Norges miljø- og biovitenskapelige universitet

Report

Light Pollution Intensity in the Aquatic Environment of the Oslo Area

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August 2024

Abstract

The rapid expansion of artificial lighting in urban areas has resulted in significant light pollution, with profound implications for both terrestrial and aquatic ecosystems. Artificial light interferes with the circadian rhythms of animals, impacting their behavior, reproduction, and migration patterns. For instance, birds and sea turtles that rely on moonlight for navigation can become disoriented by artificial lights, leading to fatal light attraction. Similarly, aquatic species may experience changes in their reproductive cycles and behavior due to altered light conditions. Previous studies observed that light pollution affects salmon migration and the reproductive timing of various fish species.

While light pollution disrupts the natural light environment crucial for many aquatic species, the Oslo area includes two endangered species, the coastal cod and the wild Atlantic salmon which reproduce in coastal areas and rivers. This study thus focuses on invesitgating the extent of light pollution in the harbor and the Akerselva river in Oslo, Norway. Utilizing a quantum light pollution sensor, we measured light intensity at various depths in these water bodies during the winter of 2022. Our findings revealed measurable light pollution at all sampling points, including depths of up to 5 meters. Some locations exhibited light intensity levels nearly half as high as those measured under a streetlight, highlighting the severity of the issue.

The study's findings highlights the pervasive nature of light pollution in urban aquatic environments and its potential to disrupt ecological processes. It underscores the need for wildlife-friendly lighting, urban planning guidelines, and increased awareness among the public and policymakers to mitigate the adverse effects of light pollution.

Introduction

As human activities stretched beyond daylight hours into late evenings, early mornings, and throughout the night, the need to supplement natural light with artificial lights increased in urban areas. Lights were added in cities for security purposes, advertising, or aesthetics, like highlighting bridges and other pleasant architecture. Additionally, light sources from buildings and houses also contribute to the production of artificial light during the night. All these lights modify natural light levels (i.e. sun, moon reflection, The Milky Way, stars), polluting our environment at night.

The last world atlas of artificial night sky brightness, which was published in 2016 (Falchi et al., 2016), provides a world map of light pollution at night based on thousands of satellite pictures, and shows that more than **80% of the world and more than 99% of the U.S. and European populations live in light-polluted areas**.

While this issue has concerned the scientific community for a while, the situation has not improved. Indeed, light pollution area and intensity have increased between 2012 and 2016 according to two published editions of the world atlas of artificial night sky brightness. And today, the new energy-efficient LED technology has become very popular and allowed us to increase both the surface and intensity of light while saving energy. **Norway is no exception**. Indeed, light pollution has also increased in many areas in Norway, especially along the coast and the rivers (figure 1).

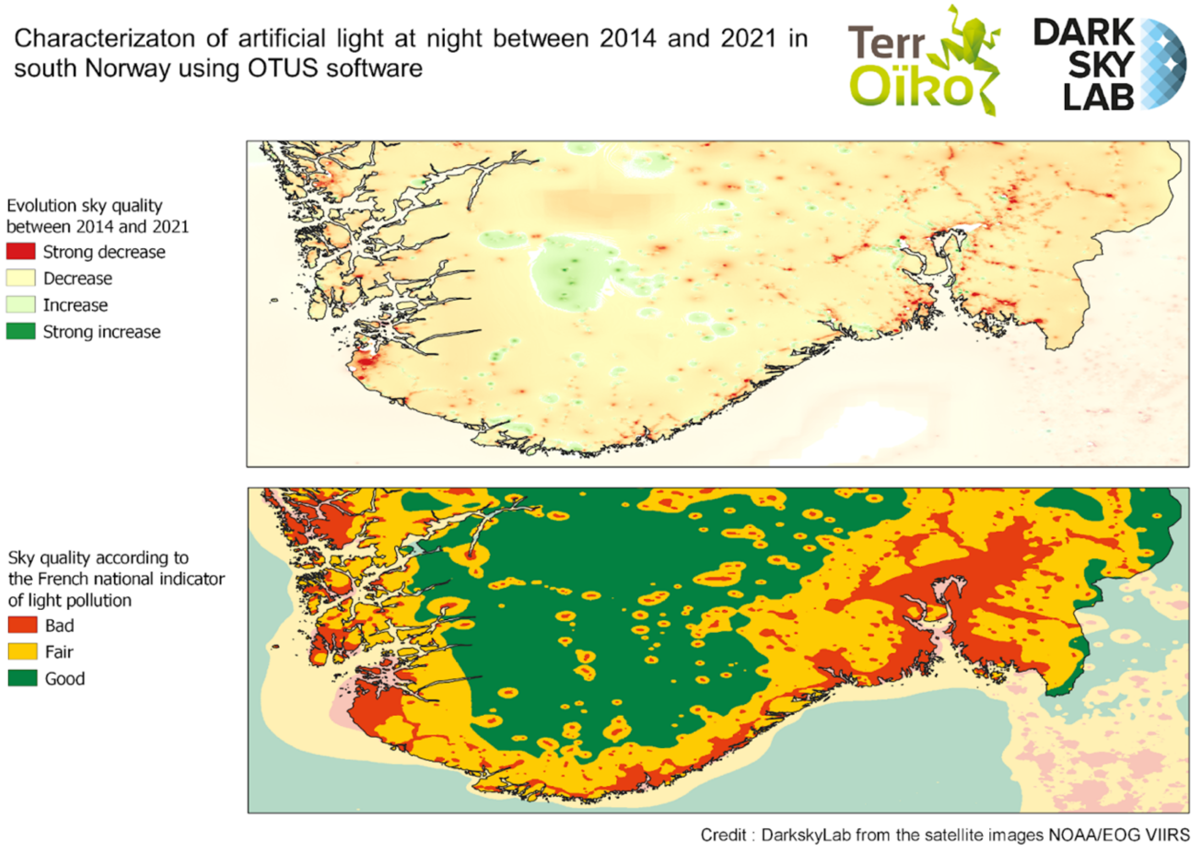

Figure 1: Light pollutions maps made by our partner in France, TerrOïko showing that most of the south in Norway has experienced an increase in light pollution between 2014 and 2021(top panel) and that most of the coast and river areas are classified as "bad" sky quality (bottom panel).

Such light pollution is not only a problem for humans because it prevents us from appreciating the beauty of the stars. But maybe more importantly, wildlife, including all types of animals (Dominoni et al., 2016), and even plants. Indeed, insects, birds, mammals, and amphibians, are affected by this light pollution present in or close to urban areas. Nocturnal light affects the circadian rhythm, the internal twenty-four-hour clock that drives most (if not all) daily physiological rhythms in animals. It also reduces the production of the hormone melatonin which is produced during the night (dark) period only.

Light pollution has thus been shown to affect animal behavior (some animals are attracted by these lights making them easier prey for their predators), timing of reproduction, migration (Dominoni et al., 2016). For instance, birds and sea turtles which use the moonlight to orient themselves during their migration, get confused by the light pollution, lose their direction, often ending up dying (a phenomenon known as fatal light attraction). And we are far from knowing all the effects light pollution has on wildlife.

Aquatic habitats have in general been poorly taken into consideration for the design of city lights. Light pollution penetrates water, affecting aquatic habitats (Jechow & Hölker, 2019). Coastal and freshwater ecosystems are hotspots of biodiversity. Unfortunately, as most of the big cities are close to water areas it is not surprising to measure relatively high levels of light pollution in the water where important species live. This is a particular concern in Norway. Coastal cod and wild Atlantic salmon, which are both considered endangered, reproduce in coastal areas and in rivers, respectively. And we know very little about the impact of light pollution on these animals. We know for instance that it affects salmon migration (Riley et al., 2012) and that it affects the timing of reproduction of several fish species (Brüning et al., 2016; Brüning et al., 2018). Our recent work on the small model fish medaka revealed that after only 3 weeks of light pollution, sperm quality is affected in some males (Closs et al., 2023). This may lead to a reduction of the genetic diversity in a population, making a fish population more at risk to disease or climate change. So, more research studies need to be performed to identify the various effects of light pollution on aquatic life.

In Norway, there is no data published so far on underwater light pollution. **In this study, which is part of *Nils Gunnar Lindbo's* Master's thesis at NMBU, we investigated the light pollution levels underwater in the Oslo area by measuring light intensity at night at different depths in the river Akerselva and Oslo's harbor.**

Method

In our study, we employed a quantum light pollution sensor (SQ-640) in conjunction with a data logger (AT-100 µCache) manufactured by Apogee Instruments (Figure 2A). This sensor is characterized by its high sensitivity, translating to 1 mV per µmol m-2 s-1, and a broad spectral range spanning from 340 to 1040 nm (± 5 nm). This wide range enables the detection of ultraviolet (UV) light wavelengths ranging from 100 to 400 nm, as well as infrared (IR) light wavelengths from 780 nm to 1 mm.

IR wavelengths are particularly relevant in urban environments due to their association with heat sources, such as tungsten light bulbs which were commonly used for city lighting until the emergence of LED technology. The sensor's capability to detect IR radiation is crucial for comprehensively assessing light pollution levels in our study area.

The light sensor was installed on a home-made floating system (Figure 2B), allowing the measurement of light intensity at different depth: 25 and 50 cm, as well as 1 and 5 m when possible.

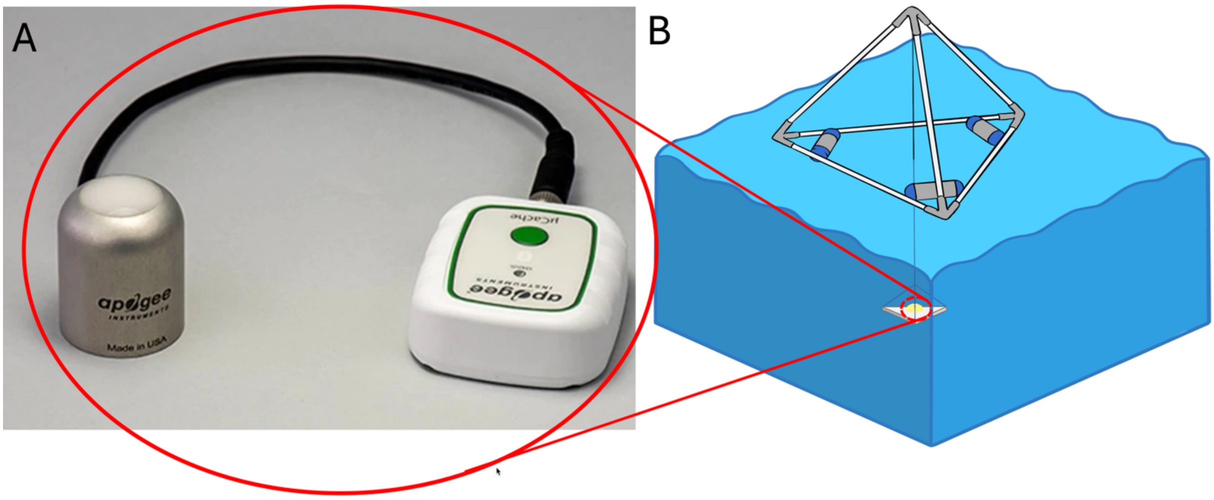

Figure 2: Equipment used to measure underwater light pollution levels. A, The sensor from Apogee with broad spectrum and high sensitivity. B, Illustration of the floating system.

The light sensor was affixed to a custom-made floating system (refer to Figure 2B), enabling us to capture light intensity measurements at various depths: 25 cm, 50 cm, and when feasible, at 1 m and 5 m depths. Our study focused on assessing light pollution levels along Akerselva, one of Oslo's main rivers (Figure 3), and in Oslo's harbor (Figure 4), during the winter of 2022 (from 26/01/2022 to 1/03/2022).

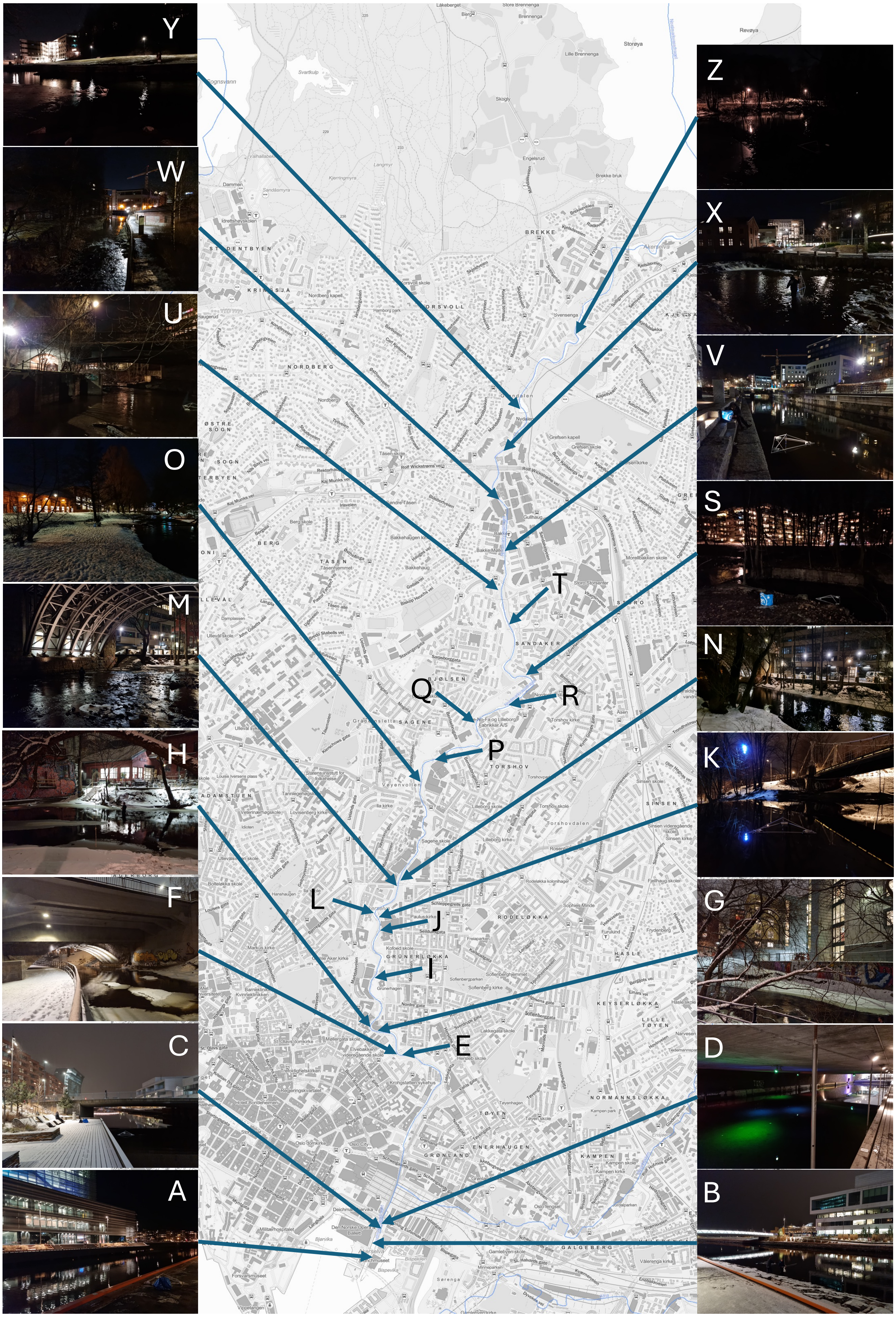

Figure 3: Location of the sampling sites in Akerselva with illustrative pictures of light pollution observed on site. Sampling point J is a known spawning site for wild Atlantic salmon. Adapted from https://www.nve.no

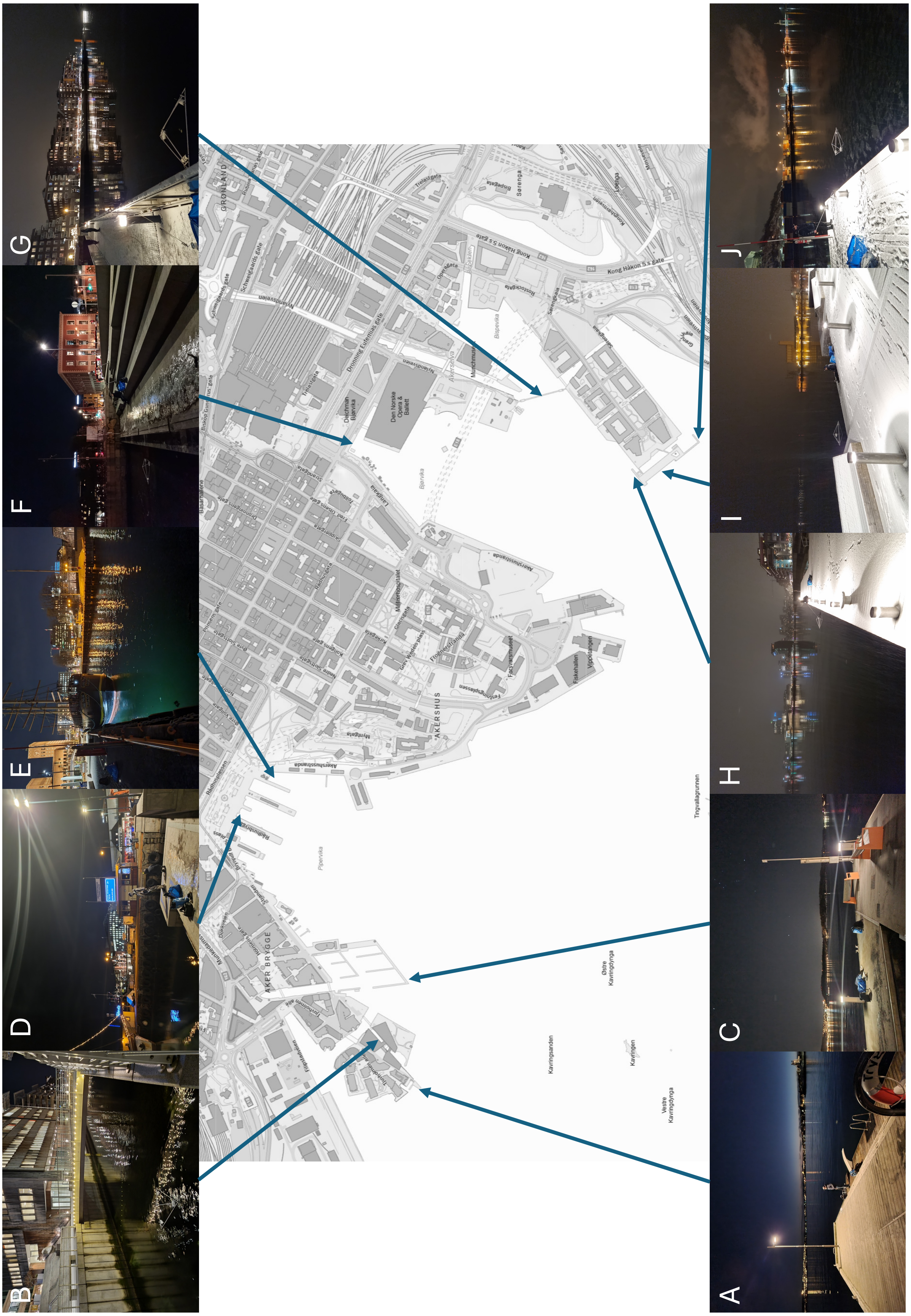

Figure 4 Location of the sampling sites on Oslo harbor with illustrative pictures of light pollution observed on site. Adapted from https://www.nve.no

Sampling activities were scheduled to avoid times when the moon was more than half visible or when ice covered the water surface. Consistent with our methodology, light intensity readings were taken at each location for a minimum duration of 3 minutes (with one recording every 10 sec). To ensure data accuracy, mean light intensities were calculated after excluding any apparent outliers resulting from passing objects like fish, leaves, or debris.

As a reference point, we established a standard by measuring light intensity beneath a city street light (see Figure 4). Additionally, we captured visual representations of different city lights using a Samsung smartphone or a Nikon camera (D800) to highlight their impact on underwater light pollution levels.

Results

In our investigation of light pollution levels along the Akerselva river in Oslo, we discovered measurable light intensity levels at all sampling points, including depths of 25 and 50 cm. Notably, at one sampling point, the light intensity approached a level similar to what we measured under a street light at the level of the road (Standard).

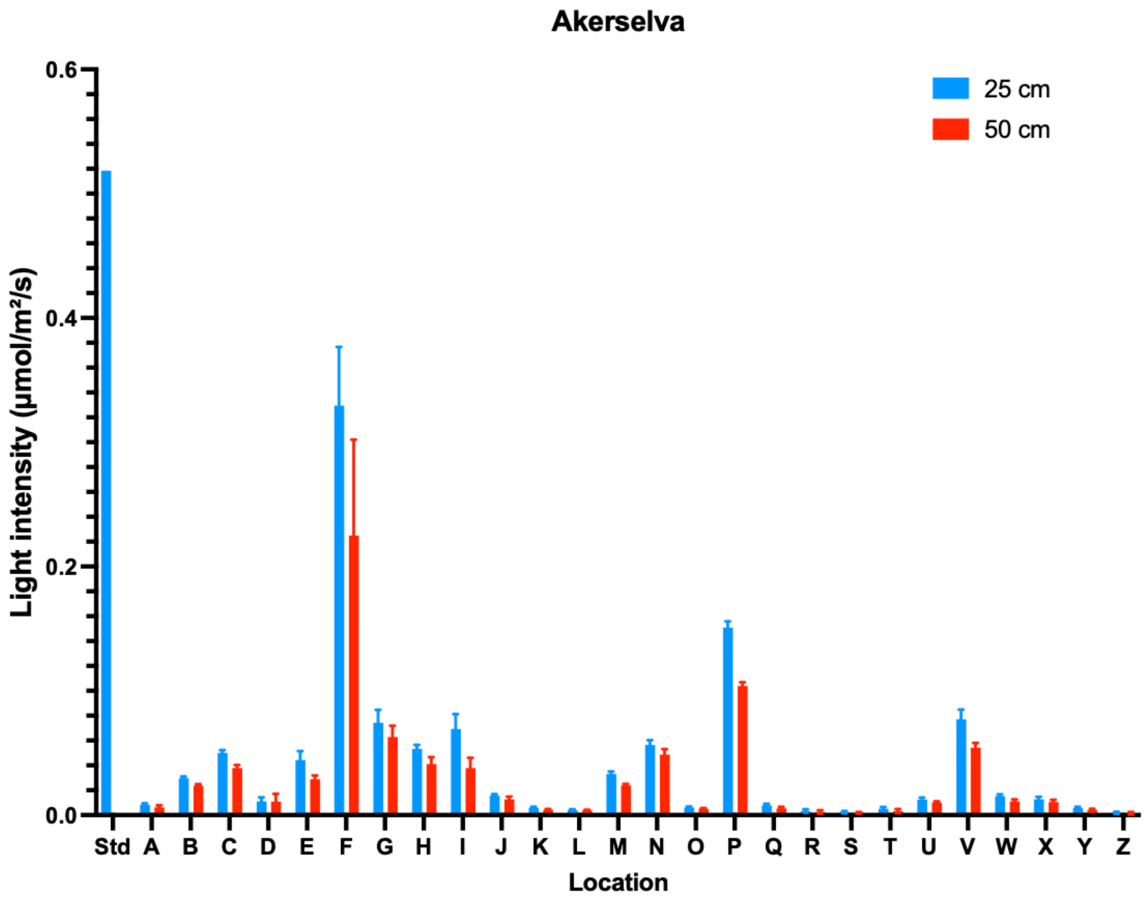

Figure 5: Light intensity levels measured at night at different places in Akerselva (Oslo river). Std: standard (light intensity level measured under a street light by placing the light sensor at the level of the road). A-Z sampling points as shown on the map in figure 3.

Our study extended to the Oslo harbor, where we observed measurable light intensity at all sampling points, and even at depths of up to 5 meters in areas with sufficient depth for measurement. In select locations, we recorded relatively high light intensity levels, approaching nearly half of our standard measurement.

An intriguing observation was the sighting of a fish actively swimming beneath a concentrated light source, likely utilizing the light to aid in hunting for prey.

Finally, while on both the river and harbor some sampling points were chosen for the obvious presence of light pollution, others were chosen for their apparent darkness. However, once one site, we could realize that the site was not as dark as it appeared and that light pollution could still be measured.

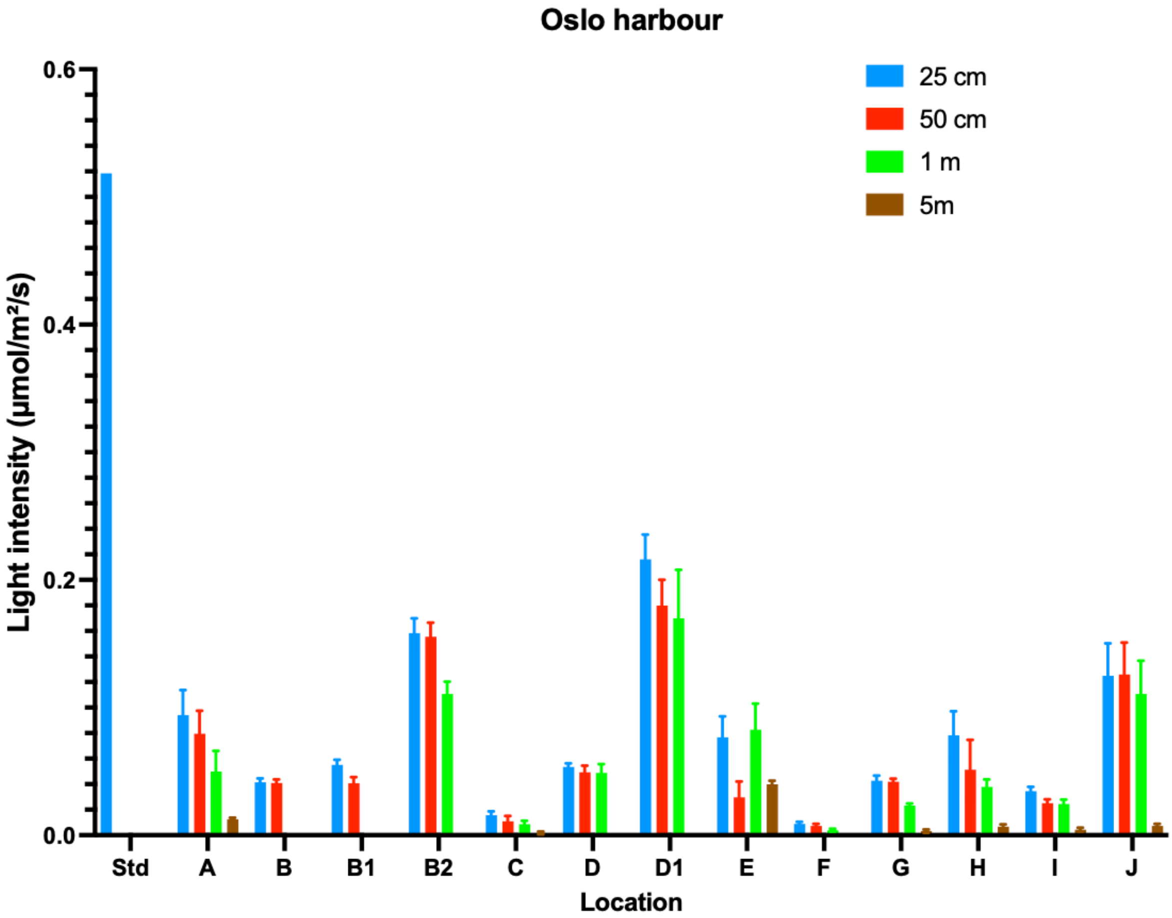

Figure 6: Light intensity levels measured at night in Oslo harbour. Std: standard (light intensity level measured under a street light by placing the light sensor at the level of the road). A-J sampling points as shown on the map in figure 4. Sampling point with the same letter represent sampling point located very close to each other.

Discussion / Conclusion

The rapid expansion of artificial lighting in urban areas has led to a significant increase in light pollution, with profound implications for both terrestrial and aquatic ecosystems. This study highlights the extent and impact of light pollution in the harbor and the Akerselva river in Oslo (Norway), providing valuable insights into the underwater light pollution levels and their potential effects on aquatic life.

Light Pollution and Aquatic Ecosystems

Our sampling during the winter of 2022 revealed substantial levels of light pollution in both the Oslo harbor and the Akerselva river. The light intensity measured in some locations was relatively high compared to that under a streetlight, illustrating the severity of the issue. The observation of light pollution at depths of down to 5 meters is concerning, as this high level of light penetration disrupts the natural light environment crucial for many aquatic species.

Aquatic habitats, often overlooked in urban planning, are significantly affected by light pollution. Coastal and freshwater ecosystems, which are biodiversity hotspots, face increased risks. For instance, in Norway, species such as the coastal cod (*Gadus morhua*) and wild Atlantic salmon (*Salmo salar*), which reproduce in coastal areas and rivers, are particularly vulnerable. Light pollution has been shown to affect salmon migration (Riley et al., 2012) and the reproductive timing of various fish species (Brüning et al., 2016; Brüning et al., 2018). Our findings support these concerns, as we observed measurable light levels even in seemingly dark areas, and known spawning sites for A. salmon, indicating that artificial light significantly alters the natural light regime in these habitats.

Behavioral and Physiological Effects on Aquatic Life

The presence of artificial light in aquatic environments can have numerous adverse effects on wildlife. Nocturnal light interferes with the circadian rhythms of animals, affecting their behavior, reproduction, and migration patterns. For example, birds and sea turtles that rely on moonlight for navigation can become disoriented by ALAN, leading to fatal light attraction (Cabrera-Cruz et al., 2018; Hu et al., 2018). Similarly, aquatic species are not immune to these effects. Fish, in particular, may experience changes in their reproductive cycles and behavior due to altered light conditions as for instance in the clown fish (*Amphiprion ocellaris* (O'Connor et al., 2019)), *Girella laevifrons* (Pulgar et al., 2019), the western mosquitofish (*Gambusia affinis* (Miner et al., 2021)), or the japanese medaka (*Oryzias latipes* (Closs et al., 2023)). Our study observed a fish utilizing the ALAN for hunting, which could disrupt the natural predator-prey dynamics in the ecosystem as previously reported. ALAN was indeed described to attract prey species and piscivorous fishes (Becker et al., 2011; Lehman et al., 2019). It was for instance shown that ALAN increases predation of juvenile salmons by increasing predator density (Nelson et al., 2021). Light was shown to increase the foraging efficiency and predatory behavior (Bolton et al., 2017), as well as prey consumption rate in fish (Mazur & Beauchamp, 2006; Mazur & Beauchamp, 2003; Vogel & Beauchamp, 1999) therefore increasing piscivorous fish predation rates and negatively impacting prey survival.

Challenges and Future Research Directions

Despite these interesting findings, several challenges and questions remain. One major limitation of our study is the lack of data on the color spectrum of the underwater light pollution and the impact of weather conditions such as snow, ice, and cloud cover on light intensity and spectrum. Different species have varying sensitivities to different light wavelengths, and understanding these differences is crucial for mitigating the adverse effects of light pollution.

Future research should focus on determining how different species respond to various light wavelengths to help in designing lighting solutions that minimize ecological disruption. Additionally, studying the effects of snow, ice, and cloud cover on light pollution levels and spectrum is essential for developing a comprehensive understanding of underwater light dynamics. Finally, identifying types of lights, such as color and intensity, that have minimal impact on wildlife will be crucial for urban planning and conservation efforts.

Policy Implications and Conservation Strategies

The findings of our study have significant implications for urban planning and conservation policies. Given the widespread impact of light pollution on aquatic and terrestrial ecosystems, it is crucial to implement measures that mitigate its effects. Adopting wildlife-friendly lighting that utilizes wavelengths less disruptive to wildlife can help reduce the impact of light pollution. Establishing guidelines for the intensity and duration of artificial lighting in urban areas, especially near sensitive habitats, is essential. Increasing awareness about the ecological impact of light pollution among the public and policymakers can drive more sustainable practices.

Conclusion

Our study underscores the pervasive nature of light pollution in urban aquatic environments and its potential to disrupt ecological processes. The high levels of light penetration observed in the harbor of Oslo and the Akerselva river highlight the need for comprehensive research and targeted mitigation strategies. Protecting aquatic ecosystems from the adverse effects of light pollution requires a multidisciplinary approach, integrating scientific research, urban planning, and public policy. By addressing the remaining questions and implementing effective conservation strategies, we can better safeguard the biodiversity and health of our aquatic environments.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Becker, A., Whitfield, A., Cowley, P., Järnegren, J., & Næsje, T. (2011). An assessment of the size structure, distribution and behaviour of fish populations within a temporarily closed estuary using dual frequency identification sonar (DIDSON). *Journal of Fish Biology*, *79*(3), 761-775.

Bolton, D., Mayer-Pinto, M., Clark, G., Dafforn, K., Brassil, W., Becker, A., & Johnston, E. (2017). Coastal urban lighting has ecological consequences for multiple trophic levels under the sea. *Science of the Total Environment*, *576*, 1-9.

Brüning, A., Hölker, F., Franke, S., Kleiner, W., & Kloas, W. (2016). Impact of different colours of artificial light at night on melatonin rhythm and gene expression of gonadotropins in European perch. *Science of the Total Environment*, *543*, 214-222. https://doi.org/10.1016/j.scitotenv.2015.11.023

Brüning, A., Hölker, F., Franke, S., Kleiner, W., & Kloas, W. (2018). Influence of light intensity and spectral composition of artificial light at night on melatonin rhythm and mRNA expression of gonadotropins in roach Rutilus rutilus. *Fish Physiol Biochem*, *44*(1), 1-12. https://doi.org/10.1007/s10695-017-0408-6

Cabrera-Cruz, S. A., Smolinsky, J. A., & Buler, J. J. (2018). Light pollution is greatest within migration passage areas for nocturnally-migrating birds around the world. *Scientific Reports*, *8*(1), 3261.

Closs, L. E., Royan, M. R., Sayyari, A., Mayer, I., Weltzien, F.-A., Baker, D. M., & Fontaine, R. (2023). Artificial light at night disrupts male dominance relationships and reproductive success in a model fish species. *Science of the Total Environment*, *900*, 166406. https://doi.org/10.1016/j.scitotenv.2023.166406

Dominoni, D. M., Borniger, J. C., & Nelson, R. J. (2016). Light at night, clocks and health: from humans to wild organisms. *Biology Letters*, *12*(2), 20160015. https://doi.org/10.1098/rsbl.2016.0015

Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C. C. M., Elvidge, C. D., Baugh, K., Portnov, B. A., Rybnikova, N. A., & Furgoni, R. (2016). The new world atlas of artificial night sky brightness. *Science Advances*, *2*(6), e1600377. https://doi.org/10.1126/sciadv.1600377

Hu, Z., Hu, H., & Huang, Y. (2018). Association between nighttime artificial light pollution and sea turtle nest density along Florida coast: A geospatial study using VIIRS remote sensing data. *Environmental Pollution*, *239*, 30-42.

Jechow, A., & Hölker, F. (2019). How dark is a river? Artificial light at night in aquatic systems and the need for comprehensive night-time light measurements. *WIREs Water*, *6*(6), e1388. https://doi.org/10.1002/wat2.1388

Lehman, B. M., Gary, M. P., Demetras, N., & Michel, C. J. (2019). Where predators and prey meet: Anthropogenic contact points between fishes in a freshwater estuary. *San Francisco Estuary and Watershed Science*, *17*(4).

Mazur, M., & Beauchamp, D. (2006). Linking piscivory to spatial–temporal distributions of pelagic prey fishes with a visual foraging model. *Journal of Fish Biology*, *69*(1), 151-175.

Mazur, M. M., & Beauchamp, D. A. (2003). A comparison of visual prey detection among species of piscivorous salmonids: effects of light and low turbidities. *Environmental Biology of Fishes*, *67*, 397-405.

Miner, K. A., Huertas, M., Aspbury, A. S., & Gabor, C. R. (2021). Artificial light at night alters the physiology and behavior of western mosquitofish (Gambusia affinis). *Frontiers in Ecology and Evolution*, *9*, 617063.

Nelson, T. R., Michel, C. J., Gary, M. P., Lehman, B. M., Demetras, N. J., Hammen, J. J., & Horn, M. J. (2021). Effects of Artificial Lighting at Night on Predator Density and Salmonid Predation. *Transactions of the American Fisheries Society*, *150*(2), 147-159. https://doi.org/10.1002/tafs.10286

O'Connor, J. J., Fobert, E. K., Besson, M., Jacob, H., & Lecchini, D. (2019). Live fast, die young: Behavioural and physiological impacts of light pollution on a marine fish during larval recruitment. *Mar Pollut Bull*, *146*, 908-914. https://doi.org/10.1016/j.marpolbul.2019.05.038

Pulgar, J., Zeballos, D., Vargas, J., Aldana, M., Manriquez, P. H., Manriquez, K., Quijón, P. A., Widdicombe, S., Anguita, C., Quintanilla, D., & Duarte, C. (2019). Endogenous cycles, activity patterns and energy expenditure of an intertidal fish is modified by artificial light pollution at night (ALAN). *Environmental Pollution*, *244*, 361-366. https://doi.org/10.1016/j.envpol.2018.10.063

Riley, W., Bendall, B., Ives, M., Edmonds, N., & Maxwell, D. (2012). Street lighting disrupts the diel migratory pattern of wild Atlantic salmon, Salmo salar L., smolts leaving their natal stream. *Aquaculture*, *330*. https://doi.org/10.1016/j.aquaculture.2011.12.009

Vogel, J. L., & Beauchamp, D. A. (1999). Effects of light, prey size, and turbidity on reaction distances of lake trout (Salvelinus namaycush) to salmonid prey. *Canadian Journal of Fisheries and Aquatic Sciences*, *56*(7), 1293-1297.