Chapter 13
Light Pollution in the Arctic Marine Environment

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13.1 Introduction

Light pollution is defined as the excessive or misdirected artificial light that alters the natural illumination of the environment, disrupting ecosystems and obscuring celestial observations [29, 42, 53]. It primarily encompasses skyglow, glare, light trespass, and clutter, each contributing to the degradation of natural darkness [3, 46]. Addressing light pollution in the Arctic is particularly important due to the region's unique environmental and cultural significance. The Arctic's prolonged periods of darkness during the winter months are crucial for the survival and behavior of numerous species, including migratory birds and marine mammals, which rely on natural light cycles for navigation, foraging, and breeding [16, 32, 43, 51]. Artificial light intrusion can disrupt these behaviors, leading to ecological imbalances and threatening biodiversity. Additionally, indigenous communities in the Arctic, who maintain a deep cultural connection to the natural environment, are adversely affected by light pollution, which impairs traditional practices such as nighttime hunting and celestial navigation [10, 15]. Furthermore, the Arctic's pristine skies are invaluable for astronomical research, with minimal light pollution being essential for accurate observations and scientific advancements [12]. Mitigating light pollution in the Arctic thus supports the conservation of biodiversity, the preservation of indigenous cultures, and the advancement of scientific knowledge, underscoring the need for targeted policies and sustainable lighting practices in the region.

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13.2 Sources of Light Pollution in the Arctic

The sources of light pollution in the Arctic can be categorized into natural and artificial origins, with the latter posing significant challenges to the region's ecological integrity and cultural practices. Natural sources of light pollution, while minimal, include phenomena such as auroras (Fig. 13.1) and moonlight; however, artificial sources overwhelmingly dominate the landscape [8]. Coastal communities and infrastructure contribute substantially to light pollution through streetlights, building illumination, and other urban developments that disrupt the natural nocturnal environment [1, 20, 47]. Shipping and maritime activities further exacerbate this issue, as vessels often utilize bright navigation lights and deck illumination, leading to increased skyglow and light trespass in sensitive coastal ecosystems [52]. Offshore oil and gas platforms are another significant source, with their extensive lighting systems designed for safety and operational efficiency, inadvertently creating localized zones of light pollution that can alter wildlife behaviors and disrupt marine habitats. Additionally, the influx of tourism and the establishment of research stations in the Arctic, often accompanied by temporary or permanent lighting installations, contribute to the growing levels of artificial light. These activities not only compromise the natural darkness essential for nocturnal species and indigenous cultural practices but also hinder astronomical observations critical for scientific research. Therefore, addressing the sources of light pollution in the Arctic is vital for preserving the ecological balance, cultural heritage, and scientific integrity of this unique and fragile region.

Fig. 13.1 An aurora (Northern Lights or Southern Lights). (Source: Noppawat Tom Charoensinphon)

13.3 Mechanisms of Light Pollution Spread

The mechanisms underlying the spread of light pollution in the Arctic are complex and influenced by various environmental factors, including reflection, scattering, and seasonal variations [12, 17, 24]. The reflective properties of ice and snow play a pivotal role in amplifying light pollution; when artificial light interacts with these surfaces, it undergoes significant scattering, resulting in increased skyglow that can extend over vast distances [4]. This phenomenon is particularly pronounced during the polar night when the absence of natural light sources allows artificial illumination to dominate the visual landscape [44]. Additionally, light transmission through water bodies can further exacerbate light pollution, as shallow Arctic waters may reflect and refract light, contributing to a broader dispersal of artificial illumination into adjacent ecosystems [30]. Seasonal variations significantly impact the ecological consequences of light pollution, with polar day presenting unique challenges as extended daylight hours can lead to continuous exposure to artificial light, disrupting circadian rhythms and natural behaviors of wildlife [9, 14, 26]. Conversely, during polar night, the sudden influx of artificial light from human activities can lead to stark contrasts that disturb the delicate balance of nocturnal ecosystems [23]. Thus, understanding these mechanisms is essential for developing effective strategies to mitigate light pollution's adverse effects on Arctic biodiversity and the cultural practices of indigenous communities.

13.4 Impacts of Light Pollution on Arctic Marine Organisms

The impact of light pollution on Arctic marine organisms is profound, primarily through the disruption of biological rhythms, including both circadian and circannual patterns, which are critical for maintaining ecological balance [23, 27]. Artificial illumination can interfere with the natural light cycles that govern the behavior of marine mammals such as seals and whales, leading to alterations in their foraging, breeding, and migratory behaviors [28]. For instance, species like the bowhead whale may experience shifts in migratory routes and calving timing due to the increased presence of artificial light along coastlines and from maritime activities [39]. Similarly, fish and invertebrates are significantly affected; light pollution can disrupt migratory patterns and feeding behaviors, with species such as Arctic cod potentially altering their vertical migration patterns in response to artificial light, thus impacting predator–prey dynamics [37]. Furthermore, the impacts extend to primary producers like phytoplankton, whose growth and reproductive cycles may be adversely affected by increased light exposure during non-productive seasons, ultimately influencing the entire marine food web. Case studies on specific species, such as the impact of light pollution on the behavior of the Arctic amphipod, have revealed changes in activity patterns and reduced reproductive success [19], underscoring the ecological ramifications of altered light conditions.

Collectively, these effects highlight the urgent need for targeted research and effective mitigation strategies to address light pollution in the Arctic marine environment, ensuring the preservation of its delicate ecosystems and the species that inhabit them.

13.5 Monitoring and Assessment Techniques

Monitoring and assessment techniques for light pollution in the Arctic employ a multifaceted approach that integrates advanced technologies and community engagement to ensure comprehensive data collection and analysis [50]. Satellite observations and remote sensing provide a crucial framework for assessing light pollution on a large scale, utilizing sensors that capture the intensity and distribution of artificial illumination across vast and often inaccessible regions [6, 11, 33, 34, 38]. In situ measurements, facilitated by established monitoring networks, complement these satellite data by providing ground-truth validation and localized insights into light pollution's ecological impacts. Additionally, the incorporation of citizen science initiatives enhances monitoring efforts by empowering local communities and stakeholders to participate in data collection, thereby fostering a deeper connection to environmental stewardship and contributing valuable on-the-ground observations [2, 7, 40, 49]. Furthermore, modeling techniques are essential for predicting the distribution and impact of light pollution, utilizing computational algorithms to simulate the effects of artificial light on ecological systems and to forecast potential future scenarios under varying anthropogenic pressures [25, 36]. Together, these methodologies form a robust framework for understanding and mitigating light pollution in the Arctic, ensuring that conservation strategies are informed by accurate and comprehensive scientific evidence.

13.6 Mitigation and Management Strategies

Mitigation and management strategies for light pollution in the Arctic encompass a range of policy, technological, and cooperative approaches designed to minimize its ecological and cultural impacts. Policy and regulatory frameworks are essential for establishing enforceable guidelines that limit artificial light emissions [5, 21, 41, 45]. These regulations can include restrictions on light intensity, duration, and the direction of lighting, particularly in sensitive ecological zones. Technological solutions play a critical role in reducing light pollution, with innovations such as light shielding and dimming technologies that direct light only where needed and adjust brightness based on environmental conditions [13, 31, 48]. Implementing best practices for Arctic infrastructure development is also crucial; this involves designing and constructing buildings and facilities with minimal light spill, using energy-efficient lighting, and prioritizing natural darkness [54]. The role of international cooperation and agreements is paramount, as light pollution does not adhere to political boundaries [18]. Collaborative efforts, such as those facilitated by the Arctic Council, promote shared standards and strategies, enabling countries to collectively address light pollution. These efforts include joint research initiatives, information sharing, and the development of transboundary policies that protect the Arctic environment [22, 35]. By integrating these strategies, it is possible to significantly reduce light pollution in the Arctic, safeguarding its unique ecosystems and the cultural practices of its indigenous populations.

13.7 Conclusion

Light pollution in the Arctic marine environment represents a growing environmental challenge with far-reaching ecological, cultural, and scientific implications. The unique sensitivity of the Arctic ecosystem to artificial light underscores the urgent need for targeted mitigation strategies. Disruptions to biological rhythms in marine organisms, such as altered migration patterns and feeding behaviors, pose significant risks to biodiversity and ecosystem health. Furthermore, light pollution threatens the traditional practices and livelihoods of indigenous communities, as well as the integrity of astronomical research in the region. Effective monitoring and assessment techniques, including satellite observations, in situ measurements, and citizen science, provide a robust framework for understanding and addressing this issue. Implementing policy and regulatory frameworks, adopting technological solutions, and fostering international cooperation are essential components of a comprehensive strategy to mitigate light pollution. By prioritizing these approaches, we can protect the Arctic marine environment from the adverse effects of artificial illumination, ensuring the preservation of its natural darkness, ecological balance, and cultural heritage for future generations.

References

1. Aguilera, M. A., & González, M. G. (2023). Urban infrastructure expansion and artificial light pollution degrade coastal ecosystems, increasing natural-to-urban structural connectivity. *Landscape and Urban Planning, 229*, 104609.
2. Alarcon Ferrari, C., Jönsson, M., Gebreyohannis Gebrehiwot, S., Chiwona-Karltun, L., Mark-Herbert, C., Manuschevich, D., Powell, N., Do, T., Bishop, K., & Hilding-Rydevik, T. (2021). Citizen science as democratic innovation that renews environmental monitoring and assessment for the sustainable development goals in rural areas. *Sustainability, 13*(5), 2762.
3. Assad, H., Fatma, I., & Kumar, A. (2022). Health impacts/risks of light pollution. In *Nanotechnology for light pollution reduction* (pp. 77–96). CRC Press.
4. Bará, S., Bao-Varela, C., & Kocifaj, M. (2023). Modeling the artificial night sky brightness at short distances from streetlights. *Journal of Quantitative Spectroscopy and Radiative Transfer, 296*, 108456.

5. Barentine, J. C. (2020). Who speaks for the night? The regulation of light pollution in the 'Rights of Nature' legal framework. *International Journal of Sustainable Lighting, 22*(2), 28–36.
6. Barentine, J. C., Walczak, K., Gyuk, G., Tarr, C., & Longcore, T. (2021). A case for a new satellite mission for remote sensing of night lights. *Remote Sensing, 13*(12), 2294.
7. Bhandari, M. (2024). Citizen science and its applicability for sustainability and a healthy planet. *Academia Environmental Sciences and Sustainability, 1*(1). https://doi.org/10.20935/AcadEnvSci7270
8. Brandi, U. (2023). *Light, nature, architecture: A guide to holistic lighting design*. Birkhäuser.
9. Cabrera-Cruz, S. A. (2021). *Nocturnal light pollution and land bird migration*. University of Delaware.
10. Caraveo, P. (2021). *Saving the starry night: Light pollution and its effects on science, culture and nature*. Springer Nature.
11. Chuvieco, E. (2020). *Fundamentals of satellite remote sensing: An environmental approach*. CRC press.
12. Cohen, J. H., Berge, J., Moline, M. A., Johnsen, G., & Zolich, A. P. (2020). Light in the polar night. In *Polar night marine ecology: Life and light in the dead of night* (pp. 37–66). Springer.
13. da Silva, E. P., Fragal, E. H., Duarte, E. D. P., Lourenço, S. A., Muniz, E. C., Sequinel, T., Silva, R., de Arruda, E. J., Gorup, L. F., & Fragal, V. H. (2022). Photonic nanodevices and technologies against light pollution. In *Nanotechnology for light pollution reduction* (pp. 211–240). CRC Press.
14. Davis, L. K., Bumgarner, J. R., Nelson, R. J., & Fonken, L. K. (2023). Health effects of disrupted circadian rhythms by artificial light at night. *Policy Insights From the Behavioral and Brain Sciences, 10*(2), 229–236.
15. Dunn, N., & Edensor, T. (2023). *17 Under the night* (Vol. 251). Dark Skies.
16. Eklöf, J. (2023). *The darkness manifesto: On light pollution, night ecology, and the ancient rhythms that sustain life*. Simon and Schuster.
17. Falcón, J., Torriglia, A., Attia, D., Viénot, F., Gronfier, C., Behar-Cohen, F., Martinsons, C., & Hicks, D. (2020). Exposure to artificial light at night and the consequences for flora, fauna, and ecosystems. *Frontiers in Neuroscience, 14*, 602796.
18. Freeland, S., & Martin, A. S. (2024). A sky full of stars, constellations, satellites and more! Legal issues for a 'Dark' sky. *Oslo Law Review, 3*, 1–22.
19. Ganguly, A., & Candolin, U. (2023). Impact of light pollution on aquatic invertebrates: Behavioral responses and ecological consequences. *Behavioral Ecology and Sociobiology, 77*(9), 104.
20. Gaston, K. J., Ackermann, S., Bennie, J., Cox, D. T., Phillips, B. B., Sánchez de Miguel, A., & Sanders, D. (2021). Pervasiveness of biological impacts of artificial light at night. *Integrative and Comparative Biology, 61*(3), 1098–1110.
21. Hao, Y., Wang, P., Zhang, Z., Xu, Z., & Jia, D. (2024). A review of the characteristics of light pollution: Assessment technique, policy, and legislation. *Energies, 17*(11), 2750.
22. Heininen, L., Everett, K., Padrtova, B., & Reissell, A. (2020). Arctic policies and strategies—Analysis, synthesis, and trends. *Polar Geography, 43*, 240.
23. Helm, B., Greives, T., & Zeman, M. (2024). Endocrine–circadian interactions in birds: Implications when nights are no longer dark. *Philosophical Transactions of the Royal Society B, 379*(1898), 20220514.
24. Heslin-Rees, D., Burgos, M., Hansson, H. C., Krejci, R., Ström, J., Tunved, P., & Zieger, P. (2020). From a polar to a marine environment: Has the changing Arctic led to a shift in aerosol light scattering properties? *Atmospheric Chemistry and Physics, 20*(21), 13671–13686.
25. Hölker, F., Bolliger, J., Davies, T. W., Giavi, S., Jechow, A., Kalinkat, G., Longcore, T., Spoelstra, K., Tidau, S., Visser, M. E., & Knop, E. (2021). 11 Pressing research questions on how light pollution affects biodiversity. *Frontiers in Ecology and Evolution, 9*, 767177.
26. Jägerbrand, A. K., & Bouroussis, C. A. (2021). Ecological impact of artificial light at night: Effective strategies and measures to deal with protected species and habitats. *Sustainability, 13*(11), 5991.

27. Johnsen, G., Leu, E., & Gradinger, R. (2020). Marine micro-and macroalgae in the polar night. In *Polar night marine ecology: Life and light in the dead of night* (pp. 67–112). Springer.
28. Kehinde, F. O., Dedeke, G.A., Rasaq, I.B., & Isibor, P. O. (2018). The Potential of visible light spectra as control measure of Mosquito, the vector of Plasmodium. *IOP Conference Series: Earth and Environmental Science, 210*(2019), 012009.
29. Kocifaj, M., Wallner, S., & Barentine, J. C. (2023). Measuring and monitoring light pollution: Current approaches and challenges. *Science, 380*(6650), 1121–1124.
30. Krapp, R. H. (2022). *Living on the dark side? Investigations into under-ice light climate and sympagic amphipods*.
31. Küçük, Z. K., & Ekren, N. (2021). Light pollution and smart outdoor lighting. *Balkan Journal of Electrical and Computer Engineering, 9*(2), 191–200.
32. Last, K. S., Häfker, N. S., Hendrick, V. J., Meyer, B., Tran, D., & Piccolin, F. (2020). Biological clocks and rhythms in polar organisms. In *Polar night marine ecology: Life and light in the dead of night* (pp. 217–240). Springer.
33. Levin, N., Kyba, C. C., Zhang, Q., de Miguel, A. S., Román, M. O., Li, X., Portnov, B. A., Molthan, A. L., Jechow, A., Miller, S. D., Wang, Z., Shrestha, R. M., & Elvidge, C. D. (2020). Remote sensing of night lights: A review and an outlook for the future. *Remote Sensing of Environment, 237*, 111443.
34. Linares Arroyo, H. (2021). *Study and characterization of light pollution in Catalonia*.
35. Loukacheva, N. (2020). The Arctic council and "law-making". *Northern Review, 50*, 109–135.
36. Ma, Y., Song, Y., & Zhang, R. (2023). Research on regional light pollution risk level measurement based on neural network model. *Academic Journal of Environment & Earth Science, 5*(5), 41–45.
37. Marangoni, L. F., Davies, T., Smyth, T., Rodríguez, A., Hamann, M., Duarte, C., Tidau, S., & Levy, O. (2022). Impacts of artificial light at night in marine ecosystems—A review. *Global Change Biology, 28*(18), 5346–5367.
38. Mertikas, S. P., Partsinevelos, P., Mavrocordatos, C., & Maximenko, N. A. (2021). Environmental applications of remote sensing. In *Pollution assessment for sustainable practices in applied sciences and engineering* (pp. 107–163). Butterworth-Heinemann.
39. Meynecke, J. O., de Bie, J., Barraqueta, J. L. M., Seyboth, E., Dey, S. P., Lee, S. B., Samanta, S., Vichi, M., Findlay, K., Roychoudhury, A., & Mackey, B. (2021). The role of environmental drivers in humpback whale distribution, movement and behavior: A review. *Frontiers in Marine Science, 8*, 720774.
40. Millar, E., & Searcy, C. (2020). The presence of citizen science in sustainability reporting. *Sustainability Accounting, Management and Policy Journal, 11*(1), 31–64.
41. Morgan-Taylor, M. (2023). Regulating light pollution: More than just the night sky. *Science, 380*(6650), 1118–1120.
42. Naqvi, S. K. H., Soban, M., Arshad, F., & Bashir, F. (2024). Unveiling the spatial dimensions of light pollution in Pakistan: An emerging environmental challenge. *Pakistan Journal of Humanities and Social Sciences, 12*(2), 1252–1263.
43. Patterson, A., Gilchrist, H. G., Robertson, G. J., Hedd, A., Fifield, D. A., & Elliott, K. H. (2022). Behavioural flexibility in an Arctic seabird using two distinct marine habitats to survive the energetic constraints of winter. *Movement Ecology, 10*(1), 45.
44. Sánchez de Miguel, A., Bennie, J., Rosenfeld, E., Dzurjak, S., & Gaston, K. J. (2022). Environmental risks from artificial nighttime lighting widespread and increasing across Europe. *Science Advances, 8*(37), eabl6891.
45. Schroer, S., Huggins, B. J., Azam, C., & Hölker, F. (2020). Working with inadequate tools: Legislative shortcomings in protection against ecological effects of artificial light at night. *Sustainability, 12*(6), 2551.
46. Srivastava, M., Banger, A., Yadav, A., & Srivastava, A. (2022). Light pollution: Adverse health impacts. In *Nanotechnology for light pollution reduction* (pp. 97–117). CRC Press.
47. Tavares, P., Ingi, D., Araújo, L., Pinho, P., & Bhusal, P. (2021). Reviewing the role of outdoor lighting in achieving sustainable development goals. *Sustainability, 13*(22), 12657.

48. Thakur, A., Ganjoo, R., & Kumar, A. (2022). Light pollution and prevention: An introduction. In *Nanotechnology for light pollution reduction* (pp. 1–23). CRC Press.
49. Vasiliades, M. A., Hadjichambis, A. C., Paraskeva-Hadjichambi, D., Adamou, A., & Georgiou, Y. (2021). A systematic literature review on the participation aspects of environmental and nature-based citizen science initiatives. *Sustainability, 13*(13), 7457.
50. Vlasova, T., Petrov, A. N., & Volkov, S. (2020). Rethinking sustainability monitoring in the arctic by linking resilience and sustainable development in socially-oriented observations: A perspective. *Sustainability, 13*(1), 177.
51. Ware, J. V., Rode, K. D., Robbins, C. T., Leise, T., Weil, C. R., & Jansen, H. T. (2020). The clock keeps ticking: Circadian rhythms of free-ranging polar bears. *Journal of Biological Rhythms, 35*(2), 180–194.
52. Welch, D., Dick, R., Treviño, K., Longcore, T., Rich, C., Hearnshaw, J., Ruggles, C., Dalton, A., Barentine, J., & Gyarmathy, I. (2024). *The world at night*.
53. Widmer, K., Beloconi, A., Marnane, I., & Vounatsou, P. (2022). *Review and assessment of available information on light pollution in Europe*. Elonet report-ETC HE 2022/8.
54. Zielinska-Dabkowska, K. M., & Bobkowska, K. (2022). Rethinking sustainable cities at night: Paradigm shifts in urban design and city lighting. *Sustainability, 14*(10), 6062.