

Artificial light can have a role in controlling disease vectors, particularly insects, but in this specific case the outcomes are much more complex. Recent research concluded that light can minimize the activity of disease vectors under certain conditions, reducing for instance the feeding behaviour of *Anopheles funestus* s.s. (van Zyl et al. 2024), but more generally acting as visual attractants for hematophagous insects (Da Rocha Silva et al. 2023). However, not all lights with the same colour temperature are equally attractive to arthropods (Longcore et al. 2015). Daufel et al. (2023) observed differential species-specific sensitivity to environmental cues such as ALAN: *Culex* spp. (and other raft-depositing genera) could be more susceptible to predation under ALAN given visual contrast as they stand vulnerably on the water surface during oviposition, at increased risk to their offspring. *Ochlerotatus* spp. (and other skip-ovipositing species), on the other hand, utilize water-adjacent terrestrial surfaces that may preclude them from strong contrast effects of ALAN and less susceptibility to aquatic predators. Findings show that localized ALAN can deter mosquitoes from oviposition sites, especially for *Culex* species, but it is important to keep in mind that ALAN effects are species-specific and may vary across levels of biological organization, potentially leading to ineffective reproduction or - in the worst case - having compounding drawbacks for other species with different ovipositional strategies (Daufel et al. 2023). In contrast, other researchers found that exposure to dim ALAN causes female mosquitoes to avert diapause and become reproductively active, and suggested that mosquitoes in highly light-polluted areas such as cities may be extending the period of disease risk for urban residents (Fyie et al. 2021). Finally, a recent review underlined how most of the studies to date have been laboratory-based, making it still unclear how ALAN modulates disease vector risk in nature, and suggested five priorities to assess how artificial light can influence disease vectors in socio-ecological systems (Coetzee et al. 2023).



Table 1.3.5 - SOIL QUALITY, WATER CONDITIONS, CLIMATE AND WEATHER

CICES Code	ES category	Group	Simple descriptor
2.3.4.1 2.3.4.2 2.3.4.3	Regulation & Maintenance (Biotic/Biophysical)	Regulation of soil quality.	Ensuring soils form and develop; Ensuring the organic matter in our soils is maintained; Creating and maintaining the structure of soils.
2.3.5.1 2.3.5.2	Regulation & Maintenance (Biotic/Biophysical)	Water conditions.	Controlling the chemical quality of freshwater; Controlling the chemical quality of salt water.
2.3.6.1 2.3.6.2	Regulation & Maintenance (Biotic/Biophysical)	Atmospheric composition and conditions (climate and weather).	Regulating our global climate; Regulating the physical quality of air for people.

In this section, we explore the possible impact of ALAN on the regulation and maintenance of soil, water and air quality.

The regulation and maintenance of soil quality typically involves the activity of soil bacterial networks. Bacteria play a crucial role in the biological decomposition of minerals (Douglas & Beveridge 1998), which is a key factor in the maintenance of fertility and, in general, of the conditions necessary for the human use of soil. Therefore, the assessment of the impact of ALAN on soil bacterial networks is bound to the studies of light pollution effects on species activities involved in such functions. A well-studied case is the impact of ALAN on the activity of bacteria in the decomposition of plant residue (litter) on the soil. According to the scientific literature, the impact of ALAN is usually negative, but it can sometimes be positive in the sense that light pollution can mitigate or compensate for the negative effect of other pollutants. It is worth mentioning that, according to our desk research, the number of studies documenting the negative effects of ALAN greatly surpasses the ones reporting positive ones. Just to mention a few, ALAN was found to potentially increase the richness of phytopathogenic fungi (Li et al. 2023); causes instability of bacterial community in urban soils (Li et al. 2024); may reduce the surface foraging activity of an anecic earthworm species and, therefore, may limit their ability to forage and mate; may boost the growth of ragweed, contributing to a further increase in ragweed infestation and even to an increased risk of ragweed pollen allergy (Mittmannsgruber et al. 2024) and; to reduce plant biomass, thereby decreasing soil water content (Cesarz et al. 2023). On the other hand, positive effects of ALAN are reported in relation to a decrease in metal toxicity. For example, ALAN was shown to change the toxicological effects of cadmium in microbial communities associated with leaf litter decomposition (Zhuangzhuang et al. 2020). In some studies, both positive and negative effects are reported. ALAN was found to potentially suppress the phyllosphere microorganisms in grassland plants but, at the same time, decrease the probability of fungal pathogen occurrence (Wang et al. 2024). It is worth noticing that, in all cases, the impact of such effects on the related ES was not directly discussed by the authors and remains to be investigated. In conclusion, the impact of ALAN on the regulation and maintenance of soil quality is



indirect (since it mainly affects the microbiota and not the soil directly) and with thin evidentiary support, but with much circumstantial evidence that highlights the need for further investigations.

A similar scenario holds regarding the effect of ALAN on water ecosystems, and in particular to the regulation and maintenance of the (chemical) quality of fresh and saltwater. The lack of direct evidence is attributable to the very recent start of dedicated scientific efforts in this regard, which dates back to a decade only for water ecosystems. Nowadays, ALAN is recognized as a significant environmental pollutant affecting marine ecosystems. For example, ALAN can impact the day-night cycle of zooplankton that ascend to surface waters at night to feed and descend during the day to avoid predators. The presence of ALAN results in increased phytoplankton biomass, potentially causing algal blooms and subsequent alterations in nutrient cycling and oxygen levels in marine environments (Marangoni et al. 2022). A graphical representation of such effects on marine environments is reported in Figure 1.3.2. Coral reefs are also sensitive to light conditions. ALAN affects their physiology and biochemistry, including disruptions to their relationships with photosynthetic organisms (Fobert et al. 2023). These disturbances can lead to changes in primary production and nutrient dynamics with reef ecosystems. In some cases, ALAN seems to cause behavioural modifications rather than physiological ones. Nevertheless, it can still impact the processing of organic and inorganic material in water ecosystems, which plays a crucial role in ES. For example, Czarnecka et al. (2021, 2022) reported behavioural changes induced by ALAN on freshwater crustacean shredders, which can impact their processing of organic matter, and in particular litter decomposition, in freshwater ecosystems.

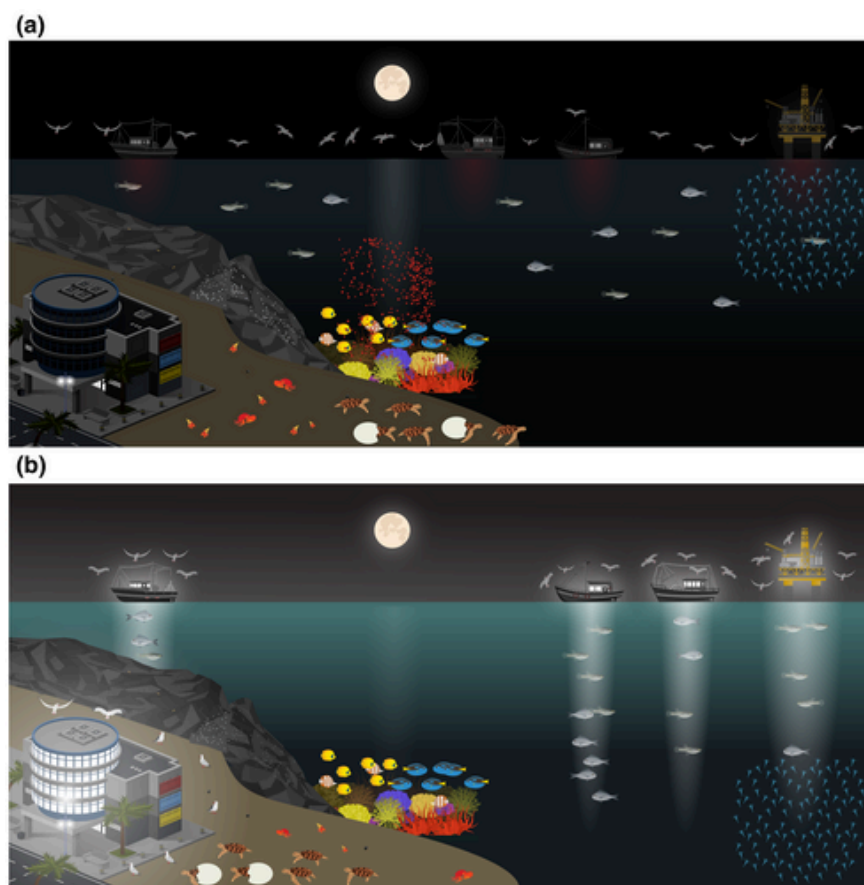


Figure 1.3.2 Graphical representation of the effect of ALAN on different marine environments (Marangoni et al. 2022, Global Change Biology, Wiley - <https://doi.org/10.1111/gcb.16264>)

Finally, the effect of ALAN on air quality regulation would appear more straightforward, but in most cases it is reversed. It is well established that light pollution significantly contributes to global



greenhouse gas (mainly CO₂) emissions, since the production of artificial light accounts for 20% of global electricity consumption and 6% of CO₂ emissions (Linares Arroyo et al. 2024). This figure is apparently increasing, since Tsao & Waide (2013) reported that 6.5% of world primary energy was used to produce artificial light. Another well-known effect is how light pollution is worsened by air pollution. In particular, Kocifaj & Barentine (2021) showed how reducing air pollution (aerosols specifically) decreased night-sky brightness by tens of percent at relatively small distances from light sources. However, it is less known that ALAN may increase air pollution as well. In fact, some chemical processes that help clean the atmosphere occur predominantly at night; thus, artificial light can disrupt these processes, potentially leading to increased levels of air pollution during the day. In particular, increased light levels at night can boost the photolysis of chemicals, such as nitrate radicals, that would otherwise help mitigate the concentration of human-emitted air pollutants (Stark et al. 2011). Similar effects of ALAN were reported to disrupt the chemistry of night-time ground-level ozone (Syabiha et al. 2022). While these effects were reported to be small, but significant, further studies are required to definitively prove the effect of ALAN on the air quality related to ES, which in any case is indirect.

Table 1.3.6 - OTHER TYPE OF ES REGULATING SERVICES

CICES Code	ES category	Group	Simple descriptor
5.3.1.1	Regulation & Maintenance (Abiotic/geophysical)	Other type of regulation and maintenance service by abiotic processes.	Regulatory power of circadian rhythms, melatonin production, depression and related illnesses.

Diurnal animals have adapted to the natural cycles of light and dark in their environment, and artificial light can disrupt their natural behaviour and physiology. Exposure to artificial light can interfere with the timing and quality of sleep in many diurnal animals, which can affect their physical and cognitive performance and increase their stress levels. Light pollution can alter the behaviour and physiology of some diurnal animals, such as birds (Isaksson et al. 2024) and insects, by interfering with their circadian rhythms and hormonal processes or brain structure (Bumgarner et al. 2023). This can have negative effects on their ability to forage, mate, defend territory, and the timing of migration and reproduction. These impacts ultimately affect their fitness and survival, with cascading effects on other species in the ecosystem.

Since humans, like animals and plants, have fundamentally evolved alongside a day-night cycle and adapted their biological structure accordingly, it's worth examining, along similar lines (sleep cycles, hormonal systems, dietary habits), whether and how the disrupted balance of day and night, caused by ALAN, affects human physiological and psychological processes. We have all experienced how, at night everything slows down, providing humans and animals the opportunity to rest, allowing movement-rich processes to be replaced by regenerative functions such as detoxification of the body and replenishment. The two most obvious values through which these processes—or the lack thereof—can be most easily tracked are changes in the body's melatonin levels and—related to this—heart health.



Figure 1.3.3 Human physiological and psychological processes affected by ALAN (DALLE AI)

Melatonin is a hormone produced by the pineal gland, and its function is to regulate circadian rhythms, meaning it is responsible for the harmony of sleep cycles. As part of the body's hormone production processes, melatonin plays a role in the regulation of body temperature. In cases where an organism is even partially exposed to ALAN, melatonin production decreases (Yang et al. 2024), disrupting the circadian cycle and potentially impairing the effective functioning of the immune system, as melatonin also acts as a potent antioxidant (Jones et al. 2015). It is unquestionable that, in addition to affecting melatonin production, ALAN can influence the development of cardiovascular diseases—which, alongside cancers, serve as one of the main causes of premature mortality (Eurostat 2025)—regardless of the extent of an individual's exposure to artificial light (Hu et al. 2024). This negative effect not only affects the elderly but also young people, among whom the negative impact of indoor artificial light on parasympathetic activity and cardiac autonomic function has been observed (Zhu et al. 2024). Examining the effects of ALAN is particularly important, as it affects not only the adult population but can also indirectly affect fetuses through gestational diabetes, the development of which has been linked to exposure to artificial night light effects (Liao et al. 2024).

Based on all of the above, it is unquestionable that ALAN can have a negative impact on human biological processes. Additionally, it's worth mentioning whether the effects can be observed, either directly or indirectly, in psychological processes; whether a correlation can be made between ALAN and the development or exacerbation of mental illnesses. Since this area requires further research (Jin et al. 2023), current scientific findings must be treated with reservation. However, current information suggests that there is a high probability of a correlation between ALAN and the development and exacerbation of anxiety disorders, depression, dysthymia, and mood disorders (Tancredi et al. 2022). Therefore, this area of research merits in-depth investigations, due not only to physical impacts, but also to psychological consequences.

Based on the above findings, natural darkness is an undervalued resource, both culturally and from a health perspective. It is indispensable for maintaining our physical and mental health in the long term, ensuring a better and healthier future for generations to come.



1.4. Cultural ES affected by light pollution

Cultural Services: These are the non-material benefits people gain from ecosystems, a cultural service is a non-material benefit that contributes to the development and cultural advancement of people, such as:

- **Recreation:** Natural areas offer spaces for outdoor activities like hiking, birdwatching, and swimming.
- **Aesthetic value:** Scenic landscapes, such as mountains, lakes, and forests, provide beauty and inspiration.
- **Spiritual and cultural significance:** Many cultures consider certain ecosystems, like sacred forests or rivers, to be integral to their identity and spiritual practices.

In this section, the cultural ecosystem services that may be significantly impacted by light pollution will be analysed. They will be selected and the effect will be explained.

Table 1.4.1 - OUTDOOR AND RECREATIONAL ACTIVITIES

CICES Code	ES category	Group	Simple descriptor
3.1.1.1 3.1.1.2 6.1.1.1 6.1.1.2	Cultural (Biotic/Biophysical) Cultural (Abiotic/geophysical)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting, i.e. broadly recreational activities; Direct, in-situ and outdoor interactions with geophysical systems that depend on presence in the environmental setting.	Using the environment for sport and recreation; Using nature to help stay fit; Watching plants and animals where they live; Using nature to de-stress.



Dark skies are essential to many recreational activities that involve direct interaction with nature. Activities such as stargazing, night-time hiking, camping, and observing nocturnal wildlife offer unique opportunities for relaxation, personal well-being, and connection with the environment. The absence of artificial lighting enhances the authenticity of these experiences, increasing both educational and aesthetic value.

Night-time observation also allows for the discovery of creatures that are active only after dark, such as owls, bats, and various insect species. Additionally, spending time in natural darkness can have positive effects on mental health, helping to reduce stress and improve sleep quality. These findings are supported by recent studies linking exposure to natural nightscapes with lower levels of psychological distress and improved emotional well-being (Barnes & Passmore, 2023).

Excessive artificial lighting disrupts the quality of outdoor experiences by interfering with natural nightscapes and reducing visibility of celestial bodies. This is particularly detrimental to amateur astronomers and astrophotographers, whose activities rely heavily on a clear, dark sky. In many areas, the growth of light pollution has negatively impacted stargazing tourism, which in turn affects local economies and the cultural appreciation of the night sky. A large-scale survey conducted by Falchi et al. (2016) revealed that more than 80% of the world's population lives under light-polluted skies, with the Milky Way no longer visible to over one-third of humanity.

Moreover, light pollution poses serious ecological risks. It disrupts the natural behaviours of nocturnal species, such as migration, feeding, and reproduction. Animals like birds and insects can become disoriented by artificial lights, leading to habitat fragmentation and a decline in populations. These disturbances can also affect recreational activities, such as birdwatching or nature photography, which rely on observing wildlife in its natural environment.

Beyond its effects on ecosystems, light pollution can harm human health by interfering with circadian rhythms. Exposure to bright artificial lights during the night has been linked to sleep disturbances, increased stress levels, and reduced relaxation, counteracting the benefits that outdoor activities should provide.

To maintain the quality of outdoor and recreational experiences, it is essential to take steps to mitigate light pollution. Strategies such as using shielded lighting, establishing dark-sky parks, and raising public awareness are crucial for protecting the natural environment from unnecessary artificial lighting.

By conserving dark skies, we not only protect biodiversity but also ensure that future generations can enjoy the same outdoor experiences that foster health, education, and cultural appreciation. Implementing dark-sky principles in urban planning and environmental policies will enhance the overall well-being of communities and help sustain eco-tourism and nature-based recreational activities.



Figure 1.4.1 - Radgoszcz Lake - (Poland) - K.Kujawa

Table 1.4.1 - RESEARCHING AND STUDYING NATURE

CICES Code	ES category	Group	Simple descriptor
3.2.1.1 3.2.1.2 6.2.1.1 6.2.1.2	Cultural (Biotic/Biophysical) Cultural (Abiotic/geophysical)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting; Direct, in-situ and outdoor interactions with geophysical systems that depend on presence in the environmental setting.	Researching nature; Studying nature.

While ALAN is now a part of our everyday lives, we often forget that, although it has formed an integral part of human cultural evolution, we may have lost as much as we have gained through it—imperceptibly. Although we have acquired a vast amount of new knowledge through the study of nature, future research—in biotic, abiotic, bio- and geophysical fields—will be significantly affected by the fact that baselines have been considerably shifted due to the nearly ubiquitous presence of light pollution (Bucher SF et al. 2023); that is, what is considered 'normal' in today's natural environment has already been significantly altered compared to the pre-industrial era, with the increase in the level of light pollution (Gaston et al. 2008). Today, in the case of scientific research conducted on the natural environment, special attention and resources must be devoted to ensuring that investigations take place in genuinely pristine areas, since if the studied area is subjected to a light effect that would not be present without human influence (i.e. any light effect excluding sunlight and moonlight,



and that is traceable to human activity), it can lead to a high likelihood of erroneous scientific research results, whether in biotic, abiotic, bio-, or geophysical studies.



Figure 1.4.2.: Visual representation of how ALAN influences nature research (DALLE AI)

Although the use of ALAN has significantly increased people's sense of security and productivity, thereby providing substantial economic benefits to individual states, researchers face fundamental difficulties, particularly in the case of in situ research (Figure 1.4.2). Indeed, it is difficult to solve the problem of how to study ecosystems in their 'undisturbed state' when the natural biological rhythms of individual animals and plants are disrupted—to varying degrees—by the application of artificial light sources (Wang et al. 2023). There is no question that, from a biological perspective, ALAN can disrupt the behaviour of numerous species: their migration, foraging, mating, and reproductive habits, and therefore their entire life rhythm, from nocturnal insects (e.g. moths) to migratory birds, the latter of which can even deviate from their usual migration routes due to the disturbance caused by urban lights, with potentially significant impact on population dynamics. If we compare this with the impact of these creatures on human culture—considering the starry night sky as the first navigational tool for sailors or the birds that form the basis of the belief systems of various peoples—it is easy to recognize that the loss, extinction, or significant behavioural change of these organisms will sooner or later also affect human culture.

From a biophysical perspective, ALAN can have a negative impact not only on the developmental rhythm of animals, which follows natural light cycles, but also on that of plants, thereby affecting not only the distribution of the given plant but also the survival chances of higher-order species that rely on it as a food source. Due to this feedback—that is, the fact that human artificial light affects the entire life cycle of both plants and animals, which, in turn, through the relationship between humans and nature, has repercussions on human culture as well—researchers will be forced, in ongoing and future studies, to consider not only the direct environmental impact of artificial light but also its cascading effects on entire ecosystems.

Considering abiotic factors (e.g. the ratio of natural to artificial light, the humidity and temperature of the given area), it is much more difficult to find a connection between ALAN and individual factors; however, it can be said that—depending on the type of light source, with larger-scale light pollution



environmental characteristics that hold cultural or historical value while impairing their heritage functions.

Different elements within biodiversity and landscapes serve as protectors of cultural and historical and spiritual value. Natural areas including sacred forests and symbolic forests, starry skies and historical walking trails demonstrate how certain environments gain worth that extends past their environmental significance. The fundamental biological operations of these areas change because of ALAN which modifies the wildlife populations and transforms how people interact with the areas throughout time.

Dark skies represent the most prominent representation of cultural heritage together with scientific heritage. The presence of visible constellations through unaided vision has become impossible for 80% of the global population due to ALAN (Falchi et al., 2016). Forests located in inland and mountainous regions during past times (and continuing today) served as locations for religious practices, work and communal festivities. Nowadays, nighttime illumination of trails together with tourist areas disrupts the life patterns of essential species such as bats, owls and nocturnal pollinating insects that define natural areas, thus forcing them to relocate to less illuminated regions. The alteration of ecological dynamics (e.g. pollination and pest control) together with the appearance and “sound” of these environments results from this effect. Local biodiversity suffers from this, while the environment loses its appeal to visitors and the landscapes become less enjoyable for them.

Iconic natural peaks and buildings that receive nighttime illumination for tourism or identity purposes, or special events, generate intense light pollution that disrupts nocturnal species, stargazing opportunities and astronomical observations. Natural environments lose their ecological operational capacity and their cultural or historical significance because of light pollution. Several locations derive their identity together with their intangible worth from the biophysical traits that control species' life cycles and interactions along with their sensory characteristics. The artificial lighting disrupts natural processes leading to possible cultural and ecological destruction. Landscape and cultural heritage conservation policies must integrate light pollution reduction measures to preserve both the ecosystems and dark skies that hold cultural significance.

A location's natural charm that makes it a scenic spot or nature reserve emerges from the equilibrium between natural systems and cultural elements and landscape features. The dark sky component, which forms the base of landscape aesthetic perception, faces a threat from light pollution in such locations. Many rural and mountainous regions experience degraded starry sky views because of ALAN, leading to damage to their scenic beauty and natural processes. The diminished beauty of these areas affects both the cultural value of astronomical observations and astrotourism practices alongside their perceptual attractiveness. The nighttime landscape quality in UNESCO areas such as Cinque Terre and Val d'Orcia remains essential for tourism, yet intensified outdoor night lighting diminishes visitors' experience of naturalistic views. Protecting dark skies needs to become a fundamental component of all planning procedures together with environmental protection measures and cultural valorization initiatives.

Table 1.4.4 - THE RELATIONSHIP BETWEEN NATURE, FILMS AND BOOKS

CICES Code	ES category	Group	Simple descriptor
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3.3.1.1 6.3.1.1	Cultural (Biotic/Biophysical) Cultural (Abiotic/geophysical)	Indirect interactions with living systems; Indirect interactions with geophysical systems.	The things in nature used to make films or to write books.
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The birth of video filming and the first cinema dates back to the 19th century. The first night-time videos were filmed at the beginning of the 20th century (Porter and White 1901), even though normally, in films, it was preferable to shoot daytime scenes and ‘darken’ them in post-production or using lenses. The first films with scenes shot at night date back to 1914 with the use of artificial lights as a support for filming (Salt 1992).

Since then, the fascination that humans and filmmakers have for the night has led to an ever-increasing interest in night scenes, the starry sky and the universe (Figure 1.4.4). Technical innovations in the world of cinema and documentaries have done the rest. From what is considered the first science fiction movie—“A Trip to the Moon” by George Méliès—films have contributed to our knowledge of astronomy and space, helping to improve the general public's scientific knowledge over the years. In the following years, films have also become more accurate and scientifically correct, helping the general public to be better informed about the night and the Universe (Alcubierre 2017).

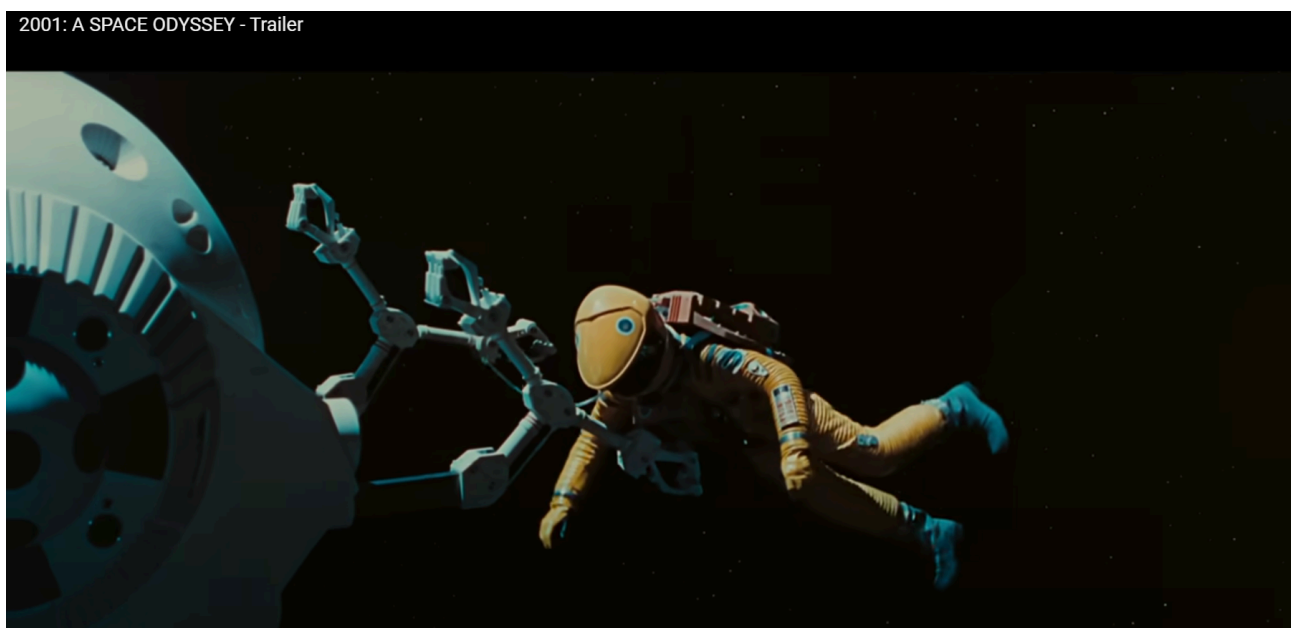


Figure 1.4.4 Scene from “2001: A Space Odyssey”. Source: Screenshot from YouTube.

Expounding on the fascination of life at night, an important development has been in the genre of nature documentaries in which scenes of animals or plants were filmed in the form of a documentary. Arising after the first night scene films, they in turn have played a major role in contributing to knowledge on natural environments and to raising awareness on environmental issues, as well as encouraging citizens to take action to preserve nature. This role can be even more important when we talk about nocturnal animals that we rarely encounter and that we normally know little about. The development of these types of documentaries has led to criticism regarding the exploitation of animals and the lack of realism in the documentaries (Norcross 2019). Criticism has also developed among those who work at night filming or photographing nocturnal animals with the use of artificial light, a factor that can create disturbances for



them in terms of their physical, emotional and behavioural aspects (Gimesy 2024). Innovations in the field of technology, especially thanks to infrared lighting, help to reduce this problem.

Can nocturnal documentaries be a tool for promoting the preservation of nocturnal habitats and amazing dark skies? Can light pollution be a problem for recording them?

Direct information is limited, but we can assume that light pollution, in fact, can significantly impact the production of nature documentaries, particularly those focusing on nocturnal wildlife and natural nightscapes. Light pollution reduces the visibility of nocturnal organisms by disrupting their natural circadian rhythms, making them less active, or altering their behaviour. Species such as owls, bats, and certain insects may avoid artificially lit areas, limiting opportunities to capture authentic footage. Artificial lighting also affects animal behaviour, influencing migration patterns, breeding cycles, and foraging habits. This can make it difficult to document these natural processes in an undisturbed state.

From a technical perspective, excessive artificial light can lead to overexposed or distorted images, diminishing the visual quality of video footage. It can also create an unnatural ambiance, making it harder to portray the true essence of nocturnal environments. Additionally, light pollution restricts available filming locations, often forcing filmmakers to travel to more remote areas to find dark skies. This can increase logistical challenges and production costs. Finally, adapting to light pollution extends production timelines, as filmmakers may need additional planning, specialized equipment, or post-production corrections to achieve the desired results.

To mitigate these challenges, documentary filmmakers can prioritize filming in dark-sky reserves, be active players in the creation of wildlife corridors, and be active partners in the fight for the reduction of light pollution.

Issues related to light pollution are reported in documentaries, both about nocturnal animals and the fight against light pollution. These documentaries are important cultural assets for the preservation of our ecosystems and their role, both from a physical and a cultural point of view, allowing the general public to learn more about the animals of the night and the challenges to their preservation (Figure 1.4.5).

The work of documentary makers, as well as that of film directors who talk about the night, can help preserve an important aspect of our culture, the starry sky.



Figure 1.4.5: Filmmaker at sunset. Source: Gemini AI-generated

Table 1.4.5 - NATURE AS CULTURAL OR RELIGIOUS VALUE

CICES Code	ES category	Group	Simple descriptor
3.4.1.1 3.4.1.2 6.4.1.1 6.4.1.2	Cultural (Biotic/biophysical) Cultural (Abiotic/geophysical)	Elements of living systems that are indirectly appreciated and have significance for people without their presence in the environmental setting; Elements of geophysical systems that are indirectly appreciated and have significance for people without their presence in the environmental setting.	Using nature as a national or local emblem, or referencing a particular area as distinctive in some way (e.g. The Yorkshire Dales); The things in nature that have spiritual importance for people.

Sacred or religious sites associated with dark skies often retain specific geophysical characteristics and ecological qualities that enhance their spiritual importance for people (Figure 1.4.6). Light pollution threatens these sites by altering the natural darkness that is necessary for cultural meaning and religious practices. Such sites can be very diverse. **Mountain peaks and elevated terrain** in Central Europe can offer clear views of the night sky allowing for the best stargazing activity and enhancing spiritual closeness to the universe we belong to, also by learning about the ancient myths and legends carved into the starry sky ([see for example](#)). Besides old religious sites that are no longer used (such as Celtic **sacred groves**), nowadays many religious landmarks and pilgrimage routes are sites for sacred rituals that are sometimes performed at night (like the Night Pilgrimage Chapel of Locherboden (Moffatt 2007) or the night



pilgrimage to the Mariathal Basilica, both in Austria). The effectiveness of worship and personal reflection may be enhanced if performed under dark skies. Astronomical alignment of religious structures is proposed in some cases to be based on *the major lunar standstill* event, such as the Vezzolano Abbey in Piedmont (Sparavigna 2017) or the Stonehenge megalithic structure and the moon is always perceived as a nocturnal element ([more info here](#)).



Figure 1.4.6: Samuel Wölfl, Stonehenge (UK)

All these sites serve as cultural emblems, linking communities to celestial phenomena. Light pollution disrupts their spiritual, cultural, and ecological integrity, weakening both religious practices and cultural heritage tied to the night sky.

Many culturally significant sites are valued for their tranquility and connection to the natural world. ALAN can diminish their sense of mystery, serenity, and spiritual presence. Stargazing activities are provided with an added value when performed in sites of high religious or cultural significance. Many iconic sites, such as churches, abbeys or old castles and fortresses, are usually illuminated at night. Although on the one hand, this can be a good way to highlight the importance of these buildings, at the same time excessive illumination can alter the way these sites are perceived by people. Regarding night-time wildlife, many animals like owls, bats, and nocturnal insects often carry spiritual significance. Owls, for example, have for centuries been considered a symbol of wisdom, spirituality and the mystery of the night (Figure 1.4.7). In many cultures, they are regarded as spirit guides or guardians of knowledge. It is worth mentioning the event entitled 'Night of the owls', organised in the Wdecki Landscape Park, Poland, including workshops and night bird watching ([See at the link](#)).



Figure 1.4.7: Long-eared owl. Source: Erik Karits

The International Dark Sky Association (IDA) (DarkSky International 2025), founded in 1988, identifies several typologies of areas distinctively associated with dark skies. Among them:

- **Dark Sky Communities** are cities and towns that are legally recognized pioneers in adopting quality outdoor lighting ordinances and undertake efforts to educate residents about the importance of dark skies;
- **Dark Sky Parks** are publicly or privately owned spaces protected for natural conservation that implement good outdoor lighting and provide dark sky programs for visitors;
- **Dark Sky Reserves** consist of a dark "core" zone surrounded by a populated periphery where policy controls are enacted to protect the darkness of the core;
- **Dark Sky Sanctuaries** are the most remote (and often the darkest) places in the world whose conservation state is most fragile. The geographic isolation of these places significantly limits opportunities for outreach, so this designation is designed to increase awareness of these sites and promote their long-term conservation.

A complete list of the Dark Sky Places approved by IDA is available ([more info here](#)). Apart from IDA, other institutions also provide similar kinds of certification.

Emblems directly related to dark skies are used by several Natural Parks (often certified by IDA or other institutions). Those emblems usually contain a starry sky (depicted in a realistic way or stylized), a constellation, the moon or a telescope.

Examples:

[Darksky](#)

[Aenos Natural Park](#)

[Zselic Park](#)

[Daruvar Dark Sky Park](#)

[Sternen Park](#)



Emblems from local municipalities are sometimes related to stars. Pino Torinese, which hosts the Astronomical Observatory of Turin, defines itself as *Il paese delle stelle* (*The town of the stars*), and has three stars in its emblem ([see the example](#)).

Table 1.4.6 - NATURAL CONSERVATION AND PROTECTION

CICES Code	ES category	Group	Simple descriptor
3.4.2.1 3.4.2.2 6.4.2.1 6.4.2.2	Cultural (Biotic/biophysical) Cultural (Abiotic/geophysical)	Other biophysical characteristics of species or ecosystems that are appreciated in their own right by people; Other biophysical elements of species or ecosystems that are appreciated in their own right by people.	The things in nature that we think should be conserved; The things in nature that we want future generations to enjoy or use.

As already mentioned, the negative effects of light pollution on terrestrial and aquatic species are increasingly studied and documented by scientific research. Some geophysical and biophysical characteristics of nature, ecosystems and living species can change or even disappear, causing not only damage to living species, a loss of biodiversity, a reduction in the resilience of the ecosystems and a reduction of ES, but also a loss of experiences and feelings that are inspired by the beauty of nature. For instance, many of us have experienced the awesome show of bioluminescent fireflies during a summer night in the countryside. Since time immemorial, fireflies have been celebrated in folklore, poetry, and art. Indeed, fireflies have inspired poets and writers such as the Italian poet Giovanni Pascoli who, in one of his first poems, wrote “...e pieno il grano è già di lucciole...” (*and the wheat is already full of fireflies*) or the writer Susanna Tamaro “Siamo qui, nell’oscurità, sospesi tra la poesia delle lucciole e il fuoco divampante delle stelle” (*we are here, in the darkness, hanging between the poetry of fireflies and the blazing fire of stars*).

The following animals serve as examples that highlight the value of natural dark night skies. Fireflies rely on natural darkness to facilitate mating. Honey bees show behavioural responses to artificial lighting. Sea turtles use natural night skies for orientation upon hatching.

- Bioluminescence is very important for fireflies because it is the mechanism individuals use for mating. If the present situation continues, night bioluminescence by fireflies could become less frequent or even disappear in areas that are affected by light pollution since artificial lighting might affect firefly movements and mating success (Owens and Lewis 2018), thus depriving people living in those areas the opportunity to witness this show of nature in the future.
- Our second example is that of the honey bee, a species that is widely known for the ES it provides as a pollinator and honey producer. It is well known that honey bees are threatened by environmental pollution, including from agricultural pesticide applications, but the effects of light pollution have still been poorly studied. Recently, the effect of artificial light on honey bees' sleep rhythm was investigated in the laboratory because they have a strong circadian



rhythm (Kim et al. 2024). Researchers found that bees exposed to artificial light experienced more sleep disturbances and attempted to find less illuminated places in the cage to sleep, suggesting that artificial light can disrupt bees' sleep with implications on their behaviour. Therefore, light pollution could be another negative effect that contributes to honey bee decline and consequently to the loss of ES that they provide. Honey is a food with exceptional nutritive properties, and beeswax is used to produce candles, soaps and other cosmetic products. These products are culturally important beyond their economic value. In many cultures, honey symbolizes divine sweetness and is used in religious rituals, weddings, and festivals. Bees represent hard work and community in various mythologies and traditions. Beekeeping is often a sustainable practice passed down through generations, connecting people with nature. Honey and beeswax are used in traditional medicine and health remedies across cultures. Bees are seen as sacred in many societies, symbolizing harmony between humans and the environment. Honey is integral in rites of passage and celebrations, representing prosperity.



Figure 1.4.8: Bee pollinating an *Asphodelus*. Source: Luciano Massetti

- Famously, sea turtles—and particularly hatchlings—are among the species most impacted by light pollution. When sea turtles hatch, they move instinctively toward the brightest horizon, which is typically the moon's reflection on the ocean. This behaviour guides them safely to the sea, where they begin their long journey. However, artificial lights from beachfront developments, streetlights, or even flashlights can disorient the hatchlings (Dimitriadis et al. 2018), leading them in the wrong direction—away from the ocean and into dangerous areas like roads, where they are more likely to be hit by vehicles, or they might wander into human-populated areas where predators pose a threat. This could be an important cultural loss for future generations. Turtles are symbols of longevity, wisdom, and stability, representing patience and endurance. Turtles are seen as spiritual protectors associated with good luck and guardianship in Polynesian and Hawaiian cultures. In East Asian cultures, they



symbolize balance and harmony between land and sea. Turtles serve as totem animals, guiding people with qualities like resilience and grounding. They are linked to environmental respect, emphasizing the need to protect nature. Turtles appear in art and crafts, reflecting the connection between humans and the natural world. Their shells symbolize protection and resilience, often used as metaphors for defence. Turtles also represent ancestral wisdom, connecting people to their heritage.

The examples above serve as a small selection of species that we are connected with and are endangered by light pollution. Cultural links could be lost if these species disappear due to the excess of artificial light.

Finally, it is important to preserve a natural and uncontaminated night sky for present and future generations so that people can continue to admire the beauty of the Milky Way and the starry sky. With safeguards to naturally dark night ecosystems, people can continue to take inspiration from the night sky as writers and philosophers such as Dante, Leopardi, Pirandello and Kant did in the past.



2. Light pollution impact on ES and stakeholder involvement

2.1. Importance of stakeholder involvement

It is important to use ES to show their role in involving stakeholders in the fundamental topic of reducing light pollution and promoting dark skies. In this section, we will describe the importance of using stakeholder involvement and stakeholder mapping tools to communicate with the stakeholders and make them understand the role played by dark skies.

In the previous section, we identified and described the major ES and how they are affected by light pollution. They provide important justification for the protection of dark skies, especially in rural settings. Light pollution is one of the most widespread and underappreciated forms of transformation in natural environments. The elimination of night landscapes has profound consequences not only for astronomy, but also for wildlife, human health, and the cultural meaning of nighttime. Dark skies are, therefore, a real ES, essential for environmental and social health. As mentioned before, ES refers to the processes of ecosystems that deliver benefits to human communities (Millennium Ecosystem Assessment, 2005).

Dialogue with stakeholders is a main step in promoting the protection of dark skies and the recognition of the ES they provide towards local communities. First of all, to analyze and involve stakeholders, it is essential to understand that a stakeholder is any individual, group, or organization that has an interest in, influence over, or is affected by the activities, decisions, or outcomes of a project, business, or policy (Tennyson, 2011; Zimmerman & Maennling, 2008). Land and natural resource management play a key role in the ecosystem through the direct involvement of stakeholders including public bodies, companies, associations, local communities, natural parks, and research institutes: it is hard to develop efficient and sustainable approaches without their involvement.

Stakeholder engagement and participation bring value to the discussion of making dark skies a relevant topic; in this way it is possible to develop an environment of trust, allowing the relationship between stakeholders and the promoters of dark sky conservation to increase, allowing the voices of the stakeholders to be heard, making the issue of light pollution relevant and known, and incorporating their needs and concerns. Through the participation and engagement of stakeholders, it is possible to reduce or avoid conflicts between them and towards the topic itself, create new relationships, increasing their responsibility and accountability. They can feel a greater sense of connection with the topic, since their views, beliefs are taken into account and could lead to the decision of promoting the dark skies and the issue of light pollution, and potentially gaining newfound support. The most positive outcome, then, could result in a development of new small-scale or large-scale policies and regulations and the increasing acceptance of management policies and decisions.

Dialogue and involvement of stakeholders within the Darkersky4CE project enables awareness-raising, training sessions and meetings to be held with stakeholders: many stakeholders are not fully aware of the impacts of the loss of natural night skies (e.g. on wildlife orientation, plant growth or human health). Stakeholders such as local authorities and economic operators, but also those directly involved in environmental education, often do not consider light pollution as a priority. In this sense, it is possible to make them aware of the connections between artificial lighting and environmental impacts, to convey scientific knowledge on nocturnal fauna, human health, energy consumption and ES, and to convey the concept which has been found that lighting up city places does not equate to greater safety (Steinbach et al, 2015). It is also possible to make stakeholders understand the value of the night sky as an element of



identity and as a cultural and economic attractor (e.g. for astro-tourism). In meetings and workshops, it is possible to discuss this topic and to publicize the significance of the dark skies, especially in rural areas. Moreover, it is possible to implement genuine stakeholder involvement, e.g. through working tables, world cafés, participatory processes, to promote the importance of dark skies and to reduce conflicts and resistance through participatory, bottom-up and transparent approaches. In fact, there are various methods to involve local stakeholders, among them, in addition to the already mentioned co-design tables and work cafés, it is possible to use online surveys to be filled in for the stakeholder's feedback, organization of conversations, and informal meetings with the community, focus groups, workshops, expert panels, public meetings, etc. However, experiential moments can also be included, such as the development of some stargazing events.

The fight against light pollution and the promotion of dark skies cannot be tackled by technical or regulatory means alone. It requires a strategy of active stakeholder involvement based on listening, training and co-planning. Therefore, a strategic and participatory approach, based on continuous dialogue with stakeholders, is essential to promote the protection of dark skies as an integral provider of ES. In order to achieve different improvements it is necessary to integrate the night sky protection into the local management and development plans. For instance, increased protection of the ES associated with dark skies, better quality of public lighting, which in turn results in the well-being of citizens, but also generates new tourism, cultural, environmental and economic opportunities. In addition, this can bring stakeholders closer to adopting innovative solutions for public lighting and the illumination of cultural monuments, helping to create a favourable environment and reduce resistance to the social acceptance of more restrictive lighting measures. The dialogue provides a platform to share specific business opportunities that apply across different sectors. The tourism industry could benefit from operators who develop astro-tourism packages or local authorities who implement this approach.



Figure 2.1.1: Parabol- The Agile Meeting Tool on Unsplash Source: Unsplash



2.2. Stakeholder mapping

Every project and policy affects stakeholders directly or indirectly because they play a vital role in both development and success. Identifying stakeholders demands a list of everyone who possesses project/policy interest and power, but their level of engagement should differ from one stakeholder group to another.

The tool of stakeholder mapping helps organizations identify key individuals and groups or organizations that affect institutional goals, project objectives and intervention strategies. This tool serves to create strategies for their engagement and participation. The stakeholder mapping process should first determine the positions and capabilities of the essential social actors (Dirección Nacional de Participación Social en Salud Ecuador: 2022). The goal is to understand who the stakeholders are, their interests and needs, and their power and influence towards the project. Stakeholders can vary from associations, public bodies, NGOs, SMEs, local communities, etc.

In this case, stakeholder mapping on the issue of light pollution is required. The **identification** process requires making a list of all stakeholders who demonstrate interest or possess influence regarding the goal or project.

Mapping: The mapping process displays the relationship between specific stakeholders and how they could be connected with the particular objectives of the project. “The goal is not only to identify stakeholders but also to gather and organize key information about each one to deepen your understanding. This may involve researching their contact details, focal points, and gaining insights into who they are, their track record, as well as their interests and activities” (1000 Landscapes for 1 Billion People, n.d.). This process can be conducted through workshops together with surveys, interviews and focus group sessions.

“**Analysing:** going deeper to understand these stakeholders’ perspectives and interests. This can be done informally (e.g. through brainstorming and conversations) or more formally (e.g. through surveying, structured meetings/engagement processes).

Prioritising: ranking stakeholder connections and interests to help work out who else to engage or involve, when timing might be significant and how or how deeply”. (Inspiring Communities. Stakeholder Mapping: 2021.)

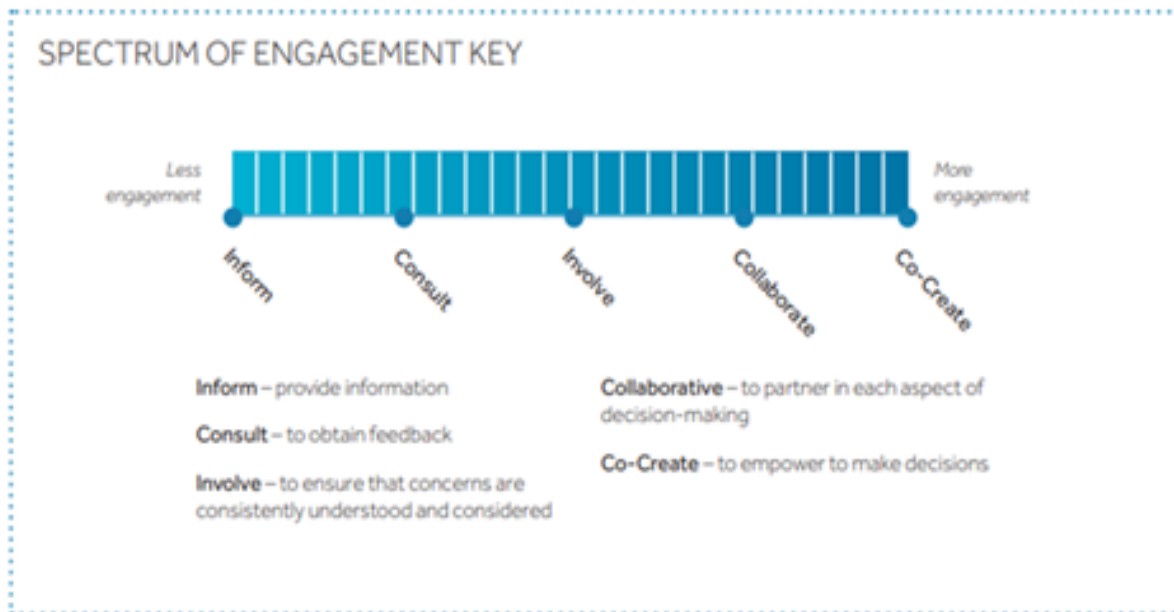


Figure 2.2.1: Stakeholder mapping guide: Mapping potential key stakeholders in reproductive health and family planning service delivery, in preparation for implementing WHO MEC/SPR guidance

Schumacher and Stybel (2016) state that organizations need to assess the following issues when they create stakeholder maps:

- The stakeholders maintain what type of interest regarding the project or policy.
- What level of influence do stakeholders possess toward the policy or service?
- What kind of reaction would stakeholders have if their ideas were not taken properly into account?
- What drives stakeholder participation?
- How are the relationships with the different stakeholders?

The process of stakeholder mapping becomes useful when we assess which stakeholders could assist the dark sky and light pollution dialogue development in rural areas. The stakeholder mapping process requires knowledge about stakeholder characteristics including their needs and interests and levels of influence (e.g. communication, political, cultural etc.). The Power/Interest Matrix represents a suitable tool for effective stakeholder mapping and stakeholder engagement analysis (Brower et al., 2015;; Stibbe & Prescott, 2020; Tennyson, 2011). This matrix assesses the power levels (also known as priority levels) and degrees of interest that stakeholders maintain toward a project or topic (Fig. 2.2.3). For example, a nature park demonstrates strong interest in light pollution reduction in a particular region but lacks sufficient power to execute change, while the Ministry of Environment from a specific country possesses significant power but demonstrates limited interest. This matrix system helps stakeholders' identification as well as strategy development for their involvement.

- Stakeholders with both high influence and interest are ideal candidates for direct engagement and collaboration in the initiative or coalition.
- Those with high interest but low power should be consulted and empowered, with efforts made to increase their influence and engagement in the initiative.
- Stakeholders with low interest but high power should be involved and kept satisfied to ensure they do not derail the initiative.



- Stakeholders with both low interest and low influence should be monitored and kept informed to prevent them from stopping or negatively affecting the initiative” (UN Environment Programme. Stakeholder mapping - Theory handout. PlanetGOLD.)



Figure 2.2.2: Curated Lifestyle on Unsplash. Source: Unsplash

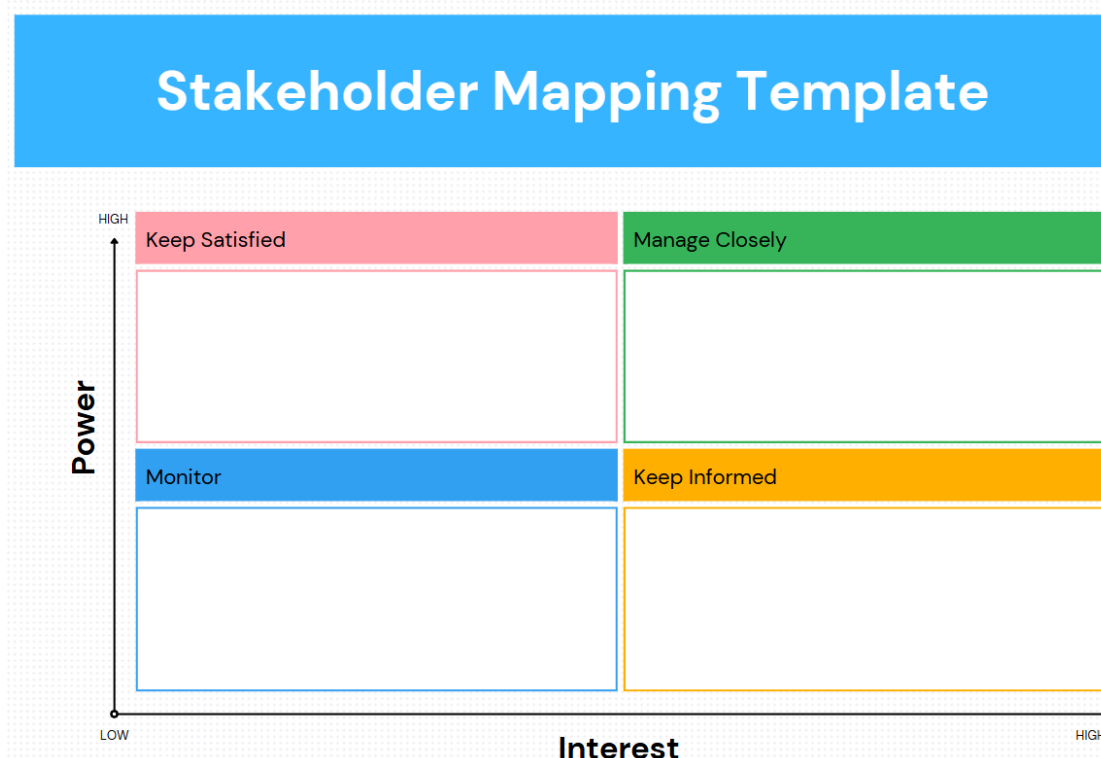


Figure 2.2.3 Power/Interest matrix

To prepare for the stakeholder map, we have developed a list of general stakeholders that could be impacted by the ES analysed in the first section of this report. This list can be observed in Table 2.2.1:



Table 2.2.1 - Stakeholder list

ES Category	Type of Stakeholders	Priority Level	Local	Regional	National	EU	ES Code
Provisioning	Agricultural producers (farmers, food industries)	2	X	X			1.1.1.1 - 1.1.2.1 1.1.3.1
Provisioning	Fishermen and coastal traders	1	X	X			1.1.4.1
Provisioning	Municipalities and relevant departments (agriculture/forestry, economy, finance, environment)	3	X				1.1.1.1 - 1.1.2.1 1.1.3.1 - 1.1.4.1
Provisioning	Ministry of Agriculture, Economy/Finance, Ministry of Environment	2			X		1.1.1.1 - 1.1.2.1 1.1.3.1 - 1.1.4.1
Provisioning	CAP (Common Agricultural Policy)	1				X	1.1.1.1 - 1.1.2.1 1.1.3.1 - 1.1.4.1
Provisioning	University researchers	2		X	X	X	1.1.1.1 - 1.1.2.1 1.1.3.1 - 1.1.4.1
Provisioning	Public and private agricultural producers (crop farmers, horticulture, greenhouses) - Agrobusiness (machines, seeds, pesticides, insurance, banks/stock exchange) - Public and private aquacultural producers (aquafarms) & harvesters (harvesting seaweed, algae etc.)	2	X	X			1.1.1.3 - 1.1.2.3 1.1.3.3
Provisioning	Public and private forestry, tree plantations	1	X	X			1.1.1.3 - 1.1.2.3 1.1.3.3
Provisioning	- Wood cutting and wood processing (sawmills, firewood/wood pellet producers) - Biofuel and biogas producers	2			X		1.1.1.3 - 1.1.2.3 1.1.3.3
Provisioning	National/Federal/Regional Ministries (Agriculture, Economy, Finance, Environment...)	2		X	X		1.1.1.3 - 1.1.2.3 1.1.3.3
Provisioning	Public and private researchers and institutes	3		X	X	X	1.1.1.3 - 1.1.2.3 1.1.3.3
Provisioning	Public and private hunting grounds and fisheries	2		X	X		4.2.1.3 - 4.2.2.3 4.2.2.4
Provisioning	Public and private mining companies (e.g. uranium)	2	X	X			4.2.1.3 - 4.2.2.3 4.2.2.4
Provisioning	Photovoltaic industry, wind power industry and hydropower industry	3		X	X		4.2.1.3 - 4.2.2.3 4.2.2.4
Provisioning	Electricity grid operators	2		X	X		4.2.1.3 - 4.2.2.3 4.2.2.4
Regulating	Environmental protection agencies	3		X	X	X	2.1.1.1 - 2.1.1.2
Regulating	Ministry of Agriculture, Economy/Finance, Environment	3			X		2.1.1.1 - 2.1.1.2
Regulating	Water and waste management authorities	2		X	X		2.1.1.1 - 2.1.1.2
Regulating	Municipalities	3	X				2.1.1.1 - 2.1.1.2
Regulating	Regions	3		X			2.1.1.1 - 2.1.1.2
Regulating	University researchers such as ecologists, soil scientists and microbiologists	2		X	X	X	2.1.1.1 - 2.1.1.2
Regulating	Composting facilities	2		X			2.1.1.1 - 2.1.1.2
Regulating	Farmers and agro-industrial businesses	2	X	X	X		2.1.1.1 - 2.1.1.2



ES Category	Type of Stakeholders	Priority Level	Local	Regional	National	EU	ES Code
Regulating	Environmental NGOs	2	X	X	X	X	2.1.1.1 - 2.1.1.2
Regulating	Local communities affected by polluted waters, or soil degradation	3	X				2.1.1.1 - 2.1.1.2
Regulating	Citizens interested in sustainability	3	X				2.1.1.1 - 2.1.1.2
Regulating	Educational institutions raising awareness on environmental issues	3	X	X	X		2.1.1.1 - 2.1.1.2
Regulating	EU	3				X	2.1.1.1 - 2.1.1.2
Regulating	University faculties: environmental science/engineering, civil engineering/architecture (infrastructure development that can mitigate nuisances)	2		X	X	X	2.1.2.1 - 2.1.2.2 2.1.2.3
Regulating	Chemical engineering: (chemical processes that create smells)	1		X	X	X	5.1.2.1
Regulating	Landscape architecture/urban design	3	X	X			5.1.2.1
Regulating	Local industries generating smells or noise (e.g. factories, waste treatment plants)	2	X				5.1.2.1
Regulating	Transportation authorities (road, rail, air) responsible for noise and emissions	3	X	X	X	X	5.1.2.1
Regulating	City planning departments	3	X				5.1.2.1
Regulating	Companies that produce noise or smell reduction technologies	2		X	X		5.1.2.1
Regulating	National and local parks	3	X	X	X		2.3.2.1 - 2.3.2.2 2.3.2.3 - 2.3.2.4 2.3.2.5
Regulating	Protected areas	3	X	X	X	X	2.3.2.1 - 2.3.2.2 2.3.2.3 - 2.3.2.4 2.3.2.5
Regulating	UNESCO sites	2			X	X	2.3.2.1 - 2.3.2.2 2.3.2.3 - 2.3.2.4 2.3.2.5
Regulating	Monuments, churches, public buildings	3	X	X			2.3.2.1 - 2.3.2.2 2.3.2.3 - 2.3.2.4 2.3.2.5
Regulating	Enterprises	2	X	X			2.3.2.1 - 2.3.2.2 2.3.2.3 - 2.3.2.4 2.3.2.5
Regulating	Agricultural agencies	3	X	X	X		2.3.3.1 - 2.3.3.2
Regulating	Local farmers	3	X				2.3.3.1 - 2.3.3.2
Regulating	Healthcare facilities	2	X	X			2.3.3.1 - 2.3.3.2
Regulating	Biomarine and ecology departments and research centres;	2		X	X	X	2.3.5.1 - 2.3.5.2
Regulating	Ports and harbours management	2		X	X		2.3.5.1 - 2.3.5.2
Regulating	Regional authorities on environment monitoring and protections (ARPA in Italy)	3		X			2.3.6.1 - 2.3.6.2
Regulating	University faculties like: geology/geochemistry, hydrology/hydrogeology, atmospheric sciences/climatology, soil science, environmental engineering, civil engineering, geography/geomorphology, chemistry/physics	2		X	X	X	5.3.1.1
Cultural	University majors like: biology/ecology, environmental sciences/environmental education, forestry/wildlife management, anthropology/sociology, psychology	2		X	X	X	3.2.1.1 - 3.2.1.2 6.2.1.1 - 6.2.1.2
Cultural	Conservation organizations (NGOs)	2	X	X	X	X	3.2.1.1 - 3.2.1.2 6.2.1.1 - 6.2.1.2
Cultural	Governmental agencies (parks, wildlife, forestry)	3	X	X	X		3.2.1.1 - 3.2.1.2 6.2.1.1 - 6.2.1.2



ES Category	Type of Stakeholders	Priority Level	Local	Regional	National	EU	ES Code
Cultural	Local communities and municipalities	3	X				3.2.1.1 - 3.2.1.2 6.2.1.1 - 6.2.1.2
Cultural	Outdoor recreation businesses	2	X				3.2.1.1 - 3.2.1.2 6.2.1.1 - 6.2.1.2
Cultural	Schools and educational institutions	3	X	X	X		3.2.1.1 - 3.2.1.2 6.2.1.1 - 6.2.1.2
Cultural	Tourism industry	3		X	X		3.2.1.1 - 3.2.1.2 6.2.1.1 - 6.2.1.2
Cultural	Museums, archives, and ethnographic institutes	3	X	X	X		3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	National heritage and cultural preservation agencies	2			X		3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	Sustainable and cultural tourism operators that also offer astrotourism experiences	3	X	X			3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	Protected areas	3	X	X	X	X	3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	Ministries of Culture (that regulates the protection of cultural heritage), Tourism, and Environment	2			X		3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	Region	3			X		3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	Writers, filmmakers	2	X	X	X		3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	Cultural festivals	2	X				3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	Environmental education centers	2	X	X			3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	Tourists	2	X				3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	Cultural associations	1	X	X			3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	Schools, universities	3	X	X			3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	International Dark Sky Association	3					3.2.1.3 - 3.2.1.4 6.2.1.3 - 6.2.1.4
Cultural	National and regional environmental authorities	2		X	X		3.4.2.1 - 3.4.2.2 6.4.2.1 - 6.4.2.2



Finally, we developed three stakeholder maps, divided into three different categories of ES (Provisioning, Regulating and Cultural), listing and placing the general stakeholders identified in the previous table. Figure 2.2.4 shows our stakeholder map for provisioning ES; Figure 2.2.5 shows our stakeholder map for regulating ES; Figure 2.2.6 shows our stakeholder map for cultural ES.

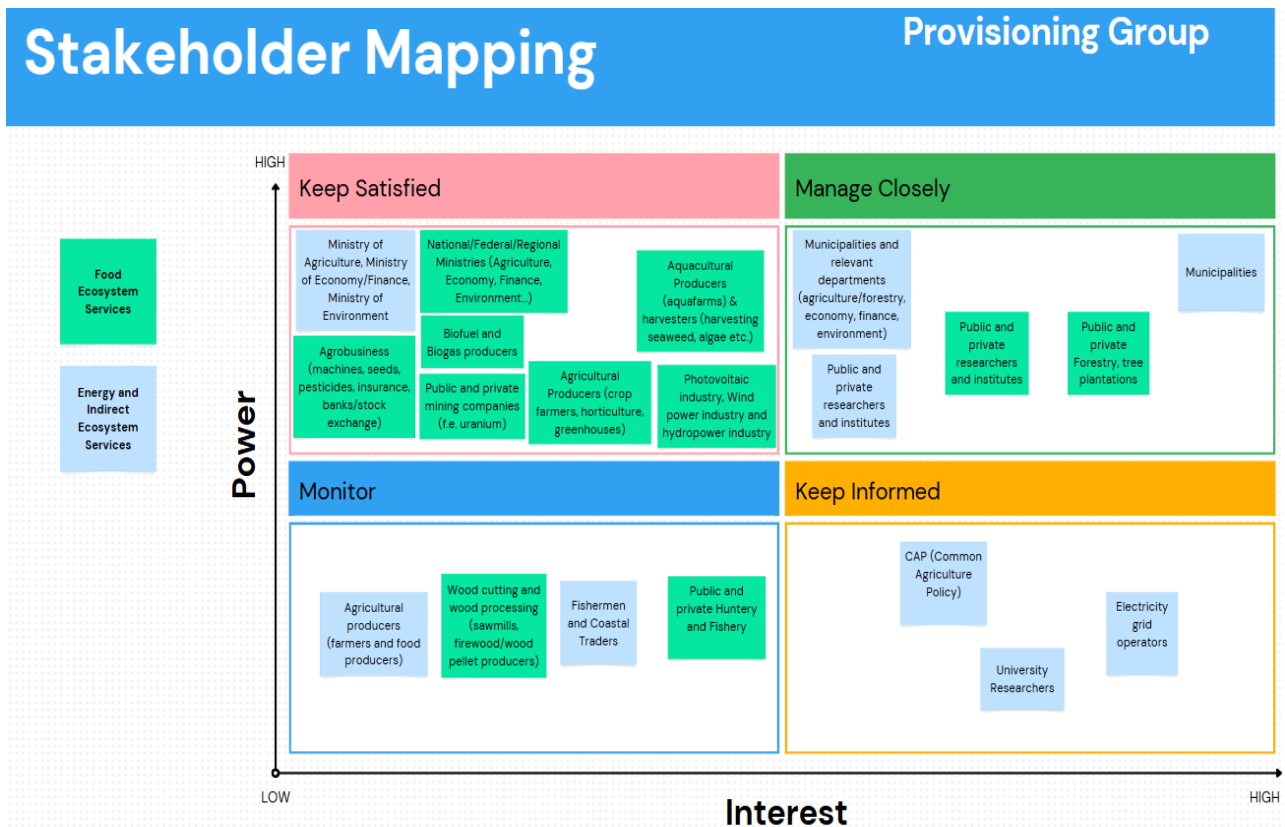


Fig. 2.2.4 Stakeholder map as developed by the Provisioning Ecosystem Services Group



Stakeholder Mapping

Regulating Group

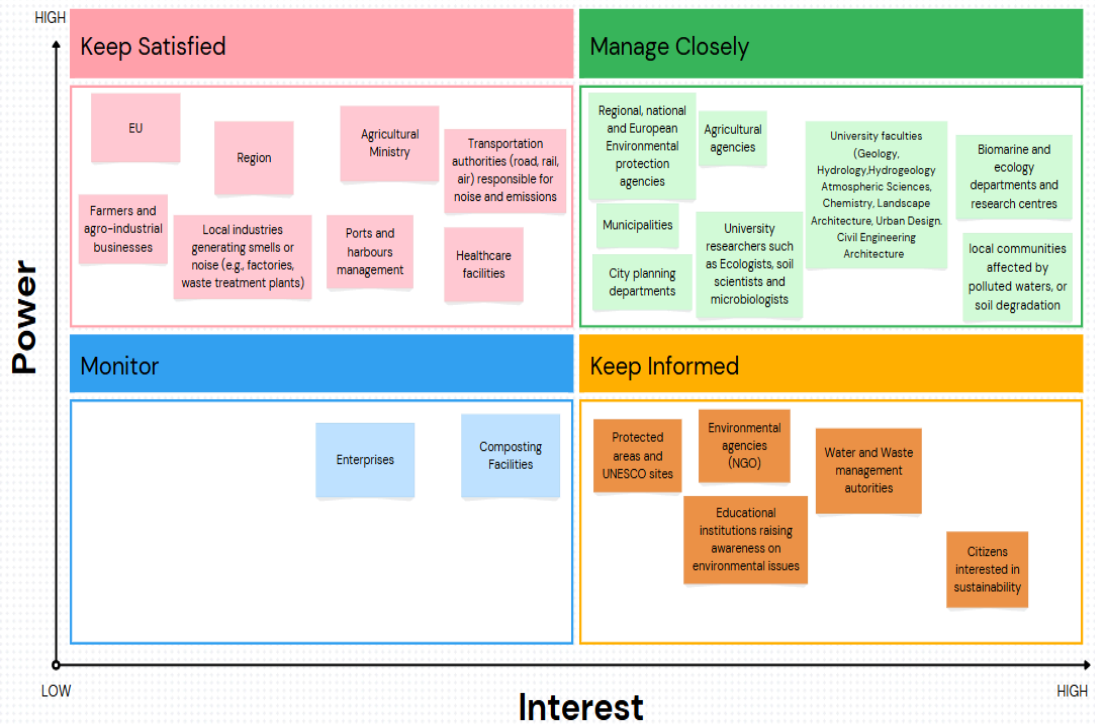


Fig. 2.2.5 Stakeholder map as developed by the Regulating Ecosystem Services Group



Stakeholder Mapping

Cultural Group

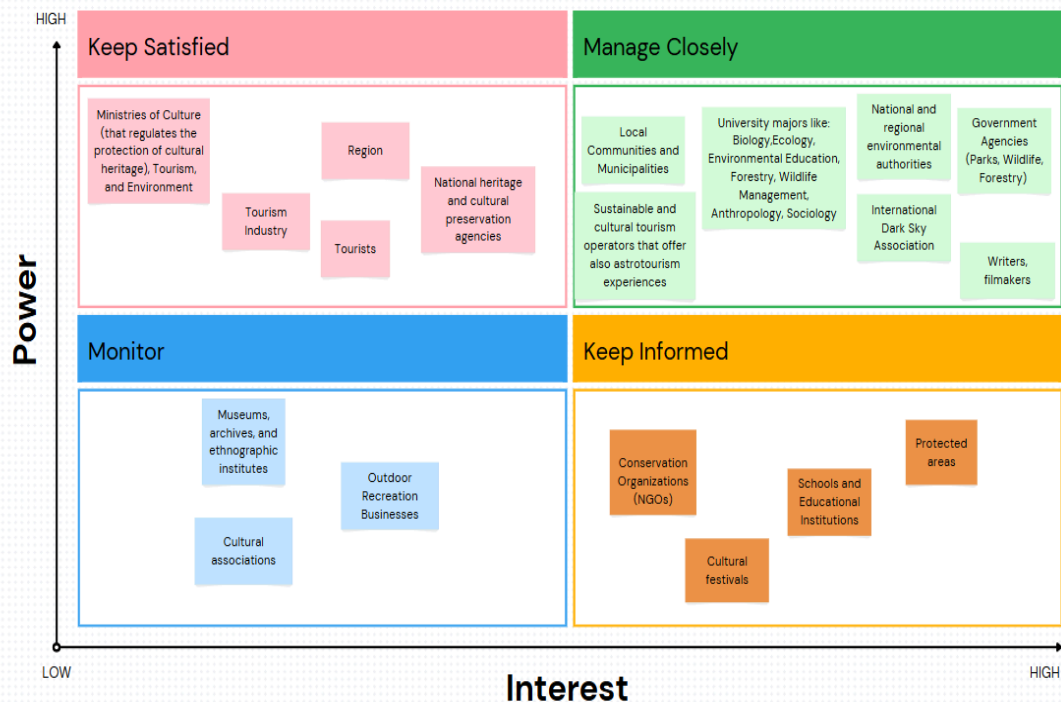


Fig. 2.2.6 Stakeholder map as developed by the Cultural Ecosystem Services Group

2.3. Stakeholders involvement

As seen above, stakeholder engagement is essential to achieving a good result. Using the right levers to convince them can be crucial. The purpose of this report is precisely to use ES as a lever to convince actors who could support the fight to reduce light pollution.

The first step is to map the stakeholders present in a given territory and understand their relevance, power and possible interest in the proposed issue. A player who is relevant in a territory and capable of activating other key players and/or citizens, if “brought over to our side”, will certainly increase the chances of success of our initiative. This point is fundamental in preparing a shared path of awareness and action on any issue, including light pollution, which is still considered to be of little relevance.

At this point, depending on the interests of the stakeholders, it will be useful to analyse the different ESES that interact directly with light pollution and dark skies. In this sense, this report can be very useful in facilitating the analysis.

Firstly, the use of cultural ES certainly has a strong impact. The connection between one's cultural history and the night (e.g. Stonehenge, stars in religion, the night as depicted in art and literature), and the intrinsic beauty of a starry night are sure to have an impact on people. Several groups may be directly interested: for example, cultural and tourist associations, or photography groups. Other stakeholders such as municipalities may also find the cultural aspects of ES “appealing”.



As for provisioning and regulating ES, although very important, they are more abstract to most people because of their technical nature. The presentation of such ES to stakeholders must therefore be carefully considered. For stakeholders who are not directly connected to the issues, it may be important to develop strong arguments related to ES, especially by linking them to issues closely related to the territory (territorial security issues, a specific animal or plant at risk of extinction) or to the direct impact on humans. However, there are stakeholders who are potentially very sensitive to the issue, such as environmental groups or nature parks, who could potentially be very interested in exploring the topic from an ES perspective and supporting its dissemination.

In short, there are many opportunities to use ES as a driver for achieving the goal of reducing light pollution. The combination of ES and in-depth knowledge of the territory and the stakeholders who live there is essential. It is therefore difficult to make general statements on the subject. This report, particularly Section 1, can be a useful tool for working on this issue.



3. Promotion of Ecosystem Services in the Territorial Context

3.1. Understand your context

Stakeholder engagement to boost ES use needs a strategic approach that combines promotion of ES with protection of dark skies and the associated reduction of light pollution. A complete analysis of operational territories should be the foundation of every stakeholder engagement process. Context analysis linked to the use of ES functions as a relevant method to read and understand territories, thus enabling multiple objectives. The analysis helps researchers identify environmental characteristics and social features together with cultural elements and economic aspects of focused territories while they locate essential actors and identify risks that threaten ecosystem functions. The analysis helps create personalized solutions for each territory because every area possesses distinct features. The first step identifies major stakeholders who may participate, helping to establish their interests while determining their potential role in ES affected by light pollution. The operational context requires organizations to recognize and predict upcoming conflicts that may stem from sectors unwilling to support light pollution reduction efforts or hold opposing views (energy sectors, public administrations, sports and tourism, etc.). Organizations must try to work with these groups through shared interests and points of commonality (for example, astrotourism development could lead to light pollution reduction policies). After completing context analysis the relevant ES become identifiable for local communities while protection requirements become apparent.

The development of context analysis requires mapping actual ES present in the specified area through indicated tools (first section of the report) followed by socio-economic analysis to determine main activities and infrastructure and demographic characteristics and common resources. The second section includes a general stakeholder map separated by categories. A context analysis demands individual stakeholder mapping for each specific area. Strategies for stakeholder participation will emerge from this work to understand light pollution issues and to facilitate light pollution reduction practices.

The successful promotion of ES depends heavily on context analysis. Strategies based on local contexts can be developed through this process while stakeholders participate actively and potential conflicts get prevented. The successful management of lands for integration and sustainability requires extensive context analysis as its fundamental component. This process helps determine strategic areas while validating ES and establishing citizen participation through joint efforts. Knowledge about the full context enables the start of a community-driven initiative that transforms the night sky into a common good with significant ecosystem value.

3.2. Interpret results and define reachable objectives

As previously mentioned, combining environmental requirements (ecosystem preservation) with stakeholder needs is essential for achieving realistic goals related to reducing light pollution. Special attention is given to the role of stakeholder engagement in determining realistic and context-sensitive objectives aimed at mitigating light pollution. Mismatch between stakeholder perceptions and ecological evidence, particularly where the impact of light pollution is underestimated, is a real issue. While technical solutions to reduce light pollution exist, their implementation is often made difficult by low awareness, competing interests, and lack of alignment of priorities among stakeholders. Policymakers often recognize the issue but may be constrained by political or economic priorities. Economic operators are concerned about regulations that might limit operational hours or visibility but may also see branding



value in supporting sustainable initiatives (e.g. dark sky tourism). Citizens may hold very different positions, from enthusiastic support connected to their interest in stargazing and natural nightscapes to resistance based on safety concerns. These relationships highlight both threats to mitigation of light pollution (e.g., conflicts of interest, low prioritization) and opportunities (e.g., synergies between conservation and economic benefit). In any case, stakeholder reactions may vary from one another and from area to area. It will therefore be necessary to clearly understand which objectives can be achieved in a given context. It is pointless to set overambitious goals if there is no basis for achieving them, whereas it is better to “seize the opportunity” if the actors in a given area are very open to dialogue. The more informed and involved stakeholders are, the more ambitious the targets can be.

Here we analyse three different levels of stakeholders engagement:

- Highly engaged stakeholders:

If there is a high level of engagement, and if stakeholders are open to dialogue, are receptive and can be mobilized toward significant change, then it is possible to reach higher objectives such as implementation of dark sky reserves, adoption of strict light pollution ordinances, investment in smart lighting technologies.

- Moderately engaged stakeholders:

If there is a medium level of engagement, stakeholders are partially open to change. They may support action if benefits are clear and risks are minimized. In this case it is possible to reach objectives like zoning regulations, pilot projects for low-impact lighting, and community education programs.

- Low-interest stakeholders:

If the dialogue with the stakeholders is difficult and they are resistant to change or unaware of negative impacts, objectives of dialog must first focus on building understanding before proposing stricter measures. In this case, feasible objectives may be, for example, awareness-raising campaigns, stakeholder-specific dialogue sessions, or evidence-sharing on economic and ecological costs of inaction.

All three levels of engagement depend not only on technical solutions, but on how effectively stakeholders are made aware of their role. This includes communicating the material costs of inaction, such as energy waste, disruption of wildlife, and degradation of an area’s touristic value. The identification of critical situations and the formulation of realistic goals based on stakeholder positioning is a core step in designing an effective light pollution reduction strategy. A flexible, engagement-centered approach ensures that actions are grounded in the realistic constraints and motivations of those involved. Future efforts must continue to deepen this engagement, ensuring that the value of dark skies becomes a shared priority in a given area.

3.3. Examples from the DARKERSKY4CE Pilot demosites

This section will connect the previous work with the reality of the DARKERSKY4CE pilot demo sites

Following the four Pilot Actions and five demo sites:

Pilot Demo Site 1, Pilot Action 1: Public lighting systems - City of Leipzig, Germany

The pilot action in the surroundings of the City of Leipzig in the Federal State of Saxony in East Germany aims at fostering a more environmentally friendly public lighting system in the context of ALAN mitigation.



The municipality has been engaging in this topic for decades and is one of Germany's good practice examples. Some 25 years ago, in 1999, the municipality developed a public lighting concept taking inventory of the existing devices, issuing the role of public lighting in designing public spaces and defining light priority areas. There, environmental criteria were not of concern yet. This started to change through participation in the EU Interreg project "Lighting Urban Community International" from 2003 to 2006. It established a network of municipalities dealing with the issue of public lighting and learning from each other, now known as the LUCI Association. Sustainability in the sense of energy conservation and first commitments to recognize effects on the environment were adopted in the LUCI chart in 2011, which acts as a voluntary guideline for designing municipal lighting systems. In the meantime, Leipzig also joined the EU Interreg project Public Lighting Strategies for Sustainable Urban Spaces from 2010 to 2012, in which a public lighting strategy and an action plan with implementation steps were developed. On this basis, the responsible department started working on a so-called "Light Master Plan" for the city in 2016 to strategically modernize the lighting systems. This makes Leipzig one of the first German cities to implement such a concept to align the public lighting infrastructure with the needs of inhabitants, tourists, maintenance offices, and environmental concerns. The document was finalized in 2019 and adopted in 2020.

One of the main innovations is the definition of so-called "light-sensitive areas", in which no additional lighting should be installed. The document further calls for reflection on whether existing facilities in light-sensitive areas can be removed. Light-sensitive areas mainly overlap with existing Natura 2000 habitats and other nature protected zones. Furthermore, the *Light Master Plan* states that lighting should be used carefully and sparingly and establishes criteria for more environmentally friendly facilities (e.g. wavelength, light colour, duration and direction of light, shape and height of light fixtures). Overall, the *Light Master Plan* goes beyond existing emission regulations and environmental protection laws in the context of light pollution, as Leipzig cannot yet refer to ALAN-specific legislation on the federal or national level.

The city has been implementing the Light Master Plan for years now and an update of the strategy is anticipated soon, taking into account the progress made so far. The pilot action during the DARKERSKY4CE project will support this process. In coordination with the responsible municipal bodies, light fixtures and/or facilities will be modernized to better suit ALAN mitigation efforts. The preferred pilot location lies in the outskirts of the city and is connected to "light-sensitive areas" to further protect them and to better detect changes in light pollution as the urban domains are illuminated by a broader range of light sources.

This pilot action is mainly connected to the broad municipal forests and parks and the overlapping nature conservation areas and habitats. These areas play an important role as a regulating ES provider for climate change management. Especially in the context of heat exposure in urban areas during the summer, the alluvial forest, canals, bodies of water and green spaces help to cool down the region. Also, they help to sustain the water quality, synergizing with the alluvial habitats. As stated in the previous sections, ALAN has significant impact on the vitality and biodiversity of those areas; thus, making efforts to decrease public lighting can play an active role to secure ES for the city.

Also relevant for the pilot action are cultural ES. The mentioned zones are a significant part of the quality of life in the region, as they are used for recreation by residents and tourists. They also act as an identifying feature and are referred to by regional marketing. The protected habitats further serve as locations for scientific research. Especially in the context of urban regions, aesthetics and nature as a value itself are important, because the contrast of the urban landscape to nature can be experienced directly in surrounding areas of the city. Protecting the local ecosystems from ALAN can thus help to ensure the future provision of cultural ES in Leipzig.



In the context of the pilot action connected to public lighting systems and ALAN mitigation as a whole, various stakeholder groups have to be engaged in the process. The main target group consists of municipal administrators, as they are responsible for implementing the *Light Master Plan* and maintaining the public lighting system (e.g. Office for Public Lighting, Department of Construction, Department for Environmental Protection). As the pilot action includes investments in facilities, close coordination will be necessary in all phases of the pilot action. Their engagement is ensured by the pilot action taking into account the existing strategy and the program directly profiting from the testing. This also reduces possible conflicts of interest.

Connected to the municipal administration are political bodies (e.g. Municipal Council, Mayor) that provide them with authority and funding. As the pilot action already leans on the *Light Master Plan* adopted by those bodies, their commitment is known from the start; thus, the aim is to keep them informed about the project's activities and provide them with reports and recommendations. Especially in the context of the anticipated update of the *Light Master Plan*, an emphasis on ES could be a strong argument for further ALAN mitigation efforts beyond energy efficiency and general environmental guidelines.

Other stakeholders are part of the local civil society (e.g. NGOs, Citizen Science initiatives) that address the problem of ALAN from the view of ecology, environmental protection and astronomy. They are more heterogeneous and differ in their interests, so ES could act as a shared framework to unite their efforts. The pilot action itself relies less on their engagement, but civil society actors are important agents and mediators to reach a broader audience. As the pilot project provides tangible changes, it acts as a conversation starter, and those groups could be included at accompanying events to increase outreach. As some of the groups pursue further commitments from the municipality and their awareness campaigns can sometimes be against the interests of the administration, events have to be prepared carefully and need to be moderated to prevent open conflict. Organizers have to be aware of the possibility that civil interest groups might try to instrumentalise the pilot for their specific goals.

Finally, the local inhabitants are important stakeholders as well. This group is heterogeneous, and their interests and goals are not as refined as with the civil society actors. The objective of the DARKERSKY4CE project is to raise awareness for ALAN and its negative effects. Because the effects of ALAN are manifold and often specific to species and context, it is difficult to convey the problem in an accessible way. ES can provide a new narrative that is more relatable and helps to better understand their interconnectedness. Thus, the pilot action yields great potential, as it provides tangible results in areas that people know from their own experience living in the city. The focus then is on inhabitants regularly visiting or living near the pilot demonstration site, so they are the target group of the Dynamic Monitoring Tool of the project. Also, accompanying events of the pilot action can connect the municipality, civil society groups and citizens to increase the reach and interest in the topic based on different perspectives.

Pilot Demo Site 2, Pilot Action 2: Astrotourism educational offer - Kujawsko-Pomorskie Voivodeship (Poland)

The pilot activity in Kujawsko-Pomorskie Voivodeship aims to develop an educational astrotourism offer that promotes public awareness of light pollution and highlights the ecological and cultural value of natural darkness. The initiative supports sustainable, nature-based tourism and environmental education by linking the unique qualities of dark sky areas with regional development strategies.

The pilot builds upon the identification of the darkest areas in the region, as highlighted in the Country-Based Report. These locations, characterised by minimal light pollution, are situated between Wdecki Landscape Park and the Tuchola Forest (Bory Tucholskie) Landscape Park. Based on this



assessment, a potential dark sky site has been selected as the focal point for future educational and tourism-related actions.

In cooperation with the park authorities, PP2 will design and implement a series of recurring astronomy-based learning activities targeted at local communities, school groups, and tourists. These include guided stargazing sessions, nocturnal nature walks, and informal educational workshops. The aim is to promote the region as a model for integrating environmental awareness with experiential, low-impact tourism.

Relevant Ecosystem Services: Opportunities for recreation and tourism / Information and knowledge for education and learning

This pilot action is based on two key cultural ES from the CICES classification:

1. **3.1.1.1 / 3.1.1.2 - Outdoor and recreational activities (biotic and abiotic)** This ES supports leisure activities such as stargazing, nature walks, and nocturnal wildlife observation that rely on the preservation of natural darkness. By connecting local tourism operators, park managers, and municipalities, the pilot action fosters a collaborative approach to sustainable tourism development. Promoting the region as a dark sky destination strengthens the economic and cultural value of its landscapes, increases visitor numbers, and extends the tourism season.
2. **3.2.2.2 - Education and learning (biotic interaction)** This ES is mobilised through informal science education activities targeting schools, youth groups, and the general public. Through night-sky observation and workshops on light pollution and biodiversity, the pilot action encourages active learning and environmental awareness. Schools, educators, and NGOs are engaged to embed these topics into extracurricular learning and promote stewardship among younger generations.

These ES are particularly important for involving stakeholders because they align with the practical priorities and long-term interests of communities, educators, conservation actors, and the tourism sector. By fostering inclusive dialogue on regional development and rural quality of life, they offer a shared value base that links sustainable tourism with environmental education and local identity. They also enable synergies between biodiversity conservation and regional branding based on natural assets such as dark skies.

The successful implementation and future sustainability of the pilot action depend on the engagement of relevant stakeholders through a tailored strategy. This includes close collaboration with the selected landscape park authority, both in the co-development of the astrotourism concept and in logistical and operational planning. Direct outreach to local communities is conducted via public stargazing events, thematic night walks, and informal education sessions that emphasize the connections between light pollution, biodiversity, and cultural value. Schools, youth groups, and educators are engaged to integrate dark sky topics into extracurricular learning and hands-on experiences. Partnerships with local tourism service providers and cultural institutions are developed to explore synergies and co-marketing of dark sky activities. Participatory tools such as surveys and open workshops are used to co-create solutions and capture public perceptions regarding artificial light and natural darkness.

The pilot action also includes measures to address potential tensions between stakeholders, including residents, businesses, local government, and conservation actors. Through structured dialogue and inclusive planning, the initiative seeks to build a shared understanding of the benefits of reducing light pollution and to support a collective commitment to sustainable regional development.



Ultimately, the pilot action in Kujawsko-Pomorskie illustrates how cultural ES related to education and recreation can support biodiversity conservation and reinforce local identity. It provides a replicable framework for other regions aiming to integrate dark sky protection with environmental learning and sustainable tourism.

Pilot Demo Site 3, Pilot Action 3: Stakeholder dialogue - Pinerolese Area (Italy)

GAL EVV will establish a territorial dialogue in the Pinerolese area (Italy) about the Fenestrelle Fortress which often stands as a point of dispute between different groups. The goal of the dialogue involves working with local administrators and stakeholders to develop a shared understanding that enables organization of awareness initiatives and meetings and stakeholder dialogue facilitation for enhancing area night sky conditions and serving as a demonstration site to advance this method in Central Europe.

The Fenestrelle Fortress stands in the central part of the Chisone Valley as a national cultural heritage site and architectural and historical landmark which welcomes thousands of annual visitors. The monument faces multiple competing interests that stem from its historical value and artistic significance, tourism development and environmental conservation needs. Stakeholders with conflicting interests live in the area of this cultural landmark. Stakeholders include ski resorts and a conservation area, the Alpi Cozie Natural Park. To develop the work that will be carried out for the pilot action, local stakeholders will be involved using some of the ES discussed in Section 1 of this report, followed by an explanation of light pollution effects on rural and mountainous areas along with their social, cultural and environmental impacts. These ES will serve to demonstrate their value, stakeholders will be involved to understand the importance of the actions that can be taken to limit light pollution. Key outputs will be identification of the methods to control light pollution, development of a light pollution management framework, and creation of dialogue between conflicting parties.

The stakeholders' pilot action could use ES 2.3.2.1 from the Regulating group which focuses on pollinators. The process of pollination through insect transport of pollen between plants serves as the essential mechanism for plant and wild species reproduction. The reproduction of many flowering plants and wild species relies on the pollination process that is carried out by insects including bees, butterflies and beetles. The mountainous landscape of Chisone Valley enables both agricultural development of local lands and safeguarding of fragile regions while sustaining natural plant species diversity and ecosystem health. The maintenance of ecosystem health together with ecosystem balance relies heavily on light pollution. ALAN disrupts natural light cycles and creates detrimental impacts on species populations including pollinators who deliver essential ecosystem services. The introduction of ALAN disrupts nocturnal pollination networks according to Knop et al. (2017) which leads to adverse impacts on plant reproductive success along with changes in pollinator behavior, movement patterns, foraging activities and reproductive cycles (Shivanna 2022). Scientists have demonstrated through current research that ALAN disrupts pollinating insect activity while producing several detrimental effects including shorter night flights, altered food exploration and mating behaviors, and impaired plant reproduction from pollination. The protection of local biodiversity benefits from light pollution reduction strategies that focus on natural and landscape areas near the Fortress including Alpi Cozie Park.

The utilization of pollinators presents itself as a useful tool to establish dialogue with opposing stakeholders because this ES provides multiple benefits. The subject unites various groups such as farmers, beekeepers, environmentalists and tourism managers along with schools, cultural institutions, administrators and citizens because pollinating insects play a crucial role. Pollinators serve as a tool to engage stakeholders and their communities for protection purposes while promoting sustainable lighting solutions that minimize light pollution and preserve nocturnal pollinator life. The responsible lighting



system would incorporate shorter night-time illumination periods which would simultaneously protect the Fenestrelle Fortress alongside cultural monuments to resolve the conflicts between tourism growth and environmental preservation.

The ES code 3.2.1.4 represents the beauty of nature and can be applied to build stakeholder dialogue for reducing light pollution. Rural areas with their inland designations value their natural landscapes, mountains, green spaces and biodiversity since they form the base for sustainable tourism development. The protection of natural ES becomes essential in this scenario because light pollution damage to the territory would increase if levels remained high or even increase. The Chisone Valley benefits from exceptionally dark skies which serve as an essential ecosystem value because it remains less illuminated than urban areas. Various activities related to astrotourism and stargazing have started to become popular. People also perform simple excursions including mountain hiking, while some stay at campsites and tourist refuges to appreciate nature completely. The dark sky stands as an essential element for these activities, although not everyone recognizes its importance. People usually ignore the value of dark skies until they disappear or start causing harm to human health. The use of the ES of conserving nature's beauty would enable stakeholders and local community members to discuss the value of dark skies while identifying measures to protect them, potentially leading to responsible lighting management for monuments and tourist sites throughout the mountainous upper Chisone Valley.

The ES framework enables stakeholder participation and during the pilot action the following stakeholder groups should be included:

- The Municipalities of the Upper Chisone Valley and Upper Susa Valley could participate in public meetings to obtain public support for discussing light pollution solutions through joint efforts to enhance dark sky quality by using sustainable lighting systems. Through this collaboration we can establish effective methods that other areas can adopt.
- The Fenestrelle Fortress stands as a crucial stakeholder because it serves as the main cultural and identity landmark of Piedmont and the Chisone Valley which attracts both tourists and residents. The Fenestrelle Fortress should work with us to identify light pollution reduction value through a grassroots approach to implementing proper lighting practices at this location. It serves as a cultural representation for the entire Upper Chisone Valley area. Various actions could result from this work, including the protection of dark skies in this mountainous area which represents a true ecosystem value, as well as enhanced nighttime experiences for visitors to the fortress that would boost the value of evening events and attract additional visitors (e.g. stargazing tours, nighttime walks, night at the fort etc.).
- The tourist consortium and ski resort operators, particularly Sestriere and Pragelato need to be involved because they drive major touristic and economic activity throughout the region, although they face operational challenges because of climate change. They use nighttime illumination to provide their services to skiers and tourists. Joint efforts should reveal their current lighting systems to establish sustainable practices that protect the darkness for ski and sports facilities. This approach offers multiple benefits, because it enables astrotourism and outdoor activities during the off-season, thus creating extended tourist periods and improved landscape-tourist facility integration.
- Local associations maintain the collective history and cultural identity of places and function as essential stakeholders in this process even though they lack substantial understanding of light pollution. Local groups can work together to show the sky's cultural significance while acting as vital participants in participatory processes that enable citizen-administrator dialogues to establish awareness and create regulations that minimize unnecessary lighting and protect starry skies. The support from local organizations enables bottom-up awareness initiatives to overcome cultural resistance. Support from these actors could enable symbolic light-switching campaigns and photographic or artistic competitions that focus on the beauty of the starry sky.



- Schools: the issue of light pollution makes it appropriate for students and schools in the area to take part in the discussion. Schools lack decision-making authority, yet their collaboration proves valuable for cultural transformation on this matter, while creating sustainability awareness that develops responsible adult citizens in their local community, especially concerning dark skies. The school could also act as an advocate to influence public authorities to implement effective strategies for reducing light pollution. Moreover, students may reach their families and influence their everyday behavior, and they can be “young ambassadors for the dark sky” to become active participants in public campaigns and events.

We will employ different tools and conduct activities to work with these stakeholders, thereby linking ES to light pollution reduction and awareness-raising initiatives. The process includes establishing dialog with local stakeholders to determine high-impact light areas for mitigation and sharing technical options for public lighting, which leads to adopting good practices for public monuments like the Fenestrelle Fortress and private facilities (sports and ski facilities). The organization of emotional events will be essential to raise awareness about this issue while creating emotional connections that lead participants to understand the value of dark skies. The activities combine stargazing and astrotourism programs with schools together with meetings about pollinators with local beekeeping groups and theatrical or musical shows about light pollution and citizen science programs for students in primary and secondary school. This last initiative would require implementing citizen science workshops that include both school participants and public involvement.

Pilot Demo Site 4a, Pilot Action 4: Demonstration of monitoring methods - Somogy Country (Hungary)

In Hungary, the results of monitoring activities can best be presented at an exhibition to be created during the project. Artificial light has several negative effects on local ecosystems, some of which—mainly related to changes in animal behavior—have already been proven, while others are still only assumptions. In any case, it is certain that many animals, plants, and insects have evolved with the cycle of day and night and when exposed to artificial light, their behaviors change in harmful ways. Nocturnal animals like bats and owls struggle to hunt or avoid predators. Insects, which are vital for pollination and as a food source, are drawn to lights, where they often die from exhaustion or become easy prey. This reduces their populations and affects species that depend on them. Amphibians may stop calling for mates under bright light, disrupting reproduction. Even plants can suffer—light exposure alters their growth and seasonal cycles. Artificial light also confuses migratory species like birds and sea turtles, leading them off course. These disruptions weaken food chains and reduce biodiversity. These serve as examples of the risks that need to be introduced to the target audience of the exhibition by also getting them understood that by dimming unnecessary lights, we help protect these delicate natural systems.

In the exhibition we'll also introduce our pilot area, the Zselic Darksky Park, which can be showcased as a best practice not only in Hungary, but worldwide. The Zselic Darksky Park (Zselici Csillagoségbolt-park) was established in 2009 in recognition of the region's exceptionally low levels of light pollution. The park was designated by the International Dark Sky Association and is considered one of the best places in Central Europe for stargazing. Due to its remoteness and the low population density, the night skies over Zselic - covering approximately 9 000 hectares - are remarkably dark, providing an unobstructed view of the stars, planets, and other celestial bodies. This unique feature can also be verified by measurements, which is a good way to illustrate the difference in terms of numbers compared to the characteristics of light-polluted areas. We use a fixed Sky Quality Meter (SQM) to measure the brightness of the night sky, installed on the roof of the visitor center. These measurements, expressed in magnitudes per square arcsecond, tell us how pristine—or light-polluted—our skies truly are. Integrating the measurement results into educational and awareness-raising activities at the Zselic Darksky Park can significantly enhance



public understanding of light pollution and its ecological impacts. Therefore, we will install interactive displays in the visitor center of the Darksky Park showing SQM readings, including historical graphs to show trends over months and seasons. To expound upon the meaning of these results we'll pair SQM readings with ecological consequences, e.g. by explaining the correlation between light pollution level and activities of nocturnal insects.

As the majority of the visitors arrive from schools, in the next step we can integrate citizen science activities into school programs: Students can be involved in data collection during night walks by providing them with portable SQMs to measure and record sky brightness at different locations. We may also encourage schools to adopt a local SQM monitoring site and compare results through seasons. These results can be also integrated into the augmented reality (AR) content of the exhibition. This way, students conducting measurements will be proud of their work, will be motivated to continue measuring, and may encourage others to participate in the program. These results could be even integrated into lesson plans to teach physics by explaining the characteristics and effects of light, improve biology courses by including observation results about animal behavior, and also introduce the geographical distribution of light pollution in geography lessons. We may even involve students in research to analyze how brightness correlates with animal activity patterns, plant behavior, or insect presence. The basis for these teaching materials could be the AR material in the exhibition, which is sufficiently attractive to the younger generation.

These awareness-raising and citizen science activities will draw the attention to the importance of protecting the ES of Zselic Darksky Park. As a Natura 2000 protected area, Zselic shelters over 46 protected plant species, 126 invertebrates, and 162 vertebrates. The region features a diverse landscape of forests and marshy valleys filled with water, which is home to a variety of wildlife, including great white egrets, gray herons, and red herons, several species of ducks, reed birds, and shorebirds. In the forests, marsh harriers, honey buzzards, green woodpeckers, black woodpeckers, and a multitude of small songbirds nest. Long-term monitoring of beetles shows the presence of 83 cerambycid species, highlighting rich insect diversity. The complex forest communities, including sub-Mediterranean species, contribute to ecological stability and resilience, the supporting ES of the region.

The protection of local biodiversity also contributes to the maintenance and improvement of the pilot site's cultural ES: in addition to hiking and cycling, Zselic Darksky Park offers excellent opportunities for wildlife watching and guided nature programs, such as bird watching, visits to Katica Farm, deer tours, and exploration of the Szenna Skanzen heritage site during the day. At night, the park offers stargazers the Zselic Star Park, which features telescopes and designated areas for night sky observation.

Understanding the value of Zselic Darksky Park's ES is essential because these services form the foundation of both environmental health and human well-being. They provide clean air, regulate local climate and water systems, support forestry, and offer habitats for diverse species. Culturally, these services create spaces for recreation, mental restoration, education, and tourism. However, they are vulnerable to threats such as light pollution, which disrupts natural cycles and diminishes both the ecological and cultural value of the region. Incentive programs (e.g. subsidies for dark sky-compliant lighting) can support adoption of low-impact lighting, while community events, like night walks and dark sky festivals, can create pride and a sense of ownership in preserving the dark sky. Schools can partner with dark sky programs and local parks to provide field-based learning experiences, reinforcing ecological awareness through direct engagement. By presenting these values for local decision makers, municipalities can adopt and promote dark sky regulations, adjusting street lighting to minimize glare and skyglow. A good practice at Bárdudvarnok in Zselic Darksky Park can be showcased. On a strategic level, integrating ES and light pollution themes into local development plans may help ensure long-term sustainability. All these planning activities can be supported by the measurements of STRIA in the project, as SQMs and data can support evidence-based decisions.



Pilot Demo Site 4b, Pilot Action 4: Demonstration of monitoring methods - Carinthia region (Austria)

In Carinthia (Austria), Carinthia University of Applied Sciences will test a non-invasive / non-lethal monitoring method for nocturnal flying insects. Insects are a crucial part of the ecosystem, and as listed in the previous chapters, they are also responsible for several ES (see Paragraph 1.3). Insects comprise more than half of all described species in the animal kingdom and account for a considerable proportion of all biodiversity on the planet (Tihelka et al., 2021; Stork, 2018). But since monitoring such a big group requires effort and a range of expertise at different taxonomic level

, DNA barcoding has been used lately as a rapid, cost-effective, and scalable method for identifying thousands of samples, often delivering species-level resolution (Chua et al., 2023). The downside of DNA insect bulk sampling, is that it requires killing the animals to extract the DNA (Chua et al., 2023; Persson et al., 2024; Wolany et al., 2024). Since we are experiencing a dramatic loss of insects in our ecosystems, a non-invasive, non-killing alternative to bulk sampling is urgently needed. The pilot site will be within natural protected areas in Carinthia, and the ES that can be impacted are numerous: pollination - since most of the pollinators are nocturnal (Fijen et al. 2023; Robertson et al. 2021; García et al. 2024; Alison et al. 2022) and for instance in Gesäuse National Park about 90% of pollinator insects are nocturnal (Gesäuse National Park information); pest control - since protecting overall insect diversity provides a huge range of predatory and parasitic natural enemies of pests (Gurr et al., 2012); last but not least, protecting biodiversity must not only have an utilitarian purpose, but it's also an ethical responsibility that we have toward future generations - protecting all the beautiful diversity in order to let our descendants experience all the variety of shapes and colors we can experience today.

Furthermore, other ES would be impacted by light pollution in natural protected areas, such as the preservation of dark natural habitat, affecting habitat connectivity, reproduction sites, feeding grounds or refuge habitats; it can have impacts on soil and water quality, while also altering photosynthetic activity in plants. Moreover, electricity consumption also contributes to greenhouse gases emission, thus pairing with other drivers that threaten biodiversity. Ultimately, inland national parks in Austria represent some of the the last dark spots in Central Europe, meaning that they should be valorised for the high sky quality and the possibility to reunite visitors with the beauty of the natural starry sky on a clear dark night.

Different stakeholders are affected by these ES: for instance, pollination can severely affect agriculture and crop production. But in our pilot action, we will mainly focus on other target groups:

1. National Park entities and Nature Park offices will be our primary external stakeholders: we will need to co-create and plan an action suited for their areas, and we have already involved them as Associated Partners in the project for the crucial role that they will have in the implementation phase. The engagement will be kept through periodic meetings updating them on the different stages of the project. The maintenance of the connection between our institution and other protected areas is guaranteed by the fact that we share our efforts on other projects in the area, and we therefore have constructive relationships and continuous opportunities for exchange with them.
2. Municipality administrators will be addressed especially during public events: it is crucial to bring municipalities on our side and support the cause, so every public occasion will be an opportunity to open the dialogue about this topic and how they can intervene with the power they have to reduce or mitigate light pollution. We are already in contact with some municipalities near our pilot sites. Most of them are already aware of the problem, and through their good examples we hope to extend the best practices to other municipalities as well.
3. External experts on the topic are continuously kept informed and updated: we need feedback from them to assure that our strategy is going in the right direction, especially from those working for a long time on light pollution. We are in contact with astronomers, astrophysicists, ecologists,



zoologists and other experts for continuous feedback on our pilot action. Professionals will be one of the ultimate users of our action, since we will propose a non-invasive alternative for monitoring insect behavioral changes due to light pollution. We will produce a set of guidelines on how to carry on nocturnal ecosystem observations, based on the limitations and knowledge gaps addressed, hoping to make them applicable across Europe.

4. Local organizations are involved in the activities and supported: they are ground-based in the local context, and they have been communicating for a long time on the issue of light pollution, so we can take advantage of their experience and from their established network, join their events and produce effective materials to spread the cause; they also have campaigns dedicated to enterprises to call to action and shut off the lights when not-necessary. Thanks to their campaign we also involved our campus in the initiative to switch off the light after 10:00 pm.
5. Visitors of natural areas will be engaged in our monitoring activities. We will support local engagement activities of the parks, conveying the importance of protecting dark ecosystems. Parks and rangers already organize activities like night tours, but we would like to engage them in “citizen science” activities, allowing them to observe the impact of light pollution first-hand, setting up an experimental prototype close to visited areas (such as campsites, visitor centres or hiking trails). Giving visitors the opportunity to contribute their personal observations has the potential to create a sense of belonging and an emotional attachment to the cause, and local citizens are crucial stakeholders to influence administrations to adopt sustainable lighting systems.
6. Last, but not least, students are key stakeholders: some national parks have structured educational programs for students, and we would like to cooperate with them and support the institutionalization of a module completely dedicated to dark sky ecosystems. Youth are the future and we need to educate them from an early age on how to be sustainable adults in our changing world.

3.4. Communication on light pollution effects on Ecosystem Services

Environmental issues are becoming increasingly important in the media. However, this increased importance does not always translate into change in the behaviour of citizens and decision-makers (political or economic). This is due to both a certain mistrust of environmental issues on the part of the public and to the real difficulty citizens have in changing their habits.

If the environmental impact of an issue, such as light pollution, is not immediately visible, changing habits is even more difficult. For this reason, a well-designed communication strategy is essential. ES, in this sense, can be of great help if used correctly.

The ES listed in Section1 can be very useful, but as mentioned above, communication must take certain fundamental aspects into account. Communicating these services effectively requires translating complex ecological functions into relatable and actionable messages for specific audiences.

Following are some points to be taken in account (Arctik.com):

1. It is possible to make generalised communication. However, **targeting is preferable in order to reach the people we want to engage with**. In this sense, the use of buyer



personas as a marketing tool can be useful. We choose a typical person from a certain demographic and try to understand their interests, needs and point of view. This will allow us to prepare more appropriate communication. If we are talking to a farmer, for example, we can use topics (and ES) related to their work, while with a tour operator, the use of cultural ES may be a good choice.

2. Environmental issues, including light pollution, are global issues and it is prudent to take them into account and discuss them at a global level. At the same time, it is important to make a connection to the local area, something clearly tangible for our audience. **Linking large-scale issues to local impact** allows us to convey the importance of the issue to everyone by combining its significance for the individual who follows us.
3. The issues are often complex and experts use a lot of technical terms. However, **simplifying the message is essential**. Conveying the concept accurately while using simple, clear terms is fundamental to effective communication.
4. **Positivity is key**. Environmental issues, especially in this day and age, can cause a feeling of doom and gloom. But this can be counterproductive. Without denying the problem, *it is important to send a positive message, maybe highlighting how small personal actions can lead to big collective results.
5. **Direct involvement is also essential**. People often do not have strong opinions on an issue, but if they are involved in actions, they can feel engaged and commit to the cause. You can use calls to action, try to mobilise people for citizen science initiatives, or simply introduce them to the beauty of the starry sky or the importance of night in their culture with dedicated evenings (and here ES can take centre stage). This also applies to the organisations we work with. If we give them importance and a role, they can help us spread the word among their members and followers.

Following are some examples of ES use for communication with a specific target group:

Table 3.4.1 - Communication with farmers

Target audience	Farmers
Target issue	Reduction in production (or animal feed) resulting from various factors such as pollution, an increase in extreme weather events, and a reduction in pollinators.
Ecosystem service that can be used (simple descriptor)	Pollination by wild bees and other insects
Communication method	Face-to-face meetings (choose the right season, when they are less engaged) and visual infographics (instead of long reports). Use immediate channels such as instant messaging (however, ask farmers which communication channel they prefer).
Strategy	The first step is to understand which tools are best suited to communicate with the farmers we are in contact with and try to understand their point of



	view. It is necessary to use a simple and clear communication style that makes them understand the benefits they can gain from adopting the practices you propose and support you in attempting to reduce light pollution. Organize on-site workshops showing how wild habitats near farms support pollinator populations, leading to improved crop yields. Use simple infographics that compare pollinated vs. non-pollinated crop outputs. Emphasize the economic value of native vegetation strips or hedgerows as "natural pollinator insurance". You need to provide practical examples of how a dark sky can increase the productivity of their farms. Mutual trust is essential (Farmwildlife.info).
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Table 3.4.2 Communication with rural communities

Target audience	Rural community
Target issue	Community members don't feel the problem too much, but they know what it means to have a starry sky and have some knowledge about the issues related to human health. In general, they feel that they are not listened to or involved.
Ecosystem service that can be used (simple descriptor)	- Regulatory power of circadian rhythms, melatonin production, depression and related illnesses - Using nature to de-stress - The things in nature that help people identify with the history or culture of where they live or come from - The beauty of nature
Communication method	- Community meetings and illustrated local case studies - Social media campaigns and storytelling - Citizen science - Recreational activities (astrophotography, activities for kids, stargazing)
Strategy	In this case, it is essential to make citizens feel involved and show them the beauty of what is being proposed (in our case, the starry sky). First, experiential events (stargazing, activities for children) and social media can be used to show the



beauty of having a dark sky. Meetings explaining the effects of light pollution are also important. There is no need to be alarmist, but it is important to use clear and understandable terminology with concrete examples. Use locally relevant examples and emphasize traditional knowledge alongside scientific data to build trust and engagement. Get help from local leaders and associations that already have the power to engage citizens.

Launch social media campaigns that feature short stories, photos, and testimonials from individuals who experienced the starry sky. Highlight the links between time spent in a night environment and improved mental health or connections to local history (for example religious beliefs). Use relatable language, avoiding technical jargon, and focus on personal benefits to build public support for green space conservation.

A next step could be to use citizen science to actively involve local residents. Active involvement is essential to make people feel part of something and, in turn, become advocates for the issue.



4. Conclusions

The concept of ecosystem services is relatively recent. It first emerged in the 1970s, but the term began to be used more widely at the turn of the 21st century. This concept seeks to address the significant challenge of communicating environmental issues to the public, particularly with regard to the importance of ecosystems for our lives. ES have therefore given ecosystems an economic value linked to the world of economics (Gómez-Baggethun E. et al., 2010). This shift has, in some cases, been overly pronounced, leading in some cases to what we could define as greenwashing policies. However, if used well, the tool of ES can be useful for communicating a topic that is still ‘niche’ and little known, such as light pollution and the value of dark skies.

The aim of this report was precisely to provide tools for both the DARKERSKY4CE project and others who wish to use them in dialogue with stakeholders and for dissemination to the public. In the first chapter, we analysed the ES categorised in the CICES system, seeking to understand which ones were negatively impacted by ALAN. This led to the analysis and explanation of the impact of ALAN on 87 of the 105 ecosystem services in the classification, providing a useful “archive” from which to draw inspiration for engaging with stakeholders.

Dialogue with stakeholders was at the heart of the preliminary discussions leading up to the drafting of this document and subsequently its second chapter. This report highlights the importance of understanding who the key stakeholders are, how to approach them, and the importance of setting realistic goals for reduction of ALAN, depending on the openness of local actors. The conclusion is that ES can be very useful in helping people understand the issue, but that nothing can be done without intensive dialogue with key players and an understanding of their needs.

Finally, in the third chapter, we attempted to combine theory and possible practical applications with examples related to the pilot demonstration sites that will be developed by the project and an analysis of communication strategies.

To conclude, this report cannot be considered exhaustive of all the relationships between the role of dark skies and ES, but it does represent an almost unexplored avenue of research into these relationships and a basis for new arguments regarding the negative impacts of ALAN and the environmental and cultural value of dark skies.



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