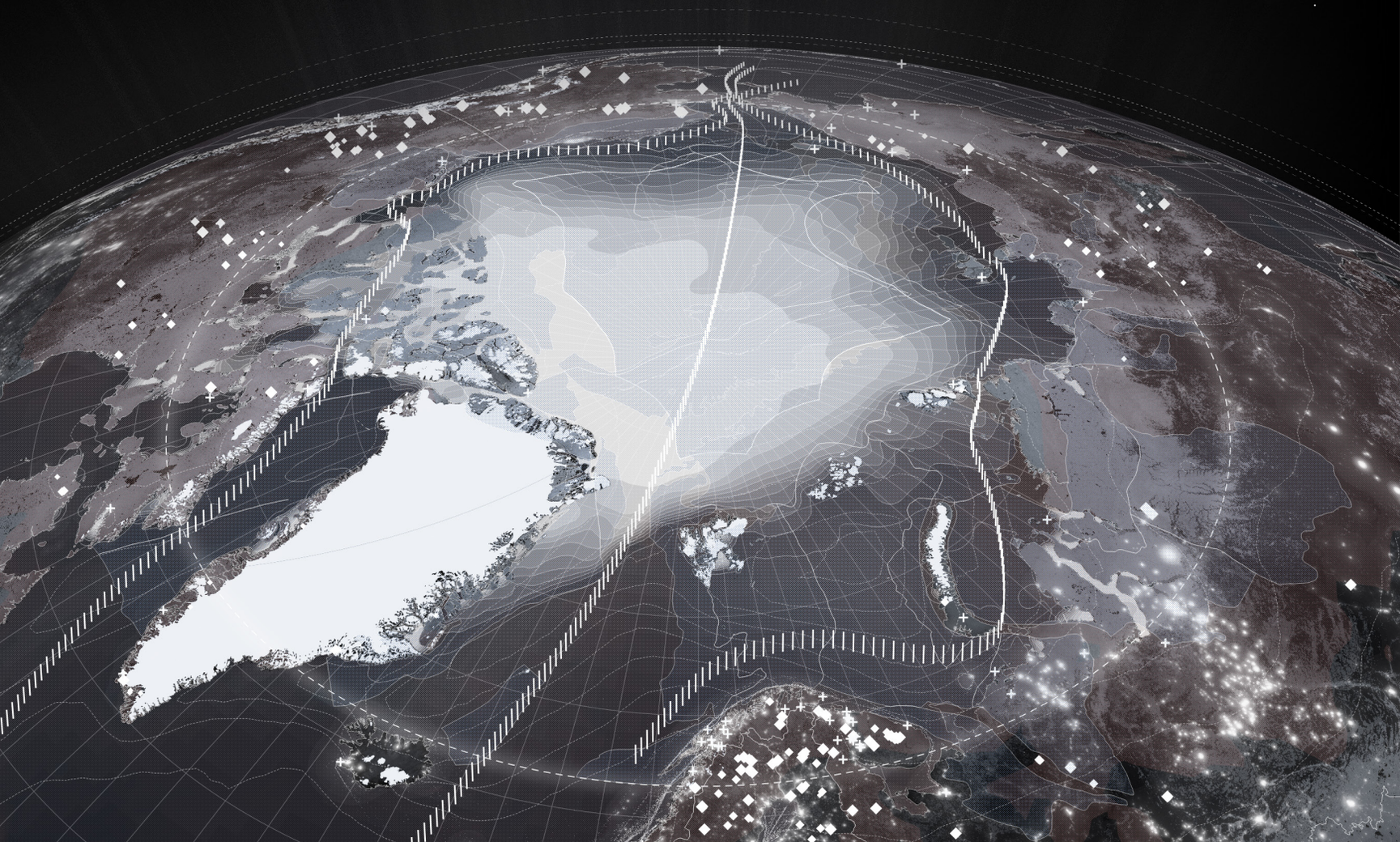
DARKNESS AS TERRITORY

a spatio-temporal understanding of light in the Arctic

master thesis

ALLARD VAN ENGELENHOVEN | DELFT UNIVERSITY OF TECHNOLOGY



COLOFON

master thesis
Darkness as Territory: a spatio-temporal understanding of light in the Arctic

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June, 2026

Critical Environments

TU Delft

Urbanism

EFL STICHTING

ARCTIC URBANISM AT TU DELFT

The Arctic is a critical environment in rapid transition.

External notions have often positioned the Arctic as a passive agent, further enabled by northbound extractive urbanisation. However, by understanding urbanisation horizontally and vertically through a more-than-city lens, global and systemic pressures into a presumed whitespace can be exposed. These pressures unfold in matters such as ecological shifts, complex geopolitical relations, and legal ambiguity to form the backbone of the research within Arctic Urbanism (AU) at Delft University of Technology.

AU adresses the need for a paradigm shift to view the Arctic as a global common, an active agent and a recognised body of its own. Through a more-than-human approach of critical cartography and visual ethnography, anthropogenic disturbance is revealed. Exposing our own actions will itself become a catalyst for change.

2026

VOLUME I - ARCTIC AS TERRITORY
instrumentalisation of offshore urbanisation towards Arctic agency
[6266770 - K.T. Hauge]

VOLUME II - DARKNESS AS TERRITORY
a spatio-temporal understanding of light in the Arctic
[4537726 - A.M. van Engelenhoven]

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With love, Allard

ABSTRACT

Arctic darkness is increasingly disrupted by expanding infrastructure and artificial light at night (ALAN). Along the Norwegian Arctic coastline, climate change, shipping, resource extraction, and coastal development are extending human activity into spaces and periods historically defined by prolonged winter darkness. While these transformations are often understood through their environmental and economic impacts, less attention has been given to the ecological role of darkness itself. Yet many Arctic species, both human and non-human, rely on seasonal cycles of light and darkness to regulate biological rhythms, behaviour, and ecological interactions.

This thesis investigates darkness as a critical ecological and temporal infrastructure rather than the mere absence of light. It asks how design can mediate the recognition of darkness as a Right of Nature to support ecological regeneration along the Norwegian Arctic coastline.

To address this question, the research develops a multi-scalar framework that combines ecological, spatial, and infrastructural analysis. It examines how terrestrial, aerial, and marine species - including reindeer, little auk, and zooplankton - depend on darkness as a biophysical regulator, and analyses how ALAN generated by shipping, industry, and coastal infrastructure disrupts these relationships. Through a case study of Tromsø, the thesis develops methods to visualise light and darkness as territorial conditions. Natural darkness is mapped through landscape characteristics such as topography, enclosure, and sky visibility, while artificial illumination is modelled through a designed method visualising *coastal light pressure*. These layers are combined into an atlas that allows to reinterpret the territory through the lens of light and dark.

The thesis argues that darkness constitutes an ecological condition with intrinsic value that can be identified, mapped, and incorporated into spatial design and planning. By reframing darkness as a subject of environmental protection rather than a residual condition awaiting illumination, it advances a spatial framework for recognising darkness as a Right of Nature and supporting ecological regeneration in the Arctic.

keywords: artificial light at night, darkness, rights of nature, industry, Arctic, Norway

light

noun [U] /laɪt/

the brightness that comes from the sun, fire, and
electrical devices, and that allows things to be seen.

darkness

noun [U] /'dark.nəs/

the quality of being without light, or a situation in which there is little or no light.

PREMISE

This thesis starts from the premise that the way we see and map the world shapes our understanding. Every representation produces a specific reading of space. In the case of the Arctic, this means there is no single or fixed way of seeing it: its meaning shifts with each representation. This thesis proposes a way of seeing the Arctic that opens it to new forms of perception and interpretation, revealing conditions that are often overlooked in dominant readings. From this position, the Arctic is not treated as a space for immediate intervention, but as an environment that must first be observed and listened to. It demands attention and understanding before any action is taken.

MOTIVATION

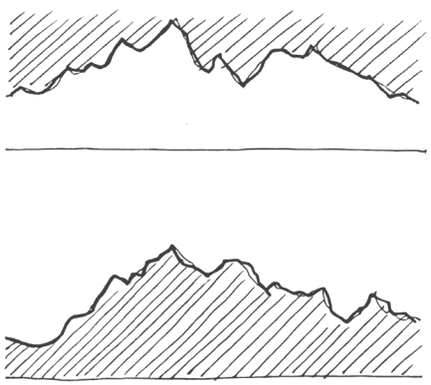
My interest in the Arctic began long before I could describe it in academic terms. Travelling through Norway left a strong impression on me. Not because of one specific moment, but because of the environment as a whole: the landscape, the wildlife, and especially the unusual relationship between light and time.

I remember staying in a cottage in Stryn during summer and being unable to sleep because it never turned fully dark outside. Even at night, the sky remained in twilight. Although Stryn is not located in the far north, the experience already felt unfamiliar to me. It made me think about what daily life would be like in places where daylight continues throughout summer, and where winter brings long periods of darkness instead.

What stayed with me most was the feeling that time and daily rhythms were shaped differently by these light conditions. Walking through towns late at night that still felt like daytime made me realise how strongly light influences how we experience space, time, and everyday routines.

These experiences returned at the beginning of my graduation research through two simple drawings that depict the same mountain against a vast sky, see Figure [0.1]. In one, a daytime scene, the mountain appears as a dark silhouette against a bright sky: its form defined by contrast. In the other, a nighttime scene, the snow-covered surface becomes the light element, while the sky turns dark. Here, the roles reverse: what was figure becomes background, and what was background becomes figure. The same mountain, but read in two opposite ways. As form and contra-form, shaped by light and darkness.

This contrast became a way of thinking about light and darkness as more than visual states. They do not only affect what we see, but also how space is organised and experienced over time.



↑ **Figure [0.1].** Sketches with which the fascination started.

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LIST OF ABBREVIATIONS

Arctic Human Development Report	*AHDR*
Artificial Light at Night	*ALAN*
Arctic Monitoring & Assessment Programme	*AMAP*
Conservation of Arctic Flora and Fauna	*CAFF*
Diel Vertical Migration	*DVM*
Emergency Prevention, Preparedness and Response	*EPPR*
Northeast Passage	*NEP*
Norwegian Continental Shelf	*NCS*
Nationally Determined Contribution	*NDC*
National Polar-orbiting Partnership	*NPP*
Northwest Passage	*NWP*
Protection of the Arctic Marine Environment	*PAME*
Rights of Nature	*RoN*
Transpolar Sea Route	*TSR*
Visible Infrared Imaging Radiometer Suite	*VIIRS*

THE FIRMAMENT OF THE ARCTICS

PROLOGUE

On Monday 16 August 1897, the Norwegian converted ship *Belgica* commenced her voyage towards *Terra Australis*[1] from Antwerp. The crew explored the territories of the South, but on 4 March 1898, the South Pole ice closed.

It is the first time that a ship and its entire crew have to spend the winter on the Southern landmass. Norwegian explorer Roald Amundsen and others experience a winter in darkness, navigating the landmass, among other things, by the firmament full of stars (De Deckker, 2018).

However, the firmament is different from that of the Northern hemisphere. Constellations like Ursa Major (the Great Bear) are invisible from their latitude. In the 19th century, Terra Australis was renamed *Antarctica,* meaning 'without bear' in Greek[2] - referring to the absence of Ursa Major. Likewise, the North Pole was named *Arctica*, where Ursa Major is visible (Bulkeley, 2016).

The etymology of the Arctics underscores the central importance of stellar visibility and reflects an intrinsic relationship with darkness.

[1] Terra Australis means Southern Land in Latin and was given as initial name to the South Pole. (Pinkster, 2014)

[2] Antarctica is derived from ἀντι- (anti), meaning 'no' and ἀρκτός (arktos), meaning 'bear'. (Van Zandbrink, 2018, p. 123)

→ **Figure [0.2].** The expedition where the Belgica got stuck in the sea ice of Antarctica in the winter of 1898.

(© Polar Memory, de Gerlache)



Expedition of the Belgica
Antarctica

DARKNESS AS A RIGHT OF NATURE

INTRODUCTION

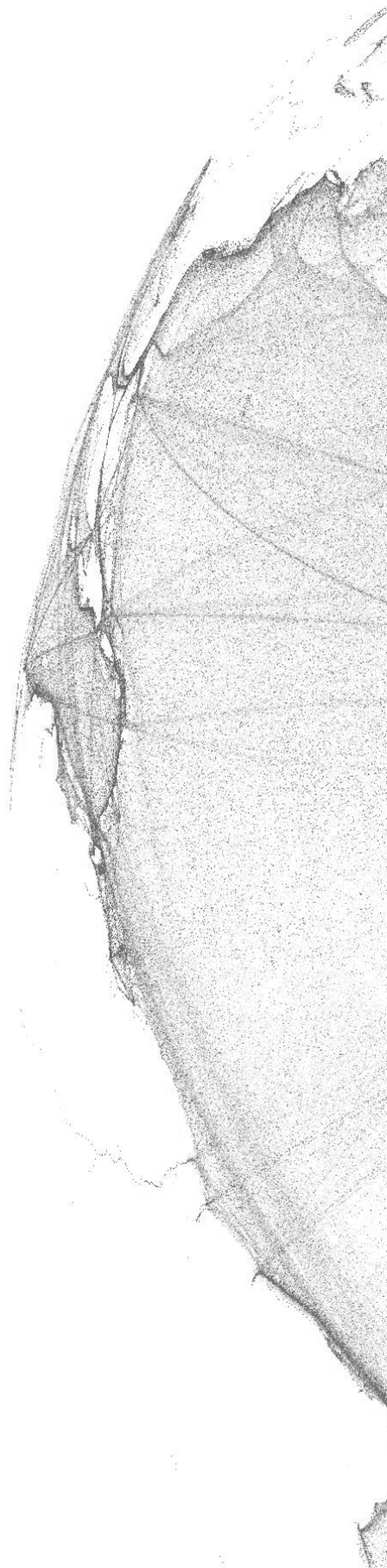
Human life has become embedded in a continuous cycle of activity. The emergence of the Anthropocene, in which urban infrastructure and industrial activity dominate the landscape, caused many societies to operate in a continuous rhythm of activity. Thanks to technology, digital connectivity, and artificial lighting, societies increasingly function as 'twenty-four seven' systems, largely independent of the natural cycle of day and night. And therefore largely independent of the natural cycle of light and dark.

The global expansion of continuous human activity even reaches the planet's most remote regions, like the Arctic. This region is experiencing significant environmental changes. The North Pole is currently warming at an average rate three times faster than the globe. Sea ice recession and permafrost is thawing at an unprecedented rate (Rantanen et al., 2022). These changes facilitate access and development in the region. New shipping routes are becoming accessible year-round. And previously inaccessible mineral and energy resources are becoming economically exploitable (Akandil et al., 2024). The growing interest in Arctic territories is accompanied by geopolitical tensions and an expansion of military presence.

At the same time, the Arctic experiences extreme natural cycles of light and dark. Within the Arctic circle, there are extended periods during which the sun remains continuously above the horizon (Polar day) or entirely below it (Polar night). The further north one travels, the longer these periods last. The Arctic winter is characterised by prolonged darkness, up to 6 months at the geographical North Pole and shapes the Arctic's space and time (Berge et al., 2015). Increasing human presence in the Arctic is altering the natural cycle of light and dark: the expansion of settlements, infrastructure, industries and transport networks introduces a continuous illuminated territory through artificial light (Akandil et al., 2024). A landscape and its ecological systems - defined by and adapted to prolonged periods of darkness - is under threat.

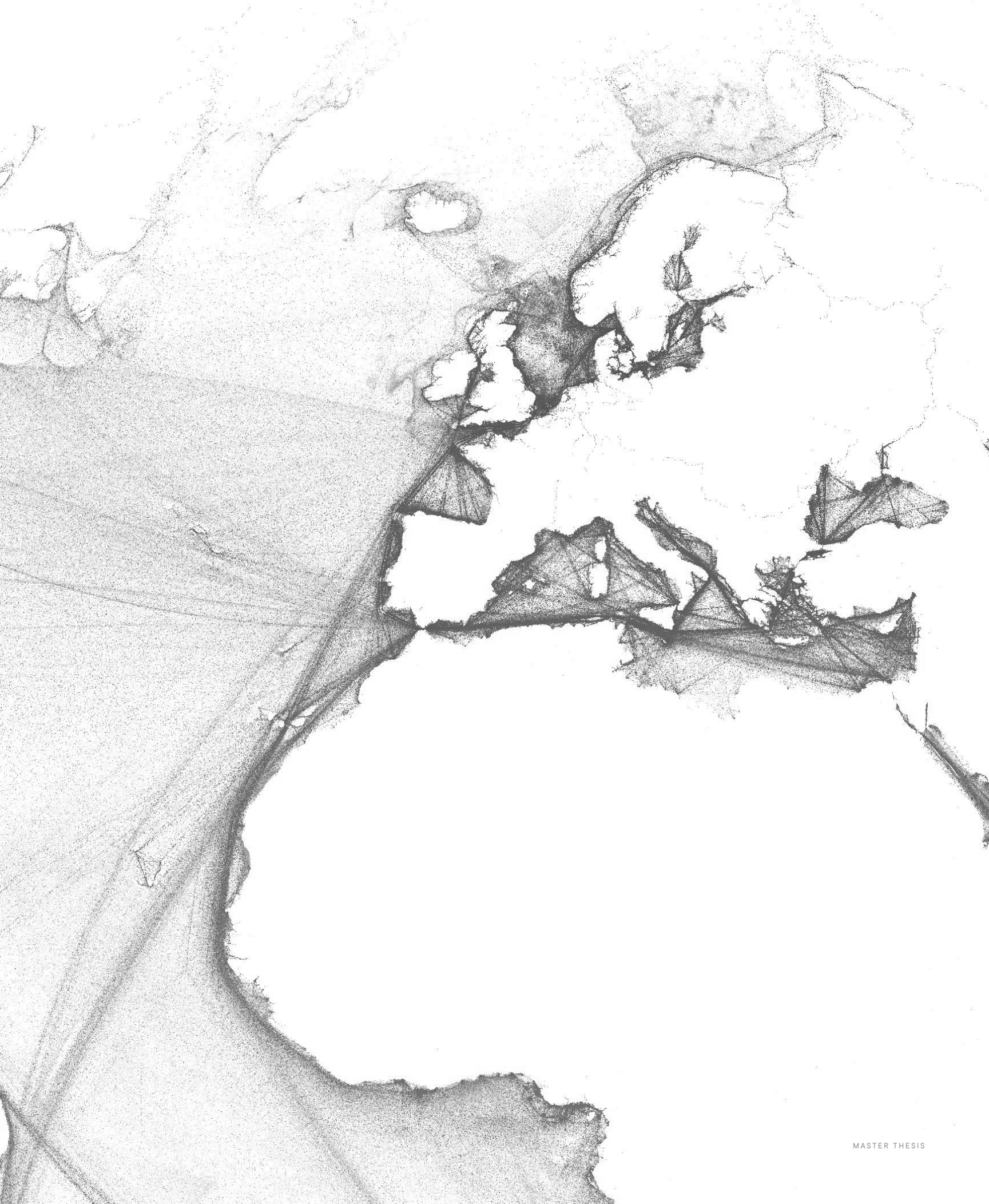
This thesis, therefore, asks how design can mediate the recognition of *darkness as a right of nature* to support ecological regeneration in the Norwegian Arctic.

An answer to this question is build up in five acts. Act I contextualises the Arctic within broader global trends. Act II presents a literature review on the exposure of the Polar night to artificial lighting and its ecological implications. Act III analyses the 'shift to the North' through the lens of artificial light and introduces an extension of the Norwegian paradoxes. These paradoxes are made visible in Act IV through a photographic documentation collected during fieldwork. Finally, Act V proposes a method for analysing and spatialising light and darkness, from both natural and artificial perspectives, and concludes with a series of gestures for the future, based on an adaptive landscape, structured to operate around its own needs and temporalities.



→ **Figure [0.3].** Global shipping density reveals the global expansion of continuous human activity at sea.

data: World Bank Group



MASTER THESIS

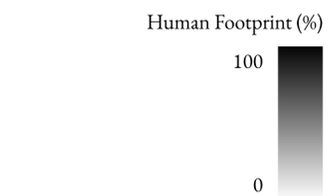
THE ANTHROPOCENE

POSITIONING

To contextualise the transformations discussed in this thesis, human activity is examined through the lens of the Anthropocene. This framework positions humanity as a dominant force shaping environmental systems that dissolves boundaries between natural and artificial conditions.

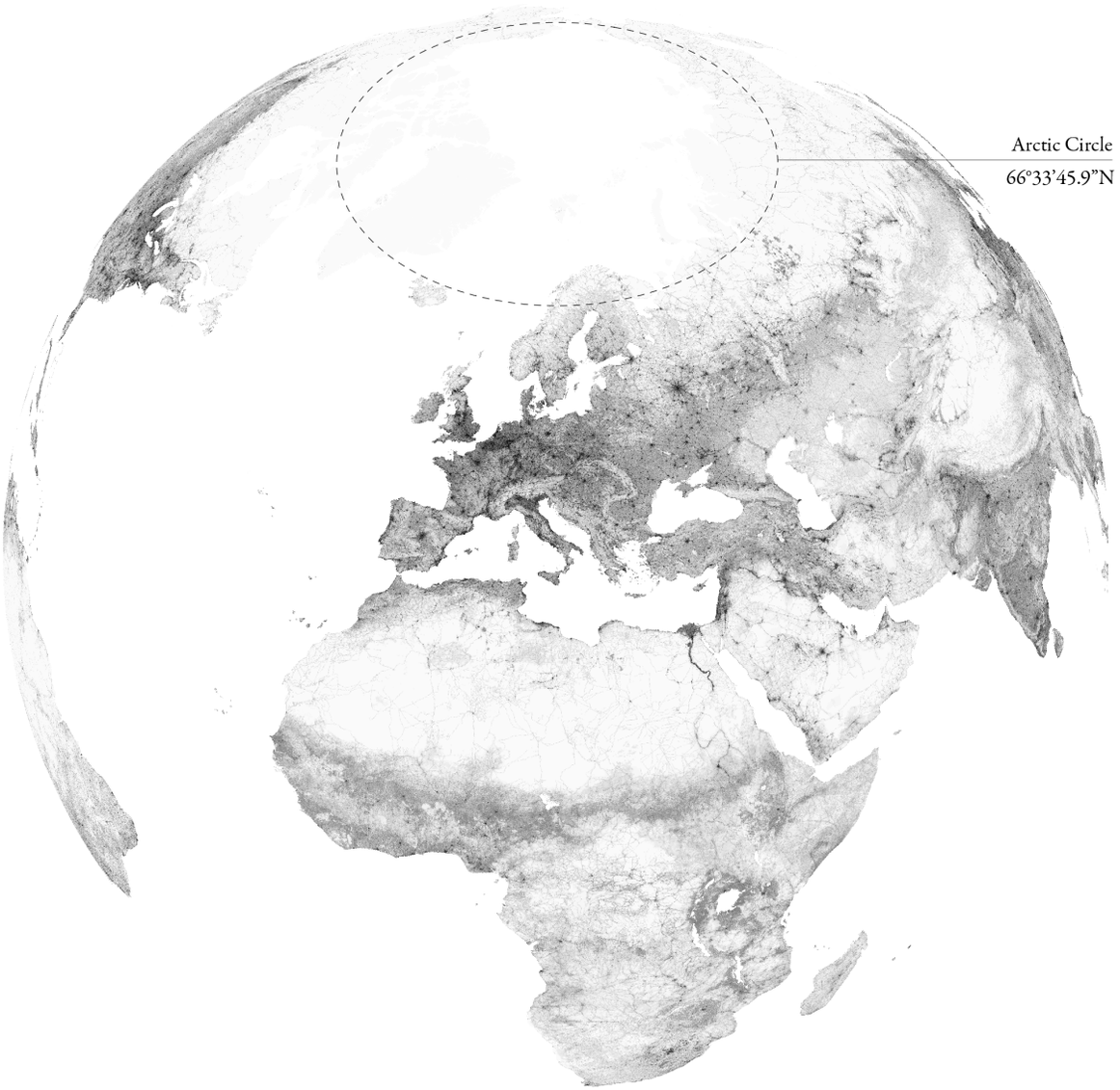
As described by Paul Crutzen (one of the co-creators of the term *Anthropocene*, among others), this marks a shift towards a state defined by industrialisation, urbanisation, and technological expansion (Steffen et al., 2011). This planetary influence is illustrated through a mapping of the Human Footprint Index, a spatial metric to quantify the global extent and intensity of anthropogenic activity on land (see Figure [0.4]). While the Arctic (i.e. the region within the Arctic Circle) currently registers relatively low values, the map reveals broader global trends of expansion and intensification.

As accessibility to the Arctic increases, similar patterns of human intervention may extend to within the Arctic circle. If current trends in industrial development persist, as much as 50 to 80% of the Arctic could experience critical levels of anthropogenic disturbance by 2050. (Akandil et al., 2024).



→ **Figure [0.4].** Worldwide human footprint as spatial metric, quantifying the intensity of human influence (%) on the terrestrial environment.

data: Wildlife Conservation Society


Arctic Circle
66°33’45.9”N

> *"We are condemned to simmer in our own electric bouillabaisse."*
> (Edensor, 2015)

THE ANTHROPOCENE

POSITIONING

Within this context, human-centred perspectives have intensified, prioritising productivity, control, and continuous activity. Enabled by artificial lighting and digital connectivity, societies are increasingly enabled to operate independently of natural cycles of light and dark. Figure [0.5] illustrates this impact, overlapping closely with the global human footprint index. Human activity can therefore be directly linked to artificial light at night.

As Latour (1993) argues, modern thinking is based on a distinction between nature and society, even though in reality they are closely connected. This separation is part of a modern way of thinking that hides how mixed and connected social and ecological systems actually are. Other approaches, including those developed by Donna Haraway, focus on more-than-human ideas that show how humans depend on and are connected to non-humans (Haraway, 2008; Haraway, 2016). This research places the Arctic within the context of the Anthropocene, while critically examining human-centred ways of thinking. In doing so, it lays the foundation for alternative, more ecologically responsive design approaches.



→ **Figure [0.5].** Global night time lights as measured by VIIRS satellites. Shown is the average radiance between January 1, 2024 and December 31, 2024.

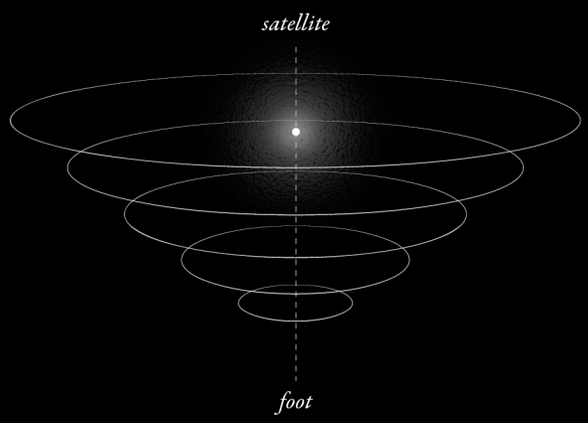
data: NASA

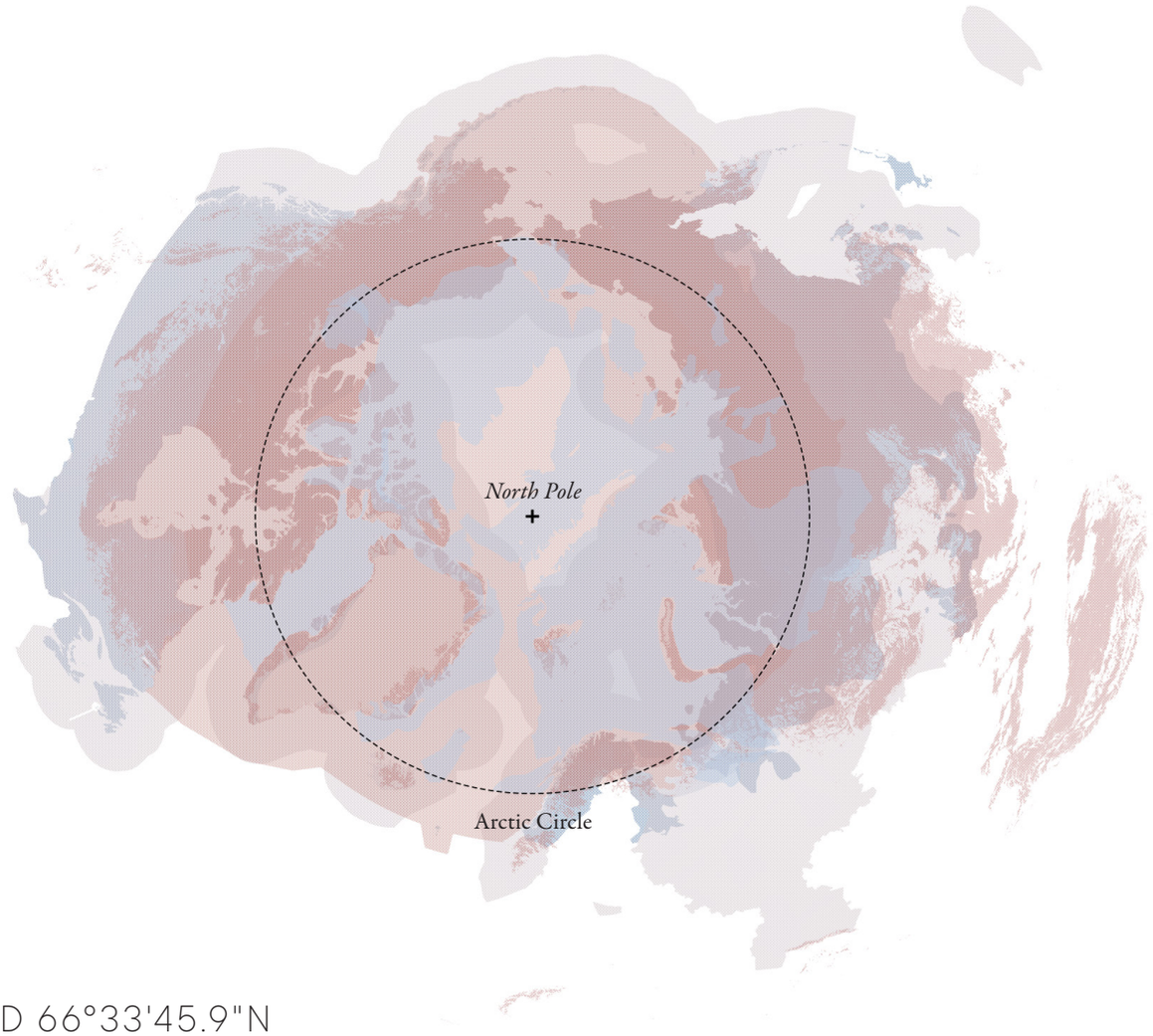

North Pole
Arctic
Randstad
Netherlands
Rome
Italy
Paris
France
New York
USA
Moscow
Russia
Shanghai
China
Shenzhen
China
New Delhi
India
Madrid
Spain
Canary Islands
Spain
Dubai
VAE
Recife
Brazil
Sahara Desert
Africa
Nile River
Egypt
Accra
Ghana
Cape Town
South Africa
Johannesburg
South Africa
Nairobi
Kenia

ACT I

THE OPENING OF A FRONTIER

The Arctic is a territory in transition, where the retreat of sea ice raises an unsettling question: what happens when a space long defined by environmental limits and seasonal extremes becomes increasingly entangled with global infrastructures of mobility and extraction?





I.1 - BEYOND 66°33'45.9"N

The North Pole is defined astronomically as the region within the *Arctic Circle*, above 66°33'45.9" North latitude, where extreme seasonal variations of light and dark occur due to the tilt of the Earth's axis. It reaches its deepest seasonal shift on the December and June solstice, where the entire Arctic circle experiences at least 24 hours without any sunrise or sunset. The Arctic Circle can therefore be seen as an *imaginary boundary of light and dark*.

Beyond the astronomical definition, the Arctic can be understood in multiple ways. Politically, it is considered the area surrounding the Arctic Ocean, in which the Arctic Council includes territories of the eight Arctic states: Denmark (Greenland), Sweden, Canada, Norway, Finland, Iceland, Russia, and the United States.

Climatically, the boundary of the Arctic territory is seen as the 10°C July isotherm line[1], that has close overlaps with the ecological definition: the Arctic tree line boundary[2].

Other definitions mention the permafrost extent as boundary. A broader, less precise boundary refers to areas traditionally inhabited by indigenous Arctic peoples and are defined by culture, livelihoods, language, and history (Arctic Portal, 2025).

These definitions highlight that the Arctic is not only the geographical territory within the Arctic circle, but also a complex socio-environmental region in which (extreme) physical conditions, ecosystems, indigenous peoples and governance bodies intersect.

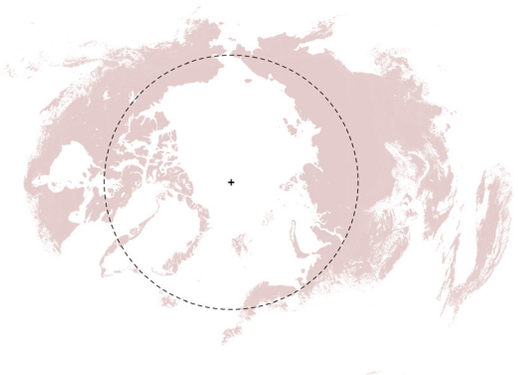
[1] Defined as the territory where the average temperature in the summer is below 10°C.
(Arctic Portal, 2025)

[2] The northernmost latitude where trees can grow, above which it is too cold to sustain trees.
(Arctic Portal, 2025)

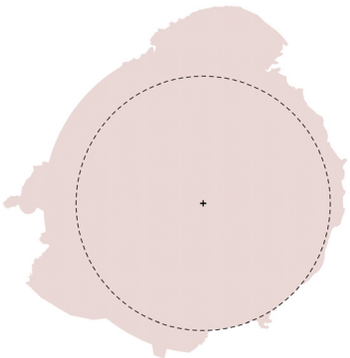
↑ **Figure [1.1].** Palette of different Arctic definitions.

→ **Figure [1.2].** The variety of Arctic definitions mapped in a stereographic projection.

data: Geonorge,
adapted from Arctic Portal (2025)



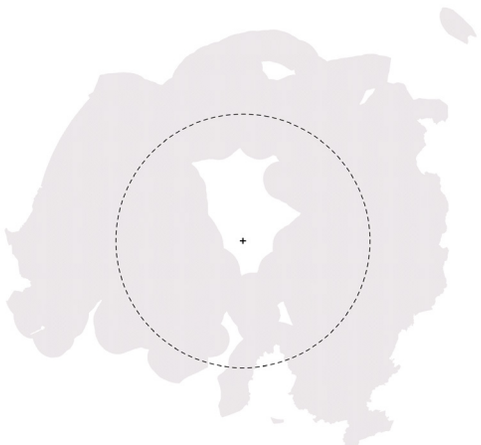
[**A**] Permafrost Extent



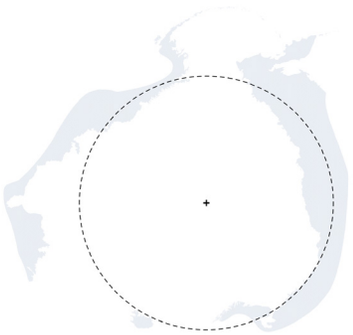
[**B**] Arctic Monitoring and Assessment Programme



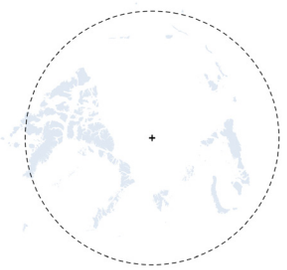
[**C**] Arctic Tree Line Boundary



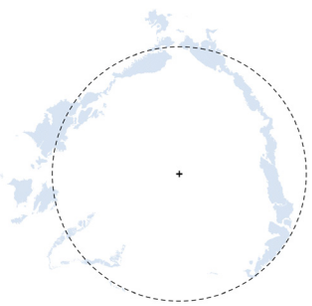
[**D**] Arctic Exclusive Economical Zones



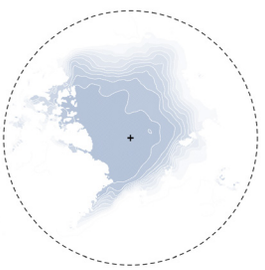
[**E**] Sub Arctic Zone



[**F**] High Arctic Zone



[**G**] Low Arctic Zone



[**H**] Ice Sheet Extent



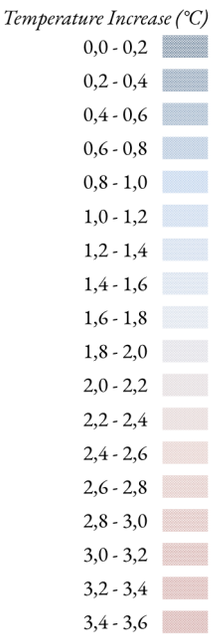
[**I**] Indigenous Language Regions

I.2 - GLOBAL TRENDS

Over the past century, the Earth's climate system has seen significant (and well-documented) changes, primarily driven by anthropogenic greenhouse gas emissions.

Global mean surface temperatures have risen significantly, with recent decades exhibiting an accelerated warming trend relative to earlier periods. This increase is closely linked to elevated concentrations of carbon dioxide and other gases, which enhance the greenhouse effect (IPCC, 2023). A substantial proportion of the excess heat associated with global warming has been absorbed by the world's oceans, which act as a major thermal reservoir. Consequently, the ocean heat has increased steadily, contributing not only to thermal expansion and sea-level rise but also to shifts in marine circulation patterns.

At the same time, the hydrological cycle has intensified, with warmer air capable of holding more moisture, thereby influencing global precipitation and increasing chances of extreme rainfall events in some regions, while exacerbating drought conditions in others (IPCC, 2023). Importantly, these changes are not distributed uniformly across the globe. Variations in geography, surface characteristics, and atmospheric dynamics lead to pronounced regional differences in warming rates and climate responses.

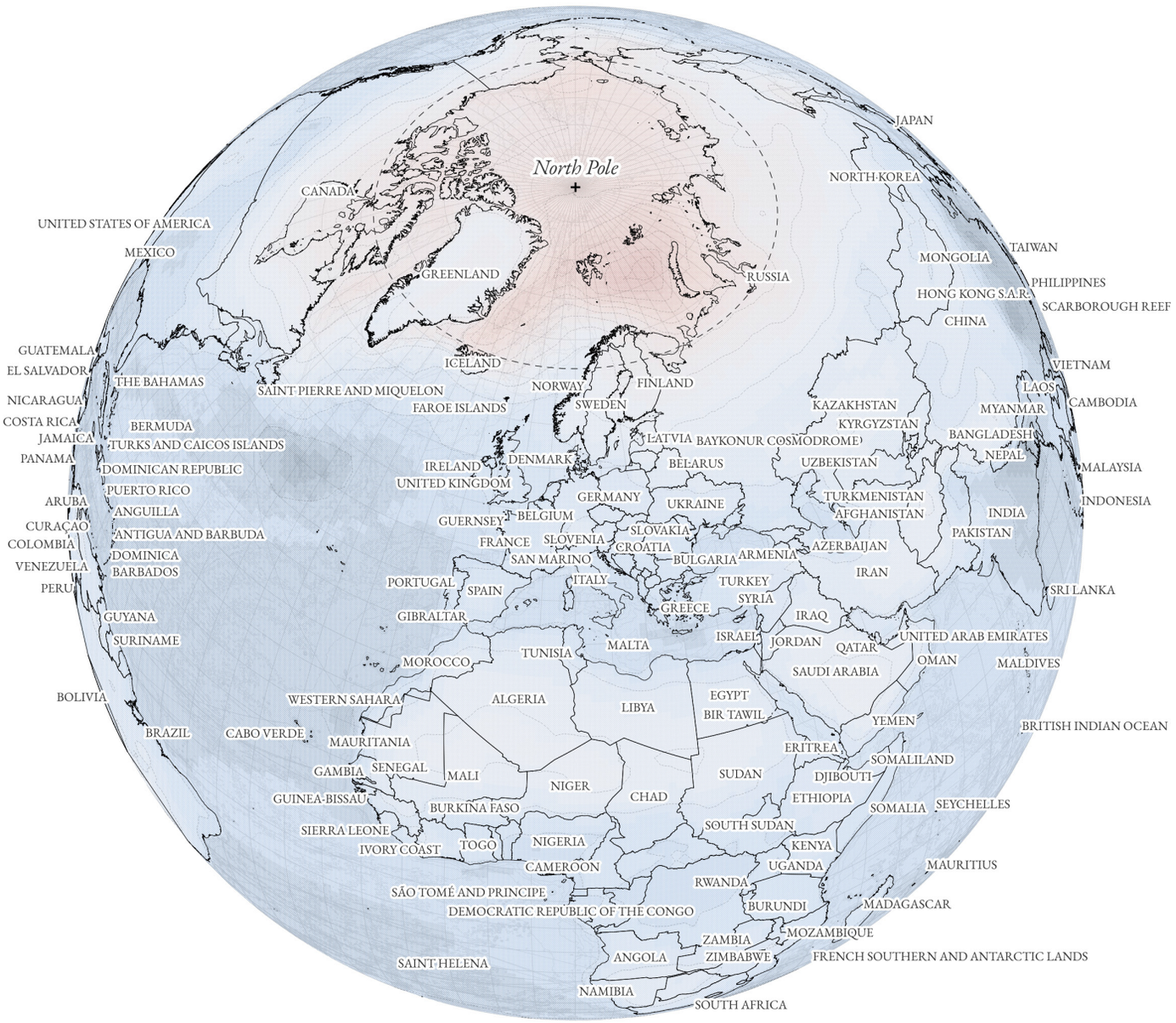


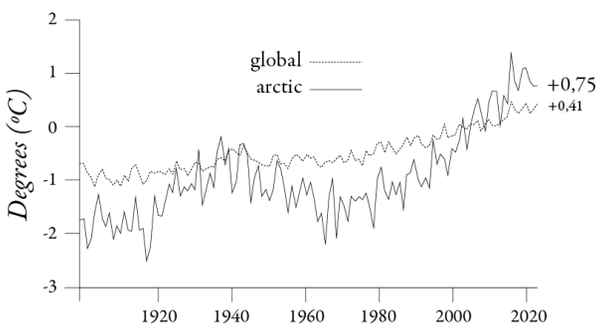
↗ **Figure [1.3].** Mean surface temperature increase from 1850 to 2010.

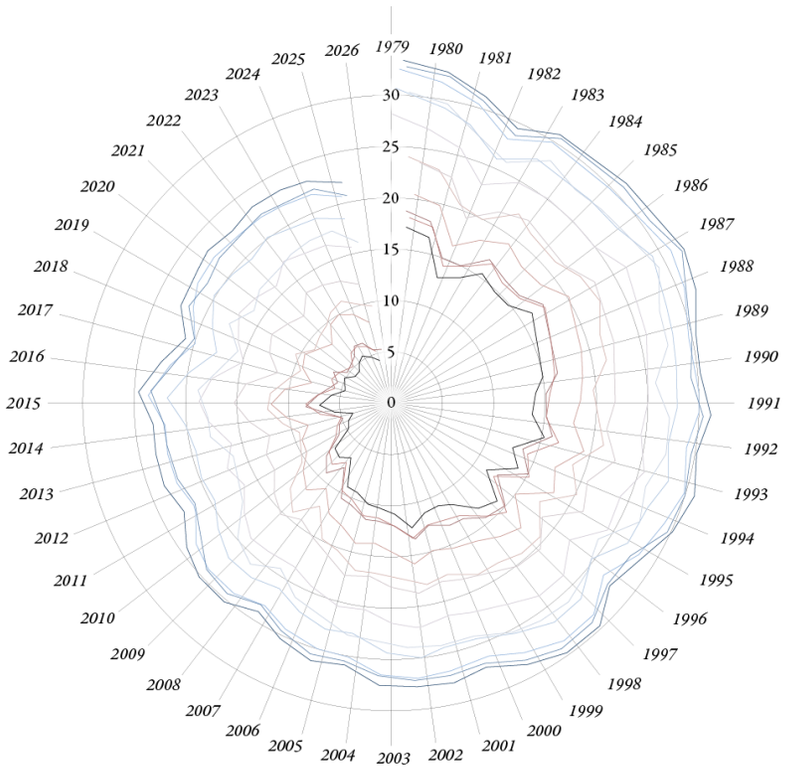
data: Copernicus Climate Atlas

→ **Figure [1.4].** Arctic and global surface air temperature anomalies (compared to 1990-2020 mean)

data: National Oceanic and Atmospheric Administration


North Pole
JAPAN
NORTH KOREA
CANADA
UNITED STATES OF AMERICA
MEXICO
GREENLAND
RUSSIA
MONGOLIA
TAIWAN
PHILIPPINES
HONG KONG S.A.R.
SCARBOROUGH REEF
CHINA
GUATEMALA
EL SALVADOR
ICELAND
VIETNAM
THE BAHAMAS
SAINT PIERRE AND MIQUELON
NORWAY
FINLAND
LAOS
NICARAGUA
FAROE ISLANDS
SWEDEN
KAZAKHSTAN
MYANMAR
CAMBODIA
COSTA RICA
BERMUDA
KYRGYZSTAN
JAMAICA
TURKS AND CAICOS ISLANDS
LATVIA
BAYKONUR COSMODROME
BANGLADESH
PANAMA
DENMARK
NEPAL
IRELAND
BELARUS
UZBEKISTAN
MALAYSIA
DOMINICAN REPUBLIC
UNITED KINGDOM
PUERTO RICO
GERMANY
UKRAINE
TURKMENISTAN
INDONESIA
ARUBA
ANGUILLA
AFGHANISTAN
INDIA
CURAÇAO
GUERNSEY
BELGIUM
ANTIGUA AND BARBUDA
SLOVAKIA
PAKISTAN
COLOMBIA
FRANCE
SLOVENIA
AZERBAIJAN
DOMINICA
SAN MARINO
CROATIA
BULGARIA
ARMENIA
VENEZUELA
BARBADOS
IRAN
PERU
PORTUGAL
SPAIN
ITALY
TURKEY
SRI LANKA
SYRIA
GUYANA
GIBRALTAR
GREECE
IRAQ
SURINAME
ISRAEL
JORDAN
QATAR
UNITED ARAB EMIRATES
MALTA
TUNISIA
MOROCCO
OMAN
MALDIVES
SAUDI ARABIA
BOLIVIA
WESTERN SAHARA
ALGERIA
EGYPT
LIBYA
BIR TAWIL
YEMEN
BRAZIL
CABO VERDE
BRITISH INDIAN OCEAN
MAURITANIA
ERITREA
SOMALILAND
GAMBIA
SENEGAL
MALI
SUDAN
DJIBOUTI
NIGER
GUINEA-BISSAU
CHAD
ETHIOPIA
BURKINA FASO
SOMALIA
SEYCHELLES
SIERRA LEONE
SOUTH SUDAN
TOGO
NIGERIA
KENYA
IVORY COAST
CAMEROON
UGANDA
MAURITIUS
RWANDA
SÃO TOMÉ AND PRINCIPE
BURUNDI
MADAGASCAR
DEMOCRATIC REPUBLIC OF THE CONGO
ZAMBIA
MOZAMBIQUE
ANGOLA
ZIMBABWE
FRENCH SOUTHERN AND ANTARCTIC LANDS
SAINT HELENA
NAMIBIA
SOUTH AFRICA


2
1
0
-1
-2
-3
Degrees (°C)
global
arctic
+0,75
+0,41
1920
1940
1960
1980
2000
2020



↖ **Figure [1.5].** The *death spiral* visualises the Arctic amplification through its sea ice volume (in 1,000 km^3) per month which continuously shrinks towards zero.

source: adapted from arcticdeathspiral.org

↗ **Figure [1.6].** Arctic sea ice extent as measured in September 2025.

data: Copernicus Climate Atlas

→ **Figure [1.7].** The ocean's Albedo effect demonstrates how sea ice reflects solar energy (high Albedo), in contrast to open water, which absorbs it (low Albedo), as measured in September 2025.

data: Copernicus Climate Atlas

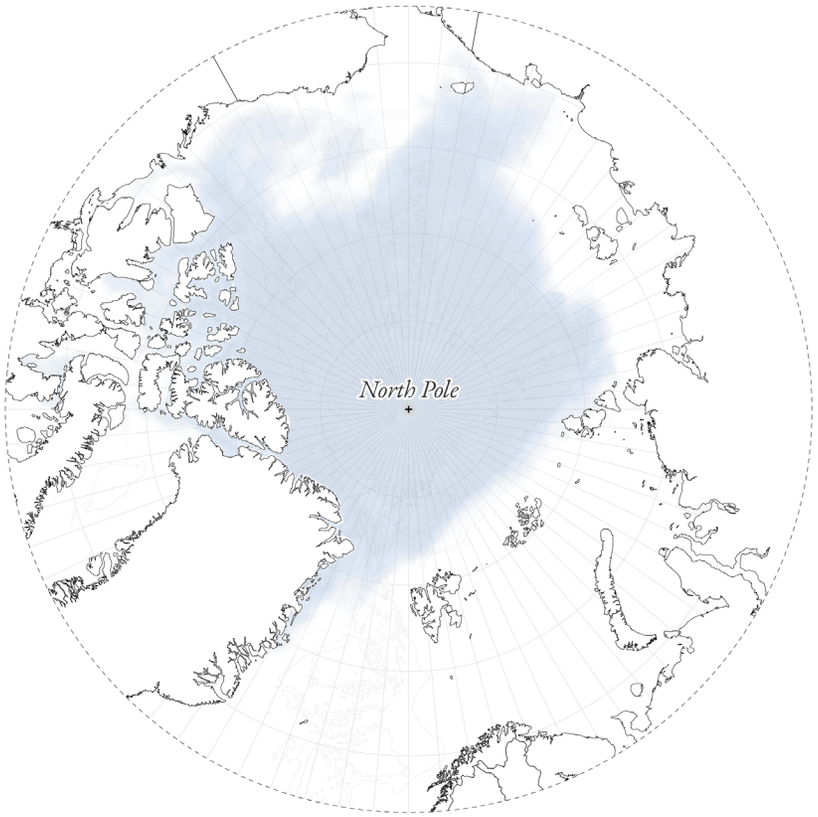
I.3 - ARCTIC SEA ICE RECESSION

Since global warming does not occur spatially uniform across the Earth's surface, a defining characteristic of the climate system is a phenomenon known as *Arctic amplification*.

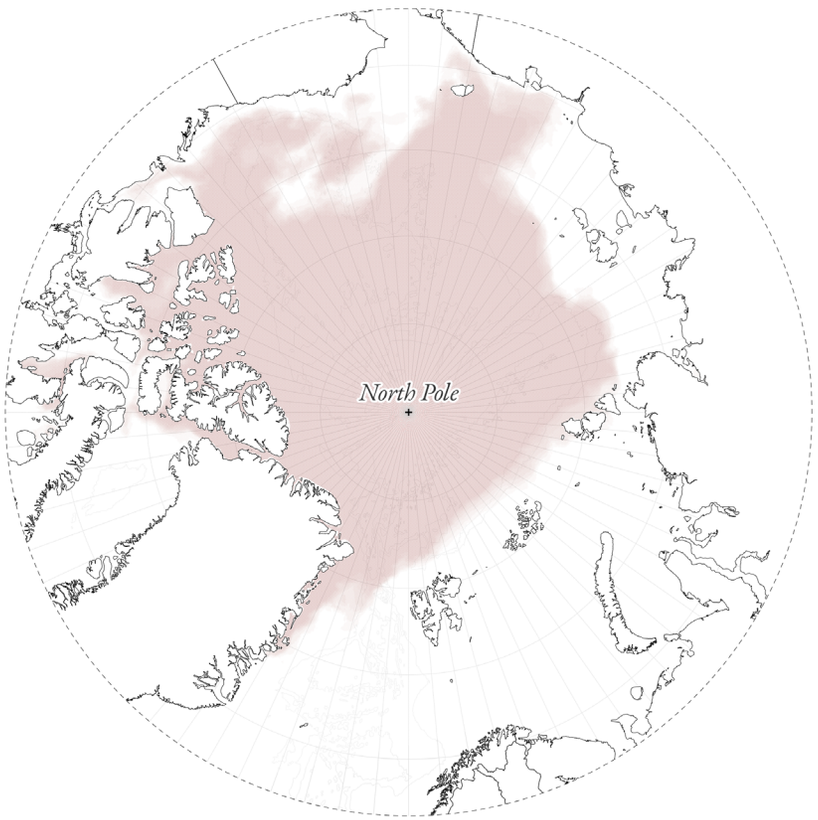
As shown in the *death spiral*, see Figure [1.5], the rate at which the sea ice declines is extreme. It also clearly demonstrates how the ice volume rapidly decreases towards zero, and which is at a faster rate than IPCC (Intergovernmental Panel on Climate Change) predictions. It is also reducing the ocean's reflective surface, see Figure [1.7], and allowing the seas to absorb more sunlight (Mann & Kump, 2015). Rising sea and air temperatures, together with higher carbon dioxide levels, accelerate this feedback loop.

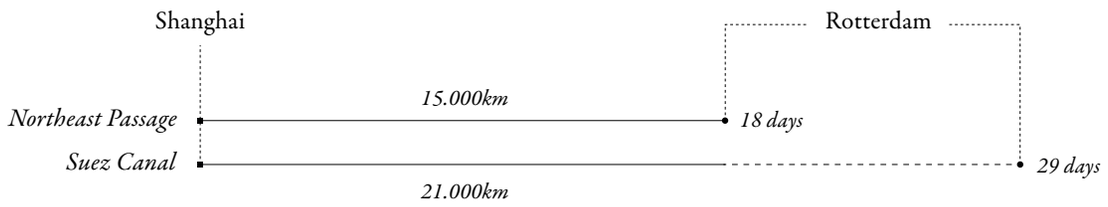
Beyond indicating rapid climate change, Arctic amplification has far-reaching consequences for both Polar and global systems. Accelerated warming intensifies permafrost thaw and releases greenhouse gases that reinforce warming through positive feedback loops (Schuur et al., 2015).

At the same time, reduced temperature gradients between the Arctic and lower latitudes can alter atmospheric circulation, potentially weakening and destabilizing the jet stream and contributing to more persistent weather extremes in mid-latitude regions (Francis & Vavrus, 2012). A rapidly changing Arctic is therefore not merely a regional concern, but underscores its broader significance for the global climate system.



ARCTIC SEA ICE





I.4 - THE EMERGENCE OF POLAR ROUTES

The sea ice decline is increasing accessibility and opportunities for development in the Arctic, which were normally limited by extreme environmental conditions (CAFF, 2013). This expansion poses risks to sustainable development in the region, known as :

> *"Development that improves health, well-being, and security of Arctic communities and residents, while conserving ecosystem structures, functions and resources"*(Graybill & Petrov, 2020).

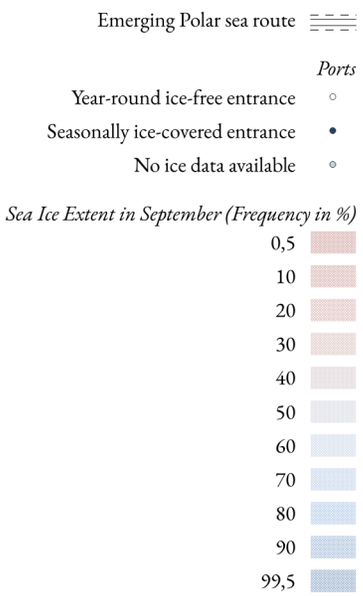
Arctic shipping routes - most notably the Northeast Passage (NEP), the Northwest Passage (NWP), and the Transpolar Sea Route (TSR) - are emerging maritime corridors. The Northern Sea Route, which runs along Russia's Arctic coast as part of the Northeast Passage, is currently the most commercially developed route, with seasonal navigation supported by Russian infrastructure, icebreaker fleets, and designated shipping regulations (Hermann et al., 2022).

The Northwest Passage through the Canadian Arctic archipelago remains more difficult to navigate due to thicker multiyear ice, complex geography, and limited infrastructure, but it is gradually seeing increased experimental and seasonal use (Chen et al., 2021).

A potential Transpolar Route across the central Arctic Ocean is often discussed in long-term projections, although it remains largely dependent on further ice loss and remains less predictable.

These three routes (NEP, NWP and TSR) are primarily significant because they can substantially shorten shipping distances between major global markets, particularly between East Asia and Europe, see Figure [1.8], reducing fuel use and transit times. Their development remains uneven and is highly dependent on seasonal ice sheet extent. They also are still less reliable than established routes such as the Suez or Panama Canal.

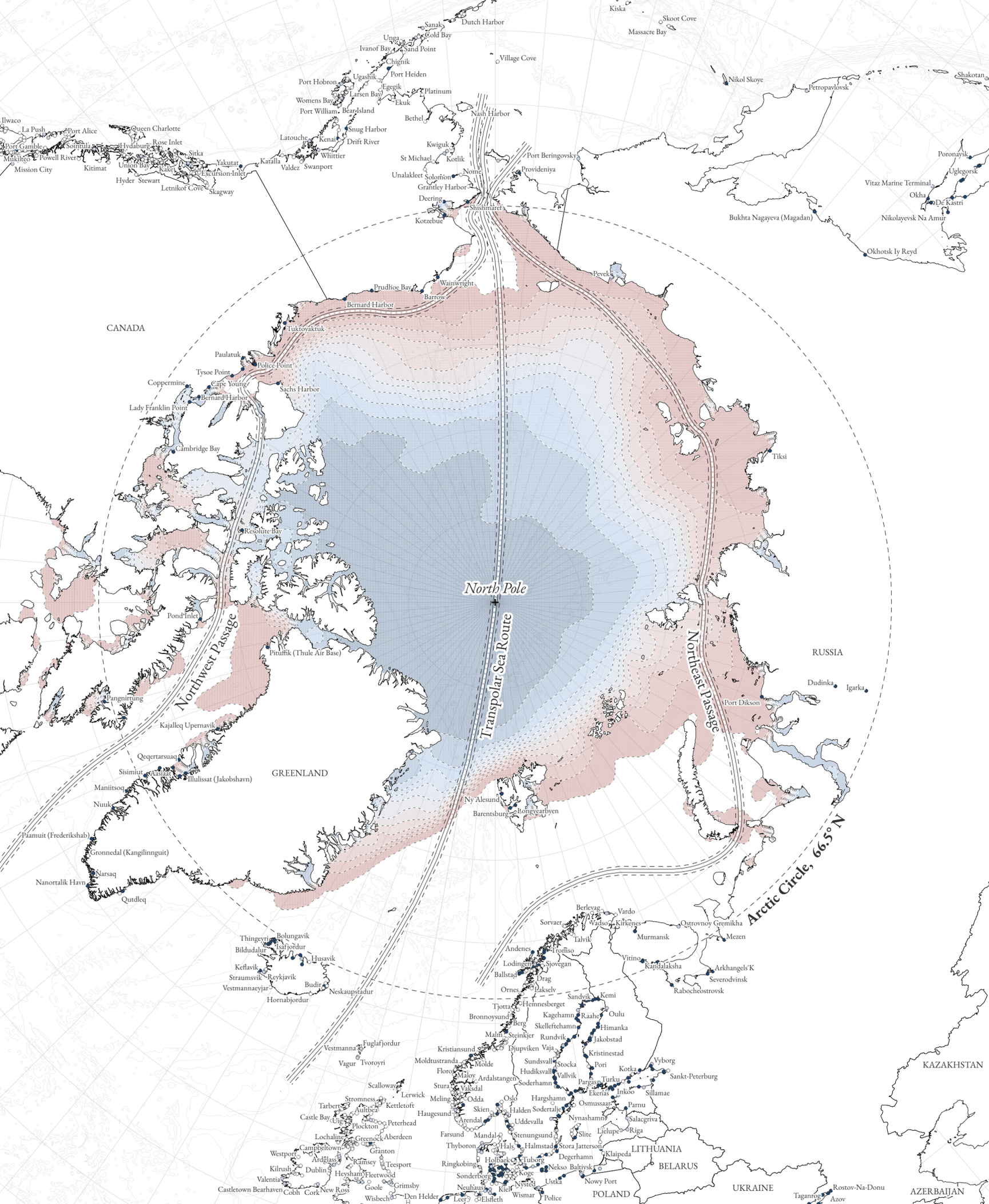
However, the Polar routes are becoming increasingly relevant, as Arctic sea ice no longer consistently regrows to previous levels in recent years. This relevance can be seen through the number of ships sailing through the Arctic oceans, with an increase of more than 40%, between 2013 and 2025. In that same time window, the number of oil tankers almost quadrupled, with a percentage of 396% (Arctic Council, 2026).



↖ **Figure [1.8].** New Polar shipping routes decrease sailing time drastically, with an example shown between Shanghai and Rotterdam.

→ **Figure [1.9].** Sea ice frequency in September and emerging Polar maritime routes.

data: NGA Arctic Open Data, Arctic Spatial Data Infrastructure


North Pole
Transpolar Sea Route
Northwest Passage
Northeast Passage
Arctic Circle, 66.5° N
CANADA
GREENLAND
RUSSIA
KAZAKHSTAN
LITHUANIA
BELARUS
POLAND
UKRAINE
AZERBAIJAN
Kiska
Skoot Cove
Massacre Bay
Dutch Harbor
Sanak
Cold Bay
Unga
Ivanof Bay
Sand Point
Chignik
Village Cove
Port Heiden
Ugashik
Port Hobron
Egegik
Larsen Bay
Platinum
Womens Bay
Ekuk
Port William
Bear Island
Bethel
Nash Harbor
Snug Harbor
Latouche
Kenai
Drift River
Whittier
Valdez
Swanport
Katalla
Yakutat
Excursion Inlet
Hyder
Stewart
Letnikof Cove
Skagway
Kake
Union Bay
Hydaburg
Sitka
Rose Inlet
Queen Charlotte
Port Alice
La Push
Ilwaco
Port Gamble
Sointula
Powell River
Mission City
Mukilteo
Kitimat
Kwiguk
Kotlik
St Michael
Unalakleet
Solomon
Nome
Grantley Harbor
Deering
Kotzebue
Shishmaref
Port Beringovsky
Provideniya
Nikol Skoye
Petropavlovsk
Shakotan
Poronaysk
Uglegorsk
Vitaz Marine Terminal
Okha
De Kastri
Nikolayevsk Na Amur
Bukhta Nagayeva (Magadan)
Okhotsk Iy Reyd
Pevek
Prudhoe Bay
Wainwright
Barrow
Bernard Harbor
Tuktoyaktuk
Paulatuk
Police Point
Tysoe Point
Cape Young
Sachs Harbor
Coppermine
Bernard Harbor
Lady Franklin Point
Cambridge Bay
Resolute Bay
Pond Inlet
Pituffik (Thule Air Base)
Pangnirtung
Kajalleq Upernavik
Qeqertarsuaq
Sisimiut
Kangaatsiaq
Illulissat (Jakobshavn)
Maniitsoq
Nuuk
Paamuit (Frederikshab)
Gronnedal (Kangilinnguit)
Narsaq
Nanortalik Havn
Qutdleq
Tiksi
Dudinka
Igarka
Port Dikson
Ny Alesund
Barentsburg
Longyearbyen
Berlevag
Vardo
Sorvaer
Wadso
Kirkenes
Ostrovnoy
Gremikha
Murmansk
Mezen
Talvik
Andenes
Tromso
Vitino
Kandalaksha
Arkhangels'K
Severodvinsk
Rabocheostrovsk
Lodingen
Sjovegan
Ballstad
Drag
Ornes
Pakselv
Sandvik
Kemi
Tjotta
Hemnesberget
Kagehamn
Raahe
Oulu
Bronnoysund
Berg
Skelleftehamn
Himanka
Malm
Steinkjer
Rundvik
Jakobstad
Kristiansund
Djupviken
Vaja
Kristinestad
Vestmanna
Fuglafjordur
Vagur
Tvoroyri
Moldtustranda
Molde
Sundsvall
Stocka
Pori
Vyborg
Kotka
Floro
Maloy
Ardalstangen
Hudiksvall
Vallvik
Soderhamn
Sankt-Peterburg
Stura
Vaksdal
Pargas
Turku
Inkoo
Sillamae
Ekenas
Scalloway
Lerwick
Meling
Odda
Oslo
Hargshamn
Osmussaar
Parnu
Stromness
Kettletoft
Tarbert
Aultbea
Halden
Sodertalje
Haugesund
Skien
Arendal
Uddevalla
Nynashamn
Salacgriva
Castle Bay
Ullapool
Plockton
Peterhead
Farsund
Mandal
Stenungsund
Slite
Lielupe
Riga
Lochaline
Greenock
Aberdeen
Thyboron
Hals
Halmstad
Stora Jatterson
Campbeltown
Granton
Westport
Ardglass
Ramsey
Teesport
Ringkobing
Holbaek
Tuborg
Degerhamn
Klaipeda
Kilrush
Dublin
Heysham
Fleetwood
Koge
Nekso
Baltivsk
Valentia
Goole
Sonderborg
Nysted
Ustka
Nowy Port
Castletown Bearhaven
Cobh
Cork
New Ross
Grimsby
Neuhaus
Kiel
Wismar
Police
Wisbech
Den Helder
Leer
Elsfleth
Taganrog
Rostov-Na-Donu
Azov
Thingeyri
Bolungavik
Bildudalur
Isafjordur
Husavik
Keflavik
Straumsvik
Reykjavik
Vestmannaeyjar
Budir
Neskaupstadur
Hornabjordur

I.5 - RESOURCE POTENTIALS

The Arctic contains many resources, such as minerals, rare metals, oil and gas, which makes it one of the last major *resource frontiers* on Earth.

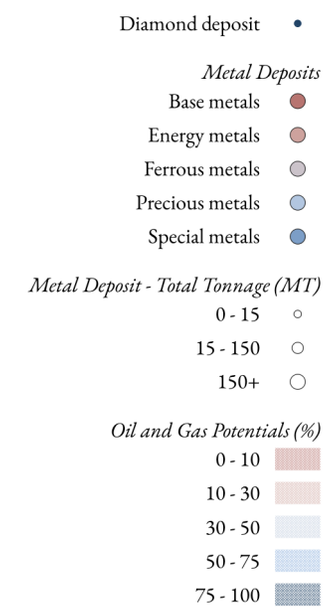
Estimates suggest that - of the world's undiscovered oil and natural gas - a significant share of approximately 22% lies beneath Arctic seabeds, alongside deposits of metals and rare earth elements essential for modern technologies, see Figure [1.10] (Arctic Portal, n.d.).

What is crucial, however, is that these resources have historically remained difficult to access due to persistent ice cover. The region's harsh environment has long constrained extraction despite its economic potential (Ren et al., 2026).Yet this constraint is rapidly changing by the sea ice decline and opening of new Polar sea routes.

From the perspective of planetary urbanisation, this shift can be understood less as a simple expansion of economic activity and more as a transformation in how the Earth itself is operationalised. The decline of Arctic sea ice does not only reveal resources, it reorganises the Arctic into an extractive extension of global urban systems.

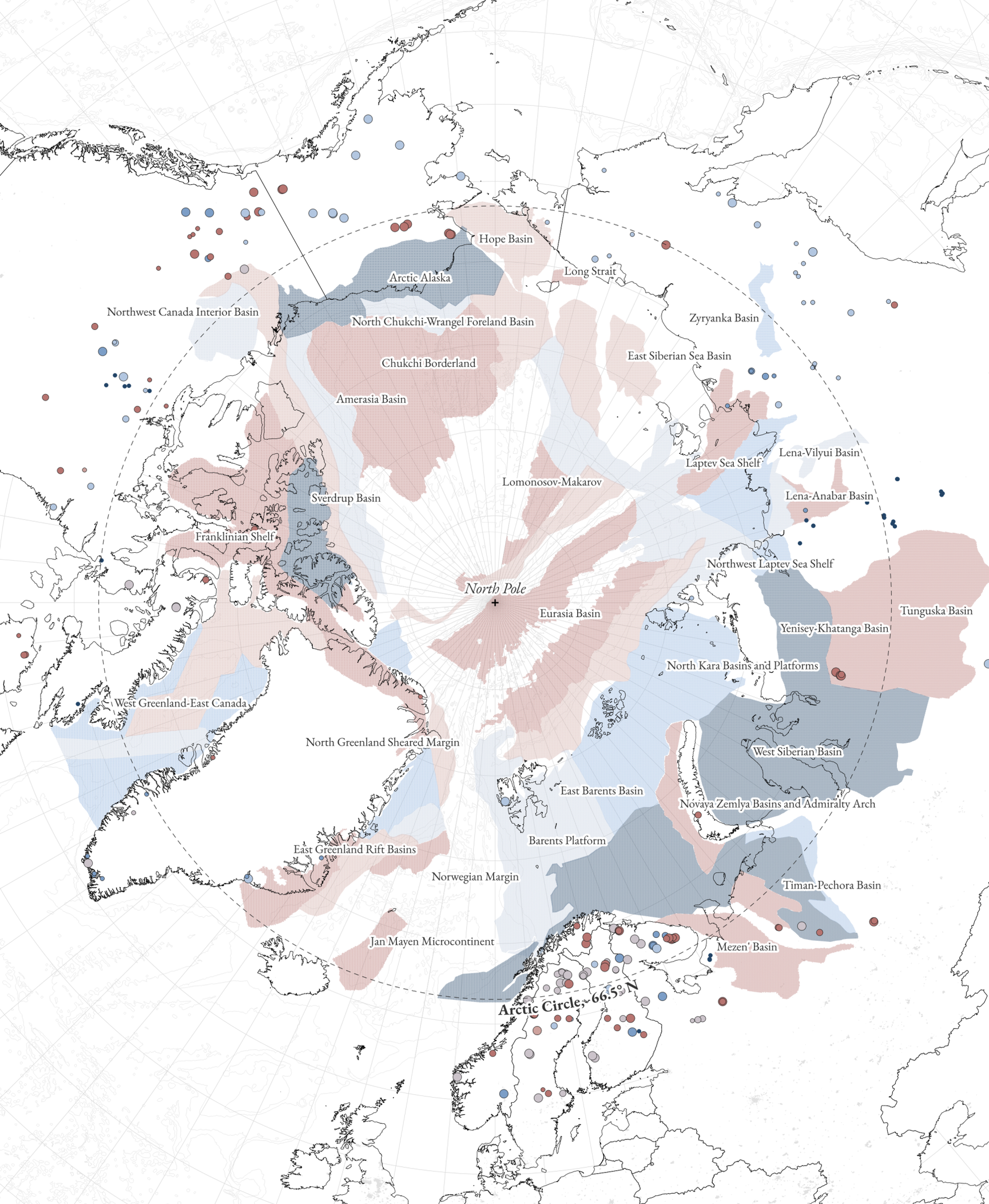
In this sense, the Arctic becomes part of a planetary infrastructure that sustains urban life elsewhere: energy flowing to cities, minerals feeding industrial production, and new shipping routes compressing global space-time.

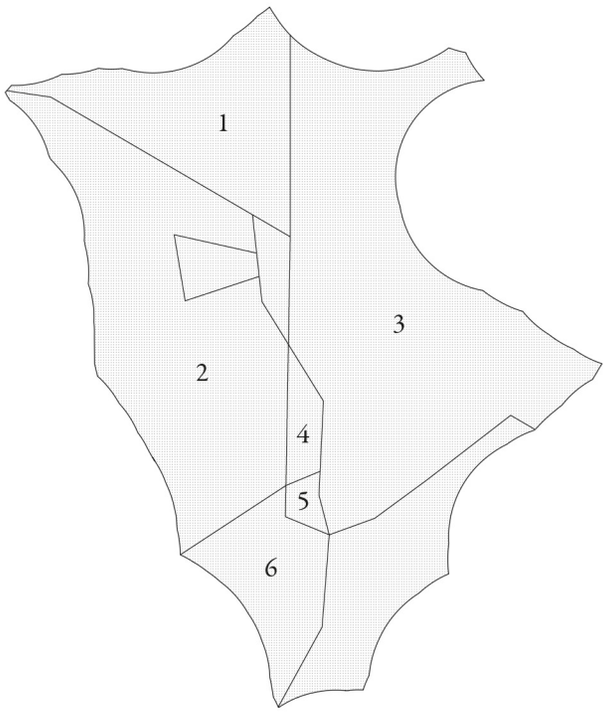
The melting ice thus functions almost paradoxically as both a symptom of environmental crisis and a medium through which capitalist urbanisation extends its reach.



→ **Figure [1.10].** The resource richness of the Arctic shown through pan-Arctic potentials and deposits of oil, gas, metal and diamonds, with partly no data availability for Greenland.

data: Arctic Spatial Data Infrastructure


Hope Basin
Arctic Alaska
Long Strait
Northwest Canada Interior Basin
North Chukchi-Wrangel Foreland Basin
Zyryanka Basin
Chukchi Borderland
East Siberian Sea Basin
Amerasia Basin
Laptev Sea Shelf
Lena-Vilyui Basin
Lomonosov-Makarov
Sverdrup Basin
Lena-Anabar Basin
Franklinian Shelf
Northwest Laptev Sea Shelf
North Pole
Eurasia Basin
Tunguska Basin
Yenisey-Khatanga Basin
North Kara Basins and Platforms
West Greenland-East Canada
North Greenland Sheared Margin
West Siberian Basin
East Barents Basin
Novaya Zemlya Basins and Admiralty Arch
Barents Platform
East Greenland Rift Basins
Norwegian Margin
Timan-Pechora Basin
Jan Mayen Microcontinent
Mezen' Basin
Arctic Circle, 66.5° N



Territorial claims
Oil & gas resource potential

Exclusive Economic Zones
Norway
Canada
Denmark
Iceland
United States of America
Russia

Military Bases
Russia
NATO

↖ **Figure [1.11].** Contested areas in international waters, where several states have overlapping territorial claims.

1. United States of America
2. Canada
3. Russia
4. Canada & Russia
5. Denmark & Russia
6. Denmark

data: US Naval Institute

→ **Figure [1.12].** Arctic countries' *Exclusive Economic Zones* and their Arctic-related military bases.

data: Marineregion.org, The Simons Foundation Canada

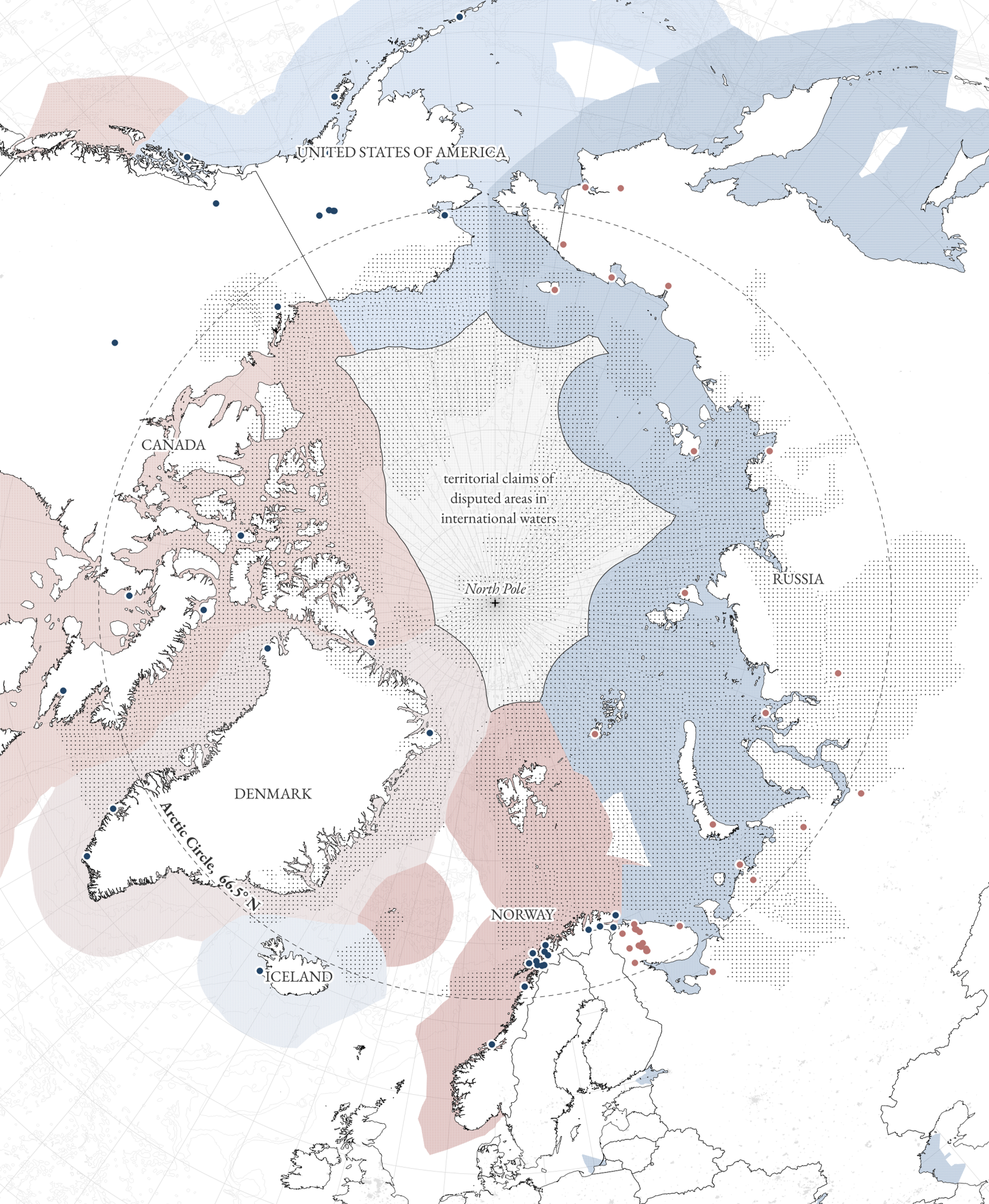
I.6 - GEOPOLITICAL INTEREST

Resource potential in the Arctic not only contributes to processes of capitalist urbanisation, but also intensifies questions of territorial control and sovereignty. The region is increasingly drawn into geopolitical tension, where economic interests and security concerns reinforce one another. This is reflected in territorial claims by multiple states and a growing military presence across the Arctic, with states such as the United States and Russia expanding bases, surveillance systems, airfields, and naval infrastructure (Regehr & Gallagher, 2024).

In Greenland, the geopolitical interest is particularly pronounced due to its location between major powers and its proximity to emerging Arctic sea routes (European Parliament, 2025). It underscores how the island figures in external strategic ambitions.

These developments are closely tied to both resource access and shifting environmental conditions. As new areas open up, attention is directed not only towards resources, but also towards control of shipping lanes and undersea infrastructure that underpin global circulation systems (Boylan, 2021).

What emerges is a layered reconfiguration of Arctic space, in which extraction, logistics, urbanisation, and military strategy increasingly converge. The growing number of *observers* within the Arctic Council further illustrates increasing international interest in the Arctic. While observers do not hold formal Arctic status within the Council, they can nevertheless shape discussions and policy development through their contributions to the working groups (Arctic Council, n.d.-a).


UNITED STATES OF AMERICA
CANADA
territorial claims of
disputed areas in
international waters
North Pole
RUSSIA
DENMARK
Arctic Circle, 66.5°N
NORWAY
ICELAND

I.7 - INDIGENOUS PEOPLES

To conclude, it is crucial to recognise and acknowledge that the Arctic is not an empty or newly available space, but a homeland that has long been inhabited and cared for by indigenous peoples, such as the Inuit, Sámi, and Gwich'in. At this point, the Arctic is home to approximately four million indigenous people, roughly 10% of the total number of inhabitants (Arctic Council, n.d.-b). Although six indigenous communities hold a *Permanent Participant* status within the Arctic Council (the leading intergovernmental forum), this status does not give legal recognition under international law. This limitation is explicitly clarified in a footnote to the Ottawa Declaration, the Council's founding document:

> *"The use of the term "peoples" in this Declaration shall not be construed as having any implications as regard the rights which may attach to the term under international law."* (Arctic Council, 1996).

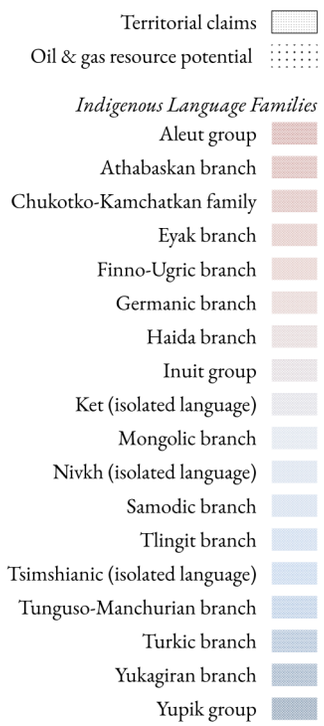
While indigenous communities make up a minority of the population, they represent a diverse range of distinct societies whose ways of life remain closely tied to land, ice, and seasonal cycles. Across the region, livelihoods, cultural practices, and identities are already being reshaped by rapid environmental change (Arctic Council, n.d.-b). Climate change is therefore not an abstract future condition but an ongoing transformation directly affecting daily life.

Their relationships with the Arctic are not only economic or territorial, but deeply cultural and spiritual. This perspective was powerfully articulated by Edward Alexander[1] at the Arctic Futures Symposium 2025 in Brussels, where he stated that:

> *"The closer you are to the land, the healthier you are going to be."*
> (International Polar Foundation, 2025).

His words point to an understanding of the Arctic that contrasts sharply with extractive and geopolitical framings: one in which land is not a resource to be claimed, but a relation that sustains life, identity, and wellbeing.

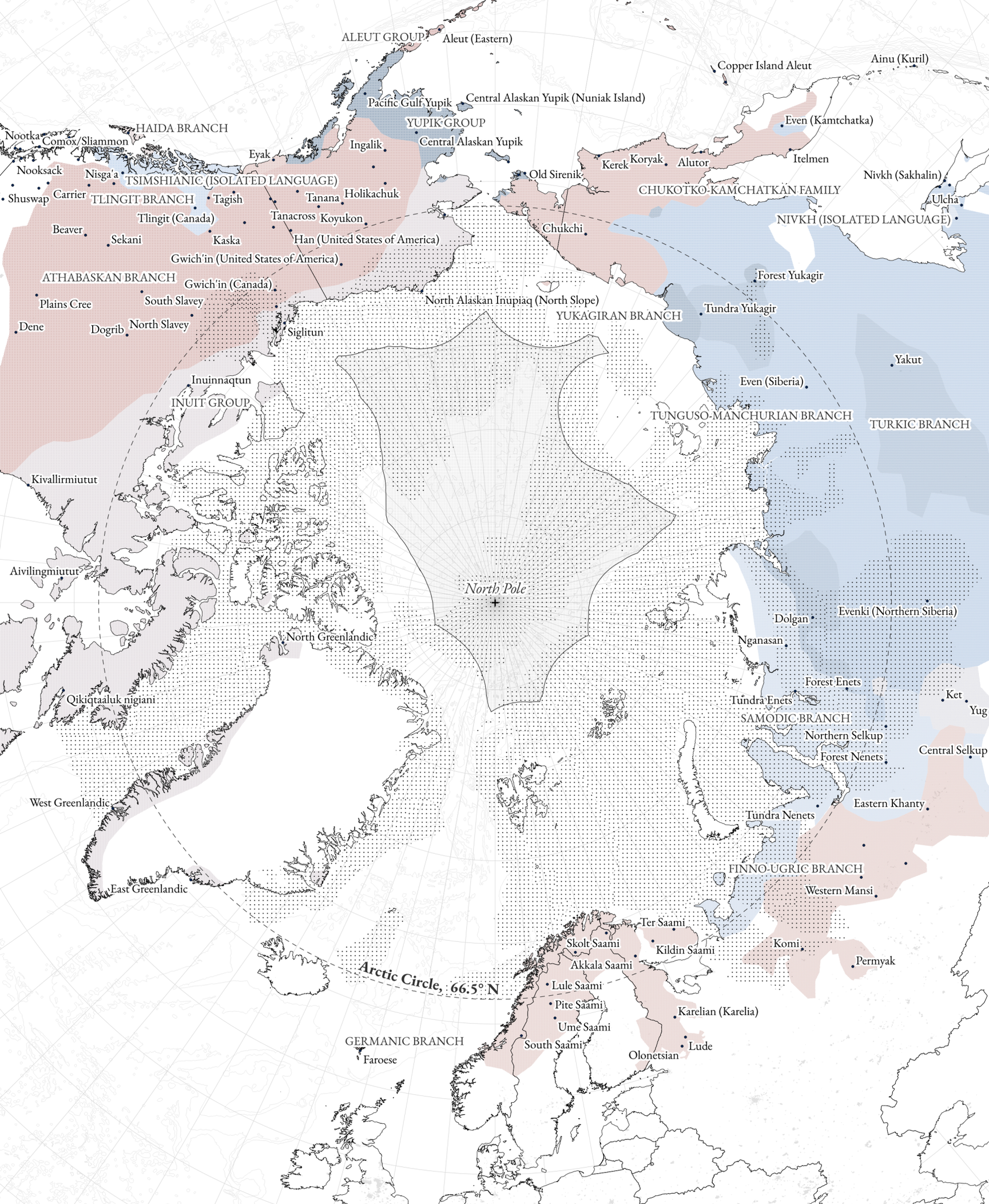
Acknowledging this reframes the broader discussion. As sea ice recedes and global interest intensifies, the Arctic is increasingly drawn into systems of resource extraction, infrastructure and territorial claims. Yet, these processes unfold on indigenous territories that have never been empty, and whose futures are inseparable from the rights and knowledge of those who live there. In this light, the central question is not only who owns or controls the Arctic, but how its transformation can proceed without severing the relationships that have long sustained both people and environment.



[1] Gwich'in Council International Head of Delefagation to CAFF

→ **Figure [1.13].** Indigenous language groups, showcasing the diversity and broad distribution of indigenous peoples.

data: Conservation of Arctic Flora and Fauna (CAFF) - Arctic Council


ALEUT GROUP
Aleut (Eastern)
Copper Island Aleut
Ainu (Kuril)
Pacific Gulf Yupik
Central Alaskan Yupik (Nuniak Island)
YUPIK GROUP
Central Alaskan Yupik
Even (Kamtchatka)
HAIDA BRANCH
Nootka
Comox/Sliammon
Ingalik
Eyak
Kerek
Koryak
Alutor
Itelmen
Old Sirenik
Nivkh (Sakhalin)
Nooksack
Nisga'a
TSIMSHIANIC (ISOLATED LANGUAGE)
CHUKOTKO-KAMCHATKAN FAMILY
Shuswap
Carrier
TLINGIT BRANCH
Tagish
Tanana
Holikachuk
Ulcha
Tlingit (Canada)
Tanacross
Koyukon
NIVKH (ISOLATED LANGUAGE)
Beaver
Chukchi
Sekani
Kaska
Han (United States of America)
Gwich'in (United States of America)
ATHABASKAN BRANCH
Forest Yukagir
Gwich'in (Canada)
North Alaskan Inupiaq (North Slope)
Plains Cree
South Slavey
YUKAGIRAN BRANCH
Tundra Yukagir
Dene
Dogrib
North Slavey
Siglitun
Yakut
Inuinnaqtun
Even (Siberia)
INUIT GROUP
TUNGUSO-MANCHURIAN BRANCH
TURKIC BRANCH
Kivallirmiutut
Aivilingmiutut
North Pole
Dolgan
Evenki (Northern Siberia)
North Greenlandic
Nganasan
Forest Enets
Qikiqtaaluk nigiani
Tundra Enets
Ket
Yug
SAMODIC BRANCH
Northern Selkup
Central Selkup
Forest Nenets
West Greenlandic
Eastern Khanty
Tundra Nenets
FINNO-UGRIC BRANCH
East Greenlandic
Western Mansi
Ter Saami
Skolt Saami
Kildin Saami
Komi
Permyak
Akkala Saami
Arctic Circle, 66.5° N
Lule Saami
Pite Saami
Karelian (Karelia)
Ume Saami
GERMANIC BRANCH
South Saami
Lude
Faroese
Olonetsian

I.8 - THE OPENING OF A FRONTIER

In conclusion, the increasing accessibility of the Arctic, together with expanding maritime routes, resource extraction, and geopolitical interests, is transforming the region into a space of continuity. These developments are characterised by permanent infrastructural and operational systems that increasingly integrate the Arctic into wider networks of extraction, circulation, and control. In this sense, the Arctic can be understood as a frontier opened to planetary urbanisation: not as an empty territory awaiting occupation, but as a region increasingly incorporated into systems that prioritise accessibility, productivity, and permanence. Such transformations are reshaping how Arctic space is organised, inhabited, and governed.

As industrial and infrastructural activity intensifies, environmental conditions that have historically structured Arctic life are increasingly subjected to external economic and operational demands. The growing presence of artificial light at night further reflects this shift, signalling the extension of continuous operational systems into environments historically shaped by seasonal darkness. This raises the broader question of how development engages with the Arctic's distinct temporal and ecological conditions, and which spatial qualities risk being overlooked in the process.



→ **Figure [1.14].** The emergence of artificial light at night as a transformation of Arctic light regimes under planetary urbanisation.



METHODOLOGY

To understand the Arctic not just as a physical space, but as a site of ethical and ecological significance with unique spatio-temporal conditions, this research engages with theories that challenge human-centred perspectives. Together, they provide the theoretical and philosophical underpinning of the thesis. Building on this, the guiding research questions and conceptual frameworks that structure the project are introduced.

RETHINKING DESIGN

AIM OF RESEARCH - A PERSONAL NOTE

During my bachelor's and master's degree at Delft University of Technology, I have become increasingly aware of the extent to which climate change shapes research and design. In particular, I have observed how many design interventions tend to focus on reducing environmental impact rather than fundamentally reconsidering the ways in which we act. From an urbanist perspective, this has led me to question whether such approaches are sufficient, or whether more radical forms of reflection and reconfiguration are required.

My interest lies in exploring how design can move beyond the dominant techno-solutionist framing of the climate crisis. I am convinced of the idea of making human behaviour visible through spatial and cartographic means (Corner, 1999), and I am interested in whether exposing our actions in this way might itself become a catalyst for change. Rather than seeing the environment as something to manage or optimise, I look at how design can reveal our presence and encourage critical reflection.

This interest has developed further through my engagement with the Arctic and, more specifically, with the phenomenon of the Polar night. I am intrigued by the possibility of reimagining darkness not as a lack or absence, but as a condition with its own intrinsic value. Darkness as a condition defining time and space: *darkness as territory*. In doing so, I aim to propose an alternative way of seeing and inhabiting Arctic landscapes.

This does not focus on designing to mitigate human impact, but on reshaping our relation to the environment. The project seeks to reveal a condition that is often overlooked in development. From an urbanist perspective, this is important because design decisions directly shape spatial transformation: including transformation of darkness as a territory. This research therefore contributes to a broader rethinking of how designers and urbanists engage with vulnerable territories, particularly in relation to landscape, agency, and responsibility in a rapidly changing world.

↗ **Figure [1.15].** Port of Narvik covered in snow.



"Mapping unfolds potential; it re-makes territory over and over again, each time with new and diverse consequences."
(Corner, 1999)

THE LOSS OF THE POLAR NIGHT

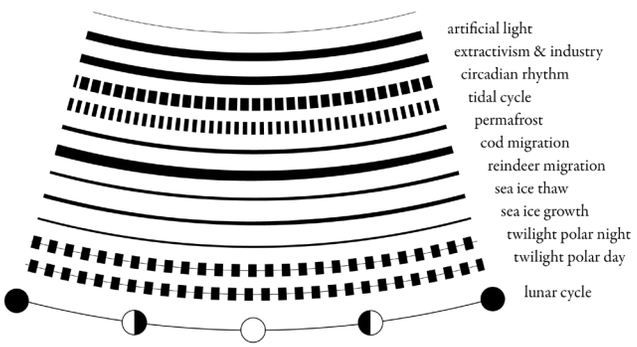
PROBLEM STATEMENT

The Arctic has historically been defined by the cycle of light and dark. During winter, extended darkness structures both ecological processes and human and non-human life. Darkness is therefore not simply the absence of light, but a spatial, temporal, and ecological condition intrinsic to Arctic systems.

In recent decades, these rhythms have been increasingly disrupted. Climate change and the retreat of sea ice have intensified human activity in the Arctic, including extraction, shipping, tourism, and infrastructural development. Many of these activities depend on continuous operation and are accompanied by permanently illuminated environments, leading to an expanding presence of artificial light at night. This trend is expected to accelerate further in the future as Arctic accessibility increases and geopolitical, economic, and infrastructural interests continue to expand in the region. The growing use of ALAN introduces a constant operational rhythm that conflicts with the Arctic's seasonal and multi-temporal conditions.

Instead of adapting to cycles of darkness, development increasingly imposes continuity, altering ecological processes.

Despite these changes, darkness remains largely overlooked as a critical spatial and temporal condition in Arctic planning and development.





↑ **Figure [1.16].** Different rhythms that both define the Arctic and are defined by the Arctic.

FROM SATELLITE TO FOOT

SCOPE OF RESEARCH

The scope of this research is on providing a multi-scalar understanding of how increasing human activity transforms the spatial and temporal conditions of darkness in the Arctic.

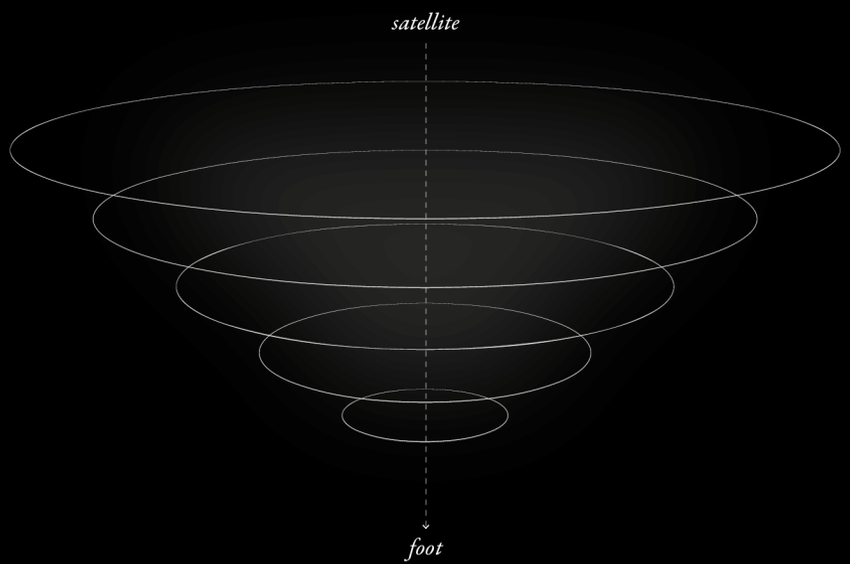
Focusing on processes such as shipping, extraction, tourism, and infrastructural expansion, the research investigates how artificial light at night reshapes environments historically structured by the rhythms of the Polar night. The project primarily operates at the regional scale - using the coastline as its main spatial framework - and uses a progressive zoom from *satellite* to *foot*. At the beginning of every chapter (act), this scale is shown, by using the same diagram as shown on the right, see Figure [1.17].

Through spatial analysis, cartographic representation, and theoretical inquiry, the project investigates darkness as a spatial and temporal condition that structures Arctic life. The research primarily operates at the mega-regional to regional scale, using the coastline as its main spatial framework.

By combining knowledge from urbanism, literature from ecology, and more-than-human theories, the research positions artificial light at night as [A] a spatial manifestation of planetary urbanisation and [B] a lens through which changing relationships between humans, territory, and ecological systems can be understood.

→ **Figure [1.17].** Multi-scalar research trajectory: from satellite to eye-level. This thesis starts at the planetary scale, gradually zooming in on the Arctic circle towards Norway and Tromsø.


planetary
Globe
territorial
Arctic
regional
Norway
urban
Tromsø
local
(non-)human


satellite
foot

→ **Figure [1.18].** Schematic project overview.

↓ **Figure [1.19].** Research questions and sub-research questions, including their form of inquiry and methods of research.

RESEARCH FRAMEWORK

LINES OF INQUIRY AND RESEARCH QUESTIONS

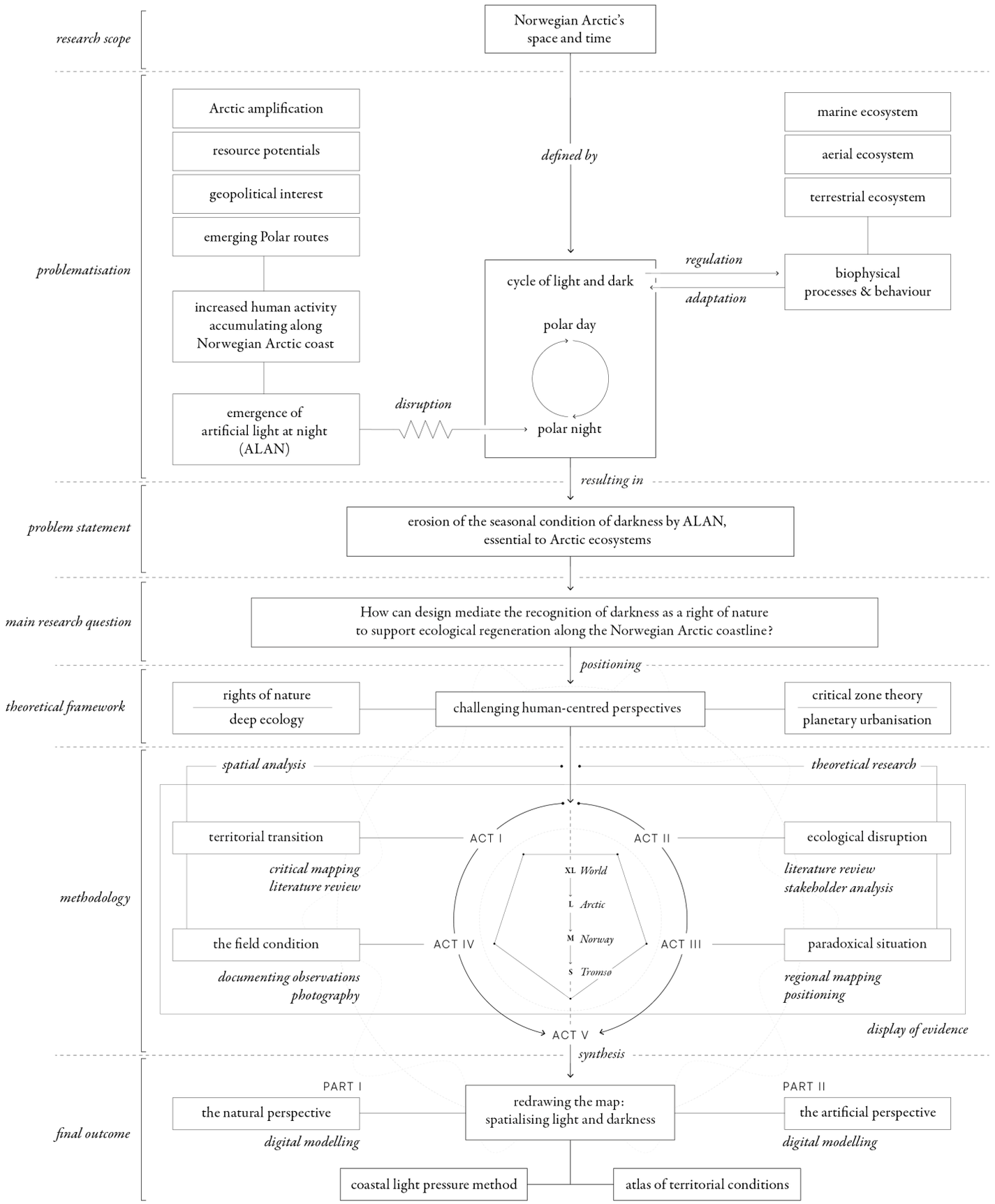
PRIMARY RESEARCH QUESTION

How can design mediate the recognition of darkness as a right of nature to support ecological regeneration along the Norwegian Arctic coastline?

SECONDARY RESEARCH QUESTION

How can the Arctic's space and time be reconceptualised through theories that challenge human-centred perspectives?

	ACTION OF INQUIRY		SUB RESEARCH QUESTIONS	METHOD OF RESEARCH
ACT I	*context*	SQ1	How is the Arctic being reconfigured through planetary processes of environmental change, economic expansion, and geopolitical interest?	*data analysis, critical mapping, literature review, meetings and (informal) interviews*
ACT II	*inform*	SQ2	How do the phenomena of Polar day and Polar night arise?	*literature review, diagrammatic explanation*
	understand	SQ3	How do Arctic ecosystems adapt to the absence of daylight?	*literature review*
	expose	SQ4	What is artificial light at night and how are Arctic ecosystems disrupted by it?	*literature review, critical mapping, diagrammatic explanation, data analysis*
ACT III	*frame*	SQ5	How is the Norwegian Arctic transformed through the intersection of energy extraction, shipping corridors, and infrastructural development?	*regional mapping, data analysis, literature review*
ACT IV	*trace*	SQ6	What site-specific conditions characterise the Norwegian coastlines under the Polar night?	*field observation, photography, (informal) interviews, local mapping*
ACT V	*display*	SQ7	How can (the transformation of) Arctic darkness be spatially visualised?	*construction of a method, digital modelling, exhibiting*


research scope
Norwegian Arctic's space and time
problematisation
Arctic amplification
resource potentials
geopolitical interest
emerging Polar routes
increased human activity accumulating along Norwegian Arctic coast
emergence of artificial light at night (ALAN)
disruption
defined by
cycle of light and dark
polar day
polar night
regulation
adaptation
marine ecosystem
aerial ecosystem
terrestrial ecosystem
biophysical processes & behaviour
resulting in
problem statement
erosion of the seasonal condition of darkness by ALAN, essential to Arctic ecosystems
main research question
How can design mediate the recognition of darkness as a right of nature to support ecological regeneration along the Norwegian Arctic coastline?
positioning
theoretical framework
rights of nature
deep ecology
challenging human-centred perspectives
critical zone theory
planetary urbanisation
methodology
spatial analysis
theoretical research
territorial transition
critical mapping
literature review
ACT I
ACT II
ecological disruption
literature review
stakeholder analysis
XL World
L Arctic
M Norway
S Tromsø
the field condition
documenting observations
photography
ACT IV
ACT III
paradoxical situation
regional mapping
positioning
ACT V
display of evidence
synthesis
final outcome
PART I
the natural perspective
digital modelling
redrawing the map: spatialising light and darkness
PART II
the artificial perspective
digital modelling
coastal light pressure method
atlas of territorial conditions

METHODS

This research combines literature review, fieldwork, photography, spatial data analysis, digital coding and design-based interpretation. This chapter on methods is structured across three interconnected components: [A] literature review, [B] data collection, and [C] design as a method of representation.

Together, these methods allow for a multi-scalar understanding.

[A] Literature review
To address the research questions, the literature presented in Figure [1.20] was reviewed. The research began with more-than-human perspectives and the Rights of Nature movement in order to position the project within theories that challenge human-centred worldviews. This theoretical grounding was followed by a broader contextual review of Arctic development, Arctic ecology, and Polar-specific light regimes and its ecosystem services. Finally, literature on artificial light at night and its ecological impacts on different species was examined to develop a scientifically informed understanding of how these systems operate and how they are disturbed by increasing illumination.

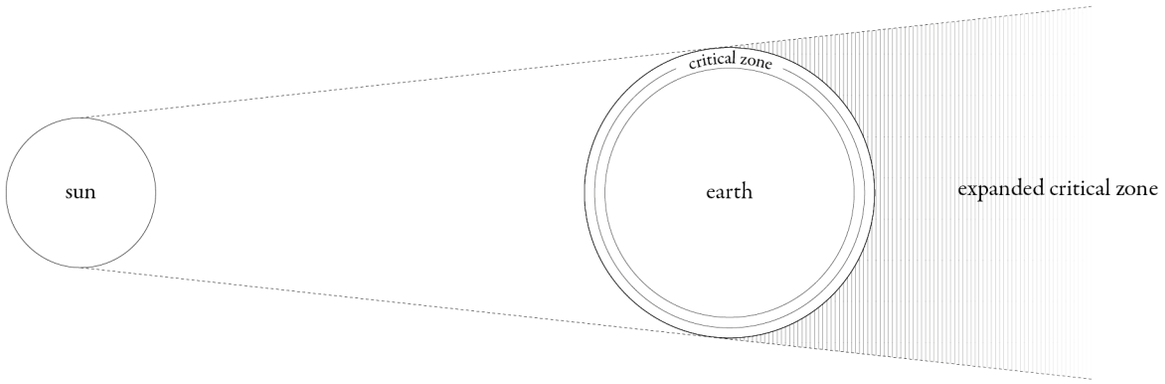
[B] Data collection
Next to the literature review, the project seeks to develop an understanding through evidence-based data, spatial observation, and direct experience of the Arctic environment. A field trip to the Norwegian Arctic was therefore made to gain a first-hand understanding of the spatial and atmospheric conditions. The research combines spatial mapping, remote sensing, field observations, photography, and cartographic analysis across multiple scales. The methods include the collection and interpretation of satellite imagery, environmental datasets, shipping and infrastructural data, photographic documentation, and site-specific observations gathered during fieldwork and recorded in a reflective field journal.

Photography and journalling are used not only as representational tools, but also as methods of spatial reading, capturing light conditions, atmospheres, temporal rhythms, and spatial relationships that are difficult to register through quantitative data alone. These datasets are translated into layered spatial drawings and analytical mappings in order to reveal relationships that are often difficult to perceive directly.

[C] Design as method of representation
The final outcome of the project functions an analytical and design methodology in itself. Rather than treating mapping as a neutral act of representation, the project approaches cartography as a critical and projective tool through which the overlooked spatial relationship of light and darkness can be revealed. In this sense, design becomes an assessment tool: a method through which relationships, patterns, and spatial conditions can be analysed, interpreted, and made visible. To support this, the research uses digital modelling techniques. Using QGIS and Python, custom datasets are created to process and visualise spatial and environmental data. This allows the project to structure and interpret complex datasets through a consistent methodological framework, while also generating new ways of reading and understanding the Arctic landscape.

→ **Figure [1.20].** An overview of the main bodies of literature per research theme.

research topics	*literature & sources*
Planetary Urbanisation / Extraction	Brenner (2014), Brenner & Schmid (2015), Lefebvre (1991), Lefebvre & Régulier (2004), Lesutis (2021)
Anthropocene / Environmental Philosophy	Latour (1993), Latour (2018), Haraway (2008), Haraway (2016), Naess (2005), Steffen et al. (2011), IPCC (2023)
Darkness / Light Theory	Edensor (2015), Gaston et al. (2015), Falchi et al. (2016), Falcón et al. (2020), Lyytimäki (2013), Rea et al. (2011)
Polar Night Ecology	Berge et al. (2015), Cohen et al. (2015), Cronin et al. (2016), Båtnes et al. (2013), Last et al. (2016), Brierley (2014)
Artificial Light and Ecological Disruption	Berge et al. (2020), Balazy et al. (2024), Akandil et al. (2024), Smyth et al. (2021), Bumgarner & Nelson (2021), Blume et al. (2019), Longcore & Rich (2016)
Birds and Navigation	Alerstam & Pettersson (1977), Muheim et al. (2005), Imber (1975), Brooke (2004), Regular et al. (2011), Johansen et al. (2001)
Adaptation of Reindeer	Hogg et al. (2011), Reimers et al. (2007), Tyler et al. (2016), Vitebsky & Alekseyev (2014)
Marine Ecology & Zooplankton Behaviour	Heath (2000), Baumgartner & Tarrant (2017), Rosing-Asvid et al. (2013), Bałazy et al. (2023), Haury et al. (1978)
Arctic Governance	Arctic Council (1996), Arctic Council (2021), Arctic Council (2009), Arctic Council (2026), AMAP, CAFF, SDWG (2013), CAFF (2013), Graybill & Petrov (2020)
Shipping / Infrastructure / Logistics	Boylan (2021), Hermann et al. (2022), Chen et al. (2021), Avinor (2026)
Arctic Definitions	Arctic Portal (2025), Bulkeley (2016)
Energy Governance & Economy	Equinor (2024), International Energy Agency (IEA) (2022), Statistics Norway (SSB) (2025), Statistics Norway (SSB) (2026), Li et al. (2026)
Climate Politics & Geopolitics	United Nations (2015), European Council (2025), European Parliament (2025), Regehr & Gallagher (2024)
Critical Energy / Socio-Political Theory	Gubrium (2024), Ren et al. (2026)
Climate	Rantanen et al. (2022), Francis & Vavrus (2012), Schuur et al. (2015), Mann & Kump (2015), IPCC (2023)
Remote Sensing / Light Mapping	NASA (n.d.), Akandil et al. (2024), Li et al. (2026), Falchi et al. (2016)



CHALLENGING HUMAN-CENTRED PERSPECTIVES

THEORETICAL FRAMEWORK

This research grounds its narrative in a deeper reflection on human-nature relations through the Rights of Nature (RoN) movement. It emphasises why making human impacts visible is crucial for rethinking risk, responsibility, justice, and the ways we inhabit fragile Polar environments.

[1] Rights of Nature

This movement represents a paradigm shift in how humans relate to ecosystems, where human impacts are widespread and growing. The recognition of the movement is gaining momentum worldwide. Instead of treating nature as a property or a resource, RoN recognises that non-human nature has intrinsic value, independent of its usefulness to humans (Gilbert et al., 2023). Natural systems and processes like the Arctic's seasonal darkness and the ecological cycles it supports, cannot defend their own rights and therefore require representation through communities, researchers, or legal advocates. By acknowledging these rights, we can better understand the ethical and ecological stakes of human presence, and explore strategies that support the regeneration of disrupted processes rather than treating nature for its instrumental value. In this sense, RoN encourages a more relational and responsible approach, where decisions about Arctic development are informed by the needs of its ecosystems.

Beyond a legal and ethical paradigm shift, RoN also enables to challenge dominant cultural assumptions about light and darkness. By questioning the idea that light represents progress while darkness signals danger (Lyttimäki, 2013), this research frames darkness as an ecologically vital condition with intrinsic value, rather than something to be overcome.

[2] Critical Zone Theory

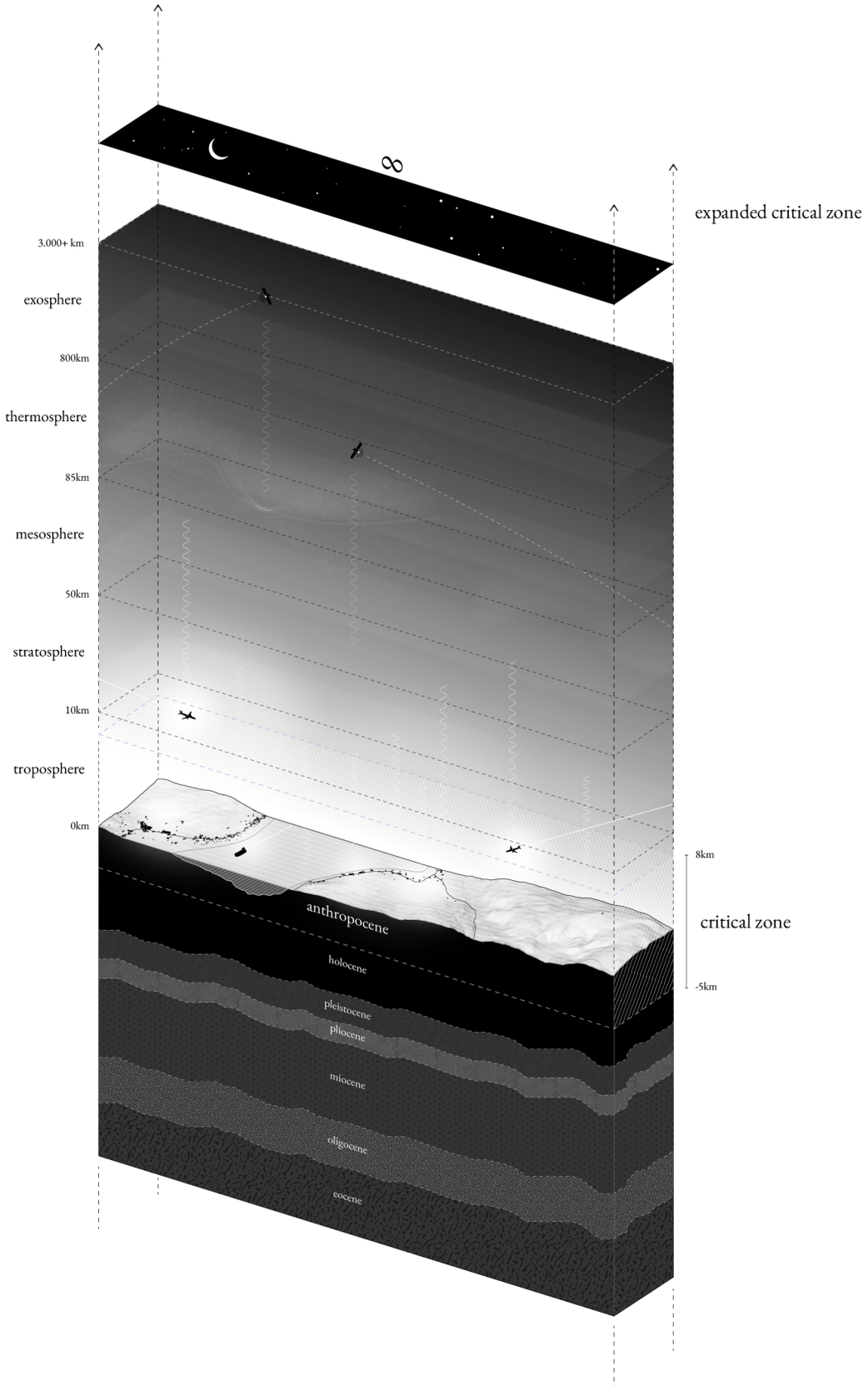
Another perspective can be found in the work of Bruno Latour, who draws on the concept of the Critical Zone. This refers to the thin, life-sustaining layer of the Earth extending from the bedrock to the lower atmosphere, where air, water, soil, and living organisms continuously interact. This zone is described as critical because it is both fragile and dynamic, and because its stability is increasingly affected by human activity and ongoing environmental change (Latour, 2018). In this thesis, I redifine its upper boundary as perceptual rather than purely physical, arguing that human's and non-human's lived space and time in the Arctic are governed by the night sky (see Figure [1.21]).

This broader, perceptual critical zone includes the 'visible depth' of the night sky that humans and non-humans relate to, adapt to, and depend on. It highlights the growing loss of natural darkness due to artificial light, which compresses this expanded zone and turns the night sky into a human-made ceiling that limits cosmic perception. This reframing positions darkness as a threatened commons, whose disappearance marks an urgent but overlooked form of ecological loss.

↑ **Figure [1.21].** Diagram of the critical zone, as referred to by Bruno Latour, and the expansion, as introduced in this theoretical positioning.

→ **Figure [1.22].** Diagram of the expanded critical zone, illustrating how artificial light at night produces a shrinking perceptual depth of darkness: a loss of the night.

source: adapted from Brouwer (2021)


expanded critical zone
3.000+ km
exosphere
800km
thermosphere
85km
mesosphere
50km
stratosphere
10km
troposphere
0km
8km
critical zone
-5km
anthropocene
holocene
pleistocene
pliocene
miocene
oligocene
eocene

CHALLENGING HUMAN-CENTRED PERSPECTIVES

THEORETICAL FRAMEWORK

[3] Deep Ecology

In his theory, Næss, A. (2005) challenges human-centred worldviews at a more fundamental level than the rights-based approach. Rather than seeking to extend legal standing to nature, Deep Ecology questions the underlying assumption that humans occupy a privileged position within environmental systems. Næss emphasises the embeddedness of human societies within larger ecological systems and argues that environmental problems arise from a failure to recognise this relational condition.

In the Arctic context, Deep Ecology draws attention to how space and time are not neutral backdrops for human activity. Space and time are actively structured by non-human processes, such as seasonal light cycles, ice formation, and ecological rhythms adapted to prolonged darkness. From this perspective, the pressure of continuous illumination, permanent infrastructure, and year-round activity reflects a projection of human temporal norms onto environments governed by fundamentally different logics.

Deep ecology therefore enables to reframe the Arctic transformation, not as a question of governance, but as a deeper mismatch. One between human modes of activity and the ecological conditions of the region.

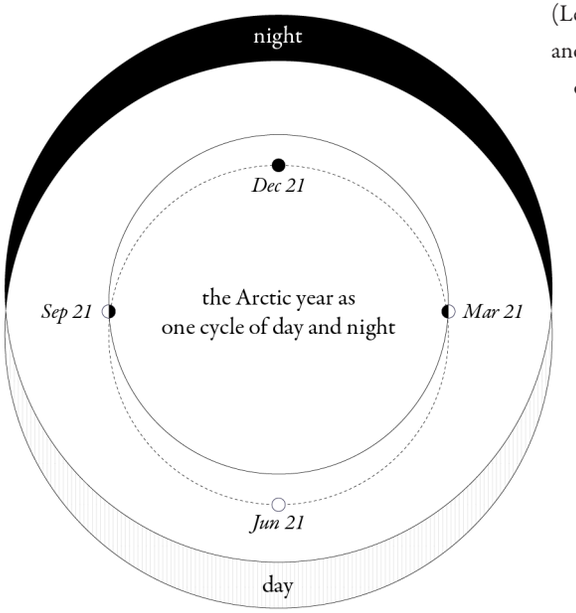
[4] Planetary Urbanisation

As artificial light at night (ALAN) becomes a key instrument in the production of Arctic space, the region is aligned with global temporalities and overrides the temporality of the Arctic and its Polar night (Lefebvre & Régulier, 2004). The Arctic is transformed by activities that do not primarily serve the region itself (Lesutis, 2021). The concept of Planetary Urbanisation understands this condition and frames the Arctic not as a peripheral or remote space. It is seen as an operational territory within planetary systems of circulation and production (Brenner, 2014; Brenner & Schmid, 2015).

In The Production of Space, Lefebvre (1991), describes space as being socially produced. Besides that, he mentioned *"I will begin with the following hypothesis: society has been completely urbanised."* (Lefebvre, 2003). Continuous human activity and its artificial light constitute a reorganisation of Arctic space according to global rhythms.

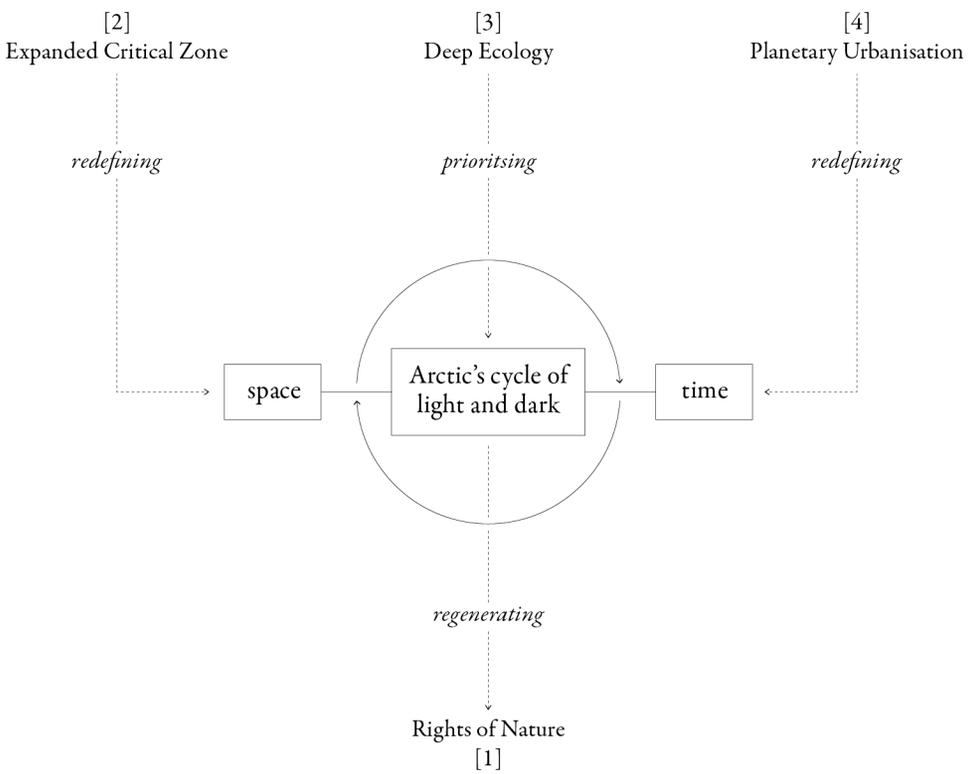
Planetary urbanisation reveals how the loss of night in the Arctic is not accidental. It is a systemic outcome of urban and industrial processes that prioritise *continuity* over local *temporal rhythms* and it therefore allows for a deeper understanding of (Arctic) time.

With this in mind, the project reframes the Arctic year as once cycle of day and night.



↖ **Figure [1.23].** Rethinking Arctic time: the Arctic year as one cycle of day and night.

↗ **Figure [1.24].** Theoretical framework. The diagram illustrates how the theories [2], [3] and [4] are used to understand, redefine and prioritise the Arctic's cycle of light and dark and serves as a base for regeneration through a rights of nature framework.


[2]
Expanded Critical Zone
[3]
Deep Ecology
[4]
Planetary Urbanisation
redefining
prioritsing
redefining
space
Arctic's cycle of light and dark
time
regenerating
Rights of Nature
[1]

A PARADIGM SHIFT

CONCEPTUAL FRAMEWORK

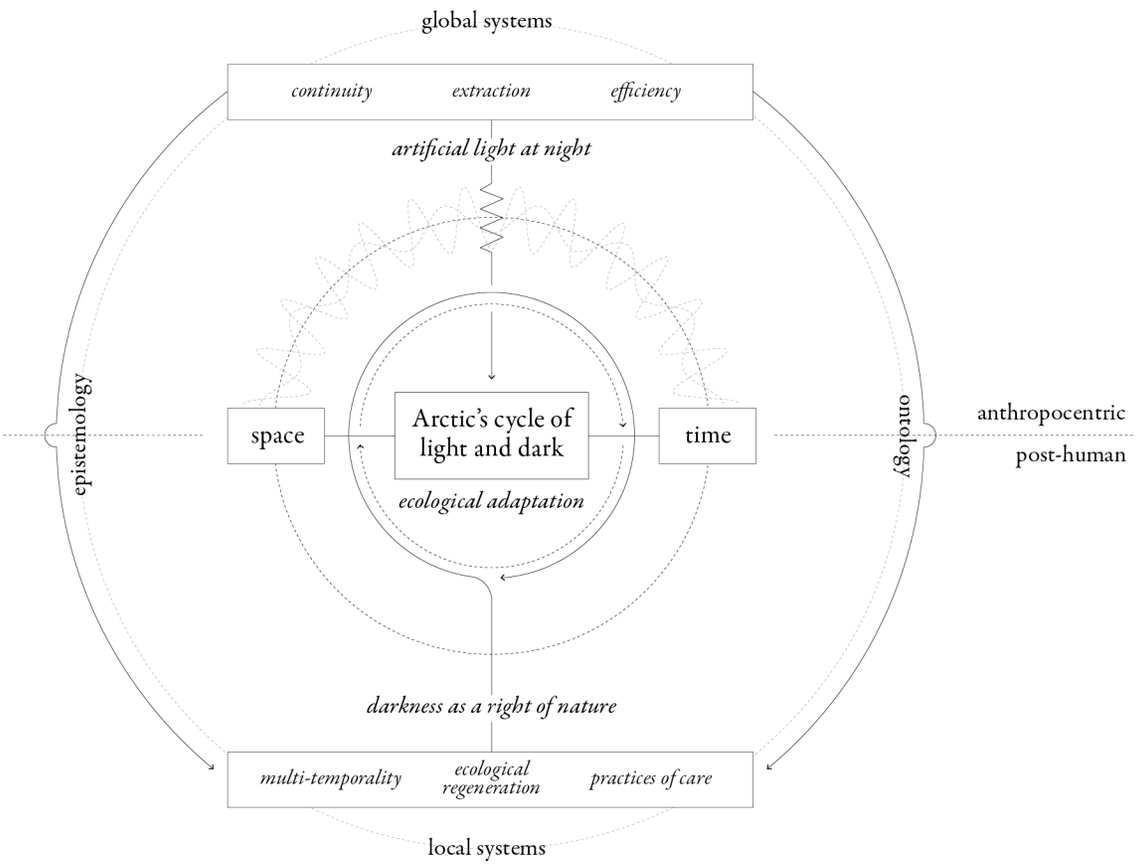
Anthropocentric global systems based on efficiency, continuity, and extraction extend into the Arctic through infrastructures of artificial light at night. In doing so, they disrupt the natural cycle of light and darkness that structures the Arctic's space and time. In Figure [1.25]. the zigzag line between *space* and *time* represents this distortion of the Arctic's spatio-temporality.

Situated within the discourse of Rights of Nature, the project challenges the anthropocentric paradigm that separates humans from nature and prioritises continuous human operation. Instead, it proposes a post-human and relational understanding of the Arctic, in which human and non-human processes, seasonal cycles, and ecological temporalities are interconnected.

The outer arrows in the framework illustrate the call for a shift; from systems of continuity and efficiency toward systems grounded in ecological regeneration and practices of care. This requires a different ontology and epistemology that recognise darkness not as absence or inefficiency, but as an essential ecological condition with intrinsic value. Within this shift, the urbanist is repositioned to work with Arctic multi-temporalities, and more-than-human relations rather than against them.

Ontologically,
the project understands the Arctic as a relational more-than-human system. It rewrites the definition of the Arctic: a system shaped by extreme light and darkness, seasonal rhythms, and interdependent human and non-human processes, rather than a passive resource landscape.

Epistemologically,
it questions how the Arctic is known and acted upon from an urbanism point of view, challenging technical and efficiency-driven approaches and instead foregrounding ecological, situated, and more-than-human ways of understanding the Arctic.



↑ **Figure [1.25].** Conceptual framework.

RELEVANCE OF THE PROJECT

[1] Scientific Relevance
By combining urbanism, ecology, and Arctic research, this project provides a deeper understanding of how human activity transforms the Norwegian Arctic. By integrating studies on Arctic ecosystems, climate change, industrial development, and artificial light at night, it creates a new scientific perspective. Besides that, it also contributes to the discourse of more-than-human perspectives.

By contributing to the discourse on Rights of Nature, Arctic ecosystems are treated as active stakeholders, emphasising their intrinsic value and the ecological systems that rely on darkness. This approach allows the project to propose new frameworks for analysing and managing human impacts. It therefore offers tools and insights that are directly relevant to scientific discussions on environmental change, spatial planning, and high-latitude development.

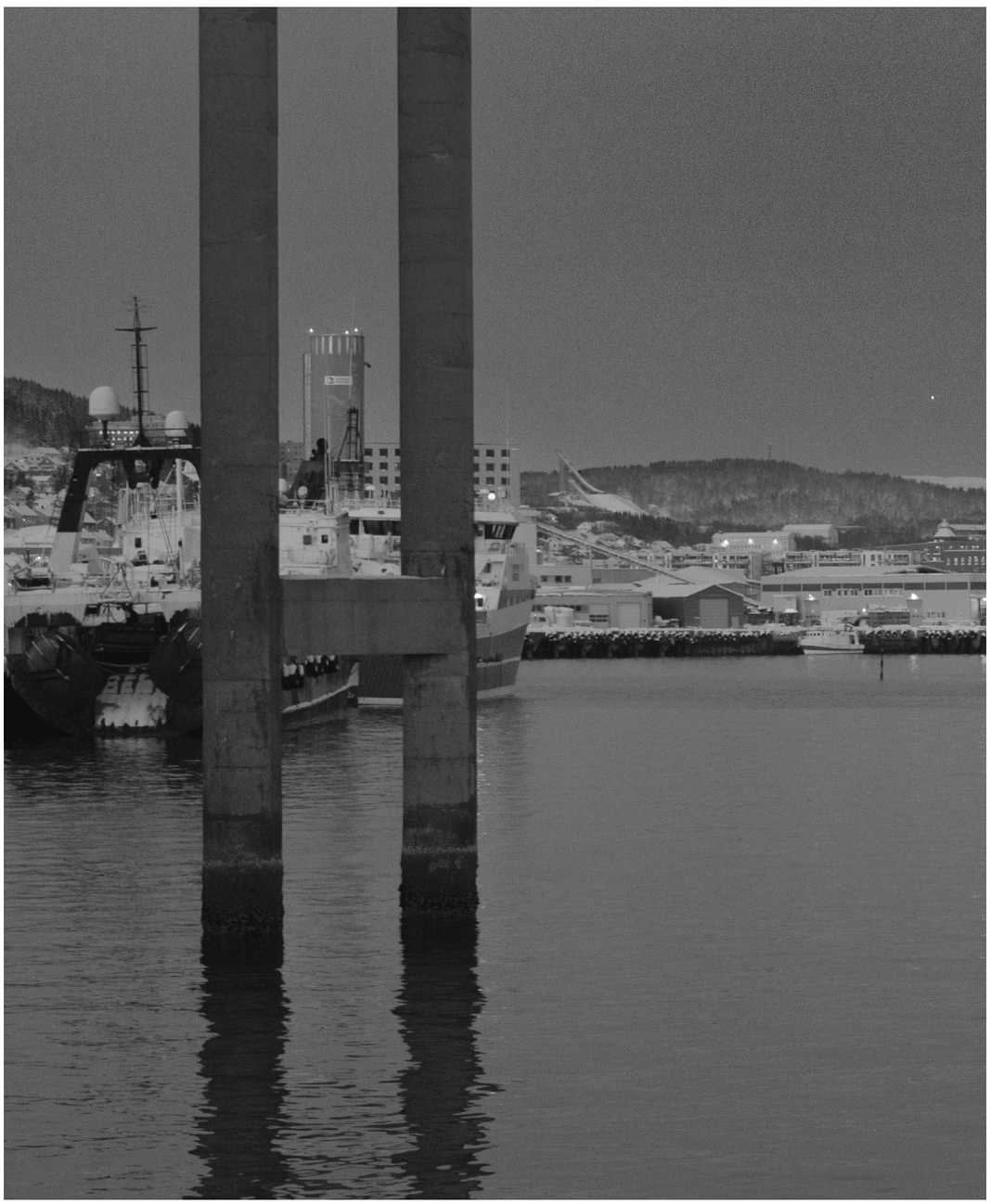
[2] Societal Relevance
This research examines the impacts of human activity on the fragile Arctic environment, including urban expansion and industrial development. It also investigates whether making these impacts visible can provoke reflection and change in how we interact with the Arctic landscape. By looking at different types of coastal settlements (industrial ports, regional urban centers, and fishing towns) the study uncovers patterns in human presence and ecological vulnerability. These insights offer guidance for more responsible planning, governance, and development in the region.

In this way, the project contributes to society by proposing ways to use and inhabit the Arctic with a better understanding of its multi-temporalilty. It encourages a more ethical relationship with natural systems that are often overlooked in high-latitude development.

[3] *Methodological Relevance*
Furthermore, the societal relevance of this research extends beyond the Arctic and has global implications. The Arctic plays a crucial role in regulating the Earth's climate system, and changes in this region have direct consequences for environments and communities elsewhere. It is also a region of significant ecological and environmental importance, often understood as the Earth's primary refrigerator, regulating global climate and driving ocean circulation (Arctic Portal, 2026) and where unique life systems persist under extreme conditions.

Understanding and protection of the Arctic environment is therefore not only a regional concern but also a global one. This project contributes to this understanding by reframing how the Arctic is understood in the first place. By rewriting dominant narratives through the lens of light and darkness, it offers methodological relevance in how territorial change can be interpreted, represented, and critically questioned. Rather than proposing a single design solution for a problem it aims at displaying evidence. This is done through representing what is often overlooked, or - as named in the final chapter of the thesis - *representing the unseen*. This is empolyed through multiple methods: literature reviews, photography, critical mapping and (digital) modelling.

→ **Figure [1.26].** Coastal urbanisation and industrialisation along the coastline of the island of Tromsø.

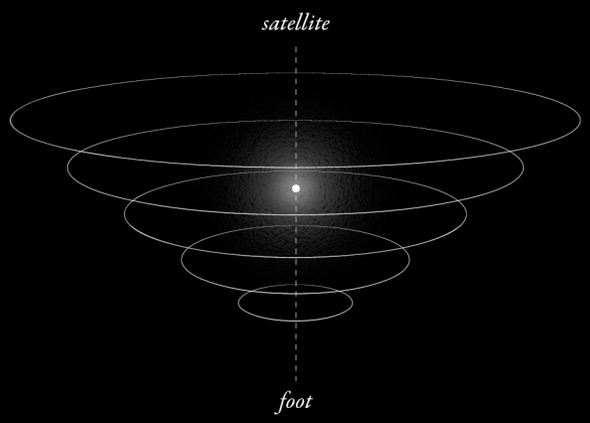


Vessels offloading goods
Tromsøya

ACT II

A GEOGRAPHY OF DARKNESS

Light defines the rhythms of most of the Earth's systems, yet in the Arctic it disappears for months each winter. What kind of geography emerges, and how does life persist, when the sun no longer rises?



II.1 - THE ARCTIC RHYTHM

The defining rhythm of the polar regions is not only based on temperature and sea ice extent, but also on the presence - and prolonged absence - of light.

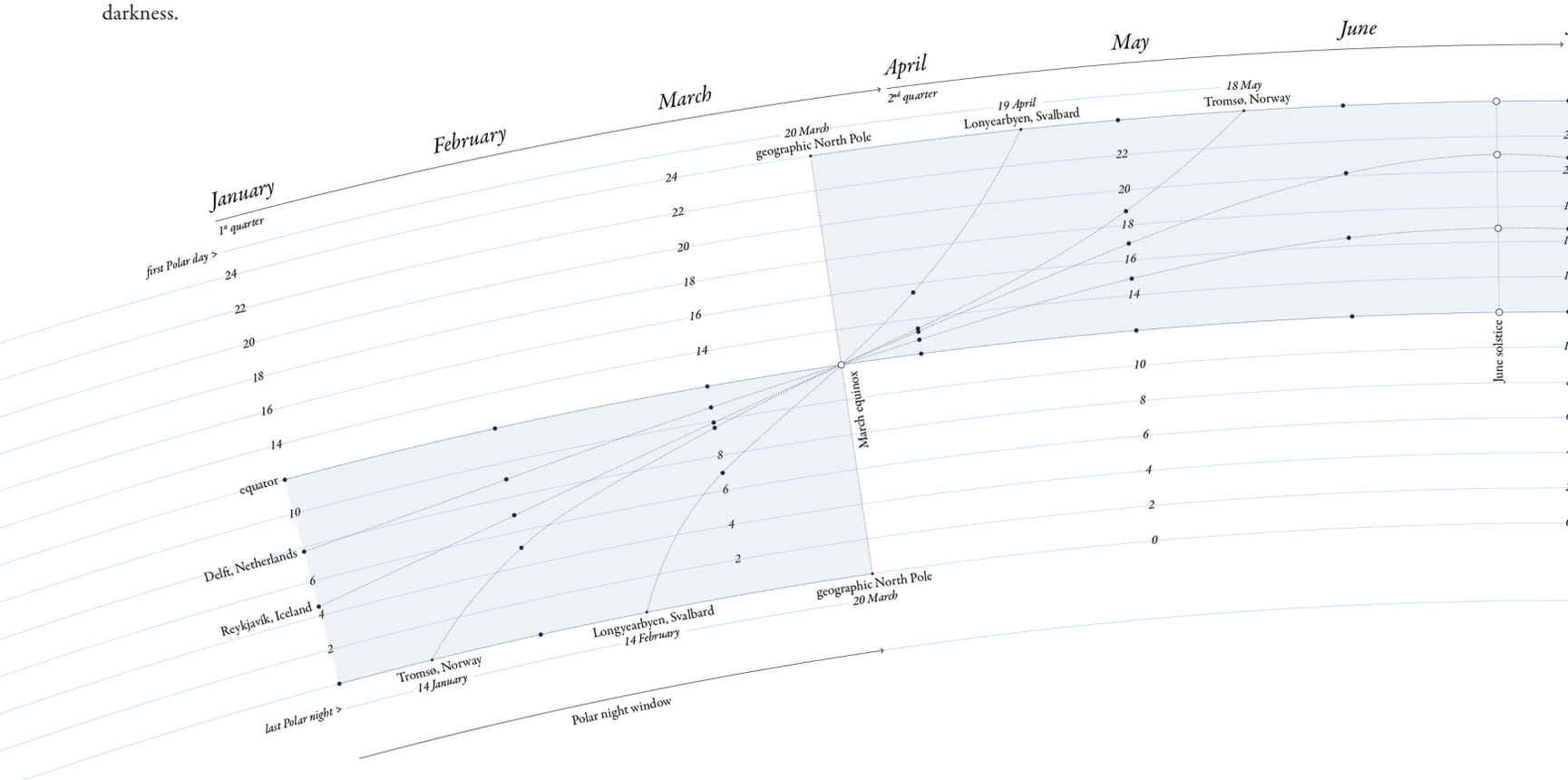
Due to the tilt of the Earth's axis, high latitudes experience extreme seasonal variations in daylight. Where regions close to the equator receive a relatively constant balance of approximately twelve hours of daylight and darkness throughout the year, this balance progressively destabilises towards the Poles. Summer days lengthen into continuous daylight (the Polar day), while winter brings a persistent absence of the sun below the horizon (the Polar night).

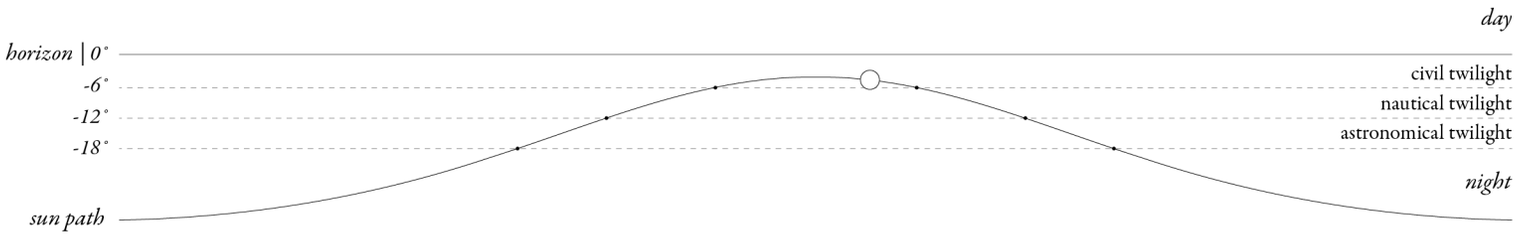
The Arctic Circle marks the latitude with at least one day each year with a full 24 hours of continuous daylight or complete darkness.

At the highest latitudes, this cycle reaches its most pronounced form. Near the North and South Poles, there is effectively a single sunrise and sunset each year, resulting in extended periods during which the sun remains continuously above, or below, the horizon. Figure [2.2] illustrates the variation in sunpaths across different latitudes on the Northern hemisphere, and the corresponding differences in daylight hours. The windows of Polar day and night are highlighted in blue, indicating that there is always a place on the hemisphere without a sunrise or a sunset.

Looking at the Polar night, lower latitudes within the Arctic circle, are characterised by prolonged phases of twilight, during which the sun remains just below the horizon (see Figure [2.1]). These twilight periods mean that even during the Polar night, darkness is not absolute, but retains a subtle level of light.

However, the Polar night, and its continuous period without any sunrise in the winter, most strongly shapes the Arctic experience of time. The structure of the diurnal cycles becomes different. The conventional alternation between day and night loses its regularity. In this way, light and darkness in the Arctic do not simply mark time: they actively structure it and reshape how cycles are perceived and lived.



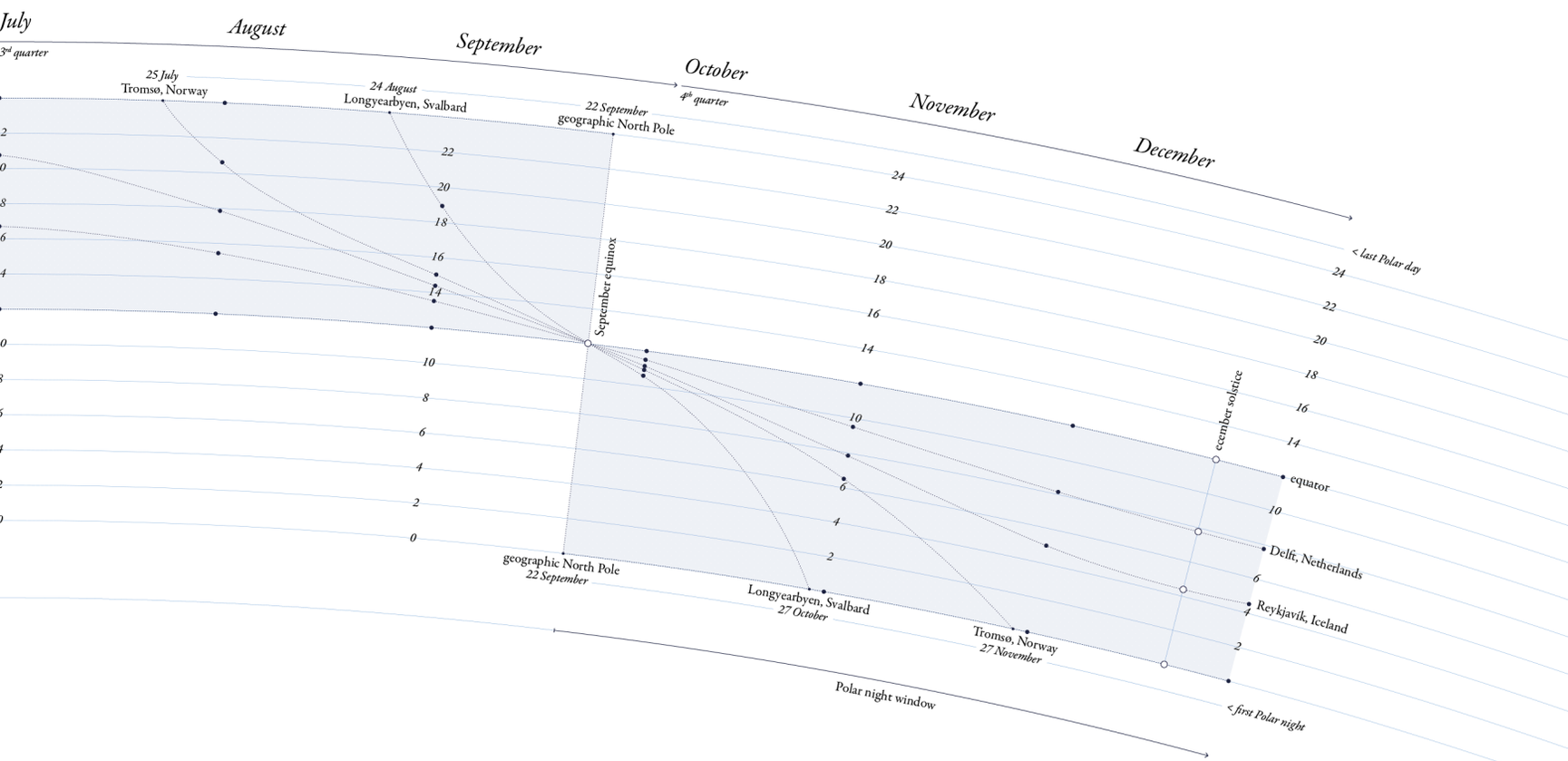


↑ **Figure [2.1].** Three different twilights between day and night and correspondingly, the elevation of the sun.

data: www.timeanddate.com

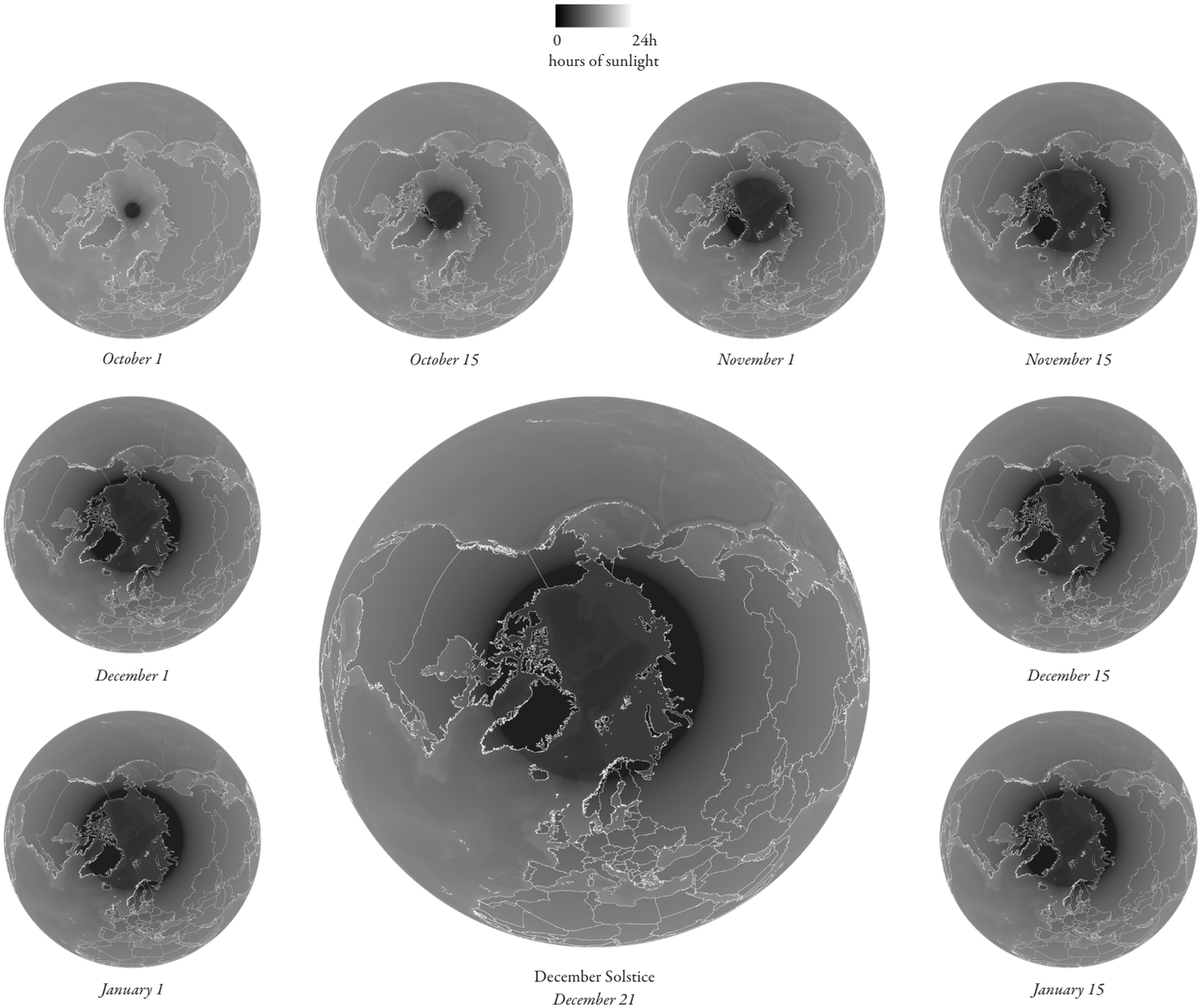
↓ **Figure [2.2].** The variation in sunpaths across different latitudes on the Northern hemisphere, and the corresponding differences in received daylight hours.

data: www.timeanddate.com



II.2 - THE POLAR NIGHT

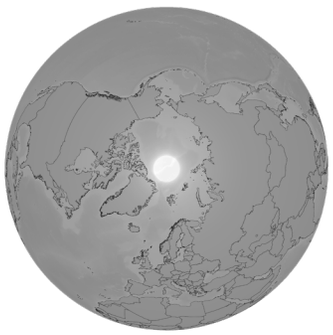
↓ **Figure [2.3].** Extent of the Polar night through the hours of sunlight per day, visualised every 15 days.



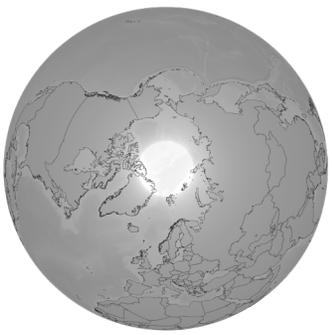
↓ **Figure [2.4].** Extent of the Polar day through the hours of sunlight per day, visualised every 15 days.

II.2 - THE POLAR DAY

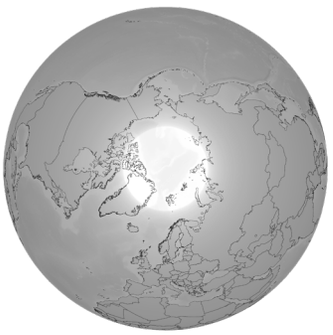




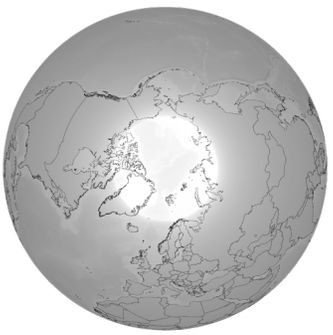
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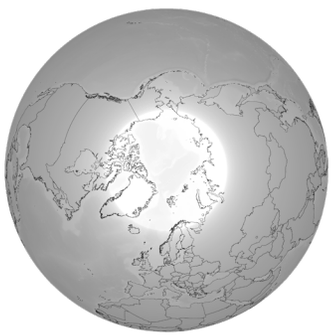
April 15



May 1



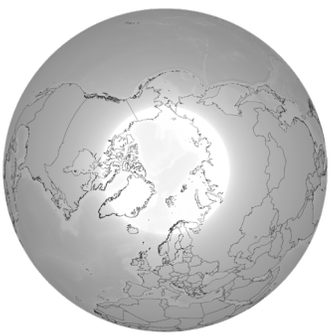
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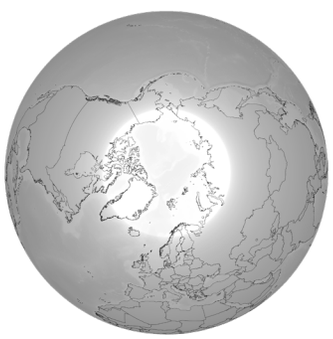
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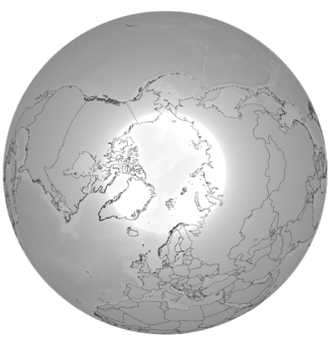
June Solstice
June 21



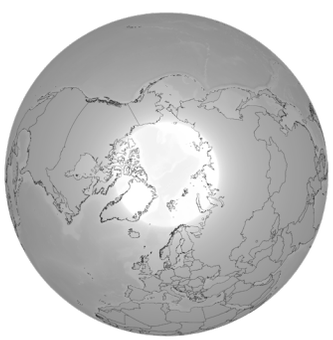
June 15



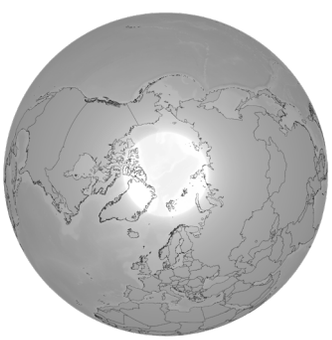
July 1



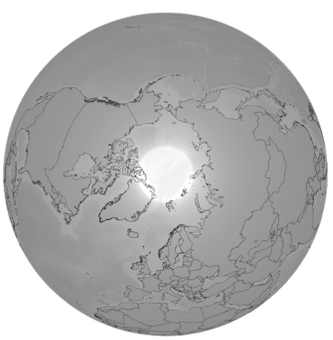
July 15



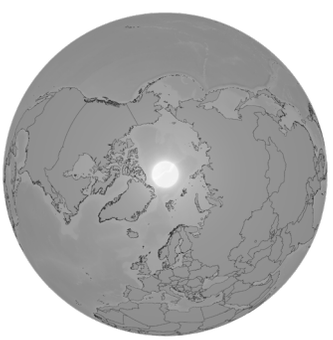
August 1



August 15



September 1

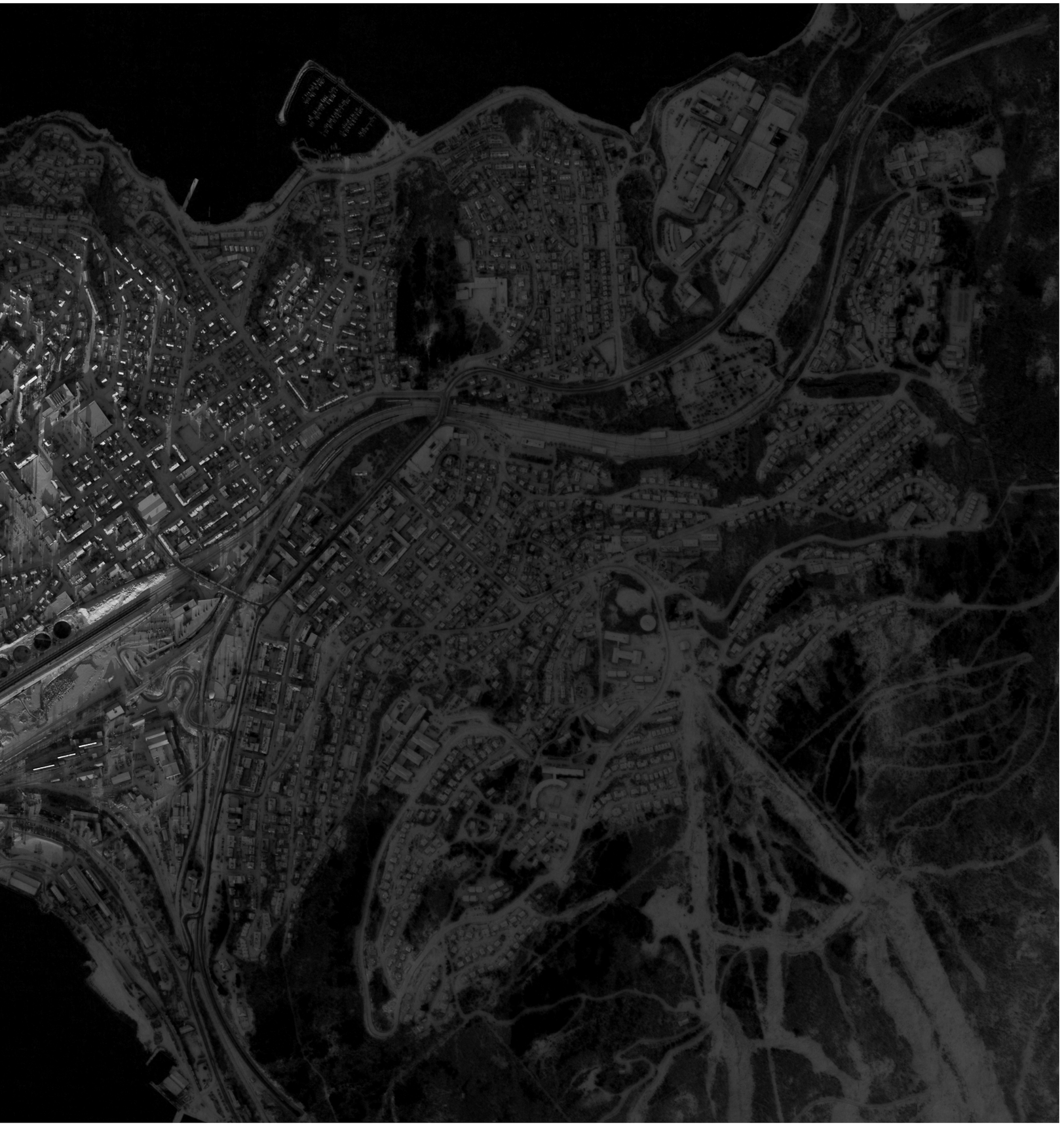


September 15



Figure [2.5]. Satellite image of Narvik (Norway) taken on October 30, 2006 at midday. The image shows how the city remains partly untouched by sunlight due to the sun's low altitude and the surrounding elevated terrain.

source: Google Earth Pro



> *"It is as if place, space and landscape are by default, conceived as being washed in a neutral daylight, rather than being dynamically conditioned by vital light and dark."*
> (Edensor, 2015)

II.3 - DARKNESS AS A STRUCTURING FORCE OF TIME AND SPACE

Light does not exist without darkness. And darkness does not exist without light. The alteration between the two is what shapes time and space. The structuring of time is closely mirrored in the organisation of space: in darkness, visibility, orientation, and perception are fundamentally altered, meaning that Arctic space is not only seen differently, but also navigated and inhabited in direct relation to light conditions. In this sense, light and darkness are not merely environmental variables, but organising principles that structure the spatio-temporality of the Arctic.

This understanding resonates with the notion of *introduction to Geographies of Darkness,* by Edensor (2015), which shifts attention towards how dark environments are lived, sensed, and socially constructed. As Edensor argues in his notion:

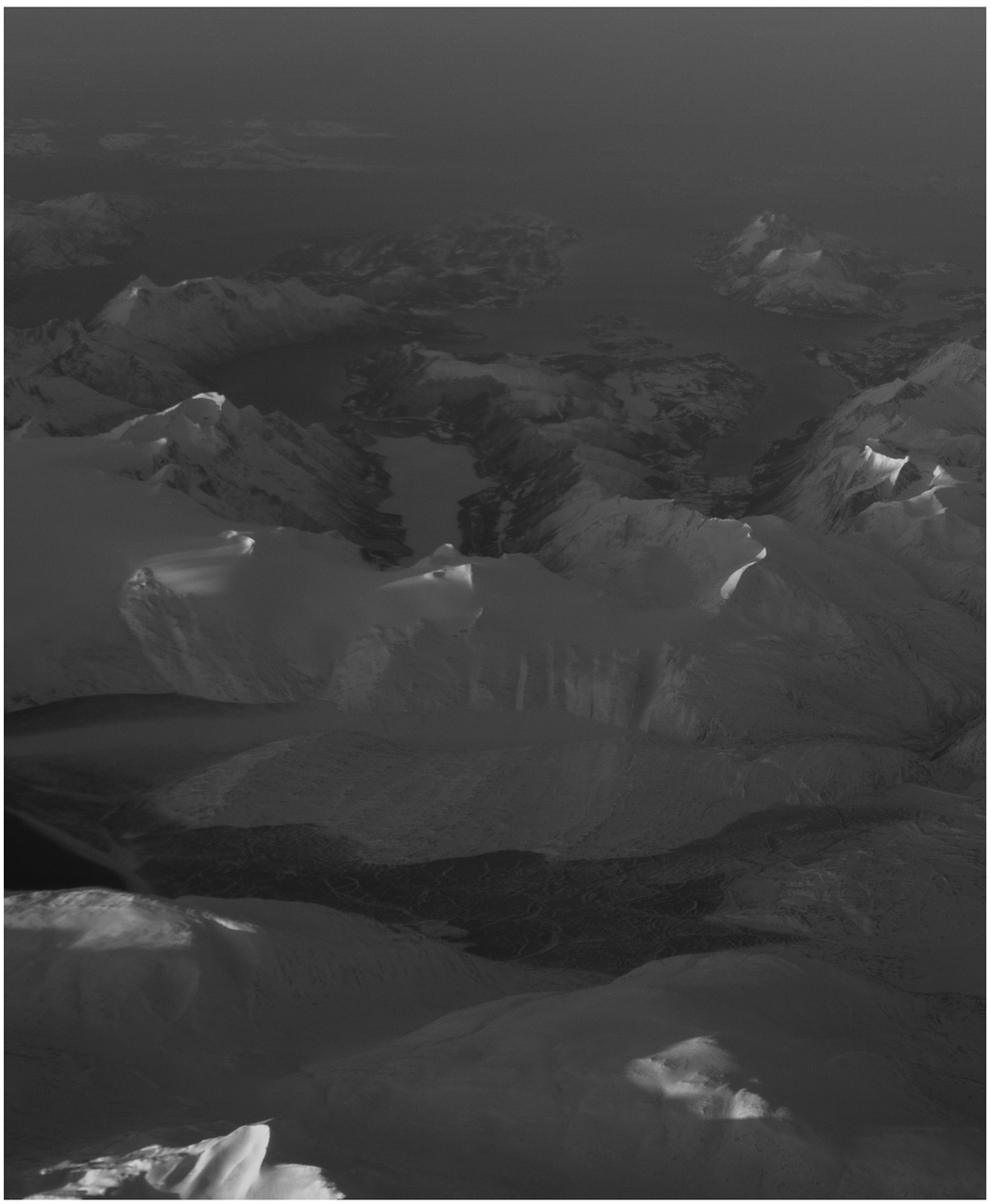
> *"The perception of light and gloom is an existential dimension of experiencing space and time."*
> (Edensor, 2015).

From this perspective, darkness should not be understood as a lack of visibility or as a condition to be overcome. Instead, it actively reorganises spatial experience, reshaping orientation and sensory engagement with the environment. Crucially, darkness is not uniform: it is relational and situated, varying across contexts and producing different spatial effects depending on cultural and environmental conditions.

Besides structuring the *human* perspective, darkness also organises space and time for *non-humans*. The Polar night is not a period of ecological inactivity, but one in which fundamental biological processes continue under conditions without light. Rather than suspending life, prolonged darkness reconfigures ecosystem dynamics, influencing timing, interaction, and energy flows across trophic levels (Berge et al., 2015). This perspective extends the notion of *Introduction to Geographies of Darkness* beyond human perception, showing how the absence of light structures ecological rhythms as well. This chapter therefore looks into the biological dimensions of the Polar night, through a literature review on Arctic ecosystem processes under extended periods of darkness.

With a *rights of nature* perspective informing this research, the following paragraph examines how stakeholders currently approach and implement ecosystem protection.

→ **Figure [2.6].** This photo was taken on January 11, while crossing the Arctic Circle, shortly after takeoff from Tromsø Airport. At 11:13am, the sunlight illuminates only the mountain peaks.



Sunlight touching mountain peaks at 11:13am, January 11, 2026
Norwegian Arctic Circle

II.4 - ARCTIC ECOSYSTEM PROTECTION

The Arctic Council is a central pan-Arctic governance body, that brings Arctic states together, alongside Indigenous Peoples and observers, to address protection and sustainable development of the Arctic environment. The Arctic Council has several working groups, such as the Conservation of Arctic Flora and Fauna (CAFF) and the Protection of the Arctic Marine Environment (PAME). They play a key role in shaping conservation efforts.

Their work has contributed to identifying areas of heightened ecological significance across the Arctic. Using criteria informed by the International Union for Conservation of Nature alongside expert knowledge, these initiatives have enhanced the comparability of conservation priorities. This effort responded in part to concerns raised in the Arctic Marine Shipping Assessment (AMSA), providing a scientific basis for prioritising conservation actions and supporting the development of measures such as marine protected areas (AMAP et al., 2013), see Figure [2.7].

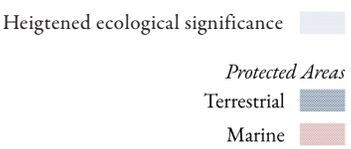
AMSA set out recommendations for guidance of future action by the Arctic Council, the Arctic states, and other stakeholders in relation to both current and future Arctic marine activities. They specifically called for measures to address protection concerns linked to Arctic shipping:

> "*The Arctic states should identify areas of heightened ecological and cultural significance in light of changing climate conditions and increasing multiple marine use and, where appropriate, should encourage implementation of measures to protect these areas from the impacts of Arctic marine shipping, in coordination with all stakeholders and consistent with international law.*" (Arctic Council, 2009).

Overall, this governance approach does reflect a clear effort to acknowledge and protect ecologically significant areas in the Arctic. This is done primarily through scientific assessment, and the mitigation of impacts from human activities, such as shipping. Nevertheless, this protection remains embedded within existing management and governance structures.

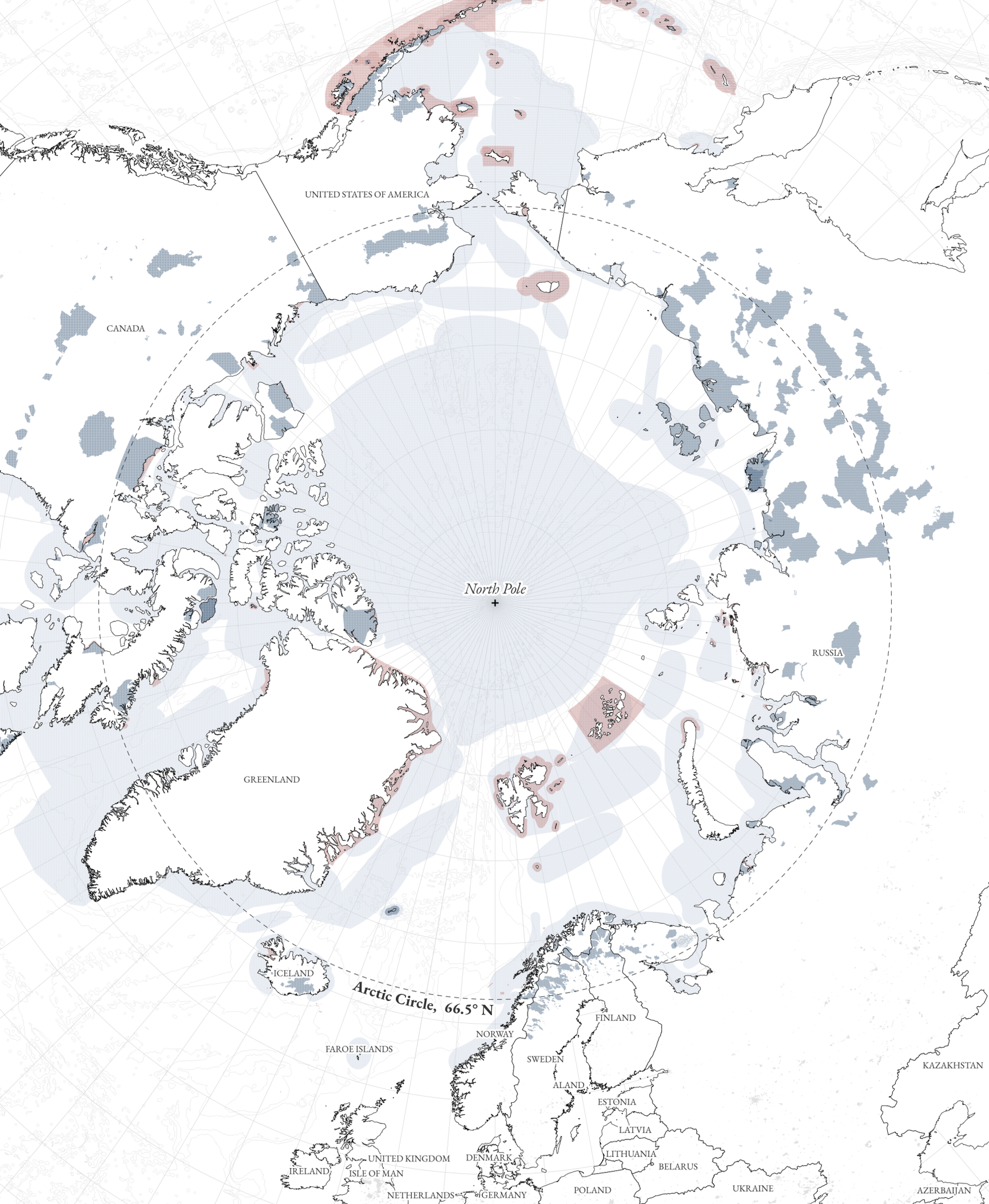
The Arctic Council promotes sustainable development of the Arctic alongside opportunities for resource use and economic activity (Arctic Council, 2021). This creates an inherent tension between conservation objectives and development-oriented priorities.

Ultimately, while the work of Arctic Council working groups contributes to the identification and protection of ecologically significant areas, it does not translate into legally recognised rights for ecosystems themselves. Instead, nature is protected indirectly through its value as an object of conservation and through the regulation of human activity. It is not recognised as a subject of rights in its own right within a more-than-human approach.



→ **Figure [2.7].** Areas of ecological signifance and protected sites.

data: Arctic Spatial Data Infrastructure


UNITED STATES OF AMERICA
CANADA
North Pole
RUSSIA
GREENLAND
ICELAND
Arctic Circle, 66.5° N
FINLAND
NORWAY
FAROE ISLANDS
SWEDEN
KAZAKHSTAN
ALAND
ESTONIA
LATVIA
LITHUANIA
BELARUS
UNITED KINGDOM
DENMARK
IRELAND
ISLE OF MAN
NETHERLANDS
GERMANY
POLAND
UKRAINE
AZERBAIJAN

> *"Challenging the prevailing view of the Polar night as devoid of biological activity is necessary for developing a holistic pan-Arctic view of ecosystem structure and function."*
> (Berge et al., 2015)

II.5 - BIOLOGICAL SYNCHRONISATION WITH LIGHT

LITERATURE REVIEW

The intrinsic value of the Arctic is closely connected to its nightscape. Darkness is not only the absence of light as a structuring element of space and time, but also an active condition shaping ecological, biophysical processes. This literature review looks into ecosystem processes during the Polar night and the ecological impact of artificial light at night.

Ecological processes are closely linked to internal biological clocks, particularly circadian rhythms, which regulate biological cycles on a 24-hour basis. This endogenous clock generates internal rhythms that require synchronisation with external environmental cues. Bright day and dark night cycles are functioning as the primary *zeitgeber* (Bumgarner & Nelson, 2021). In the Arctic conditions of extreme seasonal variation, this light-driven synchronisation becomes particularly significant. In the dark winters, minimal light exposure can influence the regulation of daily and seasonal biological rhythms (Bumgarner & Nelson, 2021; Berge et al., 2015).
Light is also widely recognised as a primary regulating factor in ecological interactions (Bumgarner & Nelson, 2021), where even very small differences in light levels - often undetectable by the human eye - can have significant effects on biophysical behaviour and ecosystem functioning (Båtnes et al., 2013).

Recent research challenges the earlier view that Arctic winter ecosystems are largely inactive. Instead, the polar night is increasingly understood as a period of ongoing biological activity (Berge et al., 2015). Many species across different trophic levels use this time for important ecological functions, including feeding, migration, and reproduction (Berge et al., 2015).

This shifts the understanding of the Arctic winter from a period of ecological inactivity to one of continued but differently structured biological processes. Endogenous circadian rhythms, which organise physiological and behavioural cycles, rely on natural light-dark patterns for synchronisation with the external environment (Bumgarner & Nelson, 2021). Annual, seasonal, lunar, and circadian cycles, which have developed over time, also play an important role in shaping reproduction, communication, and prey-predator interaction (Berge et al., 2015).



II.6 - ECOLOGICAL IMPACTS OF ARTIFICIAL LIGHT

LITERATURE REVIEW

At the same time, this sensitivity to low light levels makes Arctic ecosystems vulnerable to artificial light at night. Even very low levels of light during the Polar night can act as a strong stimulant, given the contrast with the completely dark environment (Longcore & Rich, 2016). Akandil et al., (2024) found out that an area of over 800,000 km^2 of the Arctic is lit by human activity and increases yearly with an average of 4.8%. Of this area, over 600,000 km^2 has been transformed from dark to lit only since 1992.

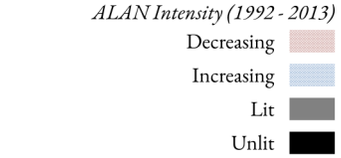
Changes in nighttime light radiance since 1992 are made visible by overlaying night time satellite images by NASA, highlighting areas of significant increase and decrease over time (see Figure [2.8]). For example, the widespread decreases observed in Ukraine can be attributed to the ongoing war with Russia. The red areas in the North Sea correspond to abandoned oil and gas platforms. In contrast, the major increase in Poland reflects its strong economic growth, which is the highest in the European Union (European Commission, 2026). Mapping ALAN in this way not only reveals long-term trends, but also provides insight into patterns of human activity.

Hence, light-dark patterns are increasingly being disrupted by ALAN (Gaston et al., 2015; Falcón et al., 2020), and it therefore is increasingly recognised as a global environmental stressor affecting terrestrial, aerial and marine environments (Lyytimäki, 2013). ALAN can interfere with circadian regulation, leading to weaker or disrupted activity patterns under constant or artificial lighting conditions (Bumgarner & Nelson, 2021).

At the behavioural level, ALAN affects reproduction, foraging, and migration. It can attract animals to unsuitable locations, temporarily impair vision, increase collision risks, and disturb breeding and migratory behaviour (Lyytimäki, 2013). It can also influence interactions between and within species, including competition and communication. The effects are not only behavioural but also physiological, including changes in immune, endocrine, and metabolic processes (Bumgarner & Nelson, 2021).

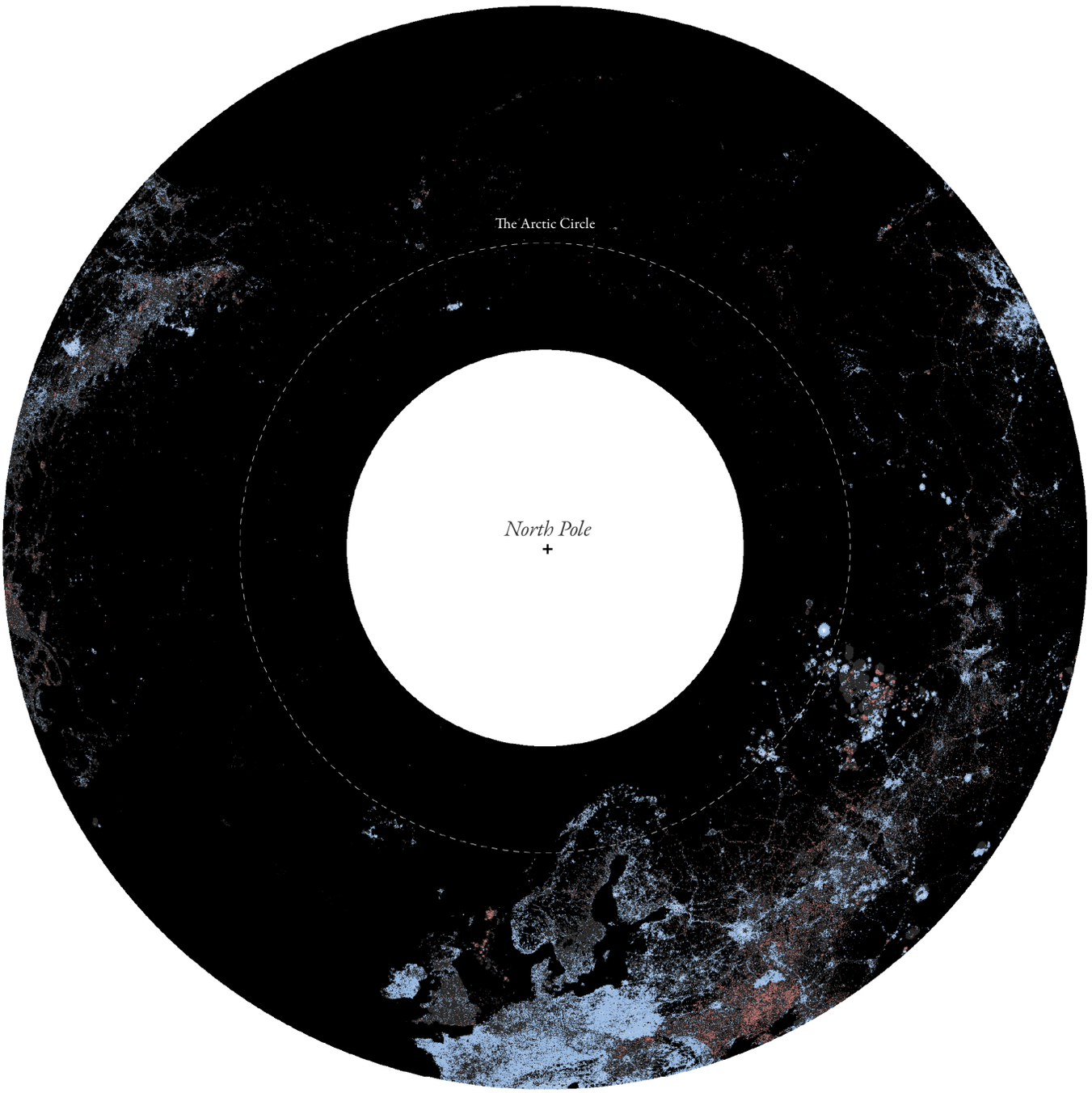
In marine environments, ALAN is intensified by skyglow, where artificial light spreads into the oceans. This means that light pollution is not limited to land areas but also affects marine ecosystems (Smyth et al., 2021). The global shift towards LED lighting is expected to increase this effect, as changes in light intensity and spectral composition may increase light penetration into water (Smyth et al., 2021). With the increasing accessibility of Arctic seas, light emissions from vessels and platforms are also likely to contribute to greater light penetration into (new) marine environments.

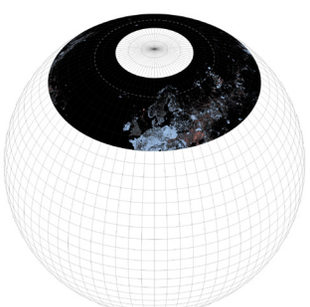
The spatial distribution of ALAN may act as an indicator of invasion risk, as it often corresponds with areas of intensified human activity (Akandil et al., 2024). In this way, artificial light reflects wider environmental pressures shaping Arctic ecosystems. Scotobiology (the study of biological systems that depend on darkness) highlights the importance of natural darkness for normal ecosystem functioning. Overall, the literature reviewed in this chapter emphasises that darkness is not a lack of environmental value, but an *essential condition for ecological processes in Arctic systems* to be protected.



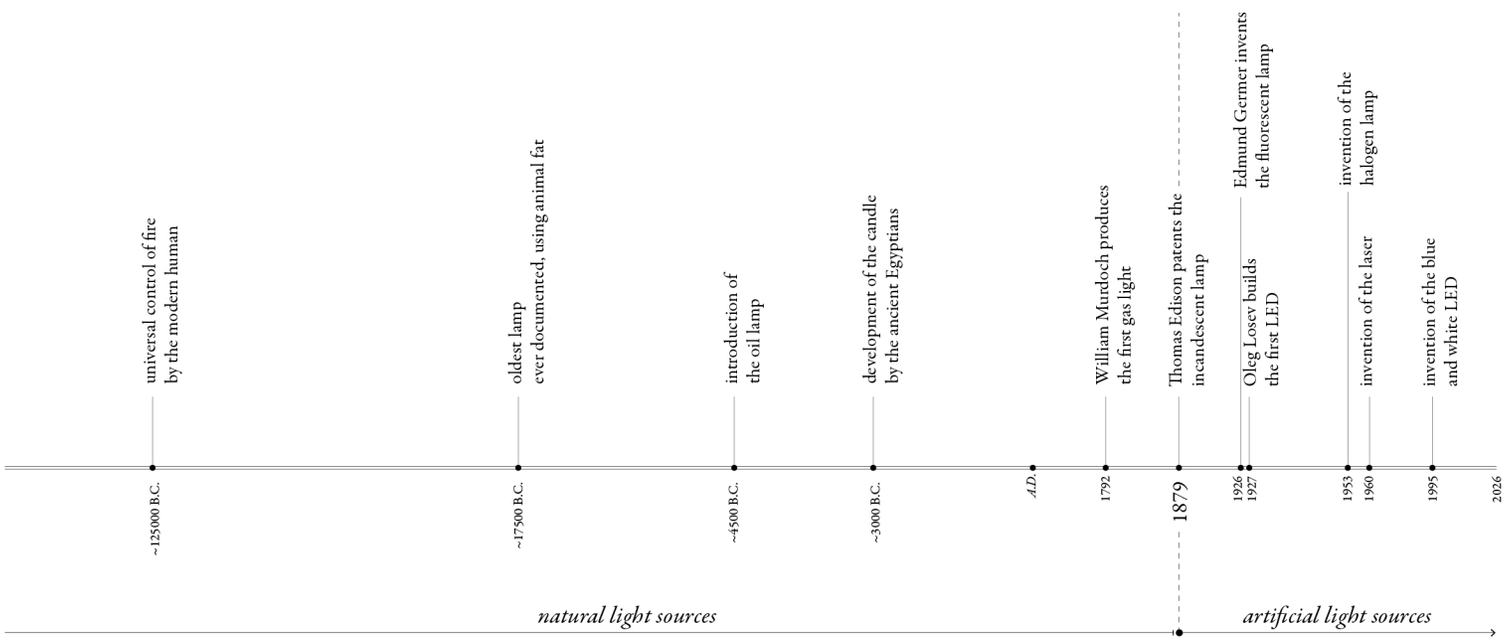
→ **Figure [2.8].** Pan-Arctic changes in ALAN intensity between 1992 and 2013, based on satellite-derived data and pixel-level trend analysis. The map highlights areas of significant increase and decrease in light intensity, as well as stable lit regions. The white disc in the middle has no data due to lack of satellites flying over.

data: Akandil et al. (2024)





"Light pollution should be considered one of the key global environmental changes". (Lyttimäki, 2013, p. e47)



II.7 - ALAN: ARTIFICIAL LIGHT AT NIGHT

Light has always been fundamental to life. Human controlling light started with the universal use of fire. Later, the use of oil lamps and candles were introduced. For ages, light has not been artificial, but was produced with naturally glowing things, like fire or glowing metal. With recent technologies of artificial light (with potentials of brightness way higher than natural light) such as LEDs, the development of ALAN has extremely grown.

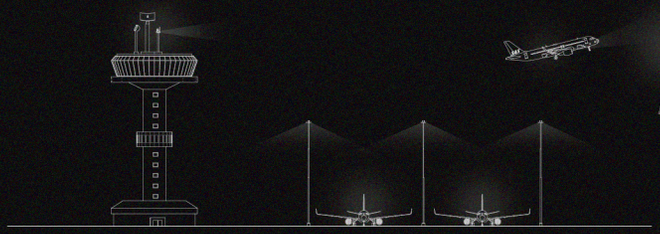
This progression has enabled new forms of work, mobility, communication and domestic life, including street lighting, ambient and decorative lighting, but most importantly: the capacity to remain active at night.

Today, artificial light is ever-present and highly diverse in scale and function, see Figure [2.10]. It ranges from small portable sources such as smartphone flashlights to larger infrastructural systems such as street lighting or oil platforms at sea. Figure [2.11] on the next spread shows through a section an example of how these different sources are often clustered along coastlines.

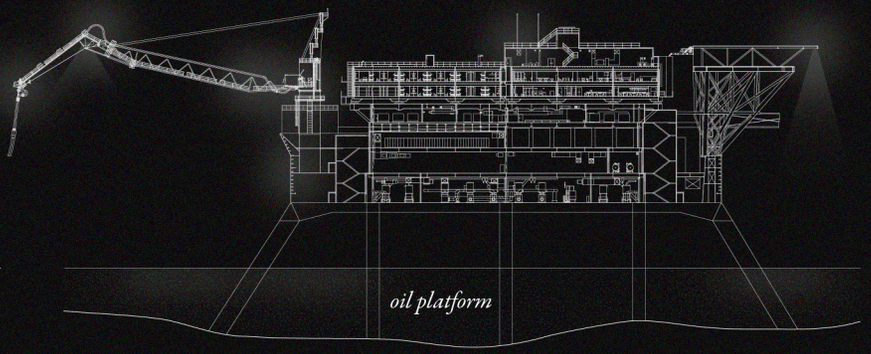
These sources differ not only in intensity and purpose, but also in how they are perceived and distributed in space. Light can be intermittent or continuous, directed or diffuse. It can radiate upwards or downwards, spill beyond its intended boundaries as light trespass, or accumulate in the atmosphere as skyglow. These different expressions of artificial light are important to distinguish, as they form distinct spatial patterns. These patterns are shown in Act IV, through photography.

↑ **Figure [2.9].** A timeline on the invention and usage of different light sources.

→ **Figure [2.10].** An inventory of artificial light sources in the Arctic landscape.



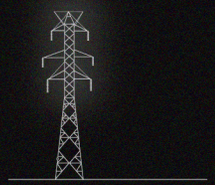
airport



oil platform



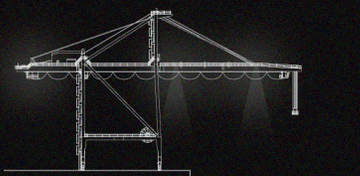
ferry



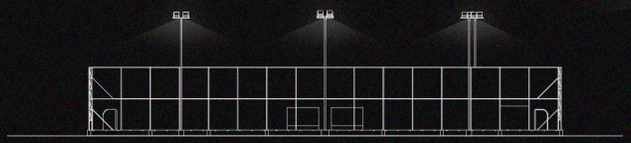
power line



aquaculture



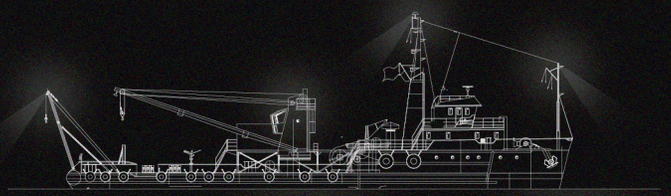
cargo harbour



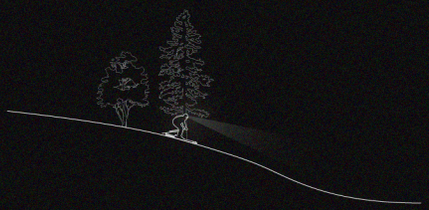
sportsfield



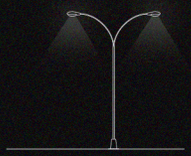
lighthouse



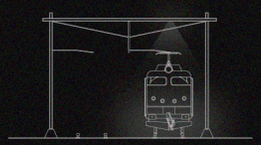
fishing vessel



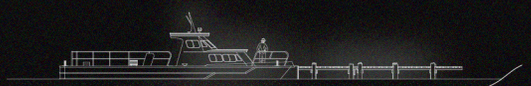
outdoor sports



streetlight



marshalling yard



pier



dwelling



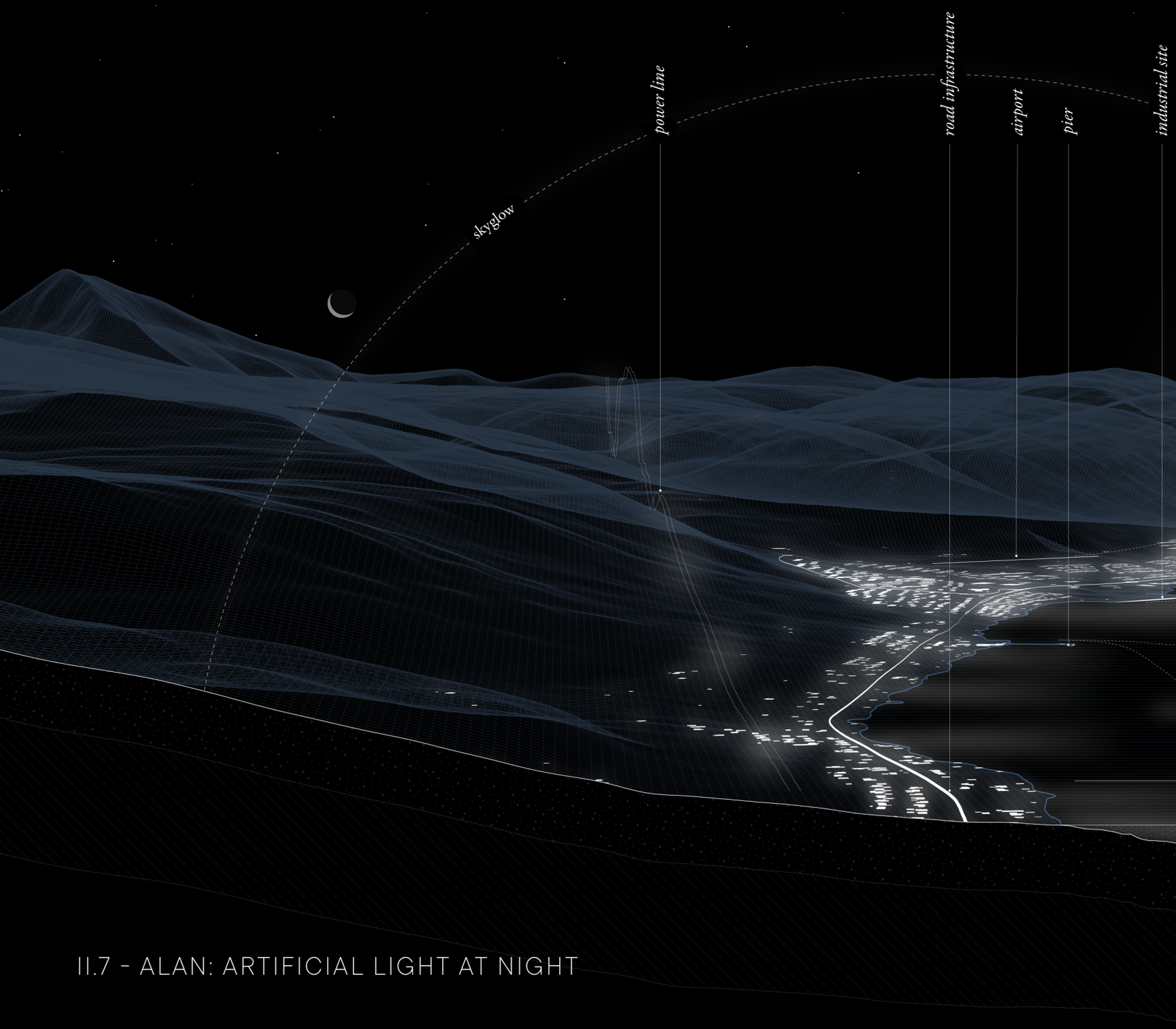
industrial site



traffic

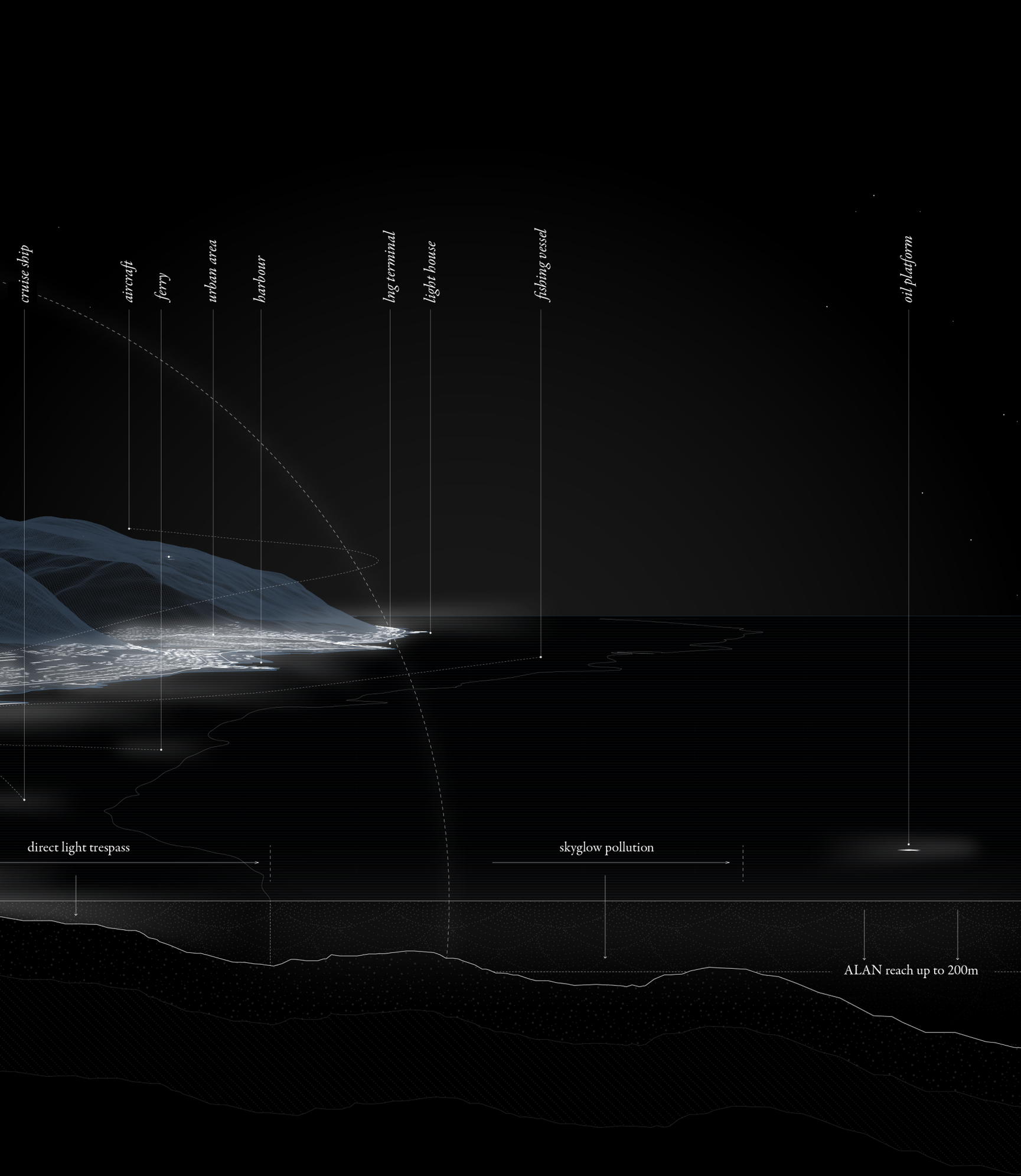


navigation buoy



II.7 - ALAN: ARTIFICIAL LIGHT AT NIGHT

↗ **Figure [2.11].** ALAN converging along coastline. (indicative territory, based on Tromsø area terrain.)


cruise ship
aircraft
ferry
urban area
harbour
lng terminal
light house
fisbing vessel
oil platform
direct light trespass
skyglow pollution
ALAN reach up to 200m



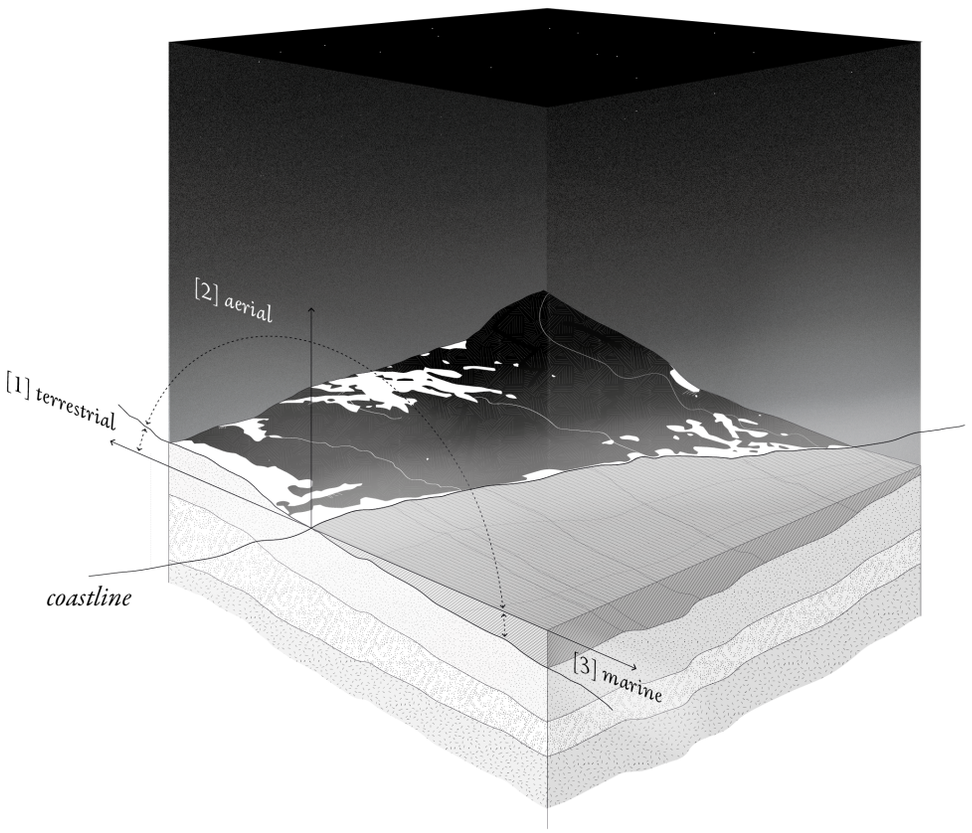
II.7 - ALAN: ARTIFICIAL LIGHT AT NIGHT

Through a different understanding of time - by taking a picture with long exposure - moving light sources are perceived as continuous trails due to temporal integration on the camera sensor. The lights of moving vehicles or airplanes produce such traces, making their movement paths visual. The photos in Figure [2.12] and Figure [2.13] display this phenomenon as lines of light carving the nocturnal landscape. (*pictures have been taken with an exposure time of 30 seconds*)

↑ **Figure [2.12].** The lights of a moving vehicle produces a light trail, illuminating its movement path.

↗ **Figure [2.13].** The same applies to air traffic, here taking off in front of the moon.





II.8 - COASTAL ZONES OF CONVERGENCE

By zooming in to the Arctic territory, its coastlines can be understood as *zones of convergence*, where spatial, ecological, and infrastructural systems meet. They form an interface between land, sea, and air, bringing together terrestrial, aerial and marine species. At the same time, coastlines concentrate human settlement and activity, and with it, sources of artificial light at night (Smyth et al., 2021). In this sense, coastlines can be approached not only as ecological transition zones, but also as sites where illumination accumulates. Neumann et al. (2015) confirm that in their research:

> *"The 21st century will see dramatic increases in coastal urbanisation".*

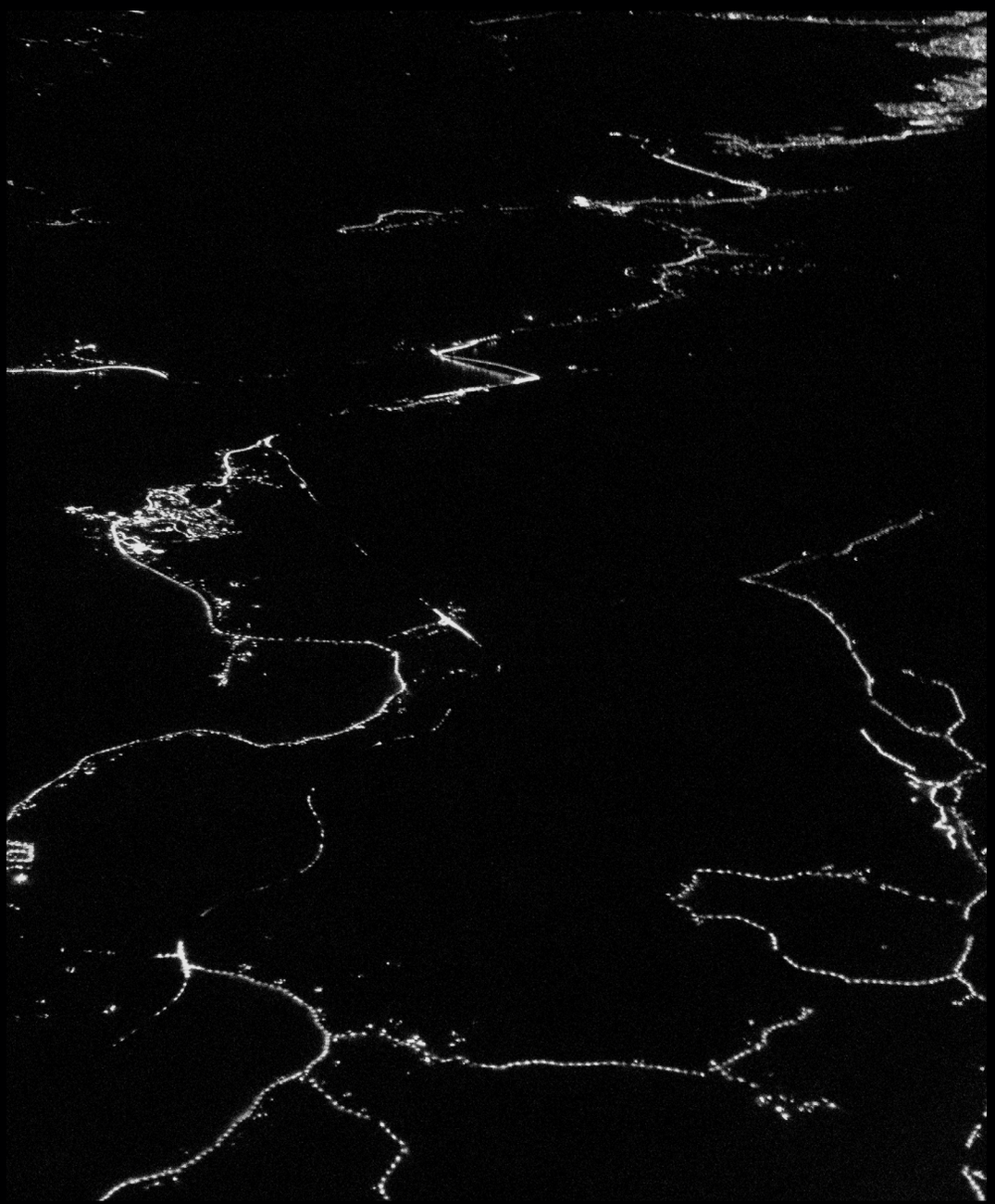
As Smyth et al. (2021) describe, ALAN in marine environments is mainly concentrated in coastal waters, where offshore development and coastal urbanisation coincide. From a bird's eye view, the coastline can be read as a visible boundary where light, human presence, and ecological systems overlap. In a region characterised by extended periods of darkness this line becomes particularly pronounced, appearing as a luminous trace in a dark landscape, see Figure [2.15]. The coastline may be understood as a transformed boundary, in which multiple ecosystems are exposed to shared light conditions. This chapter therefore approaches the coastline as a site of convergence and examines a set of *warning species*, each associated with either the:

[1] *terrestrial realm*
[2] *aerial realm*
[3] *marine realm*

displaying how light (both naturally and artificially) relates to the ecological conditions, see Figure [2.14].

↖ **Figure [2.14].** The coastline as zone of ecological convergence in a diagram.

→ **Figure [2.15].** ALAN around Evenskjær and Harstad, Norway, as captured from a plane, shows how illumination is spatially distributed along the coastline in linear patterns.

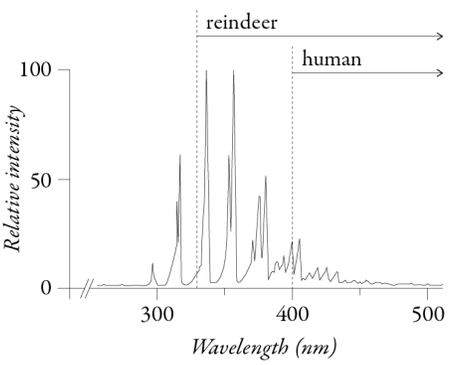


II.9 [1] - TERRESTRIAL REALM: *RANGIFER TARANDUS*

LITERATURE REVIEW

Linear infrastructure, including fences, railways, roads, and power lines, is widely recognised as a source of disturbance to wildlife on land (Berger, 2004; Forman and Alexander, 1998; Fahrig and Rytwinski, 2009). Such infrastructure can affect animal movement through *barrier effects*, which hinder passage, as well as through *avoidance* behavior triggered by the sight, sound, or smell of humans and human-made structures. They are either directly perceived or learned in association with the infrastructure. High-voltage power lines may contribute to both effects, despite their masts typically being spaced tens to hundreds of meters apart and connected by cables suspended more than three meters above the ground, making them neither a direct physical barrier to terrestrial animals nor inherently linked to traffic. Even so, barrier effects have been documented for isolated power lines (Reimers et al., 2007; Tyler et al., 2016).

A reason for this is that ALAN also extends beyond the visible range of the human eye, affecting the ecosystem in ways that humans may not directly perceive. This is particularly relevant for reindeer (*Rangifer tarandus*), whose vision is highly adapted to the dark conditions of the Polar night. During the dark winter months, the colour of reindeer eyes changes from a golden hue in summer to deep blue in winter. This seasonal adaptation enhances night vision under very low-light conditions. As part of this adaptation, reindeer are also capable of detecting ultraviolet (UV) light, outside the human sensory range, see Figure [2.16] (Hogg et al., 2011; Raiter et al., 2014).



As a result, infrastructure that seems visually insignificant to humans may still generate substantial sensory disturbance for reindeer. High-voltage power lines (>66 kV) illustrate this effect. Electrical energy surrounding the cables can ionize nearby air molecules, creating a phenomenon known as *corona discharge*, which emits UV radiation. This UV light may create the perception of movement, potentially causing reindeer to misinterpret it as the presence of predators (Tyler et al., 2016). In addition to serving as physical barriers in the landscape, power lines may also act as persistent sources of light disturbance, influencing movement patterns, habitat use, and barrier behaviour.

These impacts extend beyond ecology, as reindeer are central to the livelihoods, mobility, and cultural identity of indigenous Arctic peoples, including Sámi communities in Norway. Since reindeer herding depends on seasonal migration routes and access to grazing areas (Vitebsky & Alekseyev, 2014), expanding infrastructure and electrification associated with urbanisation may also threaten indigenous ways of life.

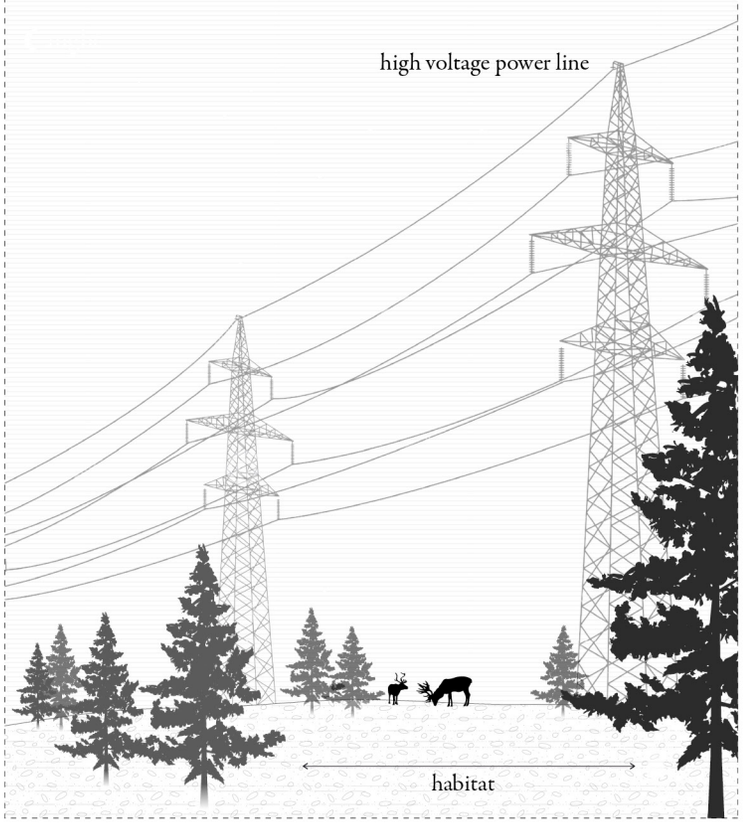
↖ **Figure [2.16].** Spectrogram of corona discharge emission in air, showing that most band heads lie outside the human visual range but within the visual range of reindeer (*Rangifer tarandus*).

Source: adapted from Grum and Costa (1976).

→ **Figure [2.17].** Avoidance of high power voltage lines by reindeer (*Rangifer tarandus*) during the night, due to ultra violet corona dicharge.

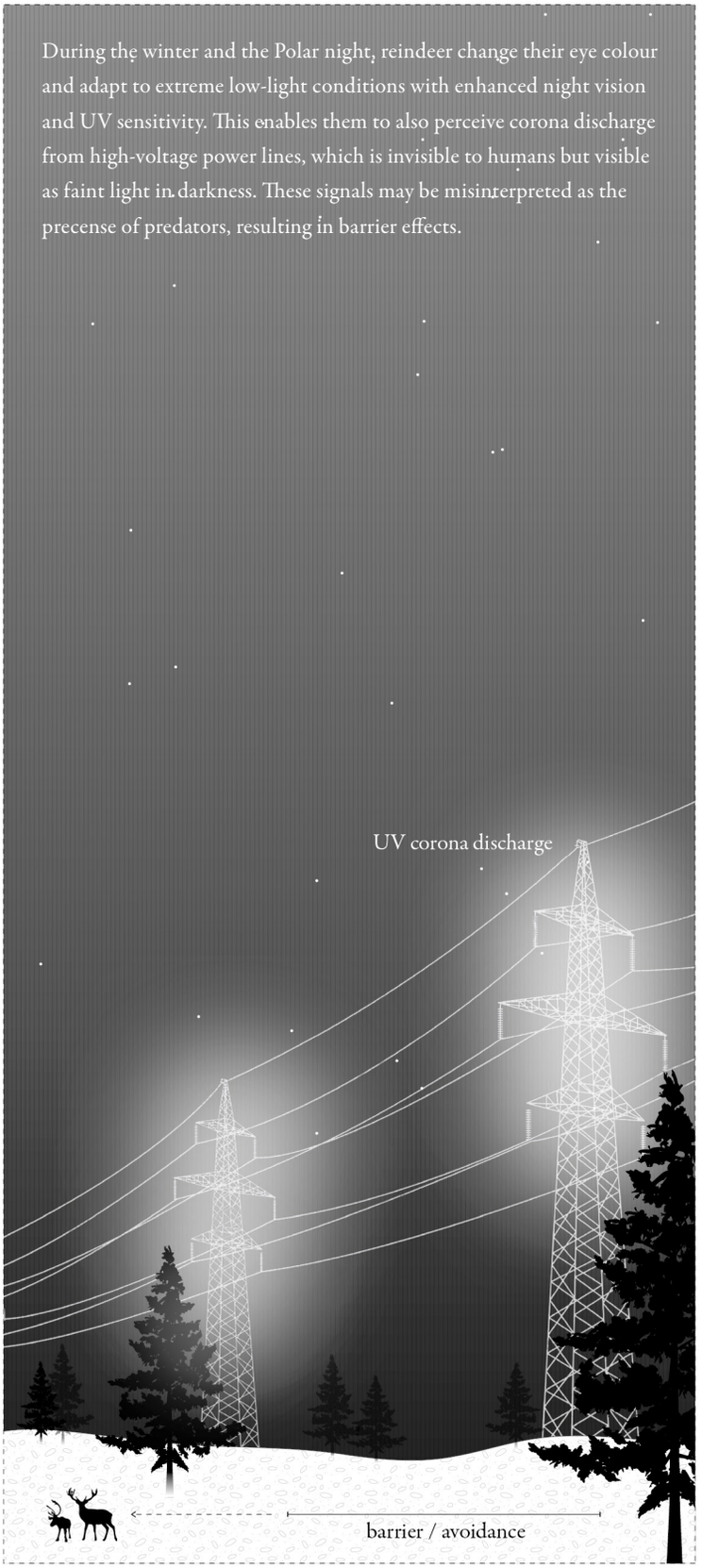
● polar day

During summer conditions, reindeer eyes are adapted to brighter light and exhibit a golden appearance, which is less UV sensitive. Although corona discharge from high-voltage power lines continues to emit UV radiation, these emissions are largely masked by ambient daylight and are less detectable to reindeer.



☾ polar night

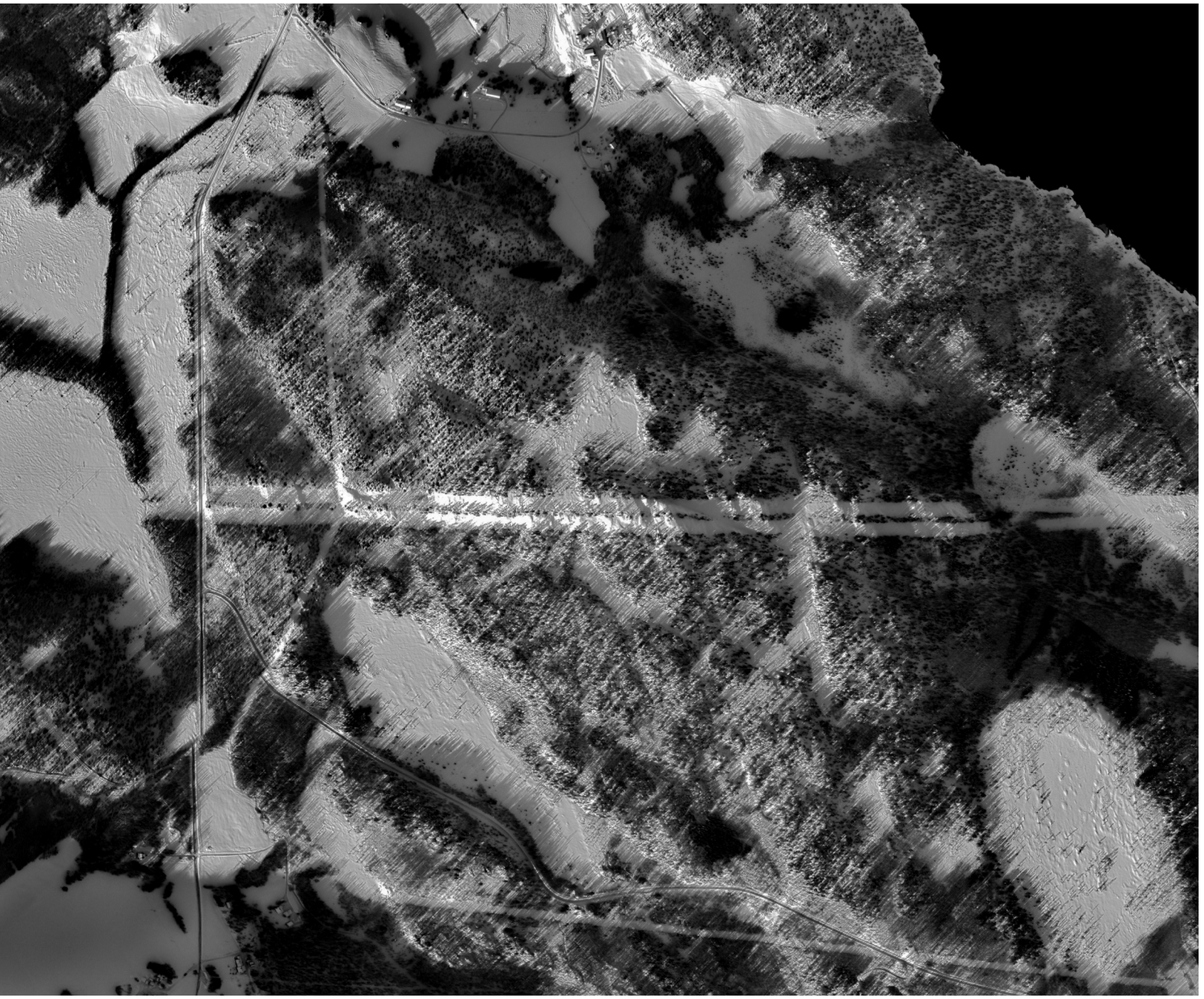
During the winter and the Polar night, reindeer change their eye colour and adapt to extreme low-light conditions with enhanced night vision and UV sensitivity. This enables them to also perceive corona discharge from high-voltage power lines, which is invisible to humans but visible as faint light in darkness. These signals may be misinterpreted as the precense of predators, resulting in barrier effects.

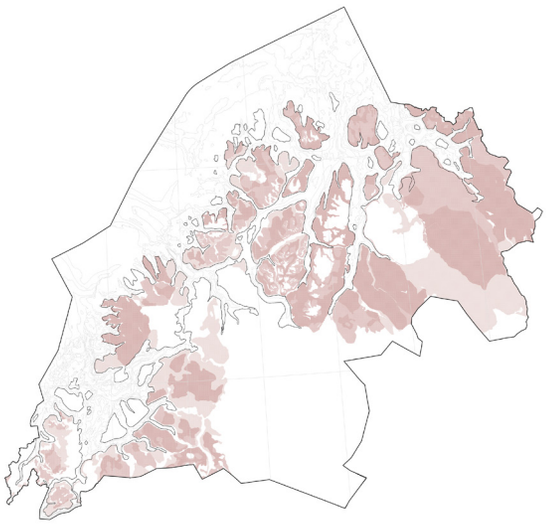




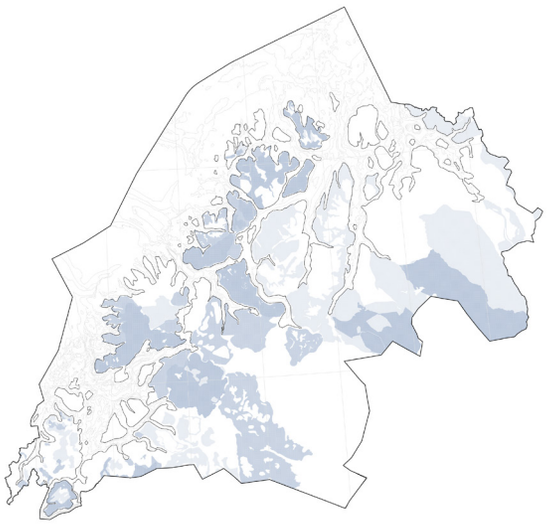
↑ **Figure [2.18].** Power line infrastructure forms a visible barrier in the landscape, however, during the Polar night its impact extends beyond the human visual range.
Location: *Mestervik, Norway*

source: Google Earth Pro





[**A**] Spring and summer pastures



[**B**] Autumn and winter pastures



[**C**] Migration corridors



[**D**] High-voltage power lines
(regional and national network)

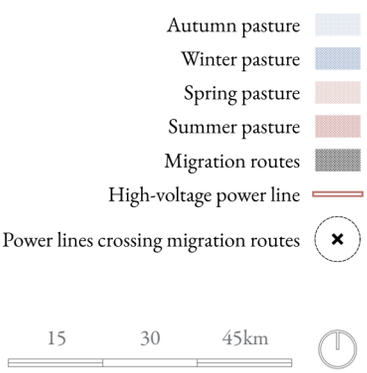
II.9 [1] - MIGRATION ROUTES VS POWER LINES

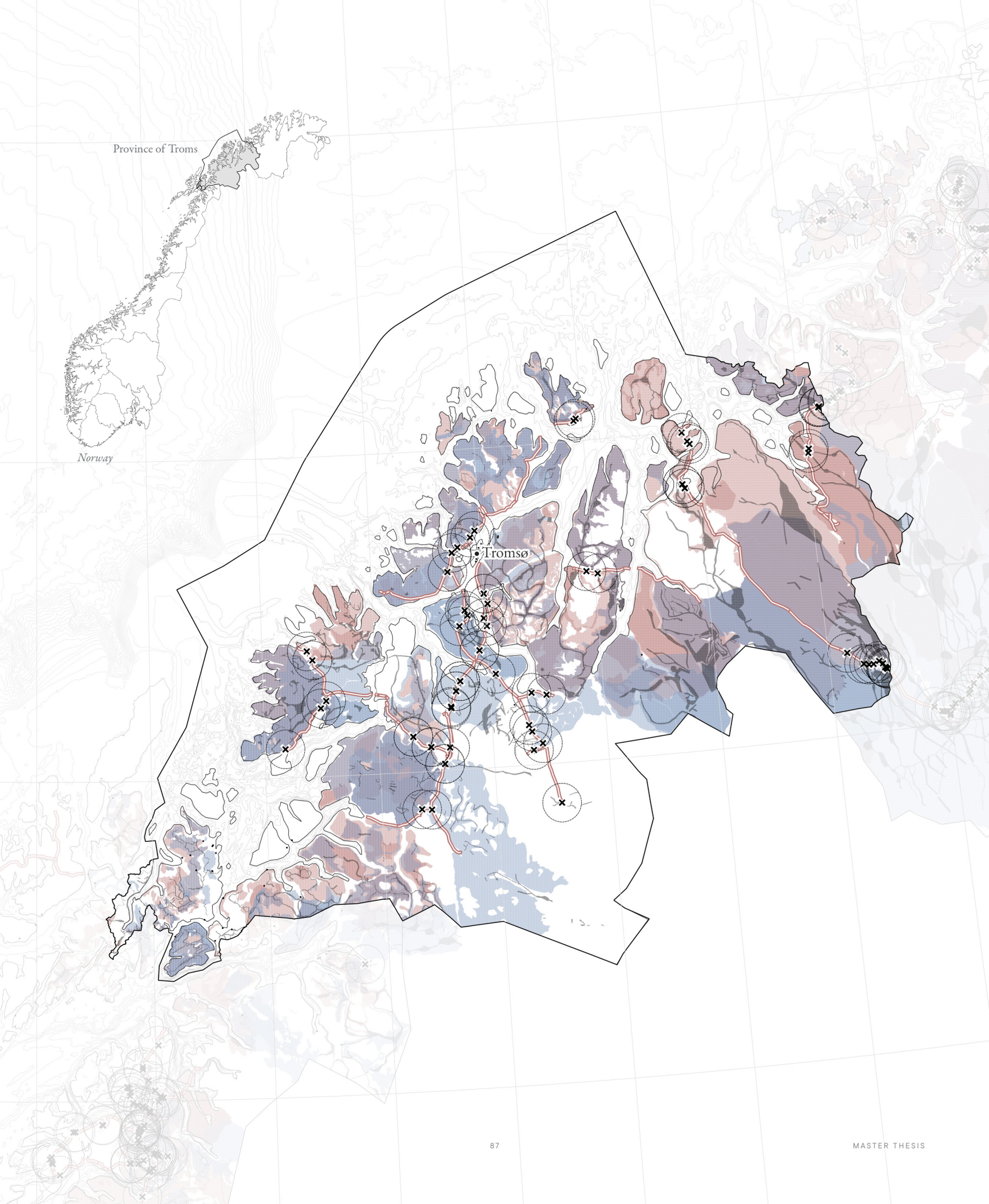
↑ **Figure [2.19].** Maps indicating the reindeer pastures in autumn, winter, spring and summer, their migration routes and the high-voltage power lines.

data: Landbruksdirektoratet, Reindriftsforvaltningen, Norwegian Water Resources and Energy Directorate

→ **Figure [2.20].** Potential impact of corona discharge at points where high-voltage power lines are crossing the migration routes of reindeer between summer and winter pastures.

The maps in Figure [2.19] show the seasonal grazing areas and migration routes of reindeer throughout the year. The migration routes, indicated in black, represent the corridors commonly used for movement between pastures, both within and between seasonal grazing areas. By overlaying reindeer habitat and migration data with high-voltage electricity infrastructure, areas where power lines intersect these migration routes were identified. These locations may represent potential disturbance zones where UV corona discharge from the power lines could contribute to barrier or avoidance behaviour in reindeer. Figure [2.20] highlights these intersection areas within the province of *Troms*.




Province of Troms
Norway
Tromsø

II.10 [2] - AERIAL REALM: *ALLE ALLE*

LITERATURE REVIEW

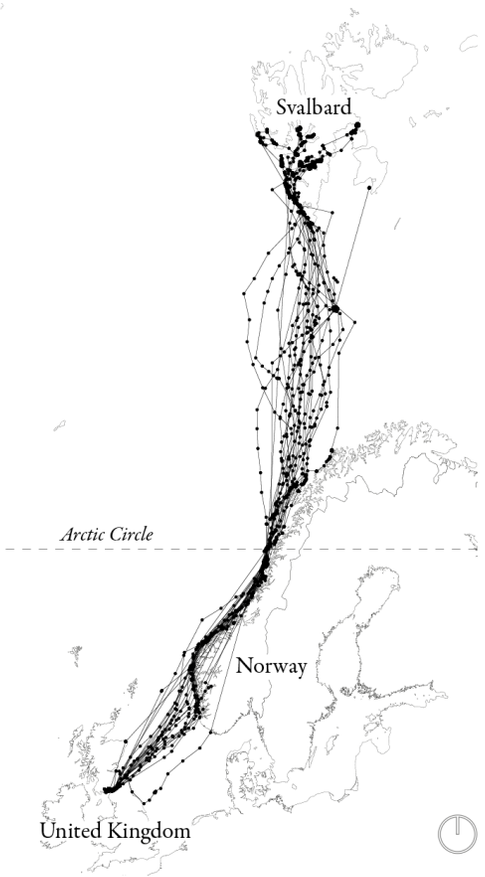
ALAN is increasingly recognised as an anthropogenic disturbance affecting orientation, movement, and habitat use in birds (Longcore and Rich, 2004; Gaston et al., 2013). Its ecological relevance is particularly pronounced in Arctic regions during the Polar night, when natural illumination is extremely limited and visually guided behaviour operates close to the perceptual threshold.

Seabirds commonly use coastlines as spatial reference structures while flying. The linear landscape features provide visual and geomorphological cues that help to navigate, particularly during commuting flights between breeding colonies and offshore feeding areas. During migration, birds also tend to follow coastlines, as these offer a more energy-efficient and reliable route, compared to crossing open water, where wind drift and navigation challenges increase the risks (Alerstam & Pettersson, 1977). Consequently, coastal zones function as key movement corridors. This can also be seen in the migration routes that Barnacle Geese (*Branta leucopsis*) take on their way from the UK to Svalbard (see Figure [2.21]).

Another example can be found in the little auk (*Alle alle*), the most abundant seabird in the Atlantic Arctic, with an estimated population of 40 to 80 million individuals (Egevang et al., 2003). During the summer breeding season, the species is feeding almost exclusively on the lipid-rich Arctic copepod *Calanus glacialis* (Balazy et al., 2023). In autumn and winter, however, these copepods undergo diapause, for which they descend to deeper seas: beyond the diving range of the little auk. As a result, the winter diet of the little auk shifts, with krill (*Thysanoessa species*) becoming the primary prey (Rosing-Asvid et al., 2013). Unlike copepods, krill does not enter diapause.

The little auk, as a visual forager, is capable of operating under dark conditions while continuing predation at sea. Several studies have suggested that Arctic seabirds may utilise weak natural light sources, such as moonlight, starlight and twilight, for navigation. Potentially, even bioluminescent prey cues are utilised while foraging under low-light conditions (Imber, 1975; Johansen et al., 2001; Regular et al., 2011). The little auk is therefore likely adapted to forage within naturally dark marine environments in which only subtle visual cues are available. ALAN may disrupt these conditions by modifying the visual environment under which the species forages. Although the consequences for the foraging behaviour of the little auk remain not fully understood, ALAN may affect the detection of krill.

However, the effects of ALAN as a disruption of seabirds' navigation system are clear. Evidence from seabird-light interactions shows that artificial light sources can act as strong attractors, interfering with orientation and leading to disoriented flight (see Figure [2.22]), the aggregation of birds around illuminated structures, and, in some cases, collisions or grounding events (Balazy et al., 2024).

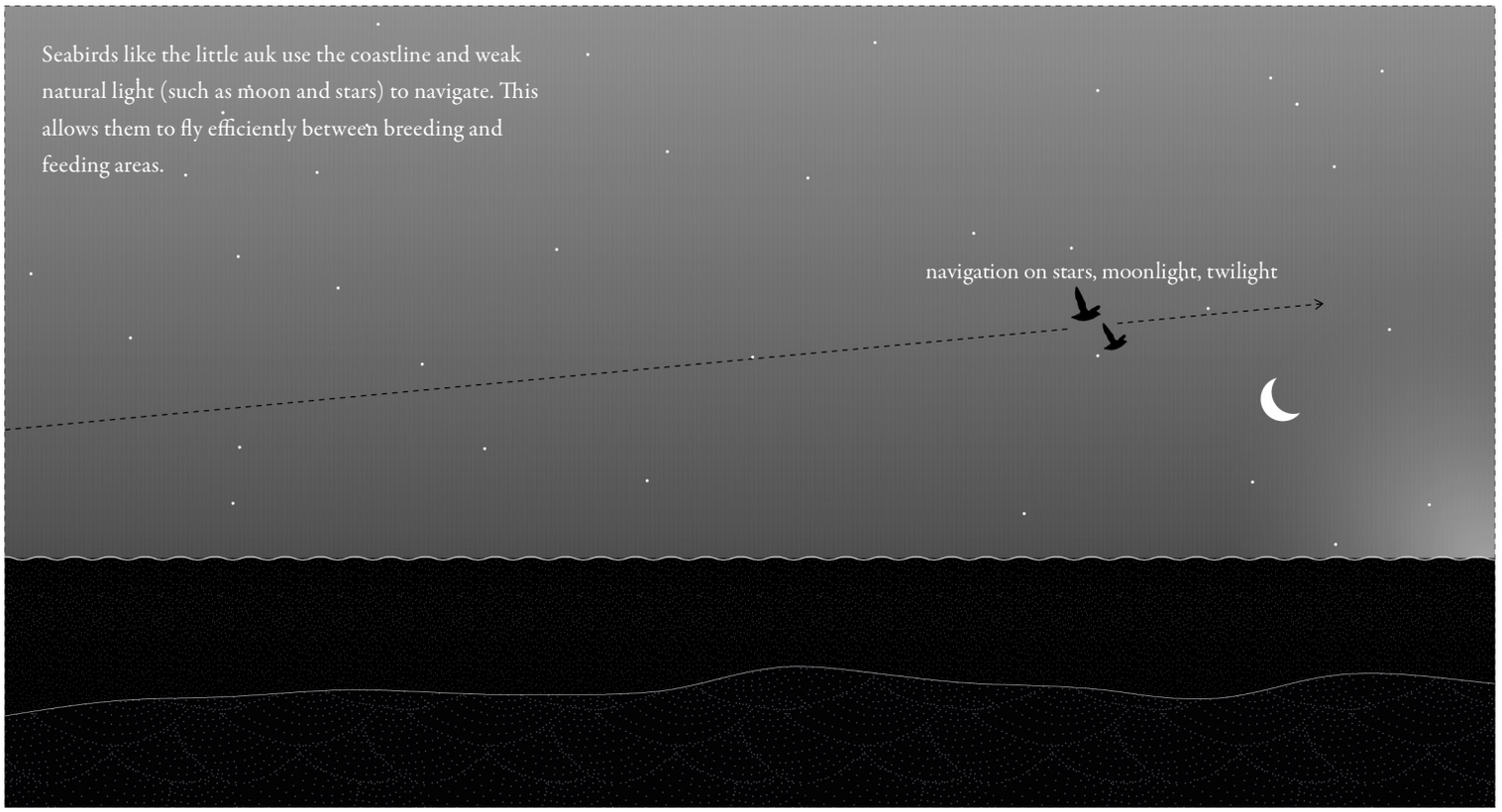


↑ **Figure [2.21].** Migration routes of the Barnacle Gees (*Branta leucopsis*) on their way from the UK to Svalbard, clearly following Norway's coastline.

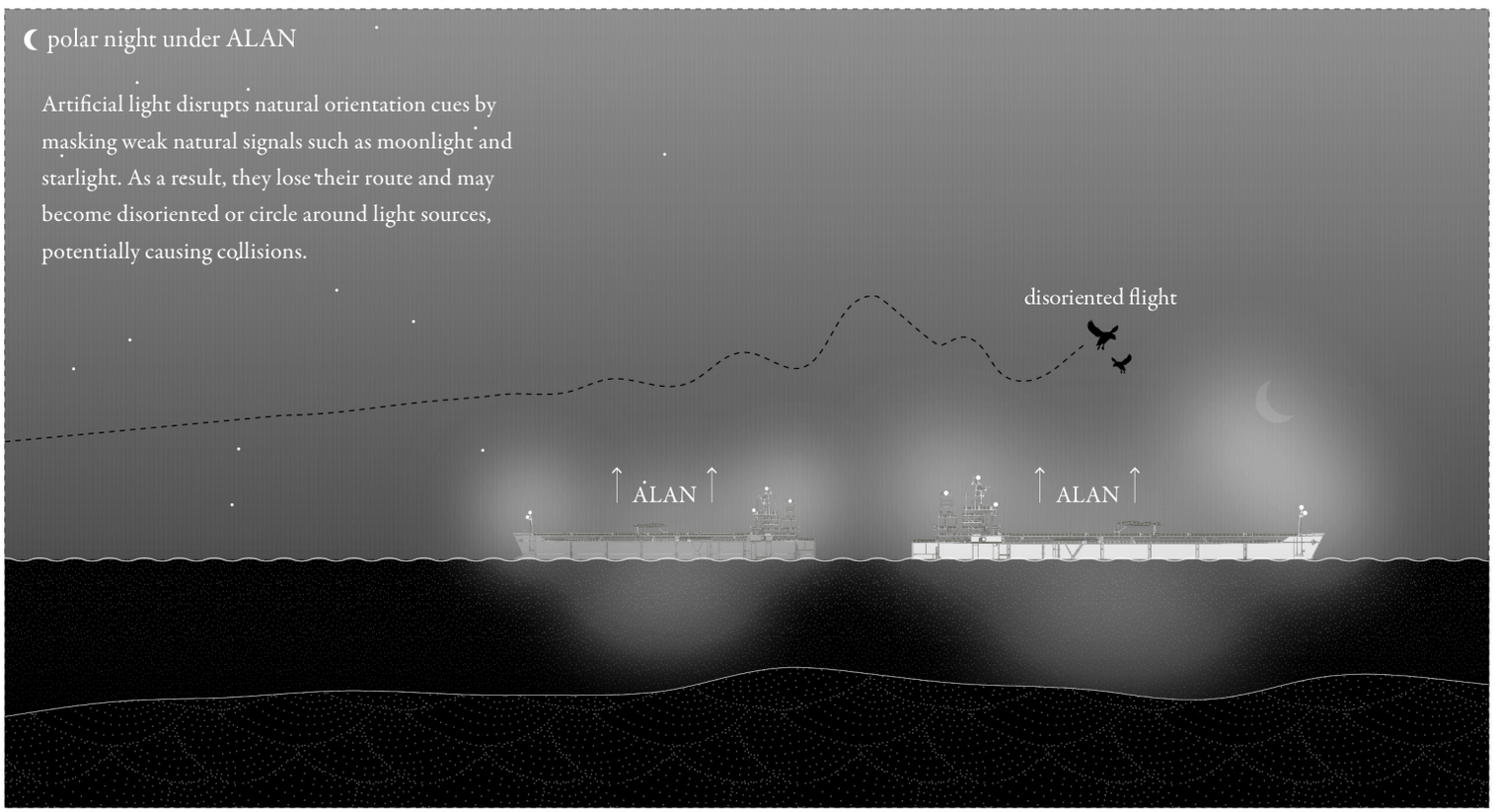
data: Movebank

→ **Figure [2.22].** ALAN interfering with navigation of Arctic seabirds based on natural light conditions.

☾ polar night



☾ polar night under ALAN



II.11 [3] - MARINE REALM: *CALANUS FINMARCHICUS*

LITERATURE REVIEW

As a warning species within the marine realm, zooplankton (in this case *Calanus finmarchicus*) provide a useful lens through which to examine the effects of artificial light at night. One of their most characteristic behaviours is diel vertical migration (DVM). This light-driven movement through the water column happens over a 24-hour cycle. Naturally, zooplankton feed on phytoplankton by ascending towards surface waters at night, where they are using darkness as a form of protection against visually hunting predators.

During daylight hours they descend to deeper, darker layers. This migration is considered the largest daily migration globally (Last et al., 2016) and reflects a balance between feeding opportunities and predation risk, structured by light intensity (Brierley, 2014). The introduction of ALAN alters these conditions. In coastal and offshore environments, artificial light can penetrate the upper layers of the water column up to a depth of 200 meter[1], reducing the darkness that zooplankton rely on for surface feeding. As a result, their DVM may be delayed or reduced, effectively shifting or compressing their feeding window (Berge et al., 2020). At the same time, artificial light can enhance visibility for predators, modifying the interaction between predator and prey within these surface layers (Cohen et al., 2015), see Figure [2.23]. In this way, ALAN directly intersects with the natural light cues that structure DVM, making it a sensitive indicator of the ecological effects.

[1] Physical upper attenuation limit under very clear conditions (Berge et al., 2020).

→ **Figure [2.23].** Section of the sea showing the diel vertical migration (DVM) of zooplankton during the cycle of day and night and the reach of ALAN impacting their migration behaviour.

night

To avoid visual predators like fish, zooplankton migrates towards the water surfaces at night, feeding on surface phytoplankton. The biophysical behaviour (i.e. vertical migration) of zooplankton is mainly driven by light conditions.

eating phytoplankton

day

During the day, when there is more predation activity, zooplankton migrates down vertically. A strategy that balances the need for food with the risk of being eaten. The diel vertical migration (DVM) of zooplankton is considered the largest daily migration on Earth.

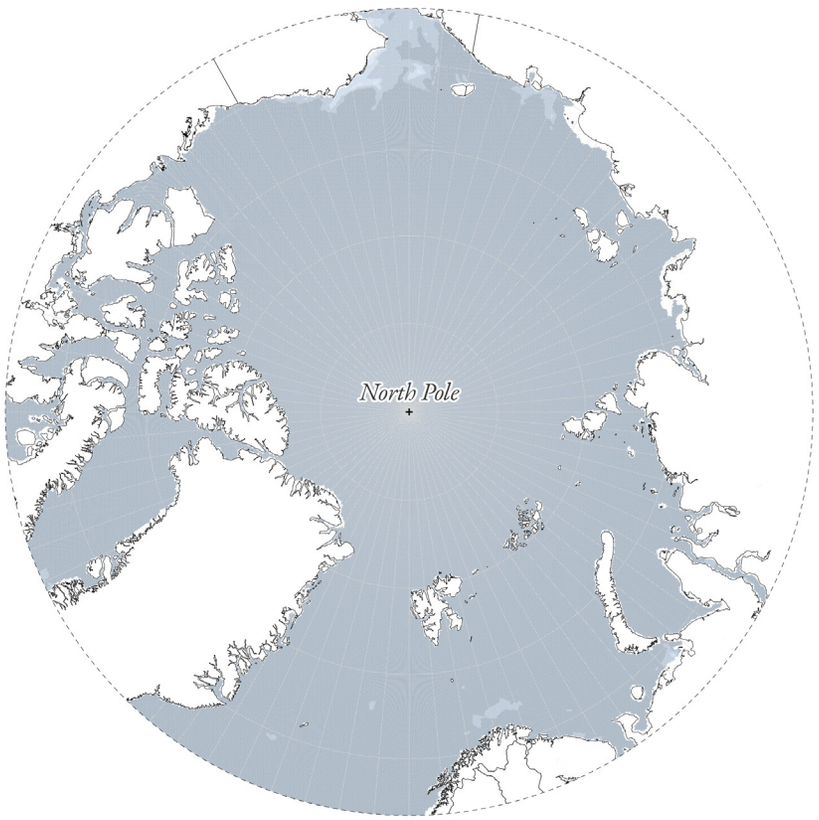
visual predation

diel vertical migration

night

Coastal activities, shipping and extractive industries at sea cause light pollution that travels into the sea up to a depth of 200 meters. It not only disrupts the zooplankton's migration behaviour, it also makes visual predation possible for their predators.

ALAN



WINTER

II.11 [3] - ZOOPLANKTON IN DIAPAUSE

LITERATURE REVIEW

Because much of the Arctic consists of ocean, and the ongoing loss of sea ice is increasing the area of water potentially exposed to human activity, this chapter focuses more closely on zooplankton - as a key indicator species of the marine realm - that play a central role in marine food webs. They serve as the primary link between lower and higher trophic levels, transferring energy from phytoplankton to fish, seabirds, and marine mammals. Their distribution in the water column is therefore closely tied to broader ecosystem dynamics, such as migration of Atlantic Cod or even beyond the marine ecosystem. Next to its trophic function, they are also integral to the ocean's carbon cycle, enabling transfer of CO_2 from atmosphere to deeper ocean layers (Brierley, 2014).

In winter months, when natural light levels are substantially reduced, many zooplankton species shift from a daily migration pattern to a state of diapause. During this period, zooplankton descend to deeper waters and remain there for a longer period, reducing metabolic activity and suspending regular feeding and migration (Baumgartner & Tarrant, 2017). This seasonal redistribution is visible, as measured by Copernicus Marine Service, in vertical profiles of zooplankton concentrations, where they move away from surface layers and accumulate at depth. This diapause-related downward movement in the winter can be seen in Figure [2.24], showing a very low concentration of zooplankton in the Arctic ocean's surface layer, compared to higher concentrations in summer. Differences in summer, between Figures [2.25] and [2.26], are mainly due to sea currents (Haury et al., 1978). Their diapause represents a critical phase, in both the life cycle of zooplankton, but also in the seasonal functioning of the marine ecosystem.

Mole Concentration of Zooplankton (mmol/m³)

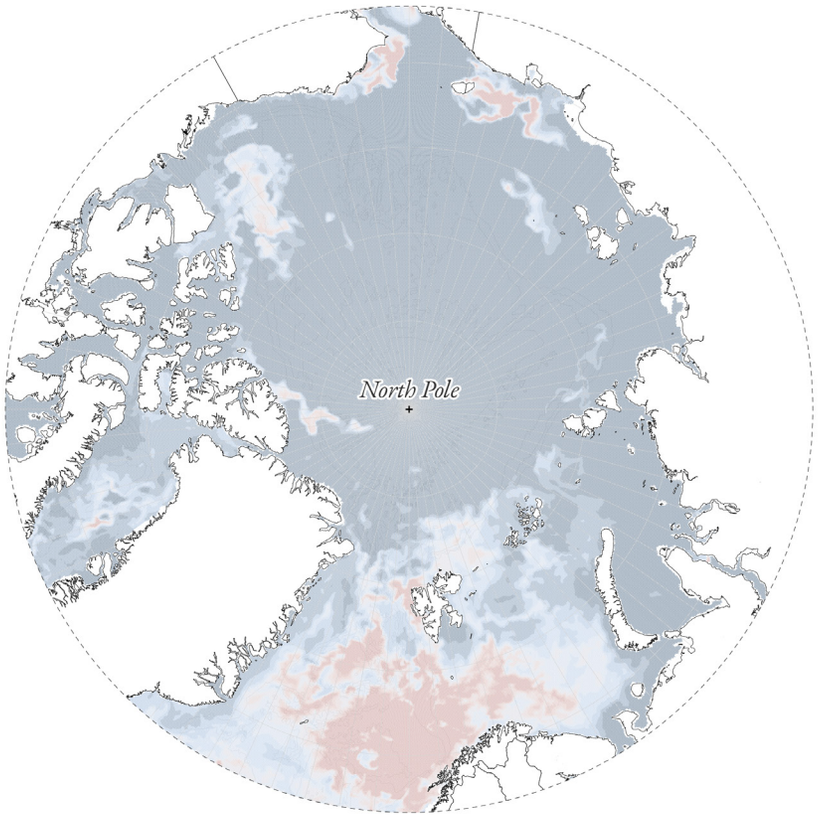
- 0 - 2,5
- 2,5 - 5
- 5 - 7,5
- 7,5 - 10
- 10 - 12,5
- 12,5 - 15
- 15 - 17,5
- 17,5 - 20
- 20 - 22,5
- 22,5+

↖ **Figure [2.24].** Winter condition of mole concentration zooplankton in surface layer (-50 to 0 m depth), as measured on 01-02-2026 .

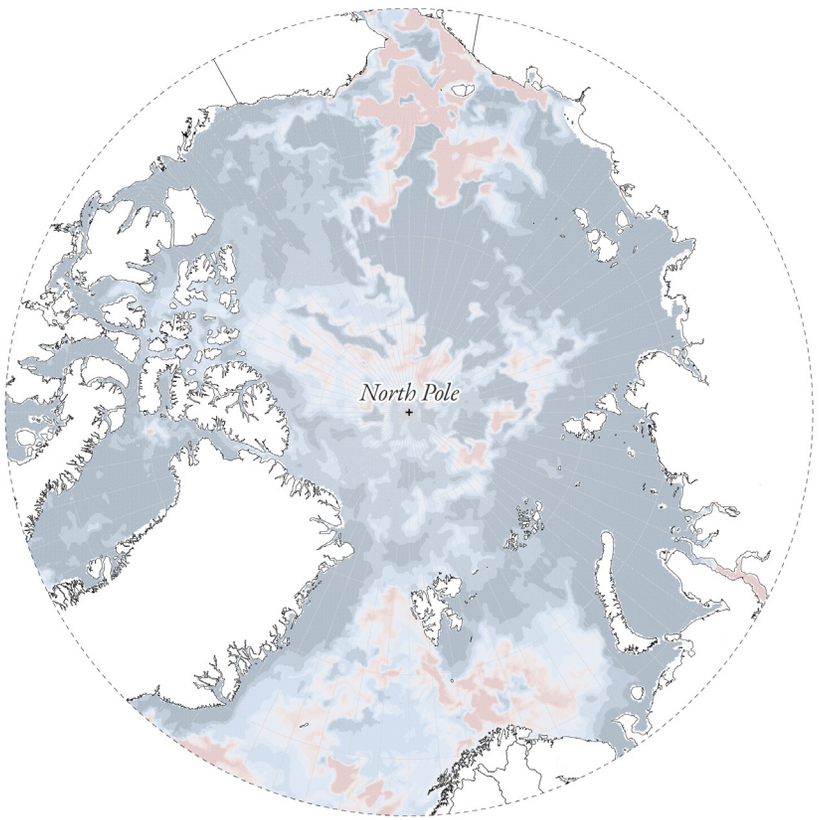
↗ **Figure [2.25].** Summer condition of mole concentration zooplankton in surface layer (-50 to 0 m depth), as measured on 27-05-2025.

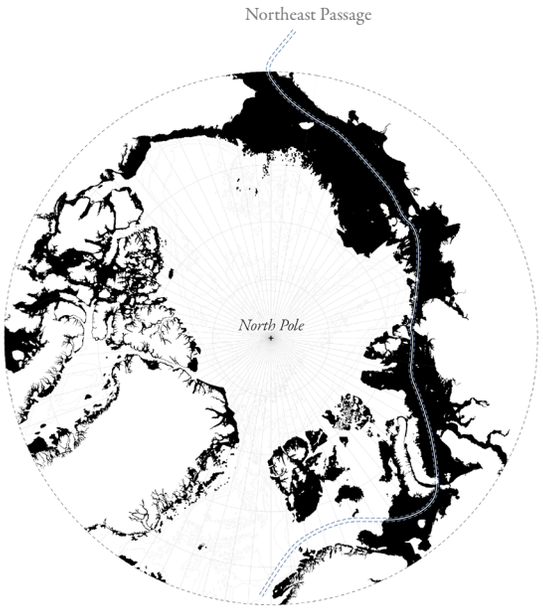
→ **Figure [2.26].** Summer condition of mole concentration zooplankton in surface layer (-50 to 0 m depth), as measured on 22-06-2025.

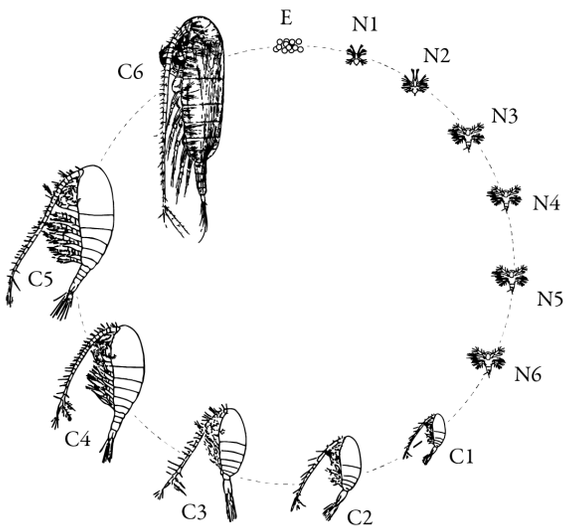
data: Copernicus Marine Service



SUMMER







↖ **Figure [2.27].** Areas with a seabed depth up to 200 meter (in black) - within the potential ecological influence range of ALAN - overlaps strongly with the emerging Northeast Passage.

source: Natural Earth Data

↑ **Figure [2.28].** Life cycle of zooplankton, comprising the egg stage (E), six nauplius stages (N1-6), and six copepodid stages (C1-6) of which C6 is the terminal (adult) stage.

source: adapted from Baumgartner and Tarrant (2017)

↗ **Figure [2.29].** Section of the sea showing the depth of zooplankton (*Calanus finmarchicus)* during their life cycle stages, as measured in the Norwegian Sea ([1]). (section not to scale)

source: adapted from Baumgartner and Tarrant (2017) , Heath et al. (2000)

→ **Figure [2.30].** At depths of up to 200 m, the entire diapause water column can be exposed to ALAN ([2]). (section not to scale)

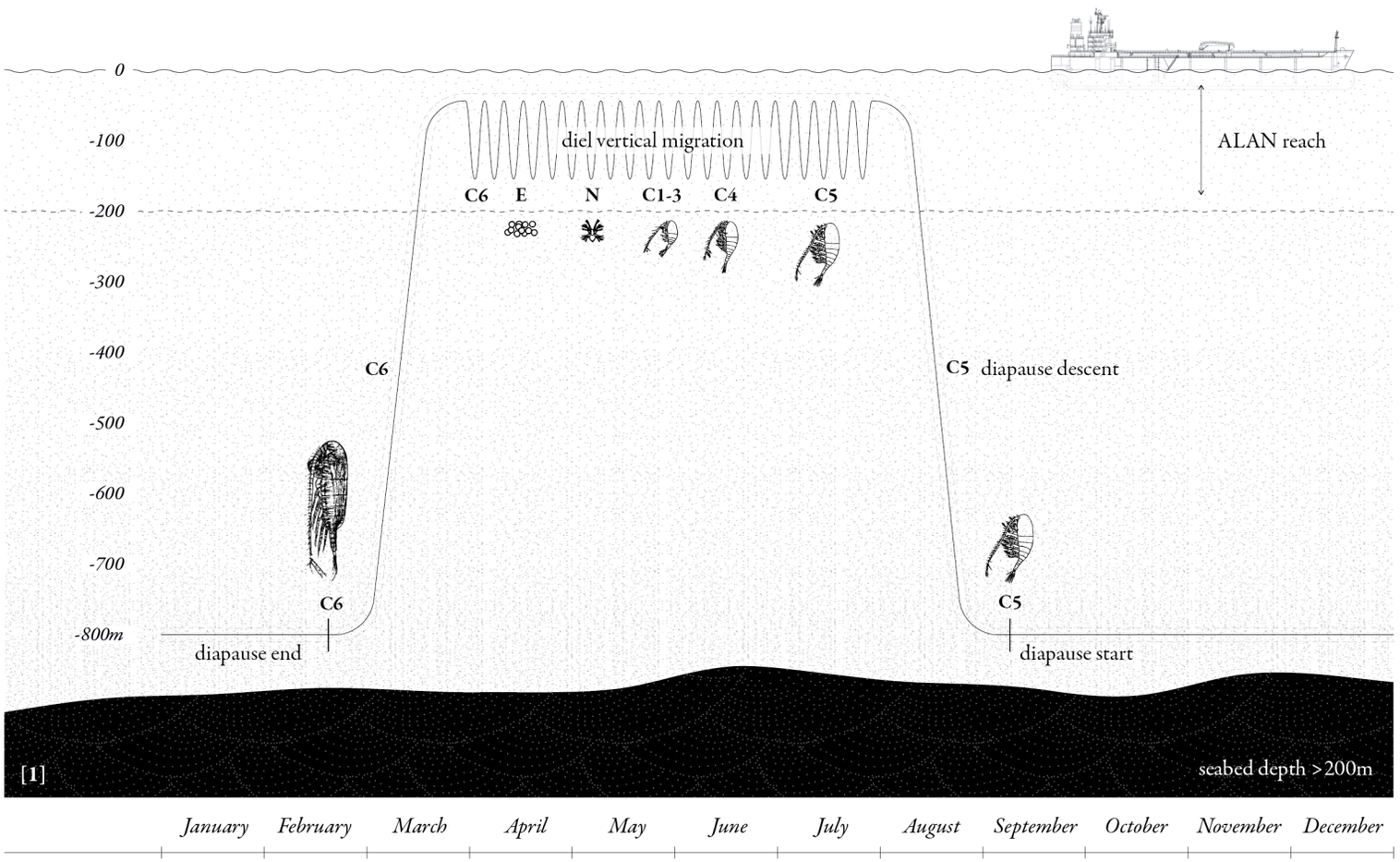
source: Berge et al. (2020)

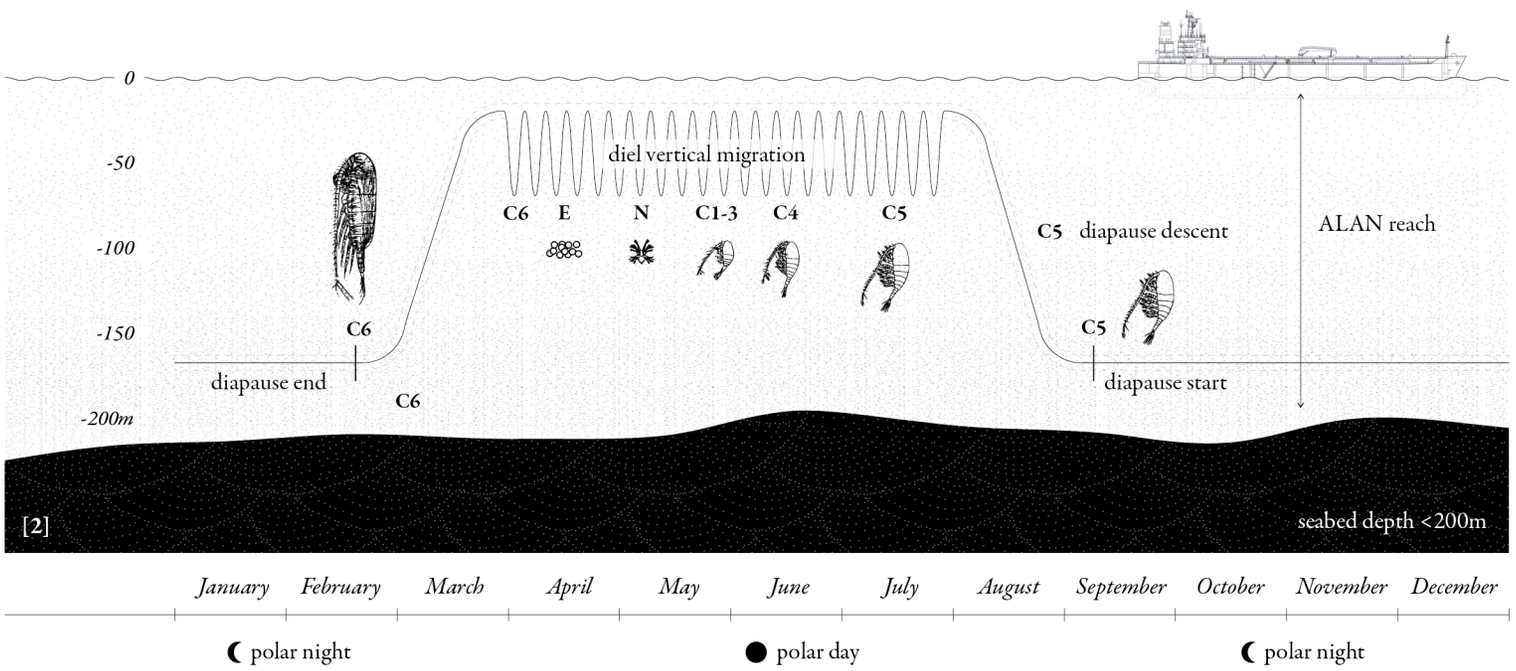
II.11 [3] - ZOOPLANKTON TRAPPED IN A WATER COLUMN

Prior to the diapause phase, energy is stored in the form of lipids, which are then used to maintain basic metabolic functions during winter. These reserves are also required for the resumption of activity in spring, including upward migration and reproduction (Baumgartner & Tarrant, 2017).

If diapause is disrupted, zooplankton may resume activity before sufficient food is available in surface waters. This can reduce survival success and reproduction, as energy reserves may be insufficient. Given the role of zooplankton as a trophic link between primary producers and higher trophic levels, disruption of diapause timing may also affect broader food web dynamics. In Arctic seas where seabed depths do not exceed 200 meter, the vertical extent of the water column falls within the range over which ALAN may still exert ecological influence. In these areas, zooplankton undergoing diapause may remain within a water column through which artificial light from surface sources could possibly propagate across the entire depth. By overlaying marine areas with a depth up to 200 meters with the emerging shipping route of the Northeast Passage, a direct threat of emerging ALAN on zooplankton becomes visible, see Figure [2.27].

As a result, they become effectively trapped within a light-affected habitat, where artificial light at night alters natural light gradients within the water column. It therefore potentially influences the signals that regulate this critical environment of the marine ecosystem.





polar night polar day polar night



point scale based on relative value

low · • • • • high

Surface solar radiation (W/m²)
Sea ice thickness (m)
Chlorophyll (mg/m³)
Dissolved oxygen (mmol/m³)
Dissolved inorganic carbon (mmol/m³)
Salinity (‰)
Sea water potential temperature (°C)
Sea floor potential temperature (°C)
Sea floor depth (m)

→ **Figure [2.31].** The body of the Arctic Ocean as a complex multi-layered biophysical system through a zonal 9-point gridanalysis.

data: Copernicus Marine Service

II.12 - THE ARCTIC OCEAN: A COMPLEX MULTI-LAYERED BODY

The impact of ALAN on zooplankton, used earlier as a representative warning species, illustrates the broader complexity of the Arctic Ocean. Conclusively, the Arctic Ocean can be understood as a highly complex, multi-layered system in which fundamental ecological and physical processes intersect. Environmental variables structuring the Arctic, such as dissolved inorganic carbon, salinity or chlorophyll (shown in Figure [2.31]), do not operate isolatedly. Instead, they form interconnected layers that together describe a multi-demensional organised environment.

Within this body of the Arctic ocean, processes such as diel vertical migration demonstrate how biological activity is embedded within these physical and chemical gradients, moving through a system shaped by variations in temperature, nutrient availability, and light conditions. When these elements are visualised through overlapping spatial datasets, the Arctic Ocean emerges as a system composed of interacting but distinct layers, each representing different dimensions of environmental condition and ecological potential.



II.13 - THE ANTHROPOSPHERE

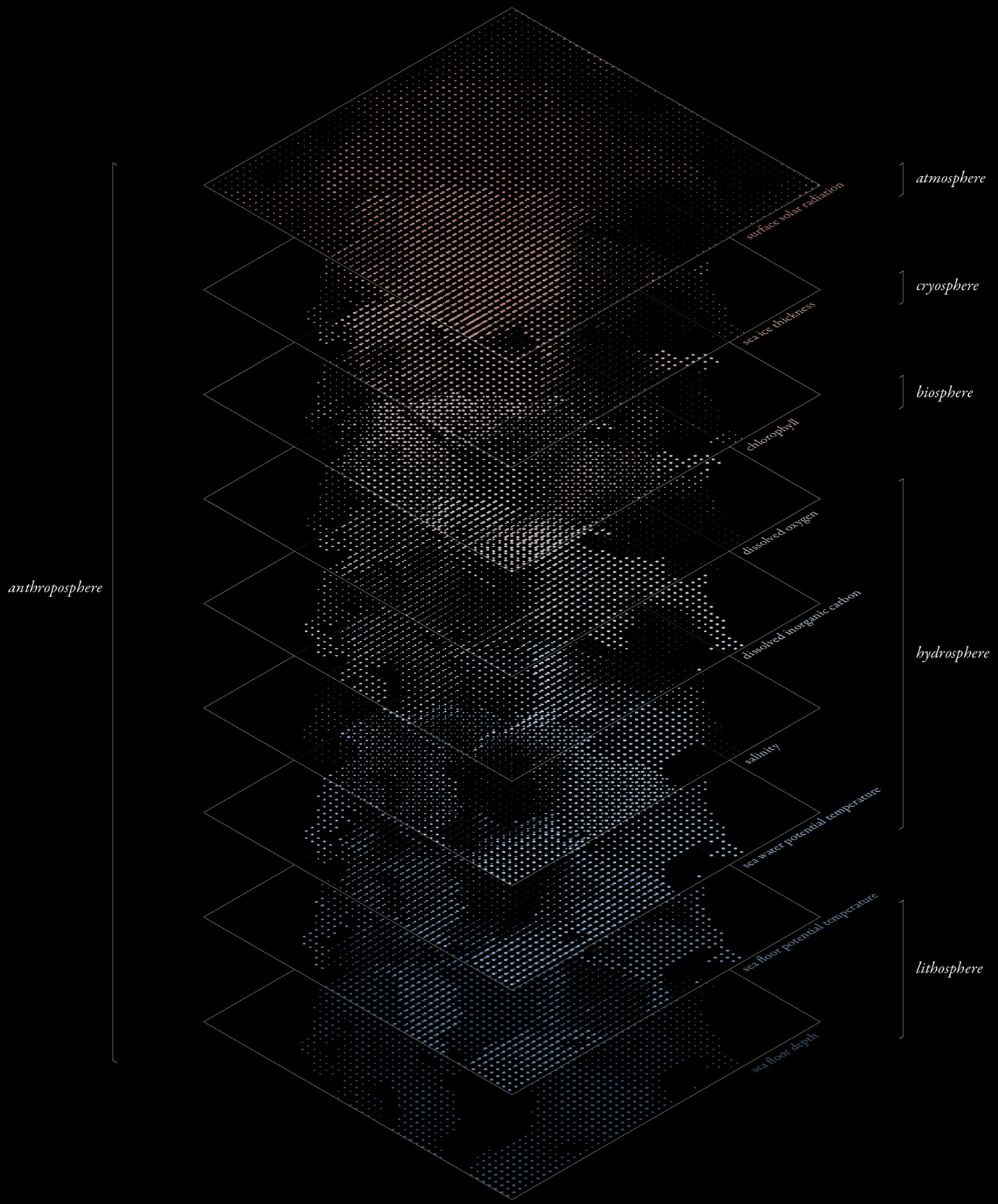
Through axonometric representation, the overlapping datasets from Figure [2.31] are separated and elevated. This allows the Arctic Ocean to be read not only as a composite surface, but as a stratified system composed of the atmosphere, cryosphere, hydrosphere, biosphere, and lithosphere (Figure [2.32]). While each of these domains operates through distinct processes, they remain closely interlinked, forming a coherent whole. Positioned within this framework, this research approaches artificial light at night as an expression of the anthroposphere: the part of Earth influenced by human activity (Steffen et al., 2011).

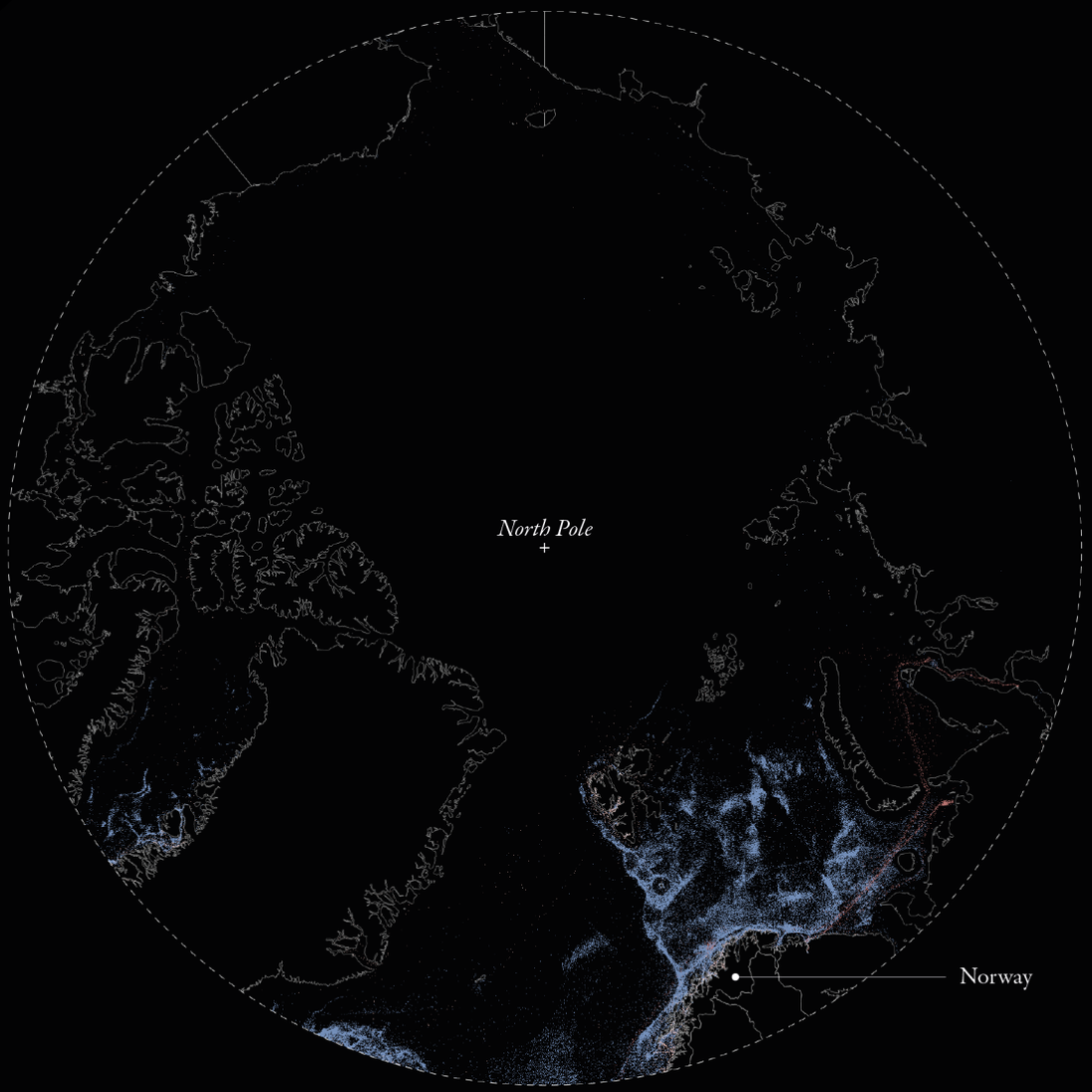
ALAN does not act on a single domain alone, but cuts across and interferes with all of them. While these environmental layers are already deeply interconnected, the anthroposphere does not constitute a separate layer within this system. Instead, it operates across all layers simultaneously.

In this sense, ALAN can be understood as a far-reaching influence within the Arctic marine system, showing that anthropogenic activity is not an additional layer alongside natural processes, but is embedded within them and shapes how they function.

→ **Figure [2.32].** Axonometric representation of the Arctic Ocean as a stratified system, illustrating that the anthroposphere is not a layer in the system but is embedded within them.

data: Copernicus Marine Service


anthroposphere
surface solar radiation
sea ice thickness
chlorophyll
dissolved oxygen
dissolved inorganic carbon
salinity
sea water potential temperature
sea floor potential temperature
sea floor depth
atmosphere
cryosphere
biosphere
hydrosphere
lithosphere



[A] Leisure vessels
[B] Passenger vessels
[C] Oil & gas vessels
[D] Fishing vessels

II.14 - PARS PRO TOTO: NORWAY

As shipping is increasing rapidly, Arctic shipping routes are a clear indicator for human activity in the region, reflecting both environmental change and expanding infrastructural presence. Figure [2.33] illustrates how Arctic shipping from 2015 to 2020 concentrated along the coastal waters of Norway.

Within this context, the Norwegian Arctic is used in this thesis as a *pars pro toto*.

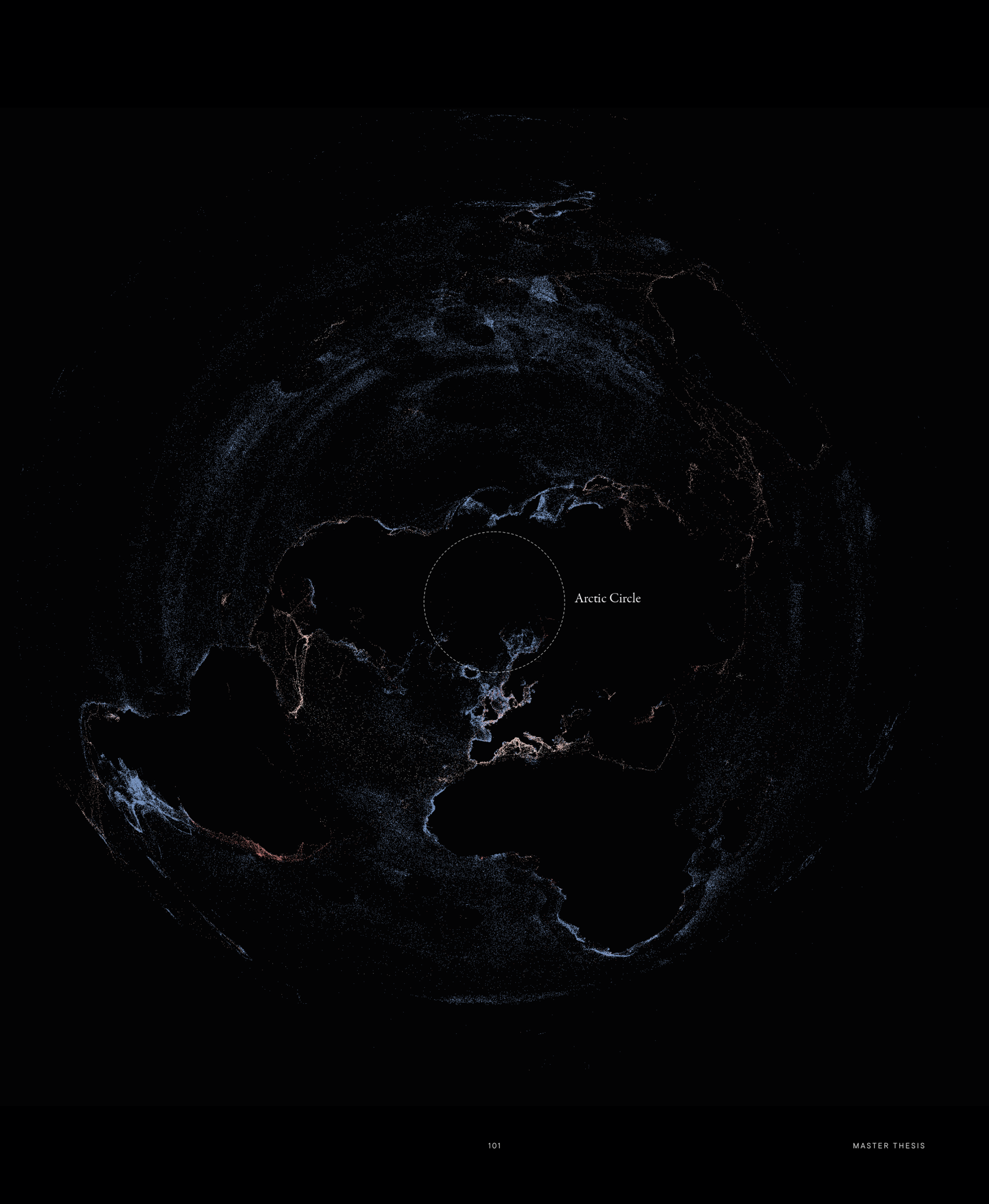
Not as a representation of the Arctic as a whole, but as an entry point through which broader Arctic dynamics can be examined in greater detail.

↖ **Figure [2.33].** Arctic shipping density (2015-2020) per sector, showing accumulation in Norwegian coastal waters.

data: World Bank Group

→ **Figure [2.34].** Global shipping density (2015-2020) per sector.

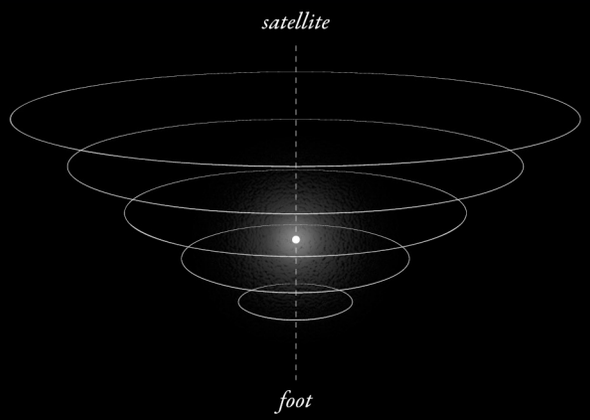
data: World Bank Group


Arctic Circle

ACT III

THE NORWEGIAN PARADOX - REVISITED

Light is culturally associated with safety or prosperity, and darkness with isolation or danger. As the Arctic is a territory governed by prolonged darkness, does it reveal the opposite to be equally true: darkness as safety and light as danger?



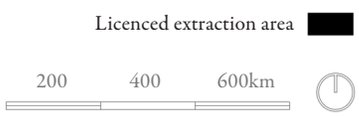
III.1 - NORWEGIAN OIL

In 2015, the Paris Agreement was signed, committing globally to limit the increase of temperature to below 2°C, compared to pre-industrial levels, while even pursuing efforts to restrict it to a maximum of 1.5°C. Every five years, all participating countries are required to submit Nationally Determined Contributions (NDCs), in which they outline their climate mitigation targets and policy measures (United Nations, 2015). At the COP30 in Brazil in 2025, countries have presented updated or revised NDCs, setting out objectives extending to 2035. The European Union is broadly on track to reduce greenhouse gas emissions by 55% by 2030 relative to 1990 levels, and in its revised NDC it aims for a reduction of between 66.25% and 72.5% by 2035 compared with 1990 levels (European Council, 2025).

Besides the international climate commitments, significant variation remains in how countries combine climate policy with economic structure. Norway is an illustrative case in this regard. Norway is widely regarded as an environmentally progressive country with a strong green identity (Gubrium, 2024). Its electricity system is almost entirely based on renewable hydropower, making it one of the least carbon-intensive in the world.
It also has one of the highest rates of electric vehicle adoption globally, reflecting a strong national commitment to transport electrification and emissions reduction.

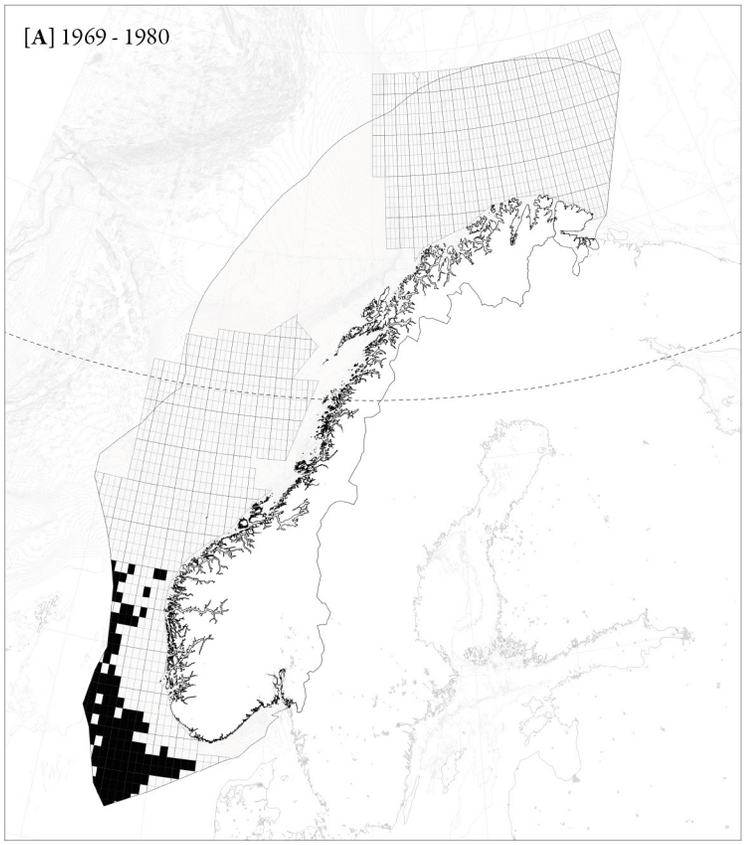
In addition, Norway has consistently invested in climate-related technologies and policies aimed at supporting long-term sustainability (IEA, 2022), reinforcing its reputation as a leader in environmental governance. At the same time, this contrasts sharply with the structure of its economy. Norway is among the wealthiest countries globally, with a GDP per capita of rougly €85,000 (SSB, 2025). A large share of this wealth is derived from oil and gas production in the North Sea.

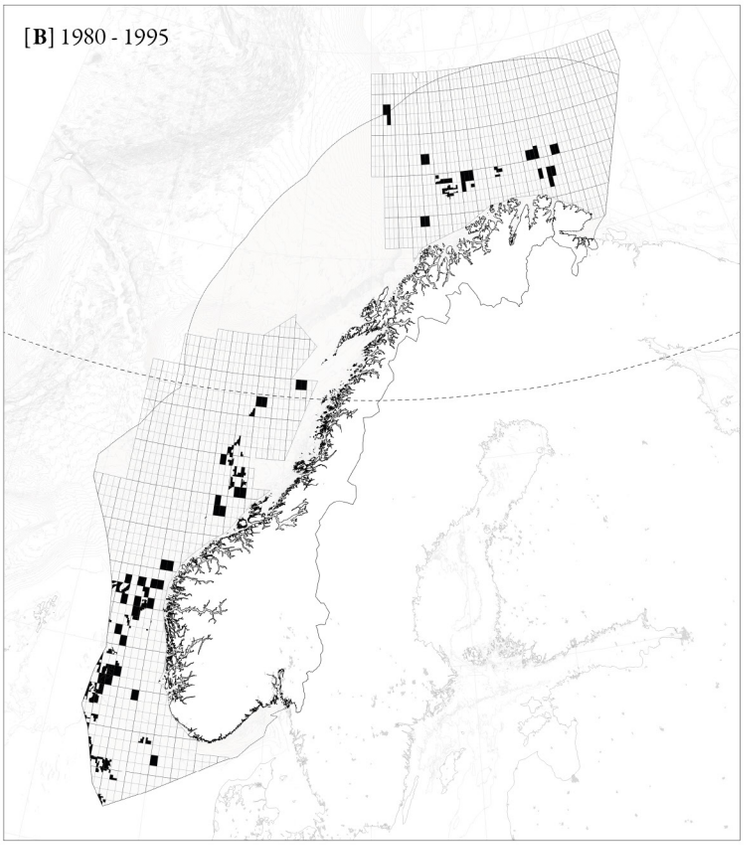
Although major exploration began after the 1969 discoveries, licensing of extraction areas has remained ongoing, including a substantial number of new licences issued above the Arctic circle within the last fifteen years, as shown in Figure [3.1].

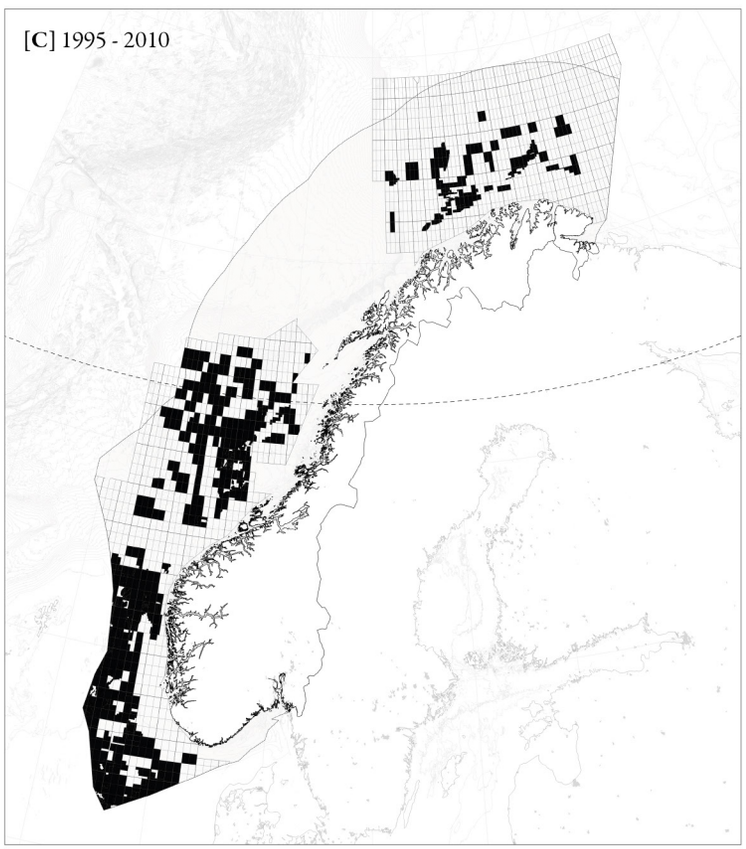


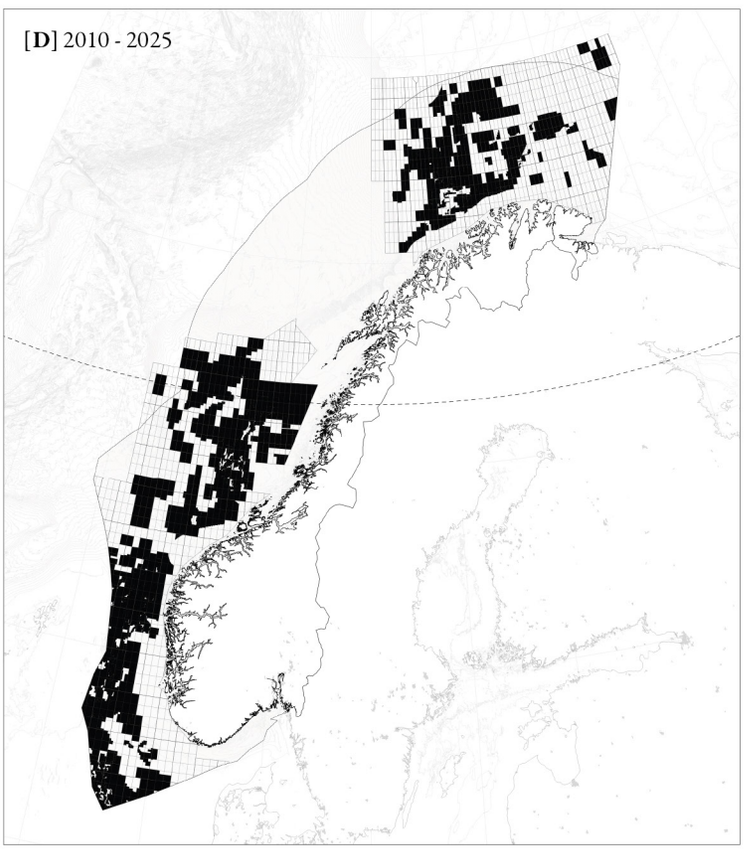
→ **Figure [3.1].** Opening of Norwegian offshore oil and gas extraction licences over time.

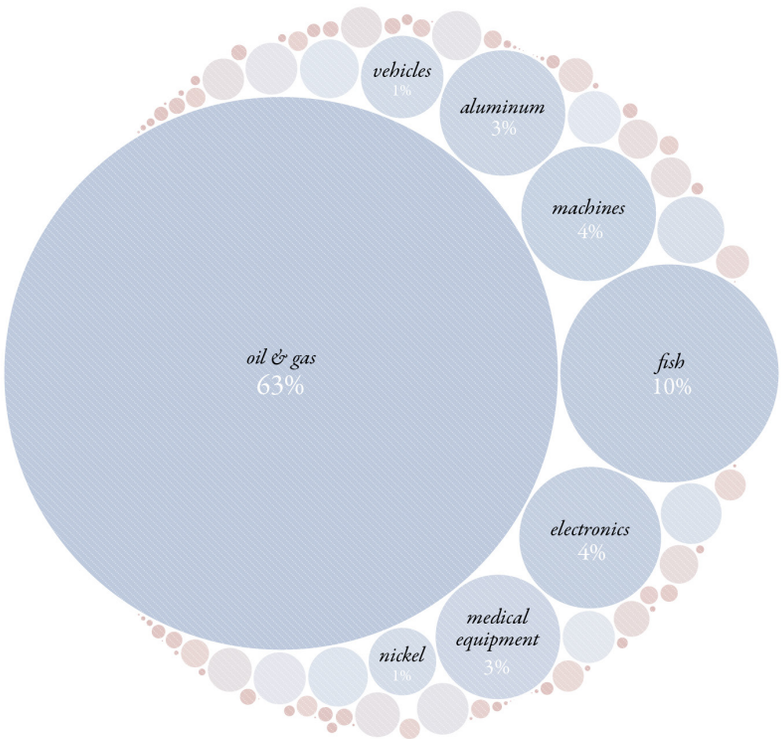
data: Norwegian Offshore Directorate


[A] 1969 - 1980


[B] 1980 - 1995


[C] 1995 - 2010


[D] 2010 - 2025



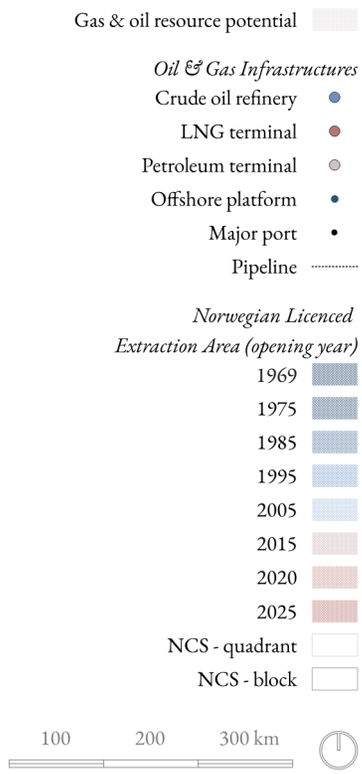
NORWEGIAN EXPORT IN 2025

III.2 - THE NORWEGIAN PARADOX

Furthermore, Equinor - Norway's main oil and gas company - is majority-owned (67%) by the Norwegian government (Equinor, 2024). Despite Norway's reputation, the petroleum sector remains central to the Norwegian economy, accounting for around 22% of its GDP and roughly 63% of its export earnings (SSB, 2026). This structural dependence highlights the continued importance of the oil & gas industry within an otherwise highly developed and environmentally ambitious country.

It is this duality that gives rise to what is commonly referred to as one of the *Norwegian paradoxes:*

While Norway is widely recognised as a leader in climate action, with nearly all of its electricity generated from renewable hydropower and strong support for low-emission transport, its economy remains heavily dependent on oil and gas production, which continues to provide a major share of national income and export earnings.

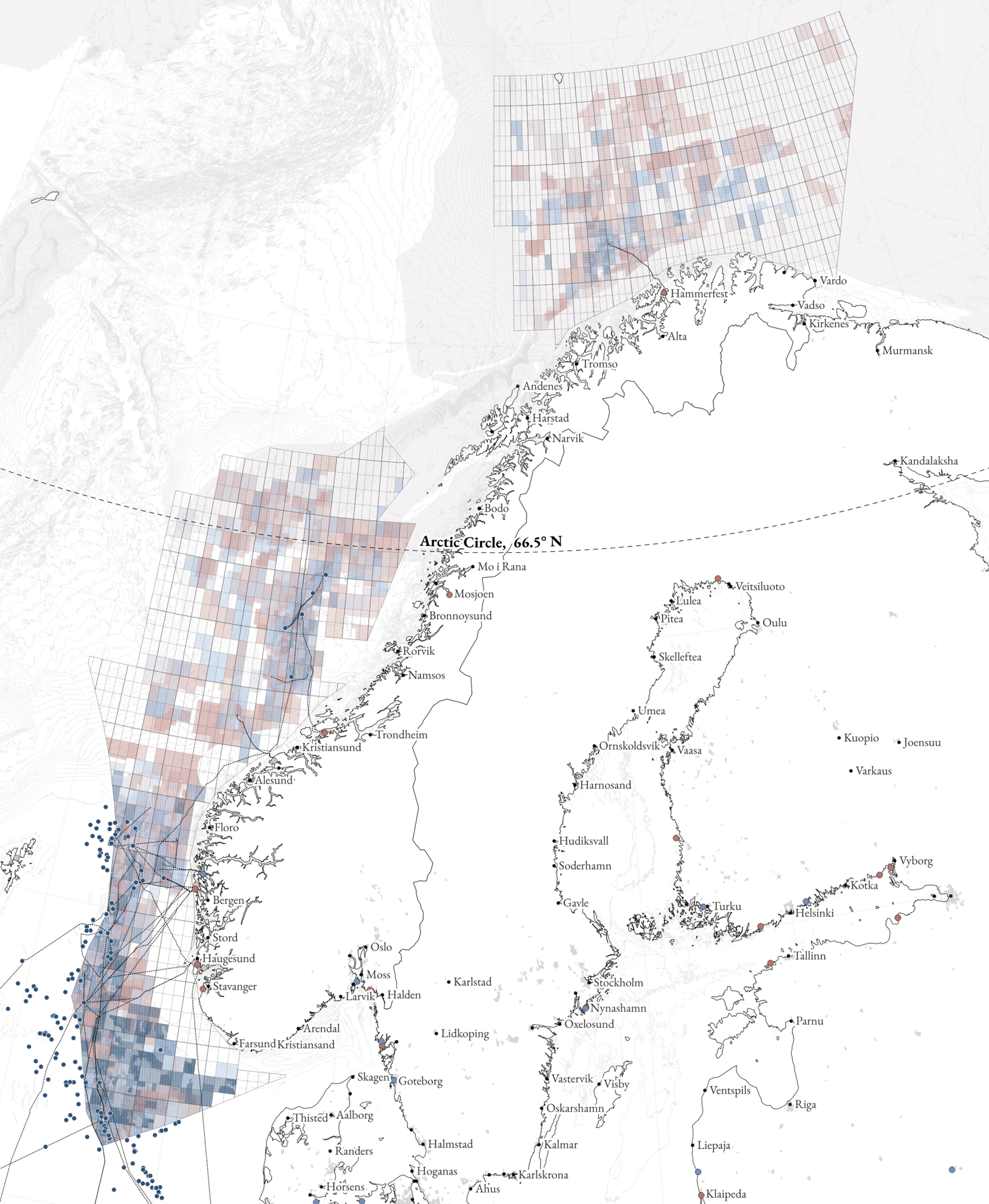


↖ **Figure [3.2].** Norwegian Export in 2025, as a percentage per sector of a total export of approximately €150 billion.

source: Trading Economy

→ **Figure [3.3].** Norwegian oil and gas industry: (in)active licences, oil platforms, pipelines, LNG facilities and petroleum terminals.

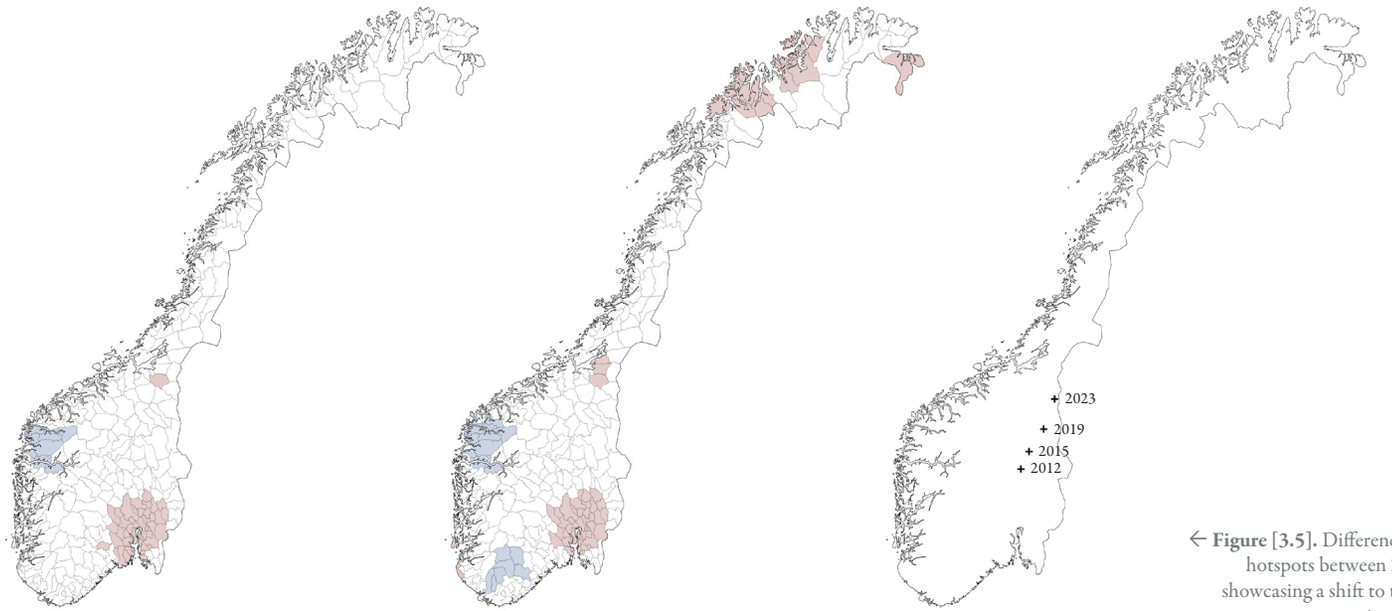
data: Norwegian Offshore Directorate, Openstreetmap


Vardo
Hammerfest
Vadso
Kirkenes
Alta
Murmansk
Tromso
Andenes
Harstad
Narvik
Kandalaksha
Bodo
Arctic Circle, 66.5° N
Mo i Rana
Mosjoen
Veitsiluoto
Lulea
Pitea
Oulu
Bronnoysund
Skelleftea
Rorvik
Namsos
Umea
Trondheim
Kristiansund
Ornskoldsvik
Vaasa
Kuopio
Joensuu
Alesund
Varkaus
Harnosand
Floro
Hudiksvall
Soderhamn
Vyborg
Kotka
Bergen
Gavle
Turku
Helsinki
Stord
Oslo
Tallinn
Haugesund
Moss
Karlstad
Stockholm
Stavanger
Larvik
Halden
Nynashamn
Oxelosund
Parnu
Arendal
Lidkoping
Farsund
Kristiansand
Skagen
Goteborg
Vastervik
Visby
Ventspils
Thisted
Aalborg
Oskarshamn
Riga
Halmstad
Kalmar
Liepaja
Randers
Hoganas
Karlskrona
Horsens
Ahus
Klaipeda



↑ **Figure [3.4].** Skjelnan Depot: a fuel storage and distribution facility just north of Tromsø.

source: Google Earth Pro



[A] 2015

[B] 2023

[C] economic centre of gravity

← **Figure [3.5].** Differences in economic hotspots between 2015 and 2023, showcasing a shift to the north of the economic centre of gravity.

data: adapted from Li et al. (2026)

III.3 - SHIFT TO THE NORTH

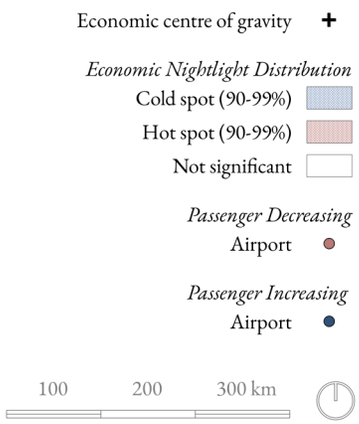
Building on the Norwegian paradox, patterns observed in nighttime satellite data reveal an economic shift to the north: The increasing night time light radiance of northern regions points to a spatial shift of economic activity (Li et al., 2026). In this analysis, hotspots refer to areas with significant clusters of high light intensity values. Cold spots indicate clusters of persistently low or declining intensity. Over time, satellite observations (NASA VIIRS) show the emergence of light hotspots across northern Norway, suggesting that economic activity is not confined to traditional southern hubs like Oslo or Stavanger.

Instead, the north is revealing increasing use of ALAN, and reflects industrial development and infrastructural expansion. In research, by Li et al. (2026) - based on night time light data - is shown that the economic centre of gravity of Norway has moved north by a distance of 112.3 km, see Figure [3.5].

Norway has experienced the largest shift among the Nordic countries, compared with shifts of 101.2 km in Sweden and 23.4 km in Finland.

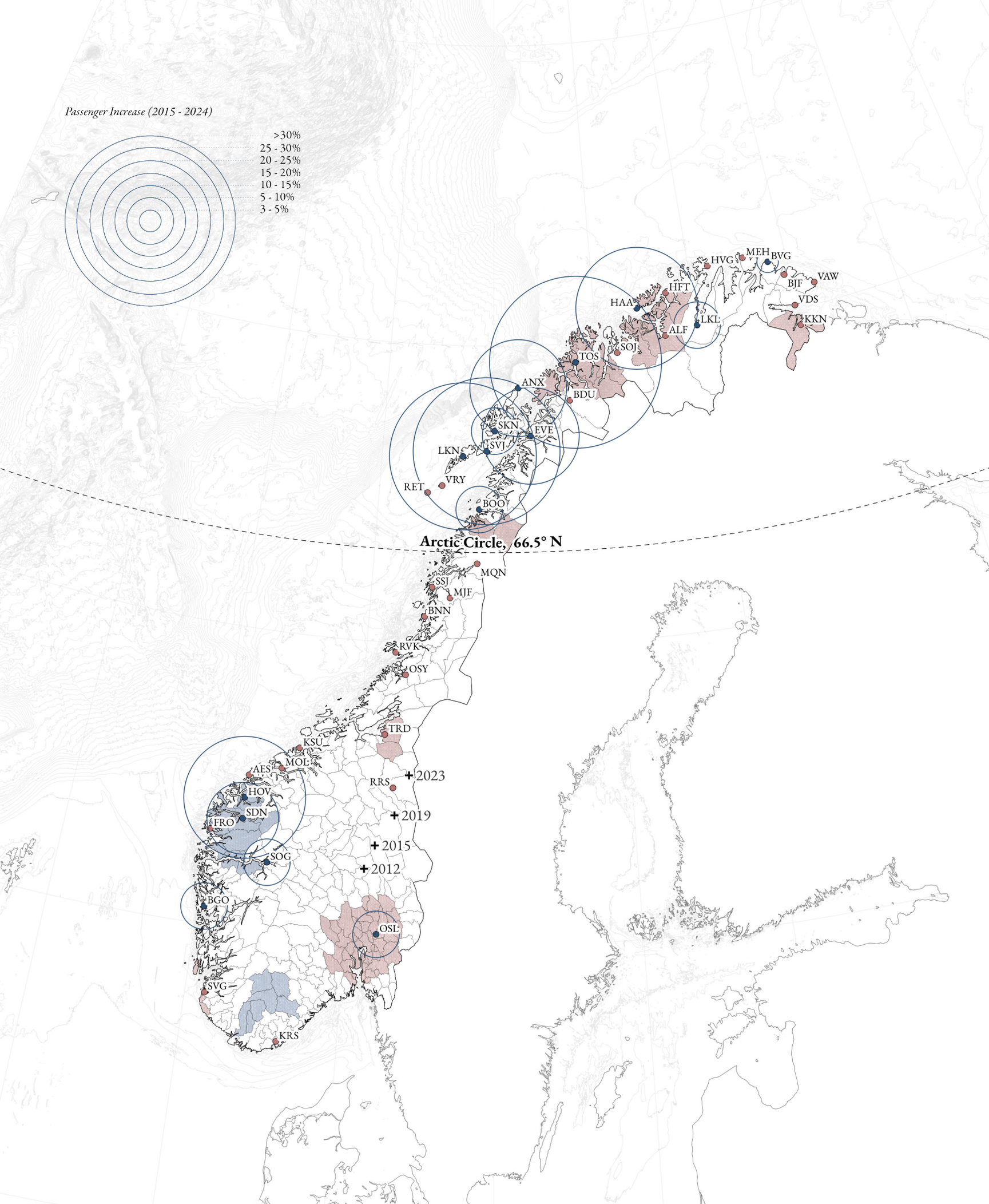
This shift to the north is also visible through airport data that show the same pattern. Several airports in northern Norway have expanded in passenger activity, whereas many airports in the south have remained stable or even experienced contraction (Avinor, 2026), see Figure [3.6].

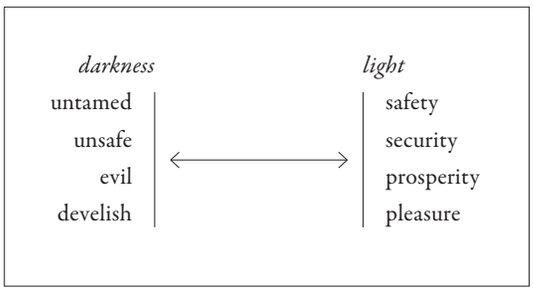
Taken together, night-time imagery and transport data point to a shift of economic activity towards higher latitudes with longer seasonal darkness.



→ **Figure [3.6].** A shift to the north made visible through (a) the movement of the economic centre of gravity, based on night time light data per municipality and (b) the increase in passengers and per airport.

data: Avinor (2026), adapted from Li et al. (2026)


Passenger Increase (2015 - 2024)
>30%
25 - 30%
20 - 25%
15 - 20%
10 - 15%
5 - 10%
3 - 5%
HVG
MEH
BVG
VAW
BJF
VDS
KKN
HFT
HAA
LKL
ALF
SOJ
TOS
ANX
BDU
SKN
EVE
SVJ
LKN
RET
VRY
BOO
Arctic Circle, 66.5° N
MQN
SSJ
MJF
BNN
RVK
OSY
TRD
KSU
MOL
AES
RRS
+2023
HOV
SDN
FRO
+2019
+2015
SOG
+2012
BGO
OSL
SVG
KRS



III.4 - INTRODUCING THE NORWEGIAN LIGHT PARADOX

Emerging from the Arctic's distinctive light regime and the increasing presence of artificial light at night, a new paradox can be identified within the larger context of the Norwegian paradoxes: the complex relationship between light and darkness.

Historically, darkness has often been culturally associated with fear, uncertainty, and isolation. As Edensor (2015) argued, Western societies have framed darkness as something negative or even threatening, while light is associated with safety, progress, and prosperity. Within the Arctic context, artificial lighting therefore becomes more than a technical necessity; it functions as a cultural response to the long winter darkness, creating comfort, visibility, and a sense of social continuity. In this way, illumination can be understood as a form of human adaptation to the Polar night.

Yet, the relationship is more complex than a simple opposition between darkness as negative and light as positive. Both humans and non-humans are biologically adapted to the Arctic's natural cycles of light and darkness. As Bumgarner and Nelson (2021) researched, seasonal rhythms influence migration, reproduction, feeding behaviour, sleep cycles, and hormonal regulation. Humans themselves are not separate from these processes, as exposure to artificial and blue light is known to affect circadian rhythms, mental health, and sleep patterns (Blume et al., 2019). At the same time, levels of ALAN in Arctic regions continue to increase, with the majority of around 85% of ALAN linked to industrial infrastructure. In the European Arctic, Norway saw the largest area with increasing light intensity trends (Akandil et al., 2024).

Here, a reversal takes place: the light that symbolises safety, development, and modernity also becomes a source of ecological disruption. Artificial light fragments habitats, alters biophysical behaviour, and weakens the seasonality of the light regime, upon which many Arctic species rely. Darkness, often culturally perceived as absence or danger, emerges instead as an essential ecological condition.

This paradox is particularly pronounced in Norway, a country internationally recognised for its progressive environmental governance. At the same time, Norway has actively promoted development in the Arctic, accelerating industrial expansion and energy-related activities across sensitive Arctic territories (Li et al, 2026). Human settlements themselves can be understood as part of the Arctic ecosystem that has adapted to extreme environmental conditions.

However, it is the scale and intensity of industrial activity - rather than human presence on its own - that transforms the Arctic into a permanently illuminated territory.

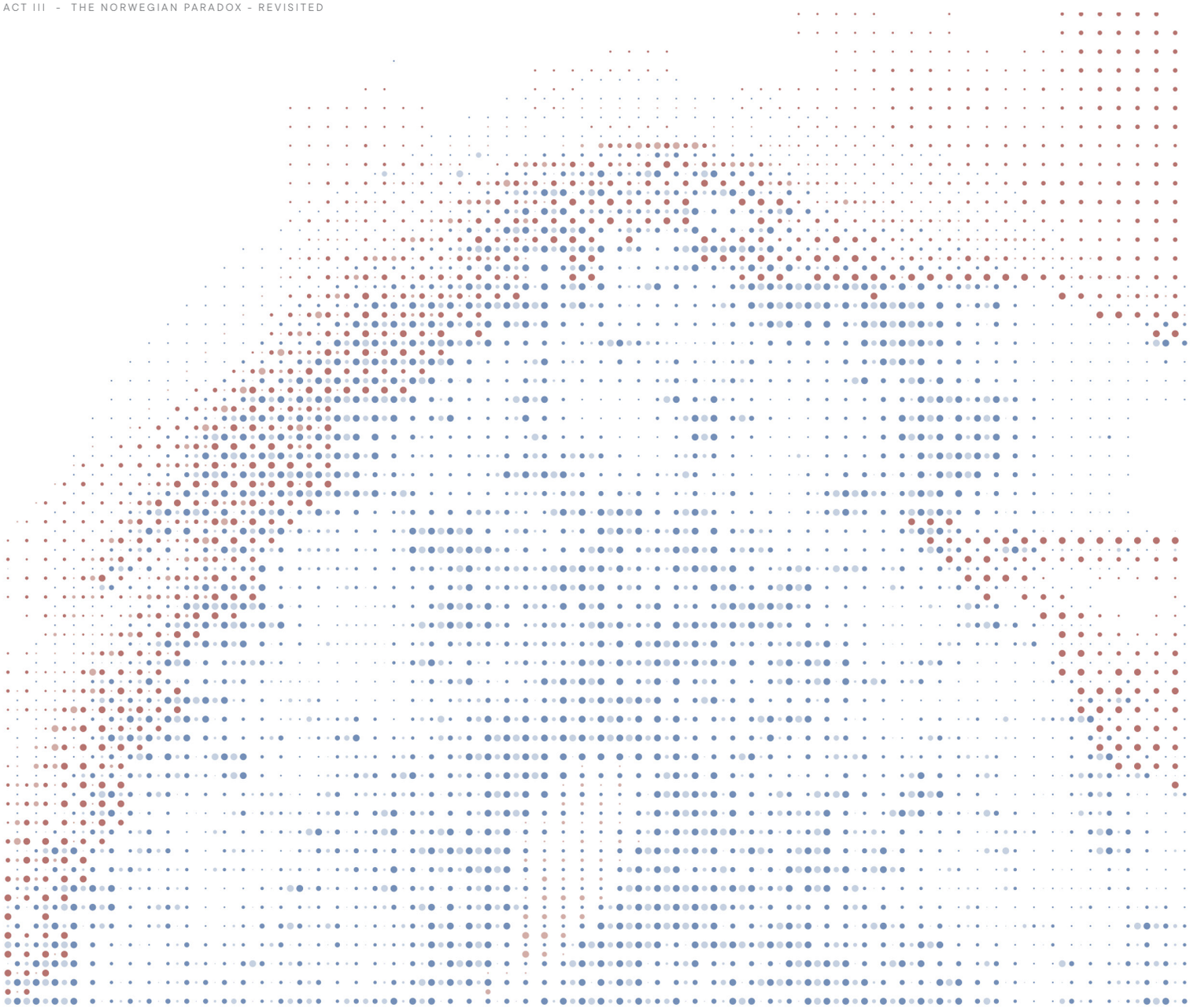
The Norwegian paradox of light and darkness therefore reflects a broader contradiction between adaptation and disruption:

While light is culturally associated with safety or prosperity, and darkness with isolation or danger, the Arctic environment reveals the opposite to be equally true. Darkness is a necessary condition for ecological balance, whereas artificial light in Norway increasingly disrupts the natural rhythms on which both human and non-humans depend.



↑ **Figure [3.7].** Primary school children watching the first sunrise after one month of Polar night.

Svolvaer, Lofoten



point scale based on relative value

low · • • • • high

Daylight fraction at seabed
Shipping density
Night time light radiance
Artificial sky brightness

III.5 - THE NORWEGIAN ARCTIC - ILLUMINATED

A zonal statistics analysis is applied for Arctic Norway to characterise the spatial distribution of (artificial) light within a marine ecosystem context. The analysis combines four grid-based indicators: light fraction reaching the seabed, shipping density, night time light radiance, and artificial sky brightness. These datasets were selected to jointly represent both marine and atmospheric dimensions of light exposure: capturing human activity at sea, surface illumination, and the propagation of (artificial) light through the water column and atmosphere. Together, they provide a multi-layered analysis framework for assessing potential ALAN pressure across Norwegian's Arctic coastline.

↑ **Figure [3.8].** Multi-layer zonal statistics of marine and coastal related light and activity conditions.

data: (Falchi et al. 2016), NASA, EMODnet, World Bank Group





hotspot concentration

low · • • • ● high

↑ **Figure [3.9].** Aggregated hotspot analysis, revealing Tromsø as largest hotspot.

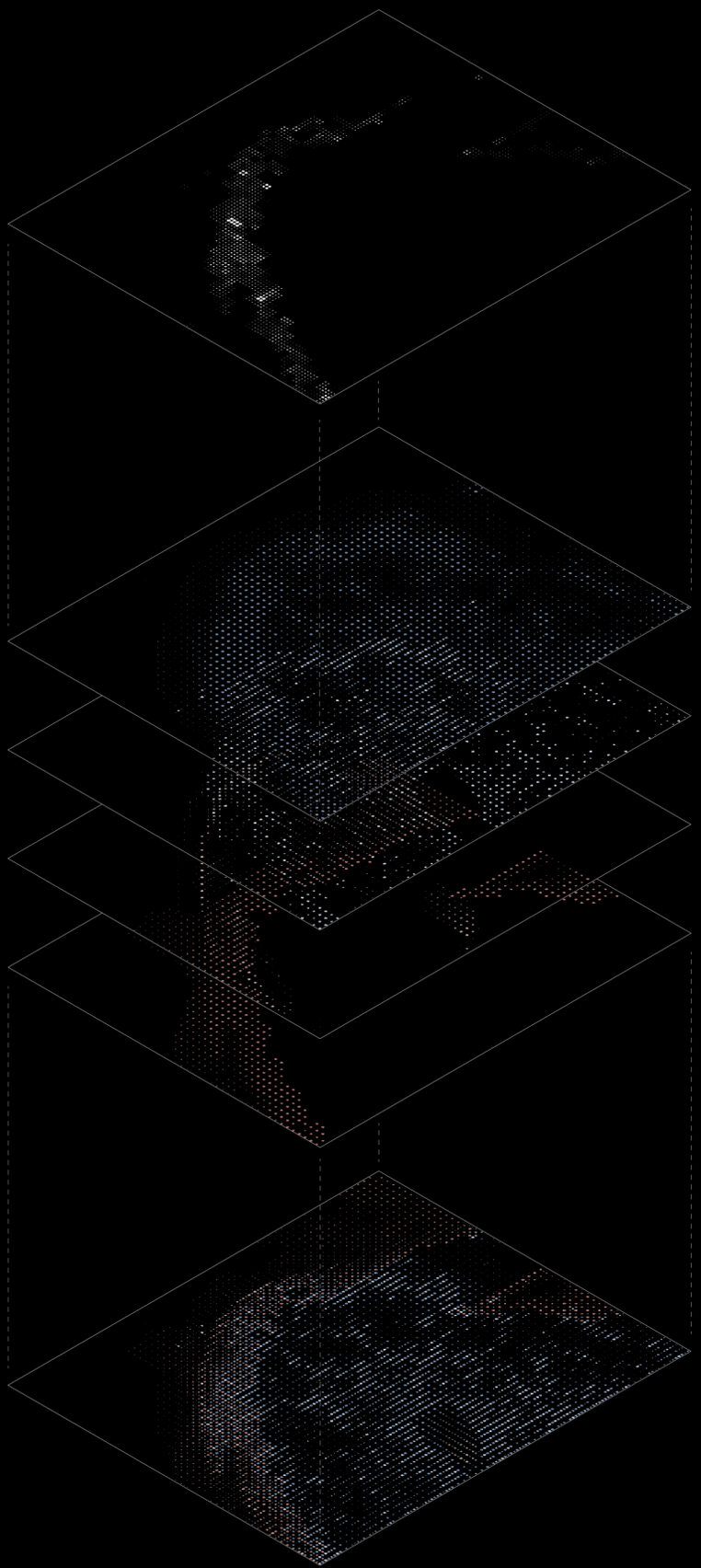
→ **Figure [3.10].** Axonometric of the employed layers to make a hotspot analysis based on [1] daylight fraction reaching the seabed, [2] shipping density, [3] night time light radiance and [4] artificial sky brightness.

data: World Bank Group, EMODnet, NASA, Falchi et al. (2016)

III.5 - THE NORWEGIAN ARCTIC - ILLUMINATED

By combining the four selected layers, areas in which the layers collectively exhibit high values become visible, revealing hotspots. Larger cities are particularly prominent, as they function as industrial harbour cities and are concentrations of coastal urbanisation, (offshore) industry and shipping activity. Figure [3.9] shows that Tromsø is by far the largest hotspot. Therefore, the research zooms in on this city and its surrounding areas.

The following chapter examines the status quo and illustrates, through photography and a fieldwork journal, how these hotspots emerge and how the impact of ALAN becomes visible.



Aggregated Hotspot Analysis

[4] Artificial Sky Brightness
celestial haze

[3] Night Time Light Radiance
nocturnal radiance

[2] Shipping Density
maritime pulse

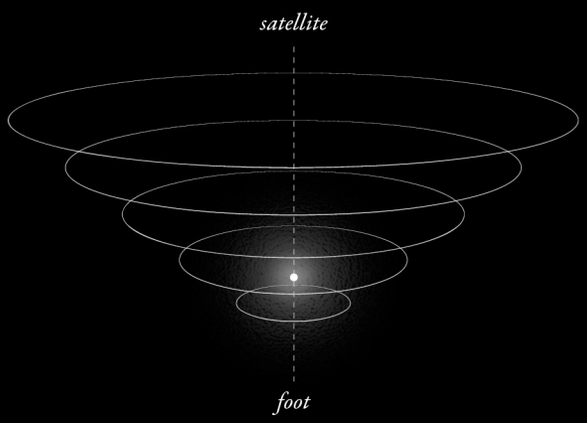
[1] Daylight Fraction reaching Sea Bed
benthic light reach

Zonal Statistics

ACT IV

THE FIELD CONDITION

Is darkness a defining condition or an increasingly contested resource? Artificial light is not confined to a specific moment in time during the Polar night. It operates as a continuous spatial force, embedded in coastal urbanisation and offshore industries: moving through these environments, the fieldwork in this chapter grounds theory through observation: to see what light and darkness reveal about the Arctic territory in transformation.



IV.1 - A FIELDTRIP INTO THE DARK

This fieldtrip was part of my thesis research on ALAN and its presence in the Arctic environment. The goal was not simply to observe, but to ground the theoretical framework I had been building in something real: to move through communities, stand at industrial waterfronts, and ask what artificial light actually means in a place where natural darkness is both a defining condition and an increasingly contested resource. Over 8 days I travelled by bus and plane through northern Norway to [1] Narvik, [2] Svolvær and [3] Tromsø, see Figure [4.1].

Today, on January 4, 2026, I depart from the Netherlands for Norway, travelling to above the Arctic Circle. My flight from Amsterdam is heavily delayed due to snowfall. The Netherlands is simply not equipped for such conditions. We wait several hours for a de-icing truck before finally departing. I land in Oslo, where I transfer onto a flight to Tromsø. Oslo Airport is covered in snow too. Yet, nothing about the airport's operation seems disrupted. Everything is designed around winter conditions: despite the weather, flights continue to depart as normal.

Once we pass the Arctic Circle, the pilot dims all the cabin lights so that we can observe the *aurora borealis,* the northern lights. When I look outside the window, I see green curtains of light moving rapidly through the sky.

From a distance, Tromsø is already visible as a large luminous glow. As soon as I step outside the aircraft, I notice how intensely cold it is. The temperature is around -15°C, and I quickly pull on gloves and a hat. The taxi journey to my first accommodation begins over a thick layer of snow.

The streets are no longer visible. Everything has become one white surface of compacted ice and snow, which explains why everyone drives with studded tyres. I had initially planned to travel around the region by car, but due to the severe winter weather and the high avalanche risk, I decide instead to rely on public transport.

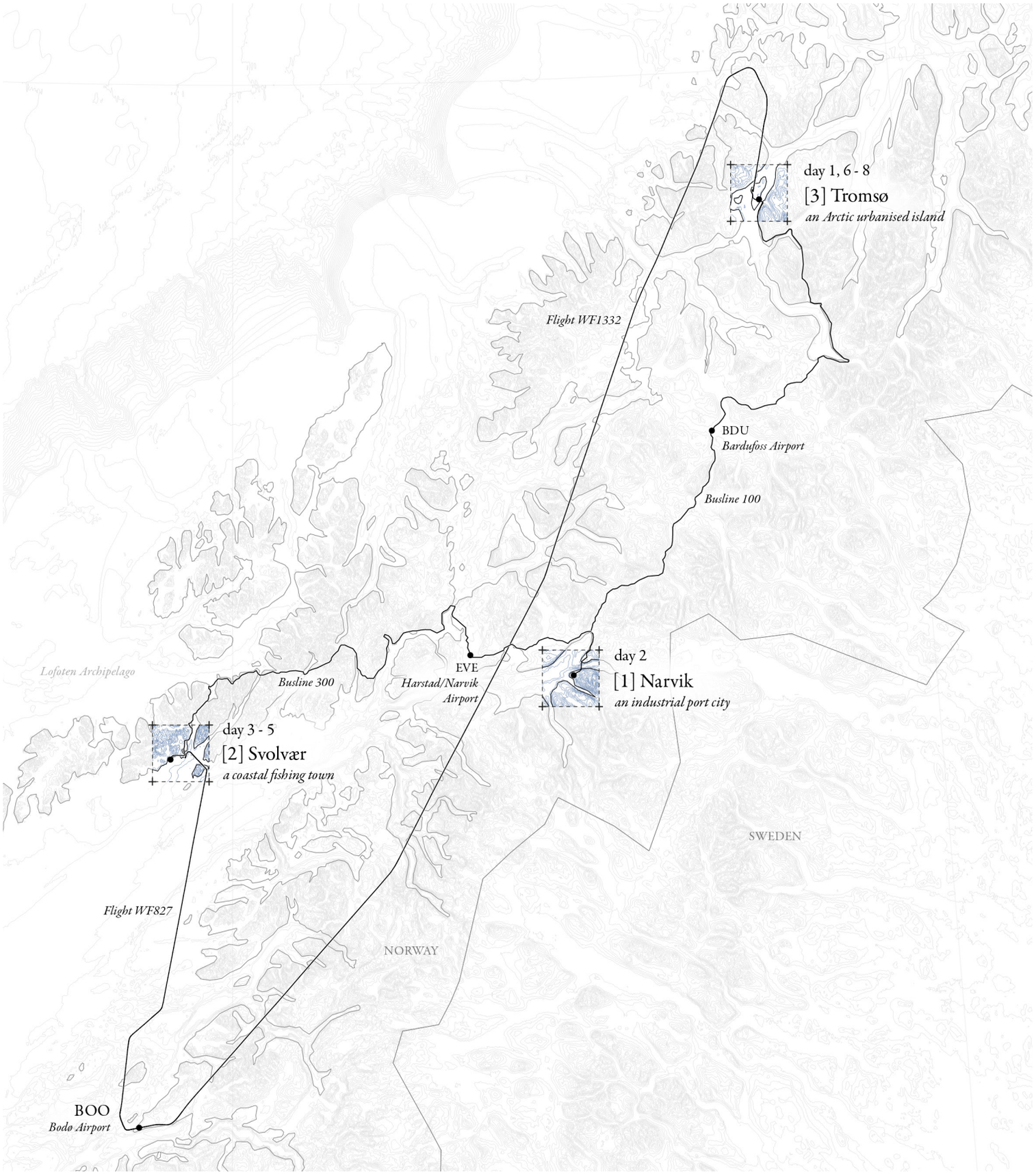
I book a bus ticket to Narvik for the following day and go to bed. I am curious to see what the skies will look like when the sun no longer rises, and I wonder how that absence of daylight will affect me.

Some pictures in this fieldtrip report are shown in black and white to give more feeling for contrast and lighting (intensity). All photos are taken by the author.



→ **Figure [4.1].** Route of fieldtrip.

data: FlightRadar24, Svipper, Reis Nordland


day 1, 6 - 8
[3] Tromsø
an Arctic urbanised island
Flight WF1332
BDU
Bardufoss Airport
Busline 100
EVE
Harstad/Narvik
Airport
day 2
[1] Narvik
an industrial port city
Lofoten Archipelago
Busline 300
day 3 - 5
[2] Svolvær
a coastal fishing town
SWEDEN
Flight WF827
NORWAY
BOO
Bodø Airport

IV.2 - NARVIK - AN INDUSTRIAL PORT CITY

January 5, 10:30

> I walk from the Airbnb to the bus stop. Although it is still dark, the city is definitly awake. People are heading to work, cycling through the streets (on bicycles fitted with studded tyres), children play outside. What strikes me immediately is that life simply continues here throughout the dark and freezing winter. Because everything is covered in a thick layer of snow, some traffic signs are projected onto the snow itself, ensuring they remain visible regardless of snowfall (Figure [4.2] & [4.3]). The moon hangs low above the horizon like a giant lantern. From Tromsø I take a direct bus, line 100, south towards Narvik, a journey of approximately four hours.

12:45

> Halfway, we stop in Bardufoss. Although it is the middle of the day, only twilight is visible along the horizon. Bardufoss is a small settlement where the (military) airport forms a major component of local activity. A freighter aircraft lands, just as we arrive. With all its lights turned on, the runway appears less as a strip of asphalt and more as a glowing strip cutting through the valley (Figure [4.3]).

15:00

> By the time I arrive in Narvik, it is already dark - or rather, the twilight has disappeared completely. Despite this, the city still feels active, almost as though it were daytime. Everywhere, people walk through the streets carrying skis towards the slopes, see Figure [4.5]. What stands out most immediately is the combination of illuminated ski slopes and artificial snowmaking, which creates a glowing mist above the mountains surrounding the city, see Figure [4.6].



Figure [4.2]. Projected traffic signs on the snow.



Figure [4.3]. Projector.



Figure [4.4]. The airport of Bardufoss.



Figure [4.5]. Ski slopes of Narvik.



Figure [4.6]. Artificial snow being lit up above the ski slopes, creating a glow of mist above the city.



IV.2 - NARVIK

January 5, 18:30

Narvik is known for the transport of iron ore from the mines in Kiruna. To ensure year-round export, the ore is transported by rail to Narvik's ice-free harbour. The railway, constructed at the end of the nineteenth century, becomes particularly essential during winter, when the waters surrounding Luleå (Sweden) - the harbour city at the opposite end of the railway line - freeze over. Near the rail yard beside the harbour, trains continuously arrive and depart. Their horns can already be heard echoing through the landscape long before they appear. The entire rail yard is covered in snow, yet every track is brightly illuminated by powerful white floodlights.

Figure [4.7]. The iron ore mine and harbour of Narvik during a snowstorm, as seen from Narvik Havn.



19:30

From the railway, the iron ore is transferred directly onto large cargo ships waiting in the harbour. I walk to the opposite side of the bay to gain a clearer overview. I stand near the cruise terminal. Despite the absence of any ship there, the entire quay remains brightly illuminated. There are no visible workers and no movement, yet the whole area glows intensely white. Across the water, the industrial landscape dominates the view. Large conveyor belts pour iron ore into the ships. The entire harbour functions as one immense light- and sound-producing machine operating continuously throughout the Polar night.

IV.2 - NARVIK

20:30

To gain an overview of the harbour city, I climb the mountain beside the ski slopes. Along the way, children repeatedly ski past me. From the top, it becomes clear how the industrial railway cuts through the city like a luminous line extending towards the waterfront. What is particularly noticeable is the contrast between the harsh white light of industrial illumination and the warmer yellow glow of the city itself. As snowfall begins, every light source reflects off the snowflakes suspended in the air. At that moment, the landscape appears brighter than anything I have seen during 'day'time.

January 6, 9:00

Today I take another bus, this time travelling approximately six hours towards Svolvær in the Lofoten archipelago. It is an important day: the bus route follows the latitude at witch, for the first time after the Polar night, the sun is theoretically visible again above the horizon. Throughout the journey I remain alert, hoping to get a glimpse of it briefly.

Upon departing from the bus terminal, I once again notice the moon hanging low above the horizon like a lantern (Figure [4.8]). The western sky turns pink and purple due to light reflecting against ice crystals. It is remarkable to observe two simultaneous twilights. In the Netherlands, I am used to twilight appearing only where the sun rises or sets, yet here a second twilight emerges on the opposite side of the sky. Throughout the journey, the sky opposite the sun retains this pink-purple hue, creating a striking contrast with the white mountain landscapes (Figure [4.9]).

10:30

Due to warm sea currents, the unfrozen coastal waters create the impression that winter is not entirely dominant. The landscape still feels active: boats continue moving, birds keep swimming. Yet, once the bus enters the inland plateau, temperatures rapidly fall below -20°C.

11:00

Suddenly, an international airport appears within the remote landscape (Figure [4.10]). Originally opened in 1972, it expanded significantly after the closure of Narvik Framnes Airport in 2017, which had previously been located within the city itself.

12:00

Much of the route feels remarkably empty. Alongside the road there are some industrial sites, harbours, and aquaculture facilities, but relatively few settlements. At one point the bus stops abruptly: reindeer are crossing the road.

When I arrive in Svolvær, I realise I have not seen the sun that day. Perhaps tomorrow there will be another opportunity.

↗ **Figure [4.8].** Views over Ofotfjord, close to Narvik, at 10:11.

→ **Figure [4.9].** View towards Kongsvika from E10, at 12:13.







Figure [4.10]. Approaching Evenes Airport.



Figure [4.11]. Reindeer crossing the street.



Figure [4.12]. Cargo vessel offloading construction materials along E10.

IV.3 - SVOLVÆR - A COASTAL FISHING TOWN

January 6, 15:00

I stay in a hotel near the harbour. At the reception, I talk to a few local residents, who immediately describe Svolvær as *the city of lights*. They explain that without light, the winter would be difficult to endure: illumination is something that sustains morale and wellbeing during the dark season.

This immediately leads me to reflect upon the concept of light pollution. People here are part of the Arctic ecosystem. If (artificial) light is necessary for people to endure the winter, can it simply be described as pollution? Or is it instead a form of human adaptation to prolonged darkness?

17:00

As I walk through the city with this thought in mind, another contrast becomes apparent. The warm decorative lights, some still remaining from Christmas, contrast strongly with the cold white lighting of the surrounding industrial buildings. Residential areas appear overshadowed (overluminated) by large boxes housing ships, processing facilities, and slaughterhouses, see Figure [4.13].

In the distance, a loud horn sounds: the Hurtigruten - Norwegian's daily coastal boat service - is arriving. As it enters the harbour, with its large floodlights switch on, the stillness of the city feels disrupted, see Figure [4.14].

↗ **Figure [4.13].** View at 15:03 over Svolvær: the industrial shoreline lighting up the surrounding water and mountains.

→ **Figure [4.14].** Hurtigruten cruiseship *MS Nordlys* arriving in Svolvær's harbour at 17:27.





IV.3 - SVOLVÆR

Svolvær is historically defined by fishing. During winter, Atlantic cod migrate from the Barents Sea towards the Lofoten archipelago to spawn. The relatively warmer waters and shallow coastal grounds create favourable breeding conditions. For centuries, the economy of this region has depended upon the trade in skrei/torsk, or Arctic cod.

18:00

I decide to visit the island of Svinøya, the oldest part of the town. In 1828, when Gunnar Berg purchased nearly half of Svolvær, it was still a small fishing settlement. He constructed his own residence, shipyards, and the town's first store on the island. Later, traditional *rorbu* fishermen's cabins were built, allowing fishermen and workers to settle permanently in the area. It marked the beginning of what would later become an industrial fishing town.

In the original shipyard from 1828, I eat locally caught fish for dinner. Next to the restaurant, a vessel has just returned from sea (Figure [4.15]). Inside the restaurant, I am told that the fish is freeze-dried on wooden racks across the island. The cold, dark winters provide ideal conditions for preserving fish naturally. It gives me a clearer understanding of how daily life here is fundamentally intertwined with the Polar night, and how the winter season itself becomes a resource that supports local livelihoods.

January 7, 11:00

The next day, I aim to observe the fishing industry under twilight conditions. With only around three hours of twilight each day, opportunities to explore are brief. The industrial character of Svolvær becomes even more apparent. The fish-drying racks (*fiskehjeller* in Norwegian) are not modest structures: they are numerous, often exceeding ten metres in height, and dominate the coastline of Svinøya. They are all lit up, mainly not for safety or active work, but rather because people consider them visually appealing. Once again, it becomes evident that artificial light functions here as a way of shaping and inhabiting darkness (Figure [4.16] & [4.17]).

Today there is another possibility of briefly seeing the sun. Therefore, the local primary school walks up to a high point in Svolvær, on the Svinøy Bridge, where the view on the horizon remains unobstructed. Unfortunately, it is too cloudy. Nevertheless, the event itself demonstrates how deeply the solar cycle and Polar night are embedded within the local culture.

↗ **Figure [4.15].** Fishing vessel *Knut Olav* returning back from sea at 15:08.

→ **Figure [4.16].** Illuminated racks (*fiskehjeller*) for drying cod fish dominate the coastline of Svinøya.

↓ **Figure [4.17].** A close-up from an illuminated drying rack. The mountains in the background are lit by surrounding industries. (see next page)


KNUT OLAV
N-3-V




N-55
SAGA 5
DO NOT TOUCH



IV.3 - SVOLVÆR

Svolvær presents a clear example of how the Polar night has produced an interconnected system of culture, ecology, and economy. The seasonal migration of cod creates ideal breeding conditions within the Lofoten archipelago, but simultaneously provides food, employment, and the possibility for permanent settlement within what is otherwise a harsh Arctic environment.

It is, however, a fragile balance. The global trends described in Act I threaten this system. I begin to wonder about the impact of these changes on cod migration routes and spawning patterns, among other things, and how such ecological shifts could place pressure on local economies. These questions remain with me as I walk through the town.
In relation to artificial light at night, it becomes increasingly clear that this is not merely a local issue. ALAN is a global phenomenon, visible even here in Svolvær. The larger industries no longer serve purely local needs. Cruise ships arriving in the harbour and fishing vessels departing for international markets are all part of wider global systems of extraction and consumption.

When I ask whether artificial light is genuinely considered problematic here, the answer eventually becomes more nuanced: yes, but primarily because of large-scale industry. Industrial activity continues twenty-four hours a day, operating relentlessly, while the surrounding landscape itself appears to slow down during winter.

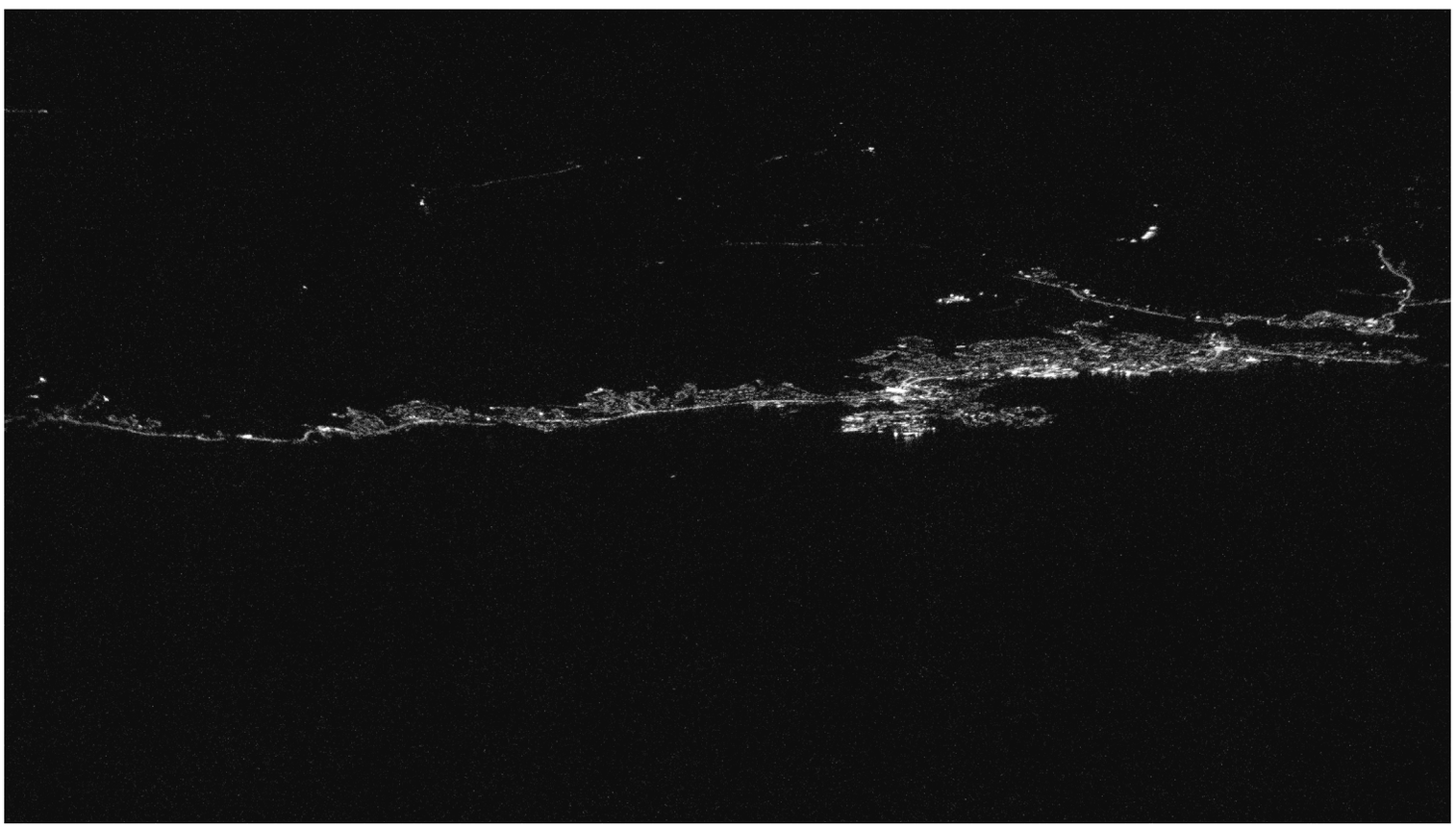
January 8, 12:00

> From Svolvær I take a domestic flight to Bodø before continuing onwards to Tromsø. The small propeller aircraft carries around thirty passengers. From the air I am able to observe the broader spatial patterns of ALAN across the Arctic landscape.
>
> The most visible scars of light within the darkness are immediately apparent. Large illuminated aquaculture rings glow bright green in the water below. Linear patterns of coastal lighting are especially striking. Even in complete darkness, it remains quite easy to distinguish land from water purely through illumination: as a continuous yellow-white contour along the shoreline.

↗ **Figure [4.18].** Approach into Bodø Airport at 12:53.

→ **Figure [4.19].** The city of Harstad highlights the coastline as a linear strip between sea and land. Photo taken from the plane.





IV.4 - TROMSØ - AN ARCTIC URBANISED ISLAND

January 8, 20:00

Upon arriving back in Tromsø, I notice how the coastal lighting reflects across the unfrozen water. Because the sea remains unfrozen, the light scatters in every direction, creating what resembles a 'barcode' of reflections stretching across the surface.

At the same time, the sky begins glowing green: the aurora borealis is visible to the naked eye. Many visitors have travelled to Tromsø specifically to observe it, especially as auroral forecasts have indicated heightened activity throughout the week. Buses gather across the city to transport tourists towards darker locations outside the urban area.

The situation feels paradoxical. Tourism itself contributes to ALAN through hotels, shops, restaurants, cruise ships, and flights. Yet visitors must subsequently leave the illuminated city in order to experience the darkness they originally came for.

January 9, 11:00

In the morning I visit the Arctic Cathedral, which during the Polar night functions almost like a luminous beacon within the city (Figure [4.21]). Concerts will soon be organised here to celebrate the return of the sun, see Figure [4.20]. Outside, the intense cold persists.

From Tromsdalen I cross the bridge towards Tromsøya, from which I observe numerous vessels entering and leaving the city, particularly fishing boats. Along the quay, two large cruise ships are docked. Beneath the bridge, industrial activity dominates much of the waterfront. Once again, it becomes clear that the coastline as a body needs further investigation.

↓ **Figure [4.20].** Banner for a concert series, celebrating the return of light.

→ **Figure [4.21].** *Ishavskatedralen* as seen from Tromsdalen.







Figure [4.22]. View over Tromsø.



IV.4 - TROMSØ

15:00

I walk along much of the eastern coastline of Tromsøya as blue hour gradually begins - the period when the sun sits far below the horizon. Against the deep blue sky, the city steadily becomes more illuminated. I realise how the arrival of darkness intensifies the visibility of artificial light. The difference between twilight and full darkness is substantial; the depth of the night creates an extraordinary contrast with ALAN, as is visible in Figure [4.23].

17:00

Along the coastline there are countless illuminated industrial sites and harbours serving ships and maritime activity. Whether vessels are arriving or not, much of the lighting remains permanently switched on. As in Svolvær, the intense white light of industry overwhelms the warmer golden glow of the city itself.

January 10, 10:00

Tromsø lies within a highly mountainous landscape, and the geomorphology of the region is complex. While observing the daily twilight around midday, I begin noticing how strongly the surrounding topography influences the experience of light and darkness.

My accommodation in Tromsdalen is enclosed by steep mountain walls. From there, I experience relatively little twilight because only a limited portion of the sky dome is visible. During the evening, I also observe less light pollution, as the mountains obstruct views towards the industrial areas of the city.

This leads me to another realisation: the impact of ALAN depends heavily upon one's position within the landscape. Certain locations are naturally darker and therefore produce stronger contrasts with artificial light, while open landscapes permit both greater natural illumination and a wider visibility range for artificial light sources.

20:00

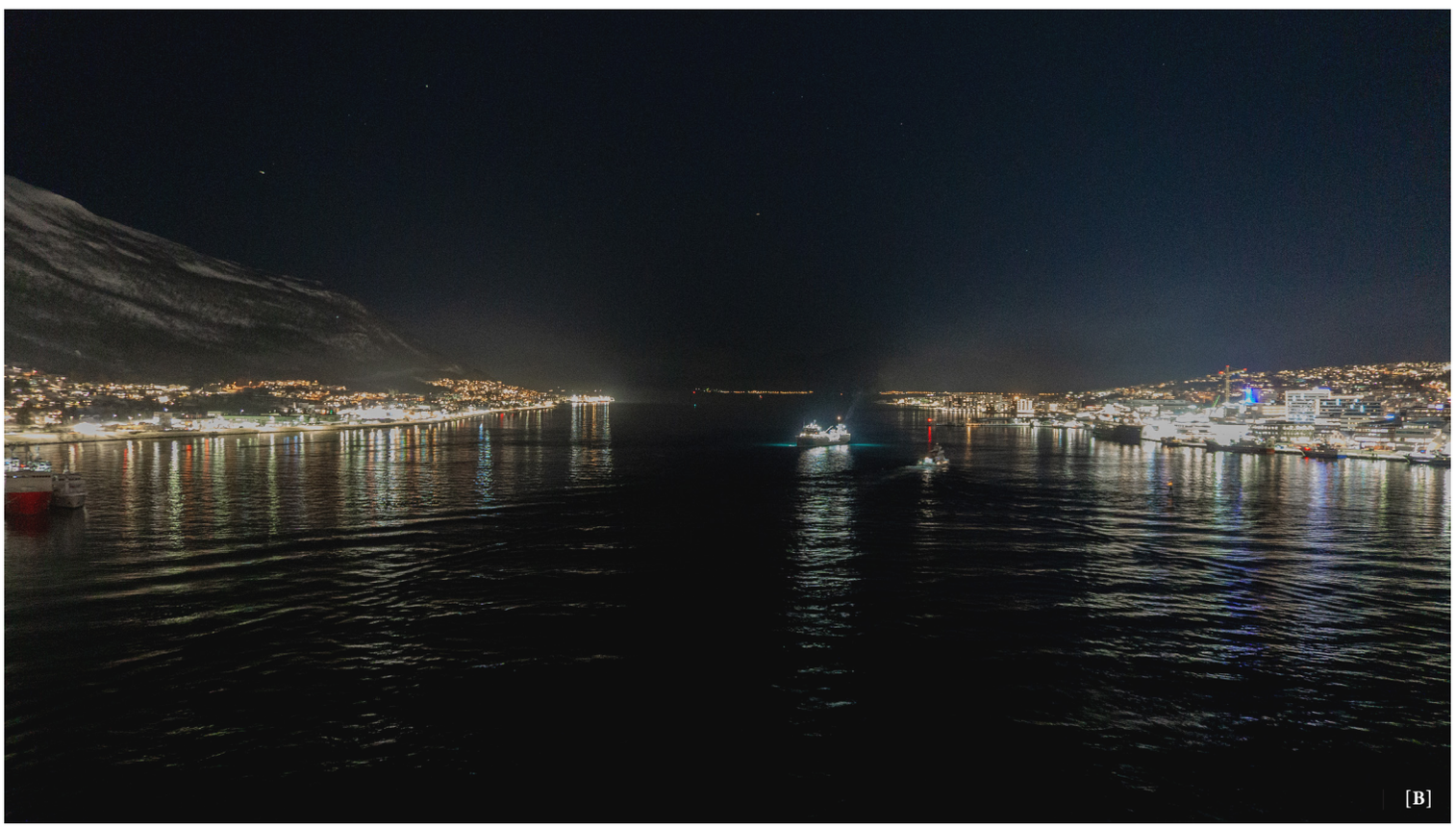
That evening I read in Akandil et al. (2024) that approximately 15% of artificial light in the Arctic originates from human settlements, while around 85% is generated by industry. The statistic fundamentally reshapes my understanding of artificial light and the broader question of what should actually be considered light pollution.

I fly home the following morning carrying the understanding that local communities are themselves part of the Arctic ecosystem. I leave with the realisation that ALAN is not inherently synonymous with pollution. Its meaning depends upon context: the source, intensity, location, purpose, and ecological impact all matter, alongside the naturally existing spatial relationship between light and darkness.

→ **Figure [4.23].** Strait of Tromsø as seen from the Tromsø bridge at [A] twilight around 11:53 and [B] without twilight around 16:22.



[A]



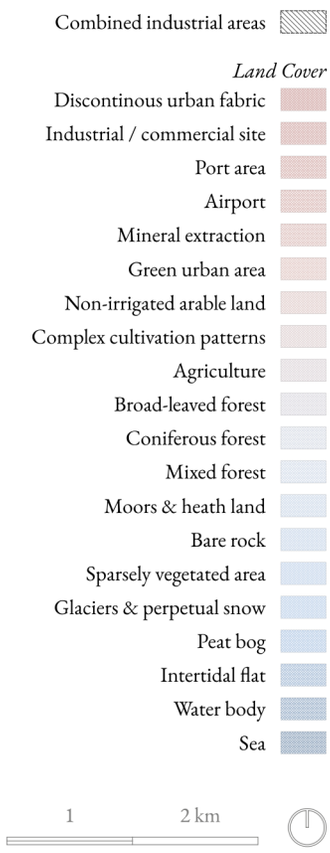
[B]



↑ **Figure [4.24].** The reflection of light in the water.

↗ **Figure [4.25].** The reflection of light on the snow creates a pronounced contrast with the surrounding darkness.





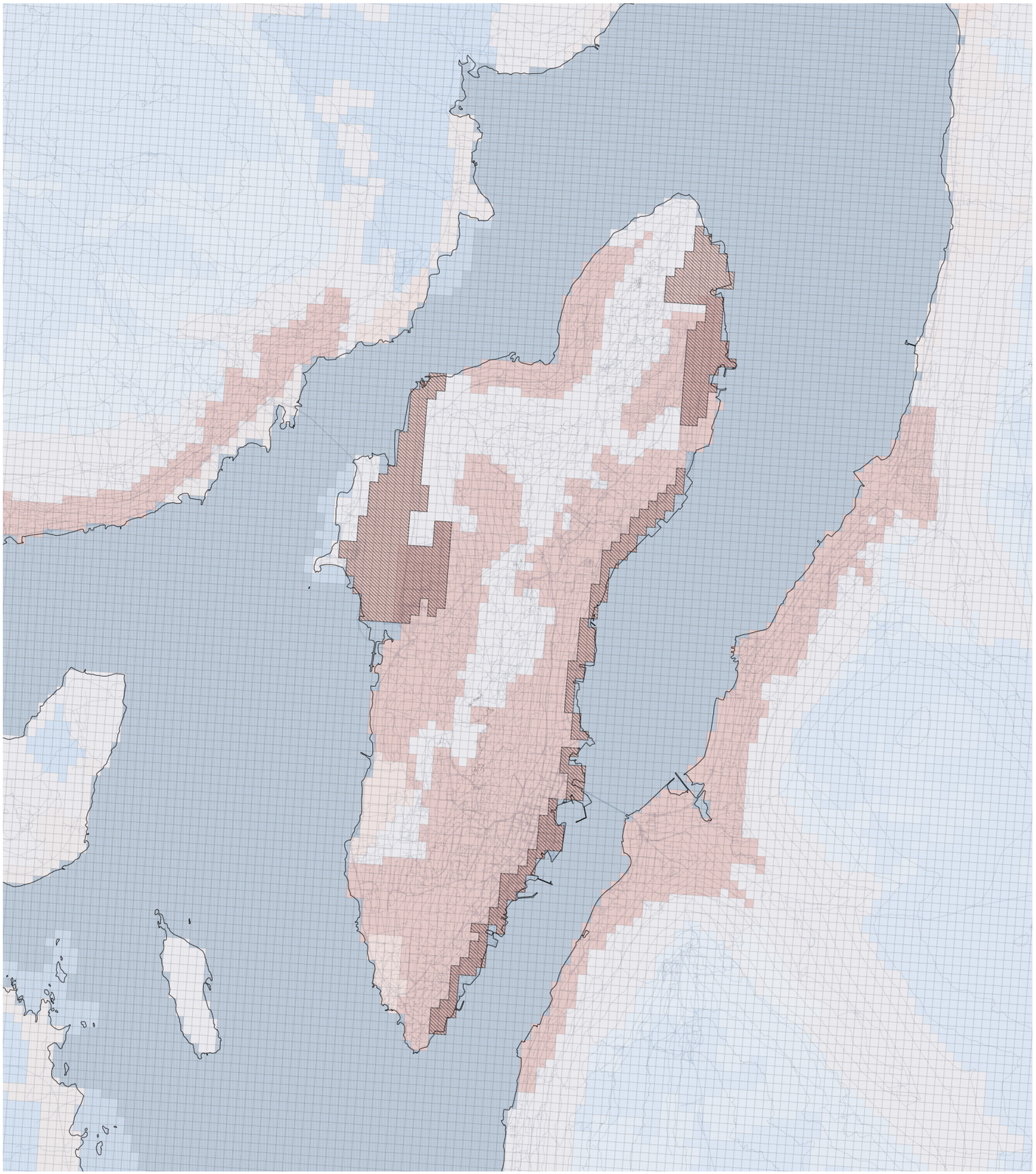
→ **Figure [4.26].** Tromsø's land cover shows the coastal convergence of human industrial activities, based on ports, mineral extraction, the airport and industrial sites.

data: Copernicus Land Monitoring Service

IV.4 - TROMSØ

In conclusion, following the fieldtrip, I mapped land use in Tromsø (see Figure [4.26]) to assess the extent to which the coastline is occupied by heavily polluting light sources. The eastern waterfront is almost entirely dominated by industrial and commercial sites, port facilities, and extraction areas. This concentration of economic activity highlights the strongly anthropocentric use of the waterfront, where the coastline is primarily treated as a resource for infrastructure and development.

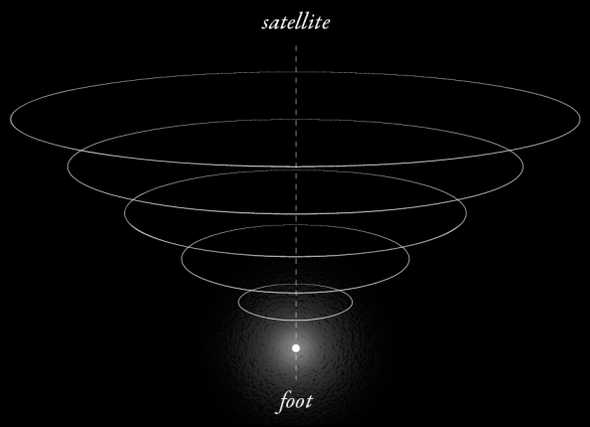
The fieldtrip made the coastal zone of convergence clearly visible, which became one of the key takeaways of the visit.

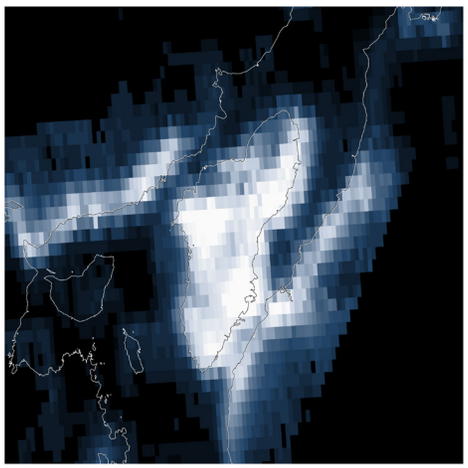


ACT V

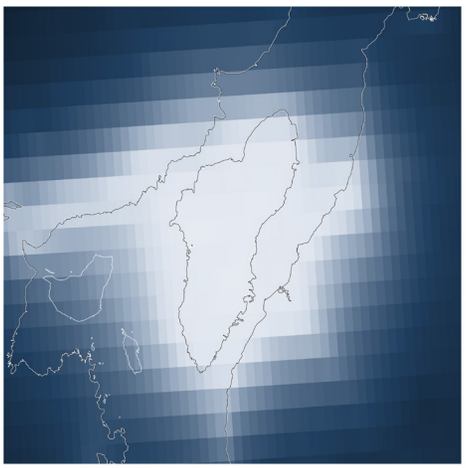
REPRESENTING THE UNSEEN

When darkness is understood as a right, the question rises how urbanism operates when darkness itself becomes a planning concern. This also requires for designers and policy-makers to understand the nocturnal landscape. How can light and darkness therefore be represented in maps?





[**A**] Night Time Light Radiation



[**B**] Sky Brightness



Night Time Light Radiance
(nW/cm²/sr)



Sky Brightness
(ratio artificial/natural)



V.1 - DATA ACCURACY GAP IN ALAN

When examining ALAN, two primary datasets are commonly used to map its distribution. The first is derived from NASA's VIIRS[1] satellite imagery, which measures the upward radiance emitted from the Earth's surface into space (NASA, n.d.). As illustrated in Figure [5.2], on a large scale this dataset shows hotspots and distribution clearly. At the urban scale, shown in Figure [5.1], the dataset becomes visible as pixels of 15 arcseconds.

A second dataset represents sky brightness, indicating the extent to which the night sky is illuminated relative to a defined baseline of natural darkness (Falchi et al., 2016). This dataset likewise exhibits limited accuracy at the urban scale in even larger pixels of 30 arcseconds. Nevertheless, both datasets allow for important general observations, for example, the high levels of light emission associated with Tromsø's airport and the city centre.

However, these datasets also have notable limitations. They do not adequately capture dynamic or transient lighting. Since satellite observations are typically composited and averaged over longer periods (NASA, n.d.), moving light sources - such as ships - are largely excluded. To address this gap in accuracy, this Act explores an alternative approach to mapping light conditions.

The aim is to investigate how the darkness as territory can be represented beyond conventional datasets. The chapter is structured in two parts. Part I examines how the landscape itself influences patterns of light and darkness: the natural perspective of the territory. Part II focuses on the impact of ALAN on the coastal zone of convergence: the artificial perspecitive of the territory. Finally, they are combined into an atlas of territorial conditions.

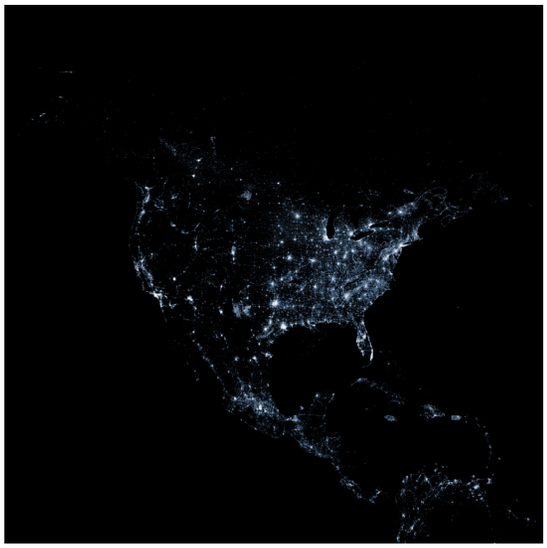
[1] Visible Infrared Imaging Radiometer Suite: a highly sensitive satellite that captures global observations.

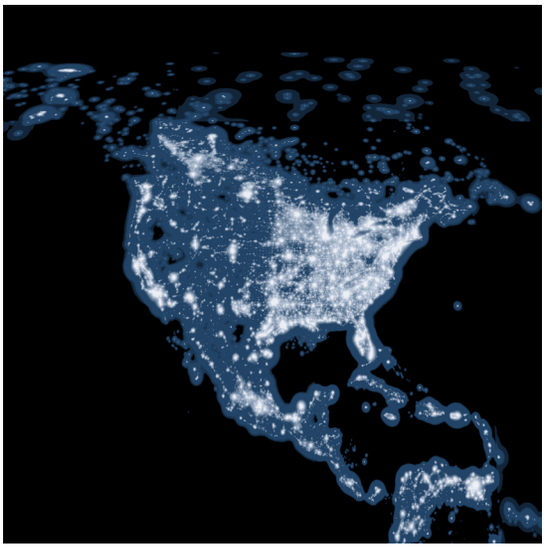
↖ **Figure [5.1].** Zooming in on Tromsø, Norway, the resolution of the datasets is visible in pixels of 15 arcseconds for [A] and 30 arcseconds for [B] from the raster grid.

data: NASA, Falchi et al. (2016)

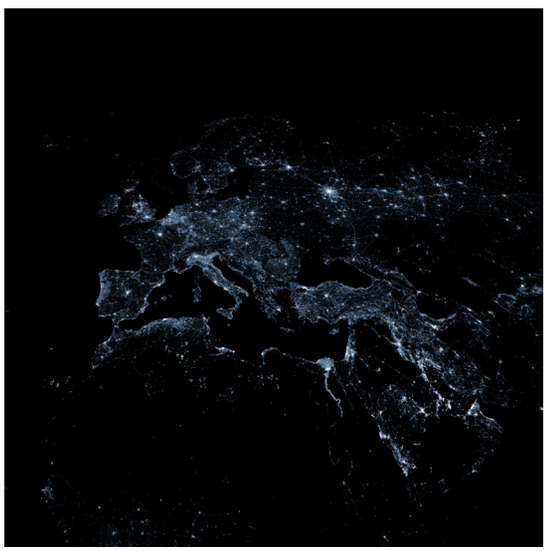
↗ **Figure [5.2].** Night Time Light Radiance [A] and Artificial Sky Brightness [B] together show the reach of ALAN throughout the skies. (legend is in logaritmic scale)

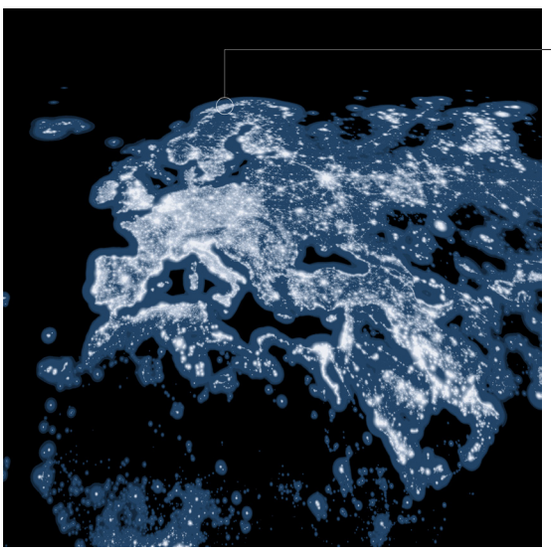
data: NASA, Falchi et al. (2016)





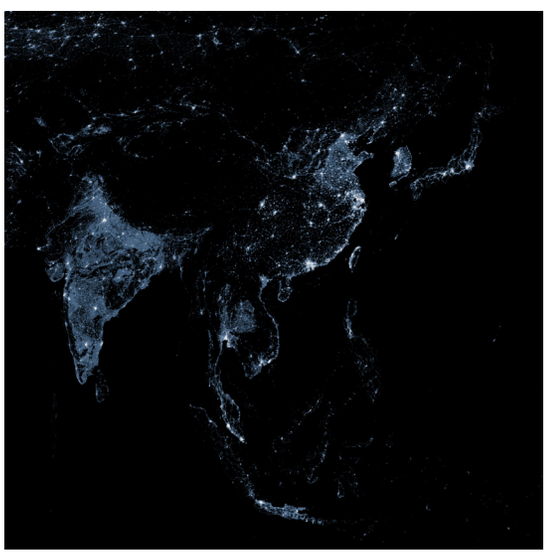
North America

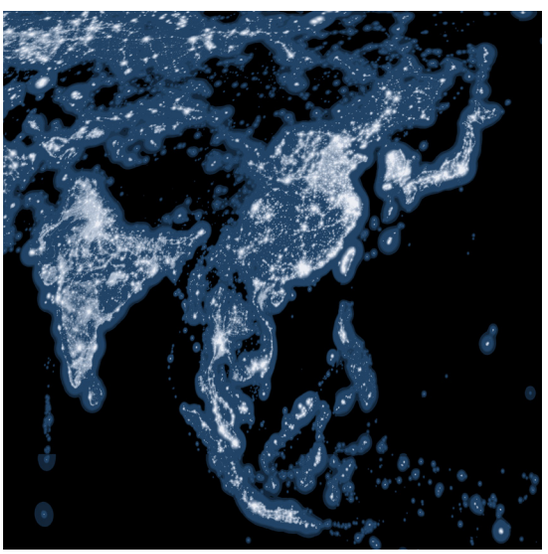




Tromsø, Norway

Europe & Middle East



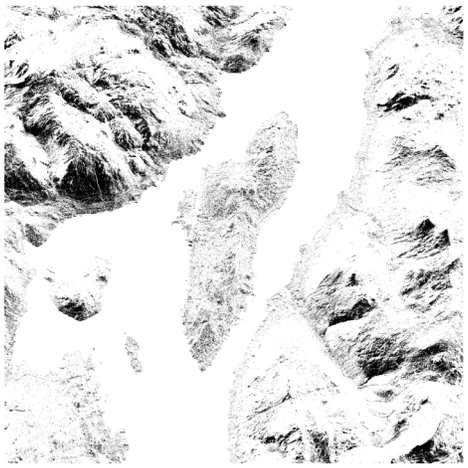


Asia

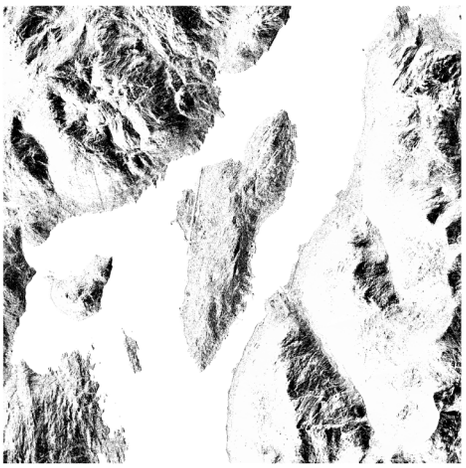
1,500 3,000 km

[**A**] Night Time Light Radiation

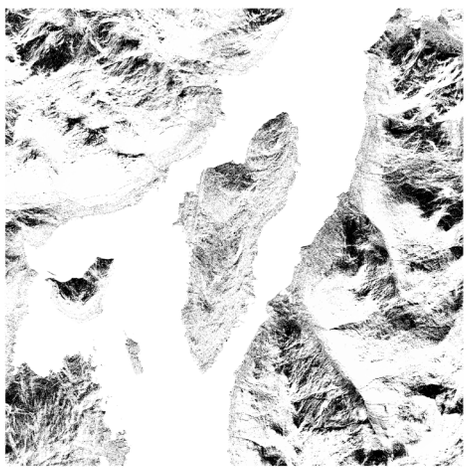
[**B**] Sky Brightness



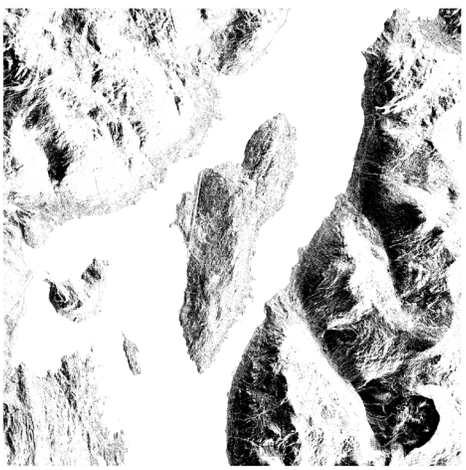
[A] South



[B] East



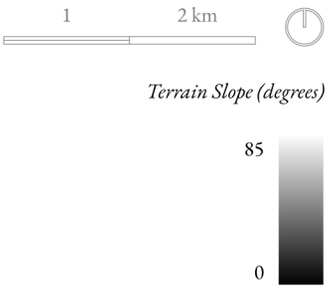
[C] North



[D] West

→ **Figure [5.4].** Slope map of Tromsø in degrees, compared to horizon (0).

data: calculated with digital elevation model from Kartverket





← **Figure [5.3].** Aspect maps: orientation of terrain highlighted in black, categorised in four wind directions. An important note is that the data used does not include sea bed terrain, and therefore shown in white in all 4 maps.

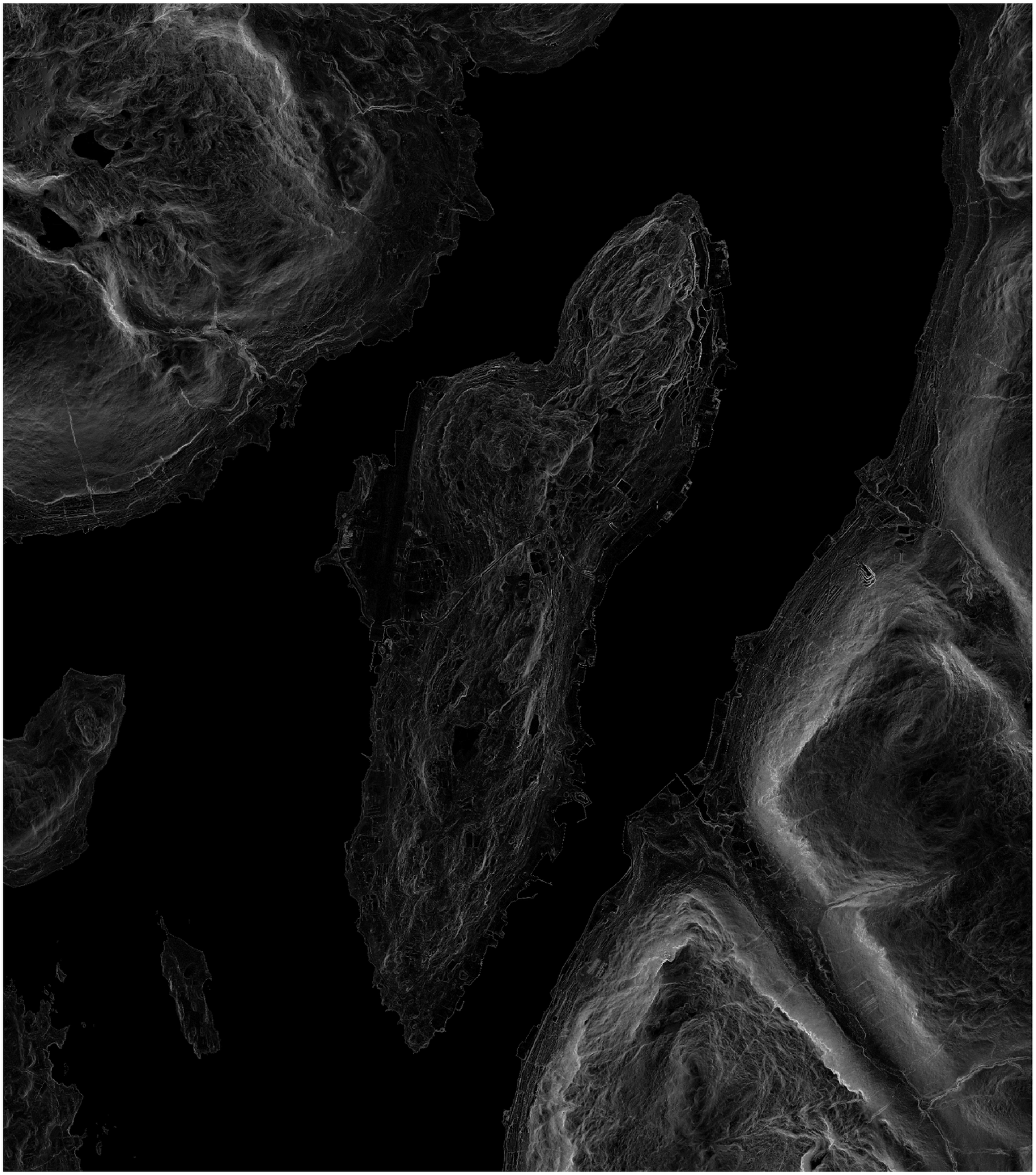
data: calculated with digital elevation model from Kartverket

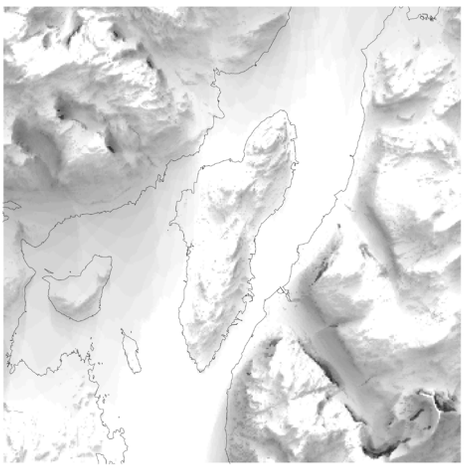
V.I.1 - GEOMORPHOLOGY

To understand the landscape from the perspective of light, it is essential to map the topographic modulation of light. This involves examining how geomorphological conditions shape areas that are inherently lighter or darker, and how these variations can be represented. Natural light and darkness are determined not only by the sun rising or setting, but also by one's position within the landscape. For example, a mountain may obstruct direct sunlight even after sunrise, resulting in locally darker conditions. This effect is particularly pronounced in regions with strong topographical variation, such as the coastal landscapes of Norway.

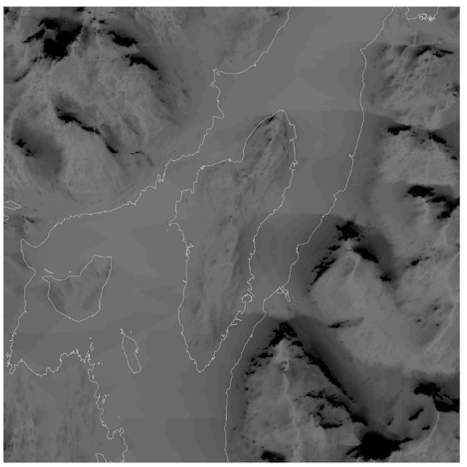
Accordingly, this chapter begins by mapping the underlying topography, which forms the basis for a solar exposure analysis to determine the amount of hours of direct sunlight touching the landscape. This analysis uses the national Norwegian elevation model (Kartverket, n.d.) to derive surface orientation (aspect) represented by four directional aspect maps (see Figure [5.3]) and terrain steepness, shown in the slope map (Figure [5.4]). The elevation data, slope and aspect combined provide the basis for assessing solar exposure.

In combination with the sun's altitude and azimuth at a given time and date, the spatial distribution of solar exposure across the landscape can be determined.

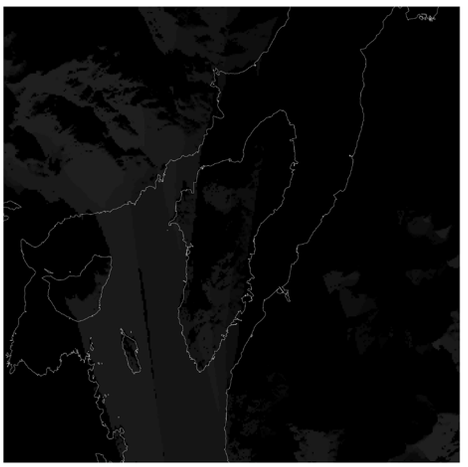




[A] June solstice



[B] equinox March / September



[C] first sunrise / year

V.I.2 - WHEN THE SUNLIGHT APPEARS

The annual average solar exposure map (Figure [5.6]) is based on four key dates: the solstices and equinoxes (Figure [5.5]), and has been calculated with algebra (Stewart, 2015). These dates capture the extremes and midpoints of the annual solar cycle, allowing conditions of Polar day and Polar night to be identified. For each pixel of the terrain data, its orientation is defined through aspect α and slope β, which determine the surface normal vector:

$$\vec{n} = \begin{bmatrix} \sin(\alpha)\sin(\beta) \\ \cos(\alpha)\sin(\beta) \\ \cos(\beta) \end{bmatrix}$$

At each time step t, the solar position[1] is described by elevation h_t and azimuth A_t and is defining the sun direction vector:

$$\vec{s} = \begin{bmatrix} \cos(h_t)\sin(A_t) \\ \cos(h_t)\cos(A_t) \\ \sin(h_t) \end{bmatrix}$$

The potential for direct solar exposure is determined by the relationship between terrain and sun through the dotproduct of these two vectors, vector $\vec{n}$ and vector $\vec{s}$:

$$\cos\left(\theta_t\right) = \vec{n} \cdot \vec{s}$$

Direct sun exposure at a specific time occurs only when a surface faces the sun: $(\cos(\theta_t) > 0)$, meaning that sunlight can reach the location geometrically. In addition, the surface must not be obstructed by surrounding terrain, which would cast a shadow. This requires accounting for topographic obstruction, where φ_t denotes the azimuthal direction used to compute the local horizon from the surrounding terrain. For sunlight to reach the location, the solar elevation must be higher than the local horizon.

$$h_t > h_{hor}(\varphi_t)$$

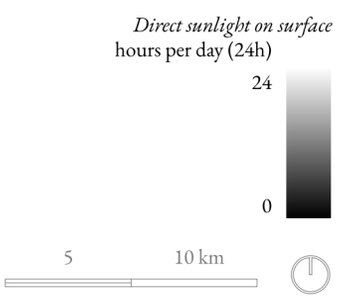
A binary classification is used, where 1 indicates direct solar exposure and 0 indicates no exposure.

Illumination at each time step is defined as:

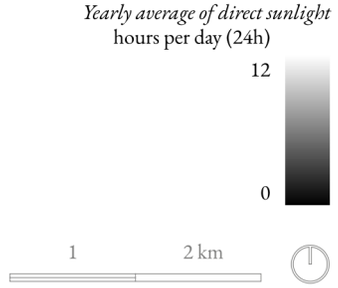
$$I_t = \begin{cases} 1, & \text{if} \quad \cos(\theta_t) > 0 \quad \text{AND} \quad h_t > h_{hor}(\varphi_t) \\ 0, & \text{otherwise} \end{cases}$$

Total daily solar exposure is obtained by temporal integration:

$$H = \sum_{t=1}^{T} I_t \cdot \Delta t$$

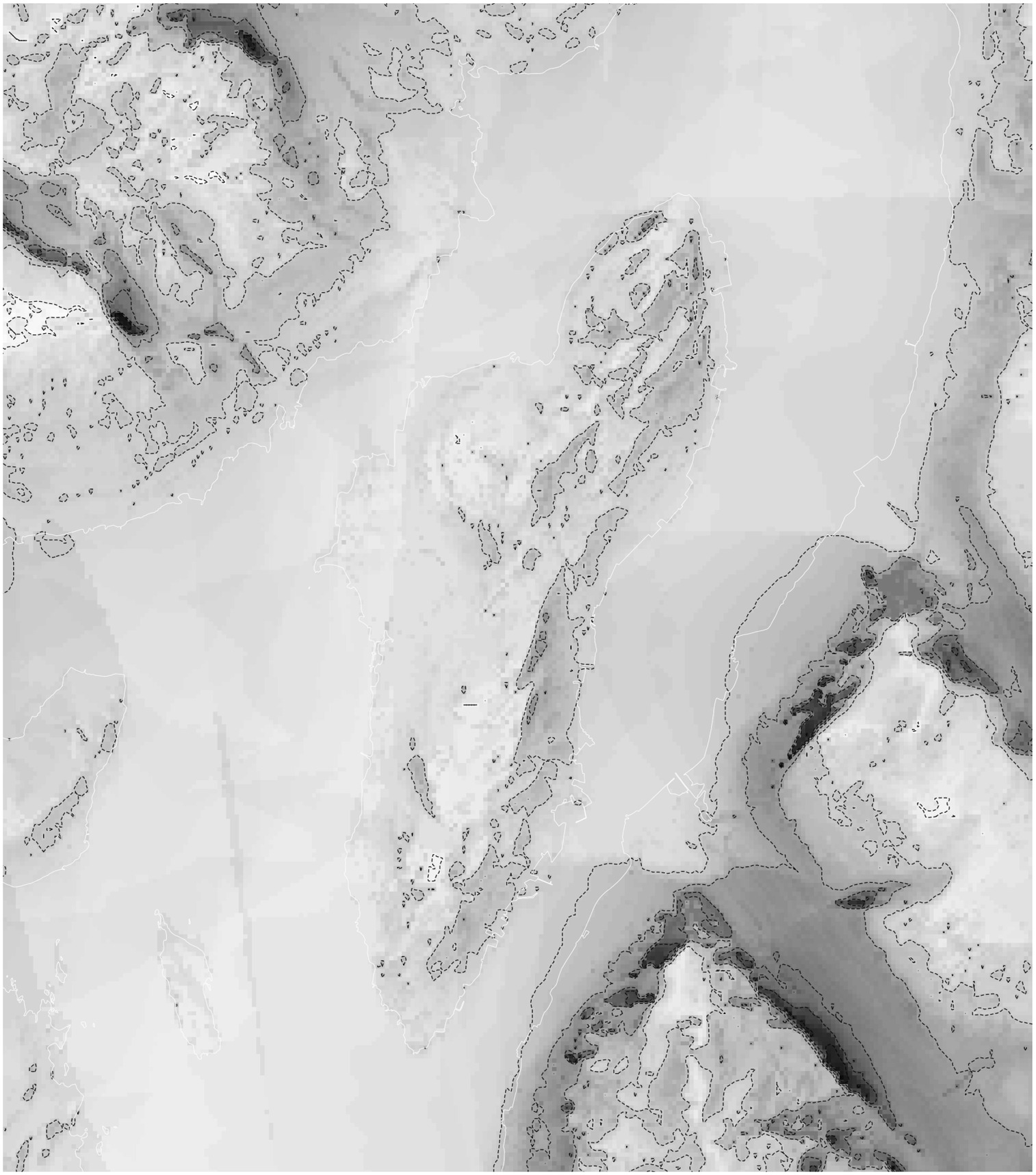


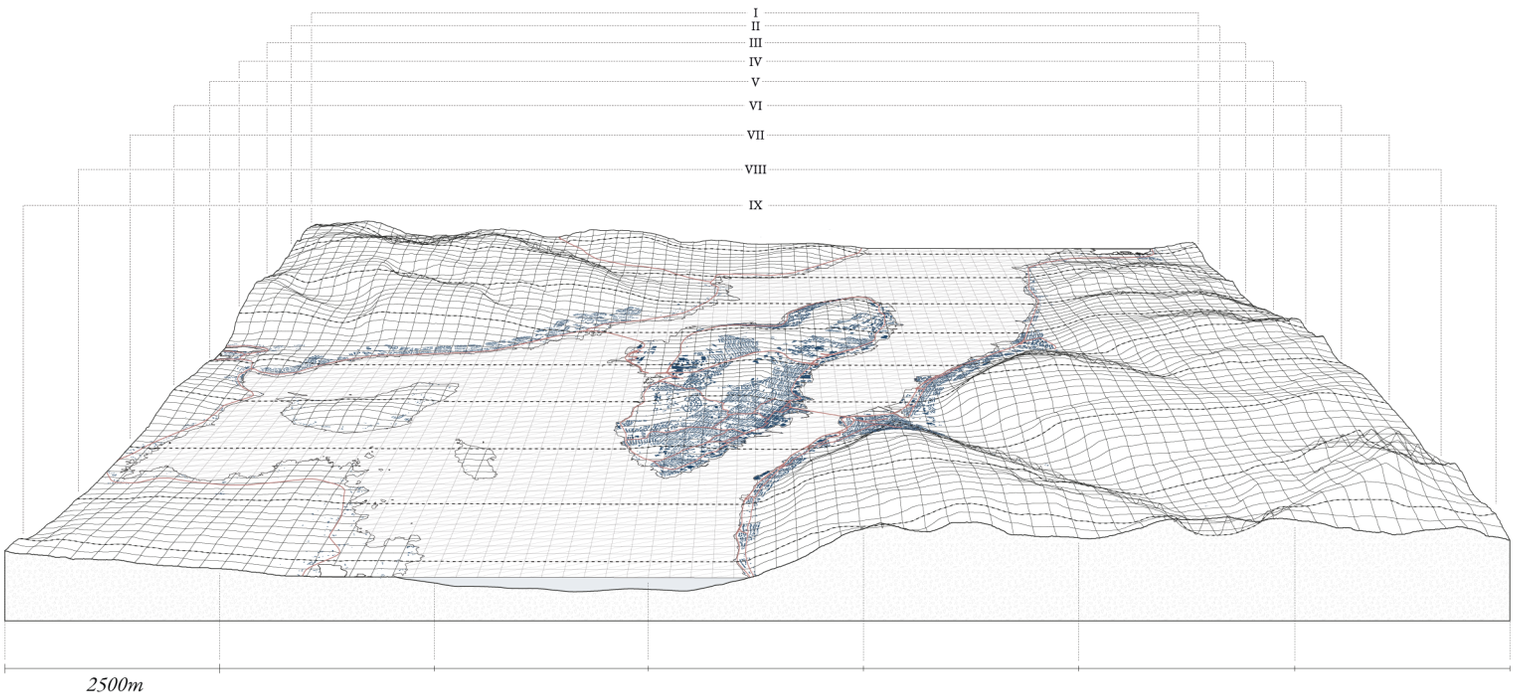
↑ **Figure [5.5].** Direct sunlight reaching the landscape, measured at three key days.



→ **Figure [5.6].** The yearly average of direct sunlight hours on Tromsø's landscape.

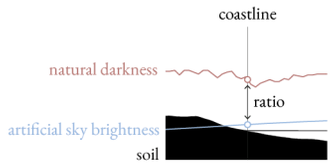
[1] data from www.suncalc.org





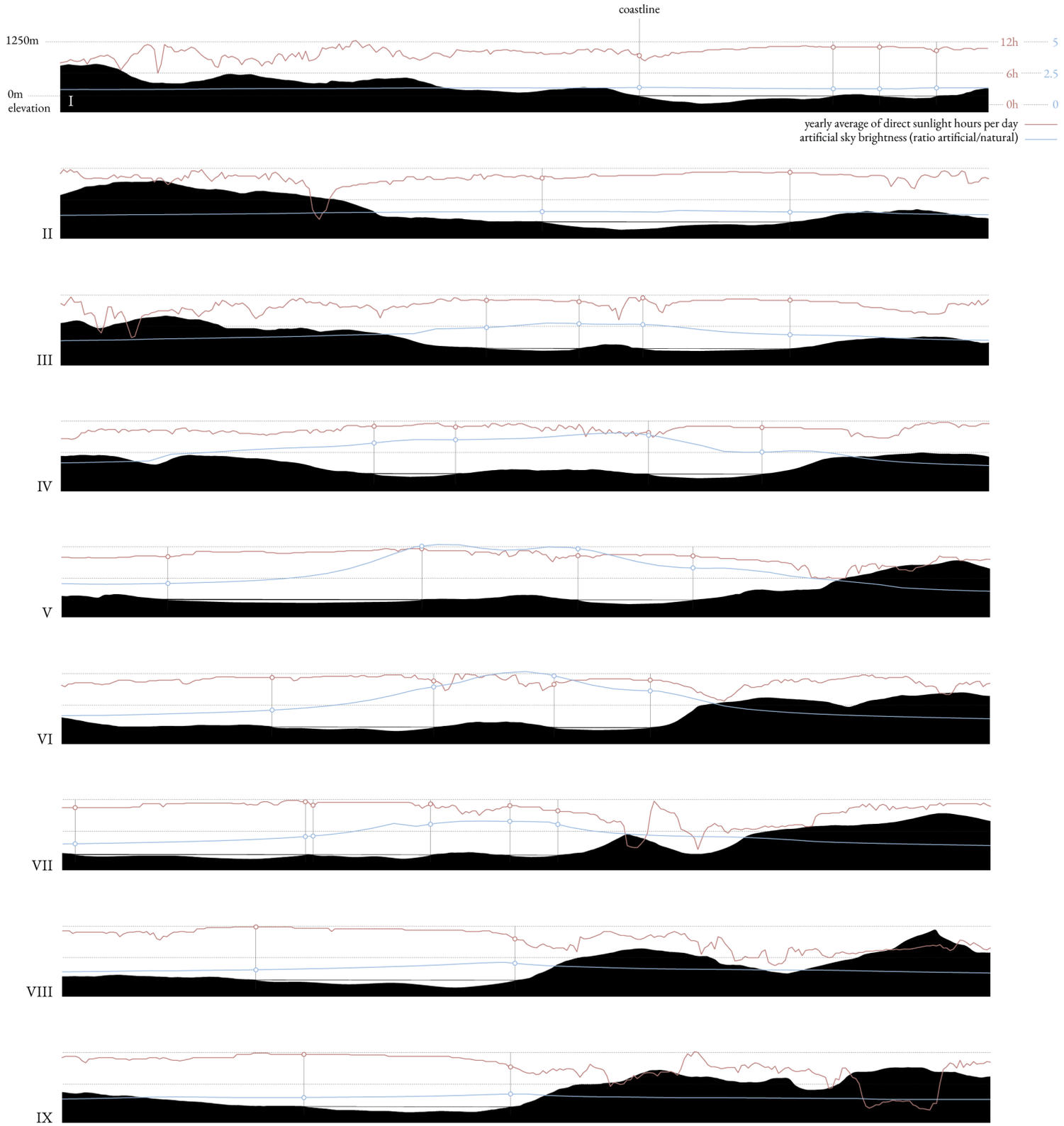
V.I.3 - ARTIFICIAL SKY BRIGHTNESS AS INDICATOR

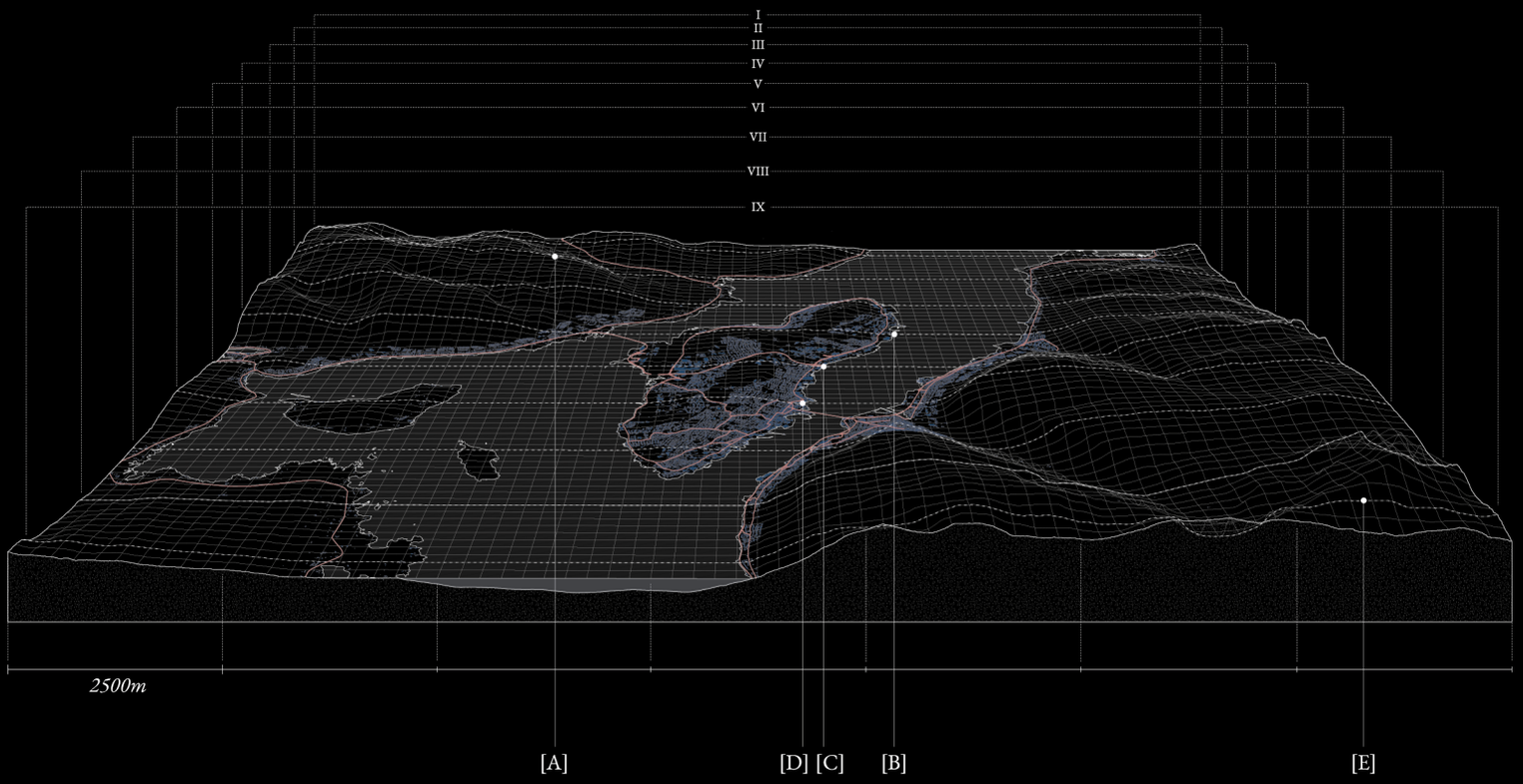
Now that a map has been generated which quantifies the amount of natural light received at each location, it can be combined with datasets representing artificial illumination, such as artificial sky brightness. By plotting the values of both datasets within a shared coordinate system, it becomes immediately apparent where the landscape is naturally dark but affected by artificial light.
In Figure [5.8], both datasets are plotted on top of the terrain elevation.
The vertical lines indicate the position of coastlines and show the ratio artificial brightness /natural darkness. The location of the terrain sections can found in Figure [5.7].



↑ **Figure [5.7].** Tromsø area with locations of sections highlighted (I - IX).

→ **Figure [5.8].** Yearly average of direct sunlight hours per day and artificial sky brightness plotted on top of terrain profiles.

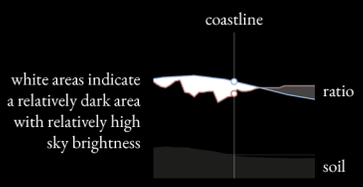

coastline
1250m
0m
elevation
I
12h
6h
0h
5
2.5
0
yearly average of direct sunlight hours per day
artificial sky brightness (ratio artificial/natural)
II
III
IV
V
VI
VII
VIII
IX



V.I.3 - ARTIFICIAL SKY BRIGHTNESS AS INDICATOR

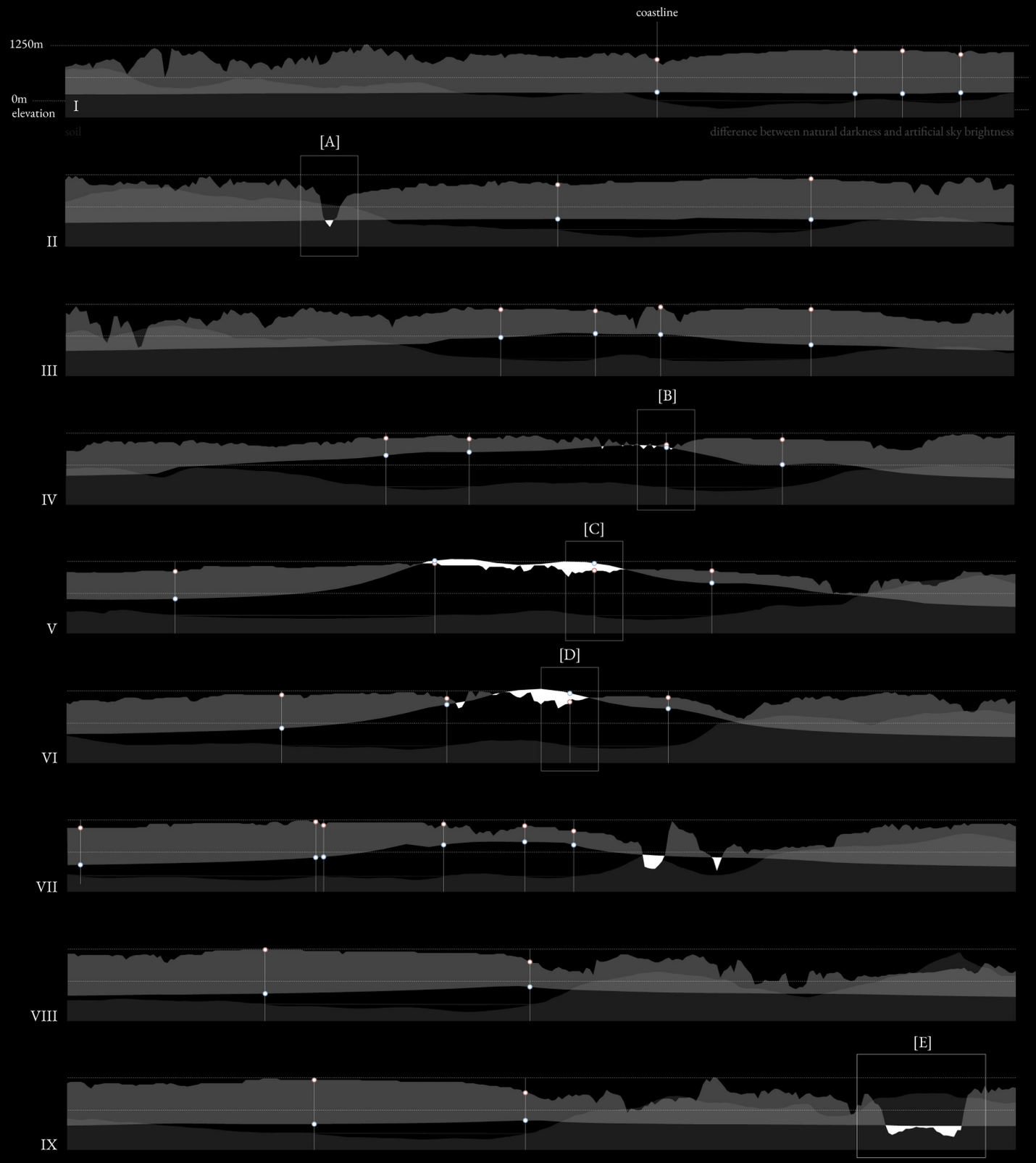
Next, this ratio is plotted in Figure [5.10], where the naturally darker areas with a relatively high sky brightness are plotted in white. The overview indicates locations where this phenomenon occurs, with [B], [C] and [D] being all three industrial sites along the coastline.

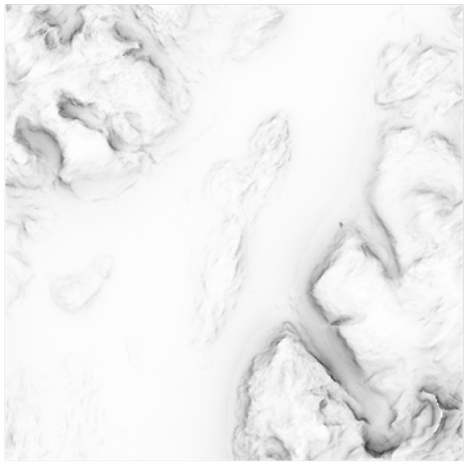
The approach used in this mapping combines two specific datasets and is made to give a first insight of how these maps and datasets can be used for spatial representation and reserach. In order to get a more holistic understanding, more light related maps have been made.



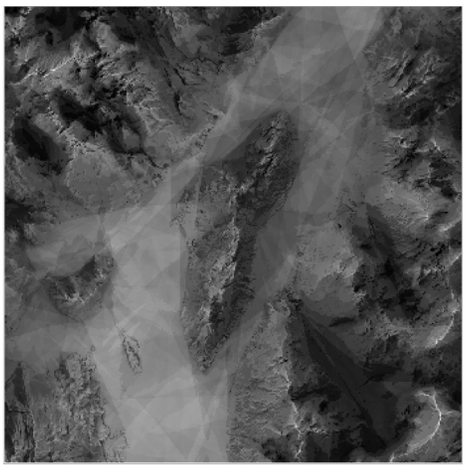
↑ **Figure [5.9].** Tromsø area with locations of sections highlighted (I - IX).

→ **Figure [5.10].** Yearly average of direct sunlight hours per day and artificial sky brightness plotted on top of terrain profiles.


coastline
1250m
0m
elevation
I
soil
difference between natural darkness and artificial sky brightness
[A]
II
III
[B]
IV
[C]
V
[D]
VI
VII
VIII
[E]
IX



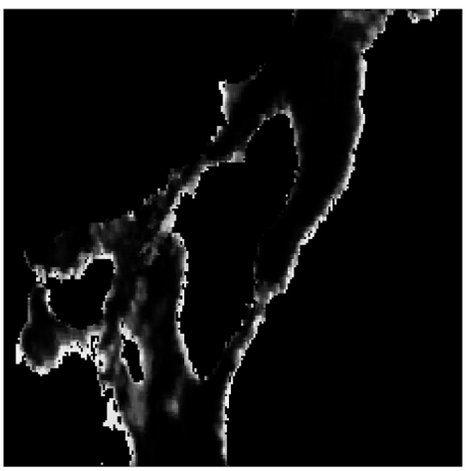
[**A**] sky view factor



[**B**] horizontal light travel distance



[**C**] seabed depth



[**D**] daylight fraction reaching seabed



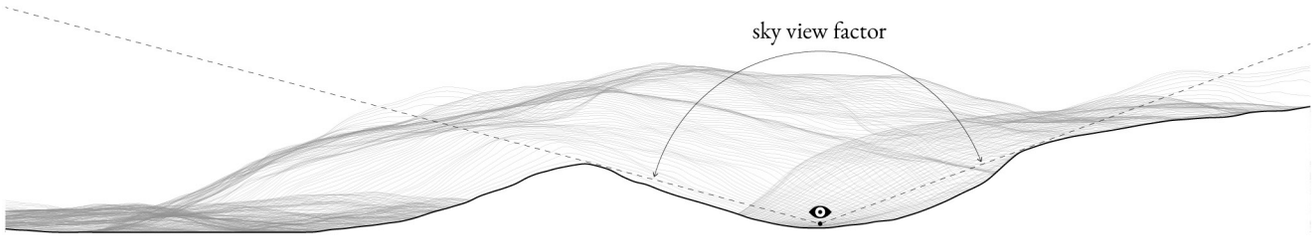
← **Figure [5.11].** Topography-driven characteristics, including [A] sky view factor, [B] horizontal light travel distance, [C] seabed depth, and [D] daylight fraction that reaches the the seabed. White represents relatively lighter conditions and black represents relatively darker conditions.

data: Kartverket, GEBCO, European Space Agency

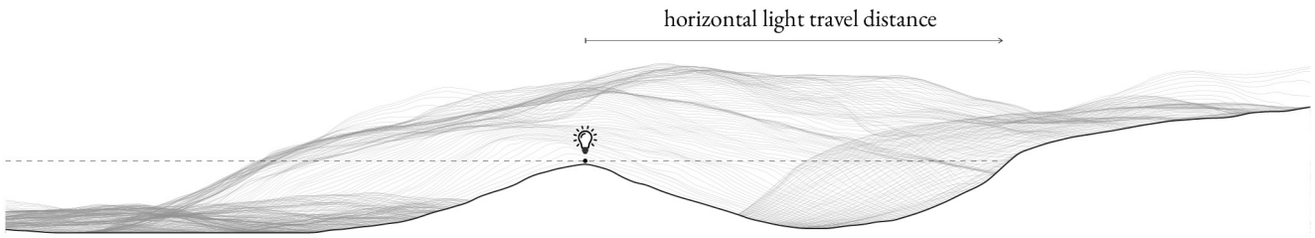
V.I.5 - THE LANDSCAPE AS MEDIUM

Light does not behave equally across a landscape, nor is it perceived uniformly. The propagation and perception of light depend on materiality (reflection), elevation, and position within the landscape. Figures [5.11, A, B & D] are based on the elevation model and show gradients ranging from white to black, where white represents relatively lighter conditions and black represents relatively darker conditions. The sky view factor describes the proportion of visible sky compared to the amount that would be visible without any topography. The horizontal light travel distance indicates the average range that light can travel from a specific point, revealing where a light source may potentially affect a larger area of the landscape. The fraction of daylight reaching the seabed is based on an existing dataset and is calculated using water clarity, seabed depth, and water currents.

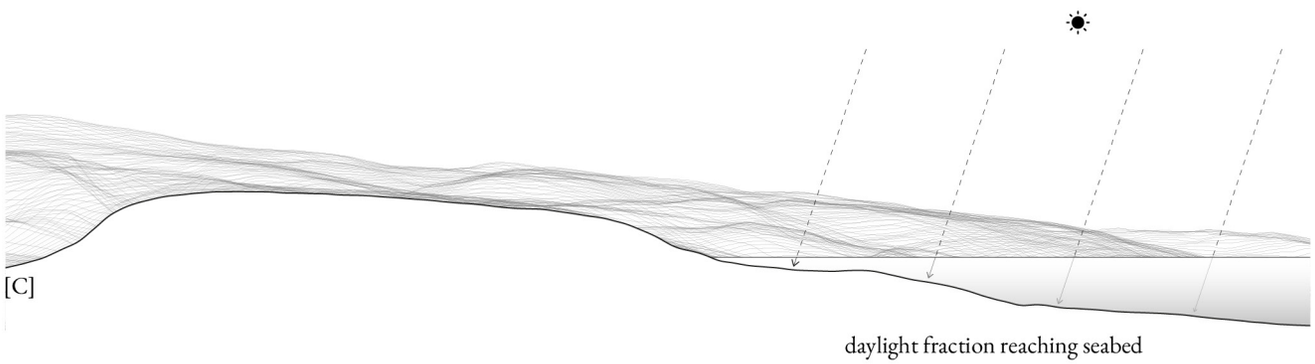
→ **Figure [5.12].** Diagrams on [A] the percentage of skies visible from a place, [B] the horizontal distance that light can travel in the landscape and [C] the fraction of light reaching the sea bed through the water.


sky view factor

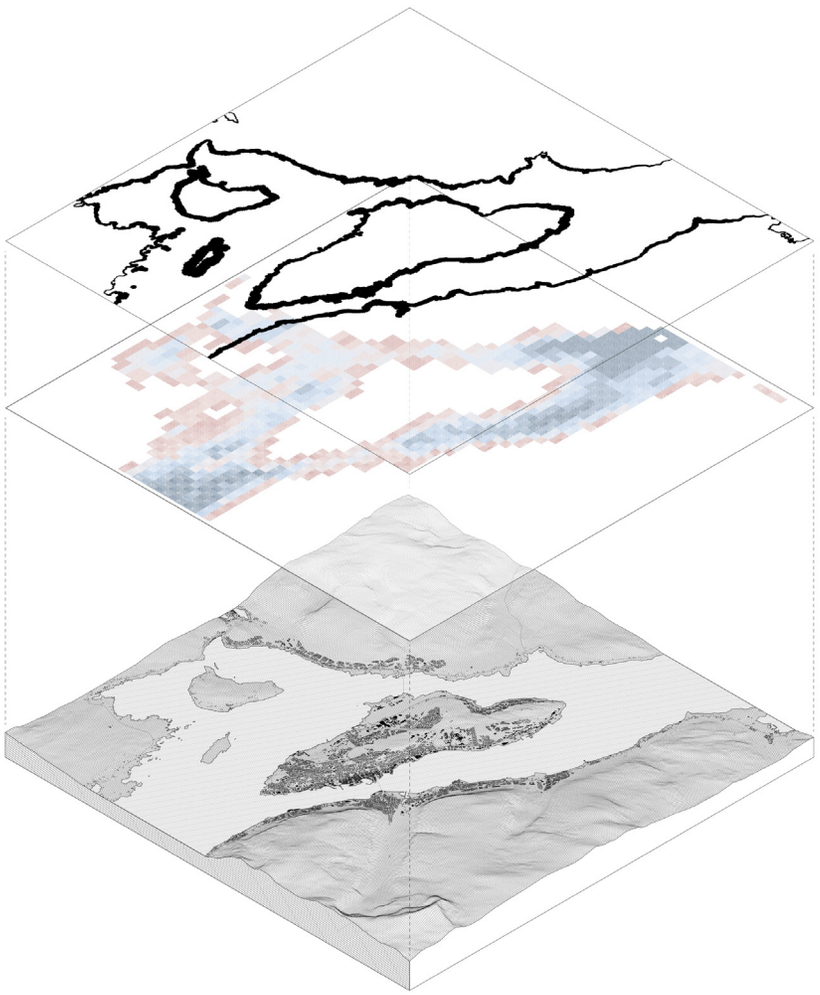
[A]

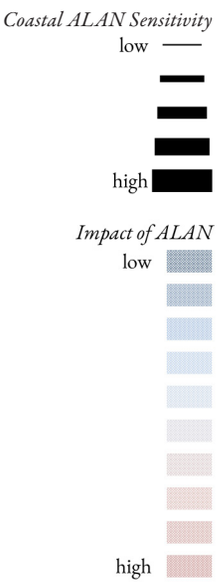

horizontal light travel distance

[B]


daylight fraction reaching seabed

[C]





V.I.6 - SPATIAL FOOTPRINT OF NATURAL DARKNESS

To approximate the spatial footprint of natural darkness, the layers illustrated in Figure [5.14] were employed. Each layer is normalised to a common scale ranging from 0 to 1, representing the relative potential impact of ALAN. Values closer to 0 are relatively darker areas, indicating higher potential impacts of ALAN, whereas values closer to 1 represent relatively lighter areas, indicating a lower potential impact. For instance, a lower sky view factor corresponds to darker locations within the landscape. In such areas, any artificial light source, regardless of its intensity, will have a comparatively greater impact on perceived brightness, due to adaptation conditions and spectral sensitivity (Rea et al., 2010).

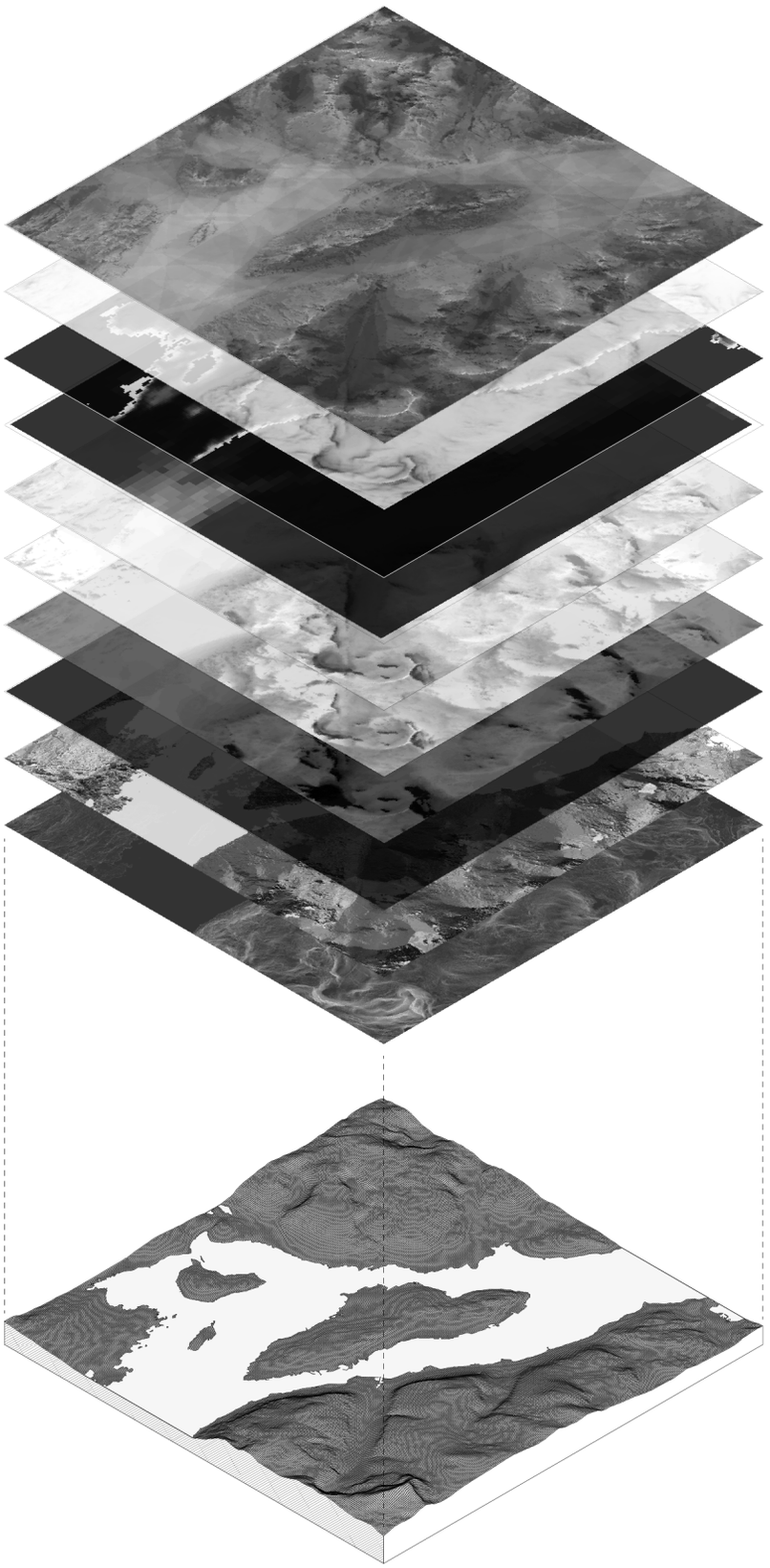
A similar relationship is observed for horizontal light travel distance. The greater the distance light can travel unobstructed, the wider its spatial reach and, consequently, its potential impact.

Ultimately, by averaging the values of the different layers, the resulting output provides insight into where ALAN is likely to exert greater or lesser influence, independent of the intensity of the light source itself.

In Figure [5.13], this effect is shown exclusively over water surfaces, as the calculation includes datasets that are specific to the focus on the marine ecosystem.

↖ **Figure [5.13].** Cartosynthesis of layers impacting natural darkness, showing the sensitivity to ALAN, based on natural darkness.

→ **Figure [5.14].** Axonometric layering towards the spatial footprint of natural darkness.


horizontal light travel distance [*m*]
sky view factor [*%*]
daylight fraction reaching seabed [*%*]
seabed depth [*m*]
yearly average sunhours [*h*]
sunhours June solstice [*h*]
sunhours equinox (Mar/Sept) [*h*]
sunhours December solstice [*h*]
terrain aspect [*N/W/S/E*]
terrain slope [*degrees*]

Light source	*Light emission (lm) per m² footprint*	*Leakage (%)*	*Light emission (lm) (approximation)*
dwelling	50	10%	5/m²
industrial site	100	50%	50/m²
airport	100	50%	100/m²
road infrastructure	50	80%	40/m²
ship	500	75%	375/m²

V.II.1 - COASTAL LIGHT PRESSURE - METHOD OF ASSESSMENT

Previous spatial exploration has shown the coastline to function as a line of convergence, where ALAN occurs in a linear pattern, following the coastline. Rather than a neutral boundary, the coastline can be understood as a spatial condition in which artificial light becomes a structuring force in the nocturnal landscape. This makes it an analytical construct for understanding how ALAN is distributed and experienced along the coastline.

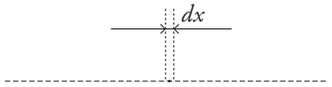
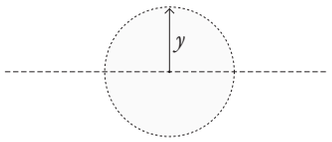
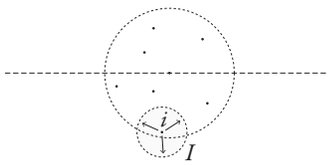
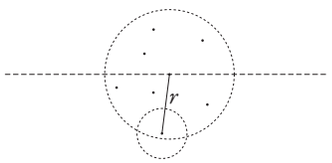
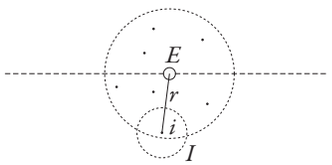
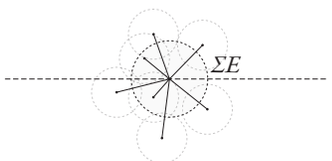
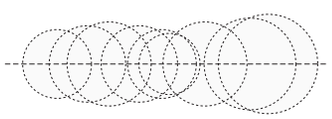
To explore this, this thesis introduces a method as a way of reading the coastline through artificial light. The method does not aim to produce exact point measurements, but rather to construct a continuous spatial representation of how light accumulates and varies along the coastline. Limitations of the method have been written in the recommendations section. The coastline is modelled as a continuous curve, divided into infinetesimal segments. For each segment, a 2,000-metre buffer is applied to include nearby light sources that most strongly affect coastal lighting. The buffer is a practical approximation rather than a strict physical limit, based on the light emission from each source. This is estimated using the inverse square law, where the emission decreases proportionally with the inverse square of the distance:

$$E \propto \frac{I}{r^2}$$

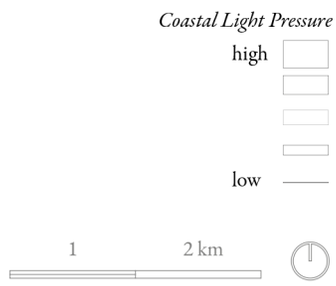
where E is illuminance, I is estimated emission, and r is distance to the coastline segment. As precise emission data are unavailable, values of emission, and leakage are approximated using categorical ranges based on asset type and scale (see Figure [5.15]). In case more data would become available - such as emission, light direction or leakage - a more detailed and correct calculation could be made. Contributions are then summed per segment to generate a continuous representation of coastal light pressure. The method enables a comparative reading of how ALAN is distributed, highlighting patterns of concentration and relative darkness.
In this research, the method is applied to five source categories: road infrastructure, shipping, dwellings, industrial sites, and the airport. Together, they represent the dominant contributors to coastal ALAN in Tromsø. By separating the source categories into different maps, it allows the spatial contribution to be analysed individually: making it possible to understand how different forms of artificial lighting accumulate and interact along Tromsø's coastline.

↖ **Figure [5.15].** Light emission values, approximated using categorical ranges based on asset type and scale.

→ **Figure [5.16].** An overview of the methodological steps to approximate the coastal light pressure.

Step		*Operation*
[1]		Define coastline *x* *the coastline is represented as a continuous curve.*
[2]		Split into infinitesimal segments *dx* *By segmenting the coastline, illuminance can be approximated through integration along the curve.*
[3]		Buffer segments with *y* = 2000m *a distance of 2,000 metres is used as an averaged approximation of the effective range over which artificial light diminishes to negligible levels.*
[4]		Define light source assets *i* within buffer and their emission *I* *the emission parameter I is estimated using approximate ranges based on asset size and estimated lighting, since each asset has different lighting characteristics.*
[5]		Determine distance *r* to coastline segment *to a maximum of 2,000 metres.*
[6]		Calculate illuminance *E* at coastal segment per asset *i* as a function of distance *r* and emission *I* $\mathrm{E_i(x)} = \frac{\mathrm{I_i}}{4\pi \mathrm{r_i(x)}^2}$
[7]		Calculate sum of illuminance *E* at coastal segment for all assets *i* within buffer $\mathrm{E(x)} = \sum_{\mathrm{i}} \frac{\mathrm{I_i}}{4\pi \mathrm{r_i(x)}^2}$
[8]		Integral of sum of illuminance *E* along the coastline $\mathrm{E_{tot}} = \int_{\mathrm{coastline}} \left(\sum_{\mathrm{i}} \frac{\mathrm{I_i}}{4\pi \mathrm{r_i(x)}^2} \right) \mathrm{dx}$
[9]		Graduated line of coastal light pressure, normalised in values from 0 to 1 *To allow comparison across light source groups, all results are normalised, representing relative spatial light accumulation and darker regions.*

V.II.2 - ROAD INFRASTRUCTURE

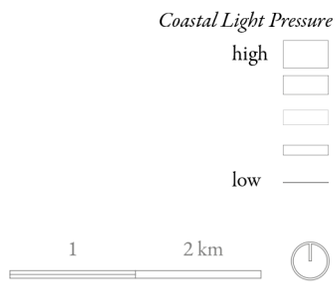


→ **Figure [5.17].** Coastal light pressure from road infrastructure.

data: OpensStreetMap

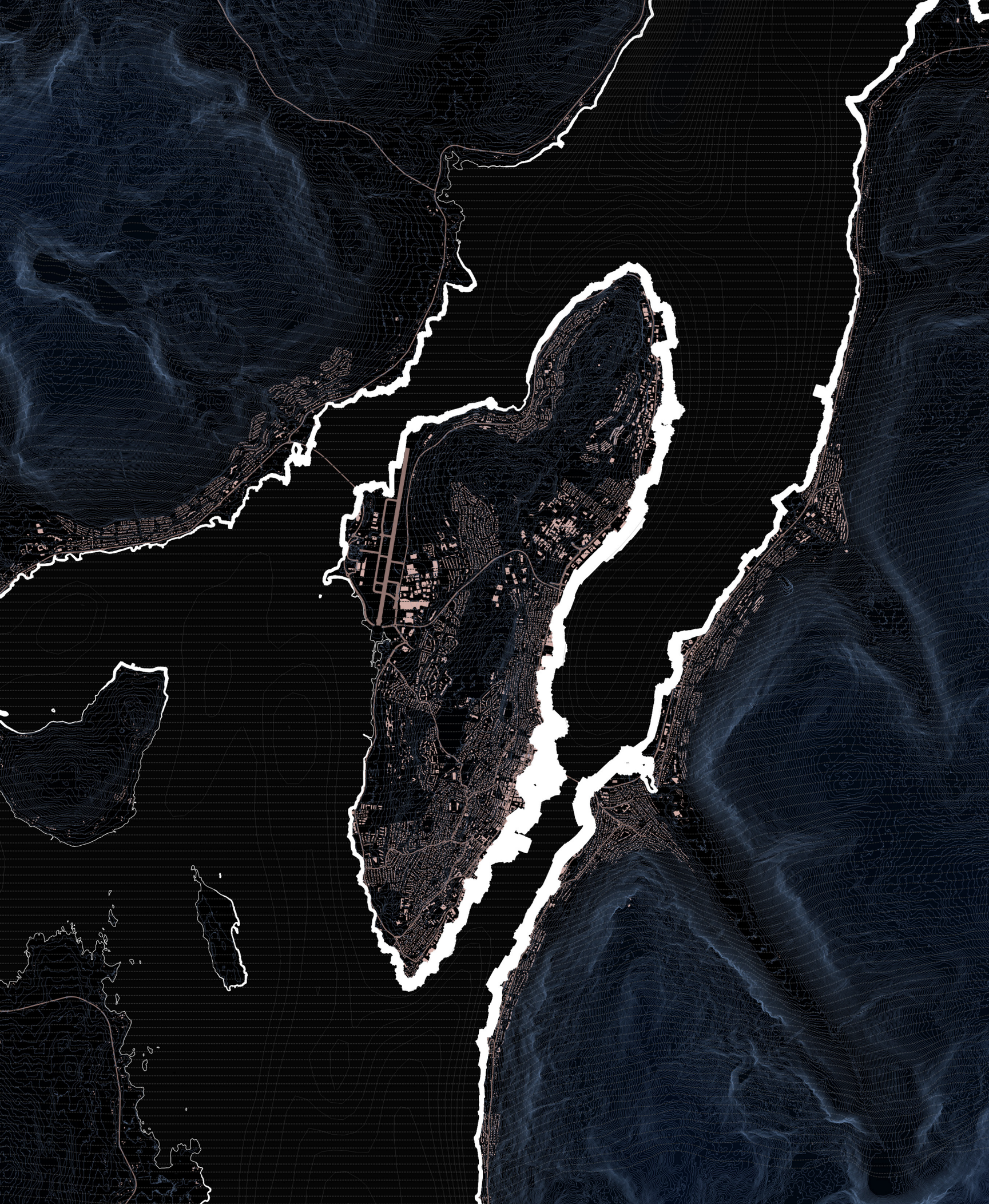


V.II.3 - SHIPPING

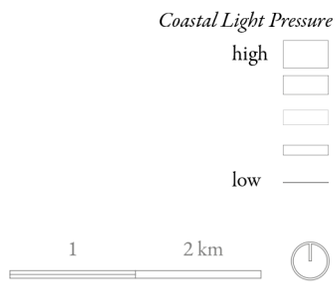


→ **Figure [5.18].** Coastal light pressure from shipping.

data: World Bank Group

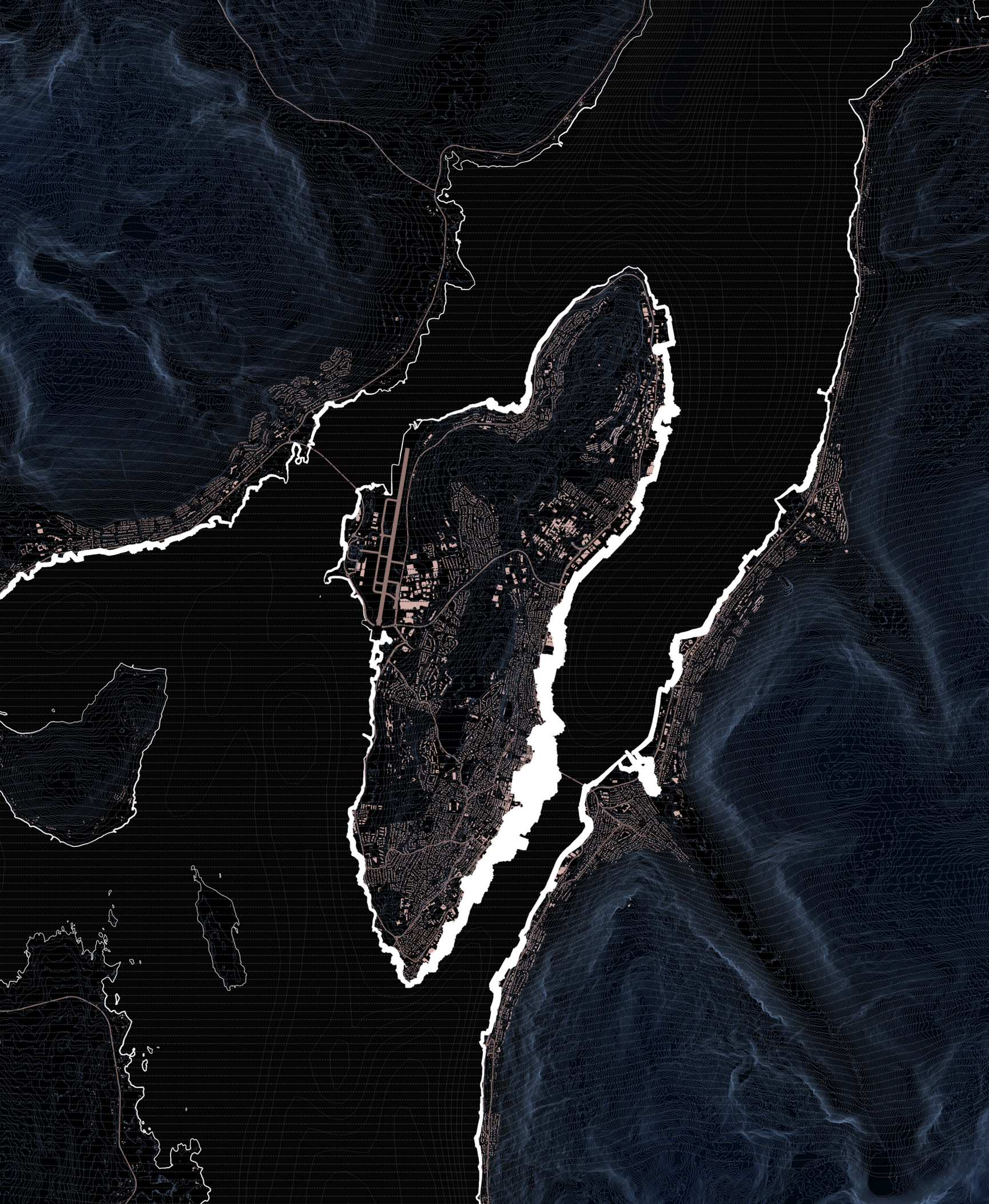


V.II.4 - HOUSES

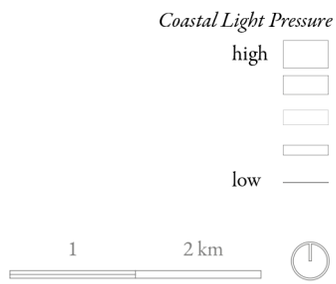


→ **Figure [5.19].** Coastal light pressure from houses.

data: OpenStreetMap

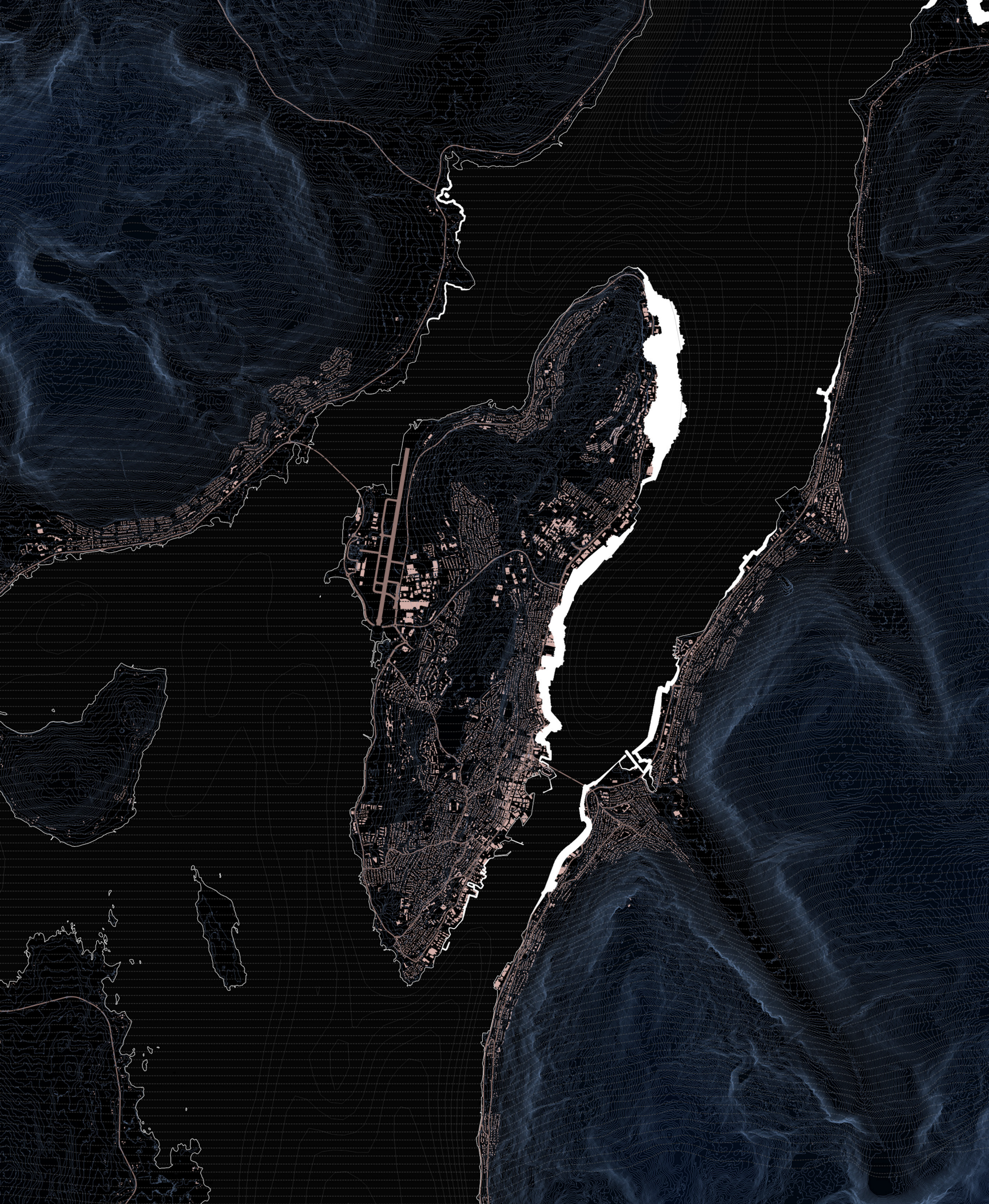


V.II.5 - INDUSTRIAL SITES

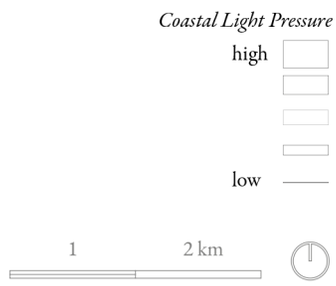


→ **Figure [5.20].** Coastal light pressure from industrial sites.

data: OpenStreetMap

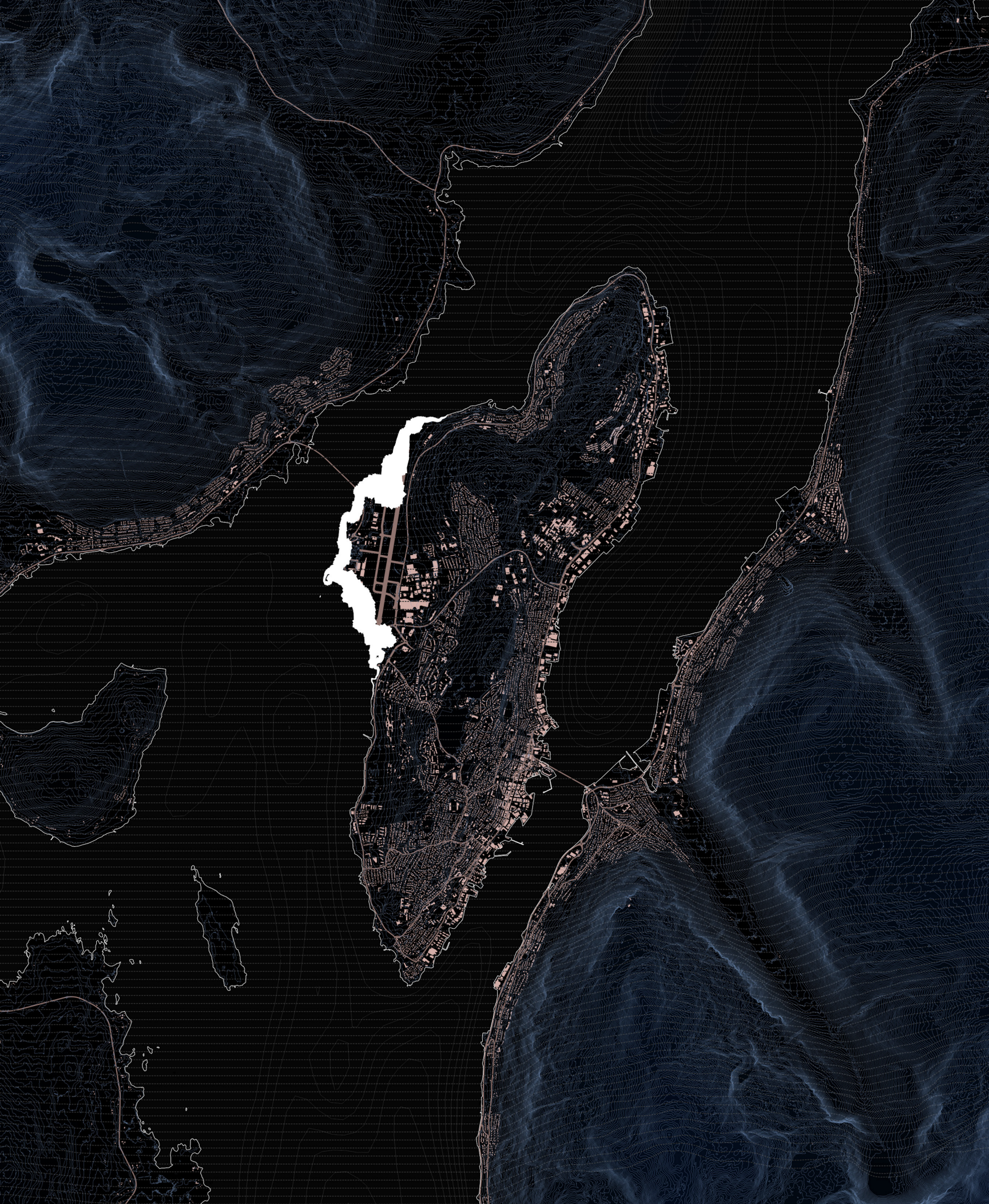


V.II.6 - AIRPORT



→ **Figure [5.21].** Coastal light pressure from the airport.

data: OpenStreetMap



V.II.7 - ALAN COASTAL IMPACT

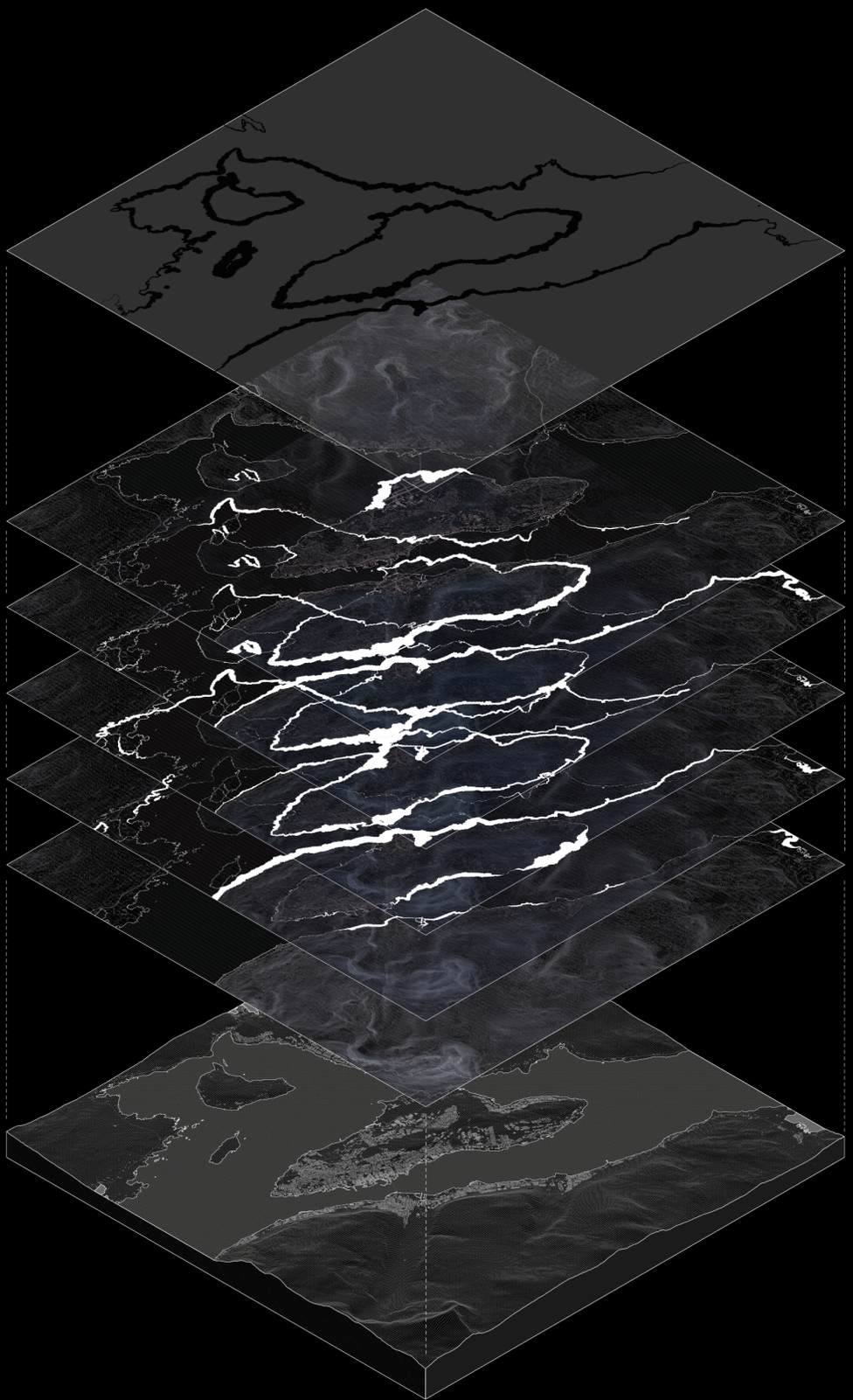
By combining the *natural perspective* from V.I and the *artificial perspective* maps from V.II, an overlay analysis is produced that reveals where artificial light accumulates along the coastline in combination with where the landscape exhibits the highest levels of sensitivity to light disturbance.

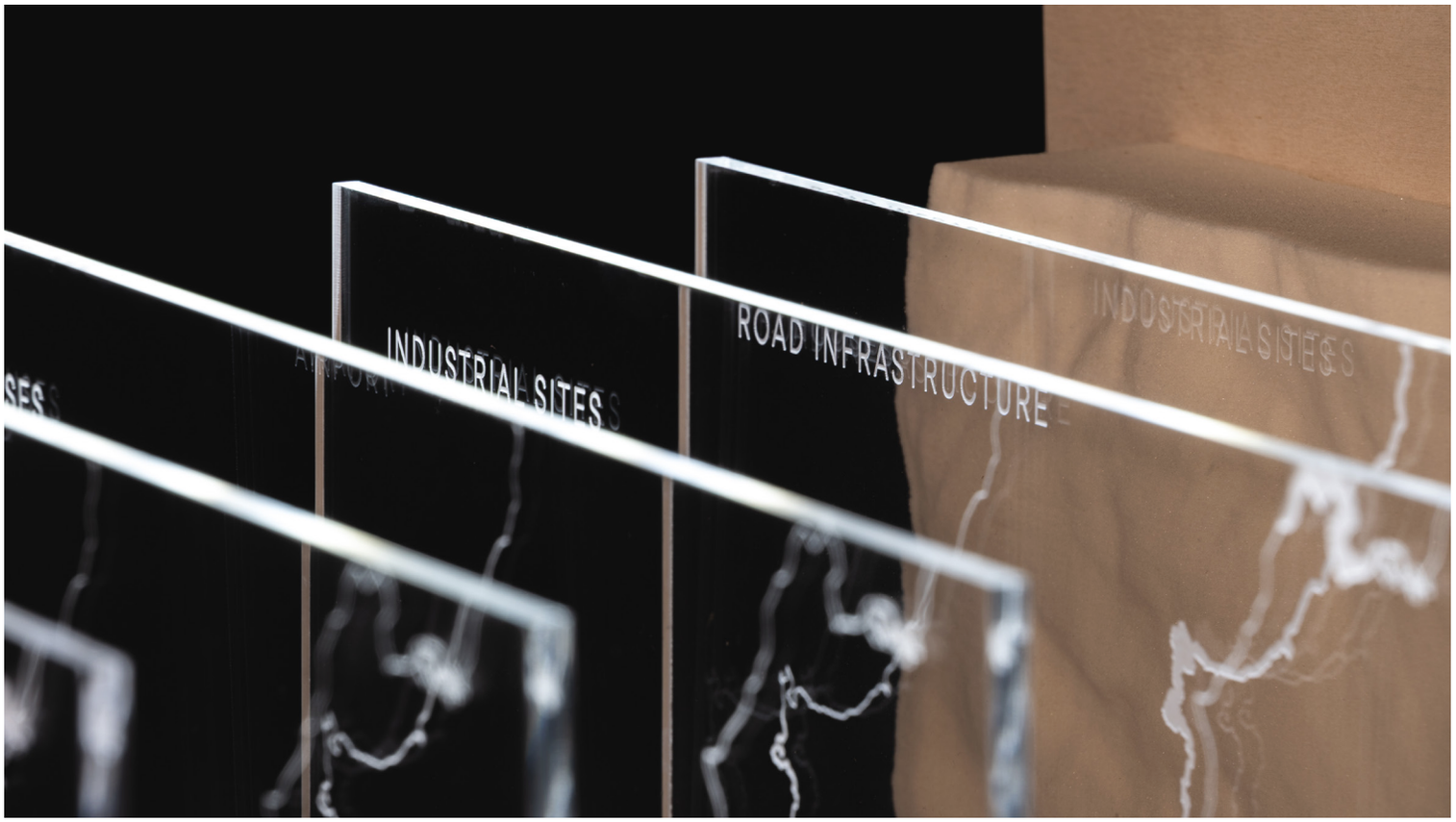
This combined reading makes two conditions explicit:

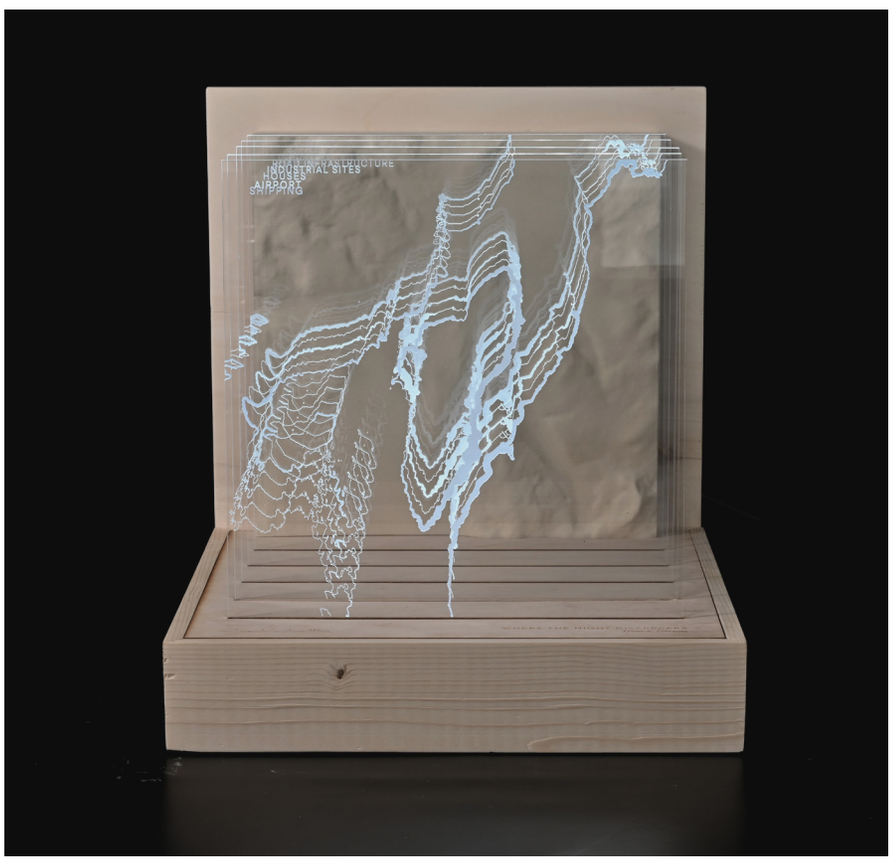
[a] zones of concentrated artificial light along the coastal edge, and
[b] areas of heightened landscape sensitivity to artificial illumination. In this way, artificial light is no longer treated as a uniform form of pollution, but is instead understood in relation to its contextual impact on specific spatial and ecological conditions.

The resulting map (see Figure [5.22]) allows existing infrastructure to be assessed in terms of its actual spatial impact on dark conditions. At the same time, it provides a tool for future spatial planning, identifying areas where the landscape calls for a more restrained or 'dark-led' approach to development and illumination.

→ **Figure [5.22].** Combined axonometric of coastal light pressures and landscape sensitivity to ALAN, highlighting the coastline's most disrupted areas.


ALAN sensitivity
Airport
Shipping
Houses
Road infrastructure
Industrial sites



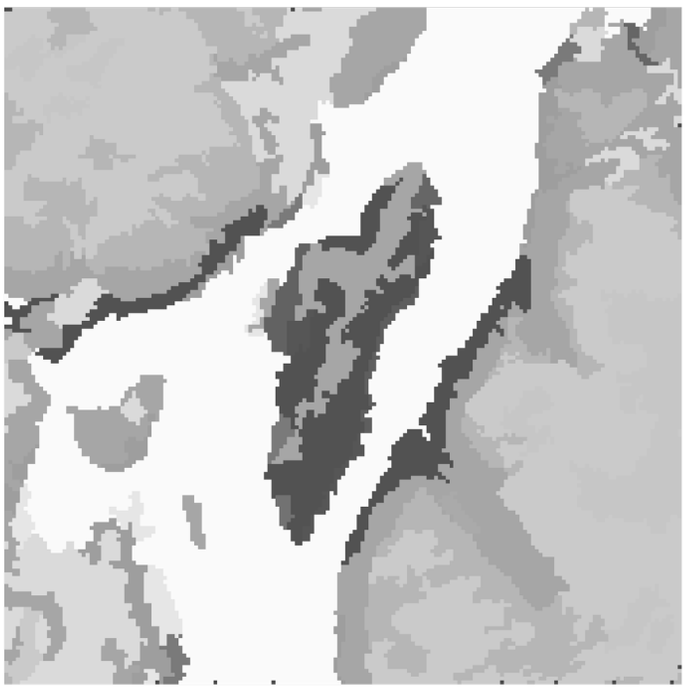


↑ **Figure [5.23].** Zoom in on model with engraved glass, lit up by LED's.

← **Figure [5.24].** Display for exhibition showing the five layers of coastal light pressure, as calculated in chapter V.II.

→ **Figure [5.25].** Display for exhibition showing the five layers of coastal light pressure, as calculated in chapter V.II.


ROAD INFRASTRUCTURE
INDUSTRIAL SITES
HOUSES
AIRPORT
SHIPPING



V.III.1 - DARKNESS AS A PLANNING CONCERN

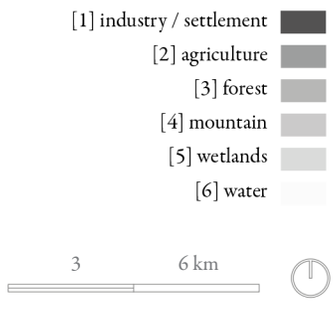
By using a rights of nature framework, darkness is positioned as a condition with intrinsic, ecological value. However, once darkness is understood as a right, the question rises how urbanism operates when darkness itself becomes a planning concern.

Which parts of the landscape should remain dark, which parts can absorb illumination, and where do critical conflicts emerge between ecological sensitivity and human activity? And above all: how can we design for this?

The data collected and produced throughout this research is used. By pairing two layers at a time, it becomes possible to identify how different environmental conditions interact, reinforce one another, or are in conflict with eachother. For every combination either the low or high values are taken into account, see Figure [5.27].

Furthermore, by overlaying the land cover map (Figure [5.26]), the outcomes reveal a range of 360 nocturnal spatial conditions: from highly sensitive dark ecologies, where artificial light can have significant ecological consequences, to more resilient or already urbanised territories, where illumination can be negotiated more actively, see Figure [5.28].

Through this approach, the landscape is no longer understood as a neutral surface to be illuminated, but as a differentiated field of nocturnal conditions. In this way, the research moves beyond conventional light pollution mapping towards a broader territorial framework for future planning. The aim is therefore not simply to reduce artificial light, but to understand how darkness itself can operate as a structuring principle for Arctic urbanism and environmental governance.

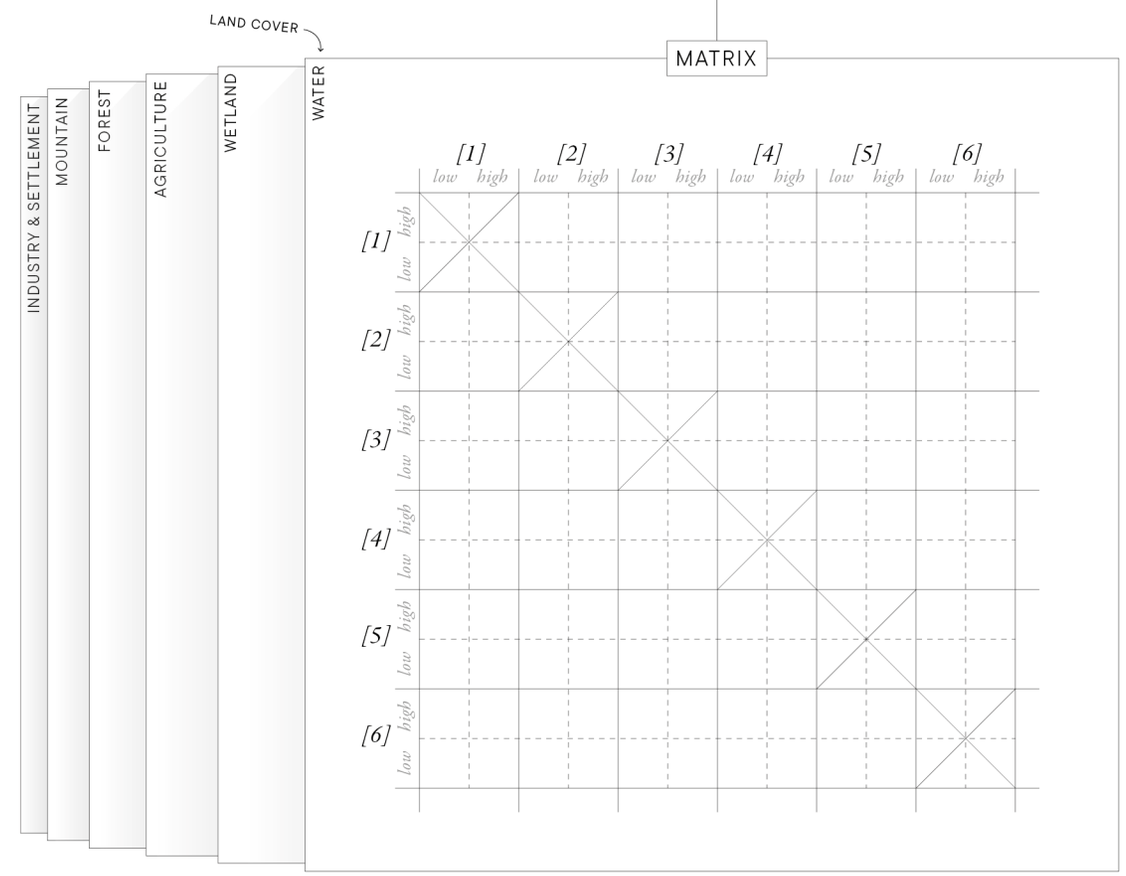


↖ **Figure [5.26].** Land cover of Tromsø, divided in 6 groups.

data: Copernicus Land Monitoring Service

↗ **Figure [5.27].** Matrix used to overlay the datasets into an atlas of 360 maps

LAYER	LOW VALUE ⟷ HIGH VALUE	
[1] NTLR - Night time light radiance	*low ALAN intensity*	*high ALAN intensity*
[2] SB - Sky brightness	*dark sky*	*bright sky*
[3] HLTD - Horizontal light travel distance	*low ALAN impact*	*high ALAN impact*
[4] SVF - Sky view factor	*enclosed, darker*	*open atmosphere, lighter*
[5] SH - Average sunlight hours	*prolonged darkness*	*prolonged light*
[6] LFSB Light fraction at seabed	*dark water column*	*illuminated water column*



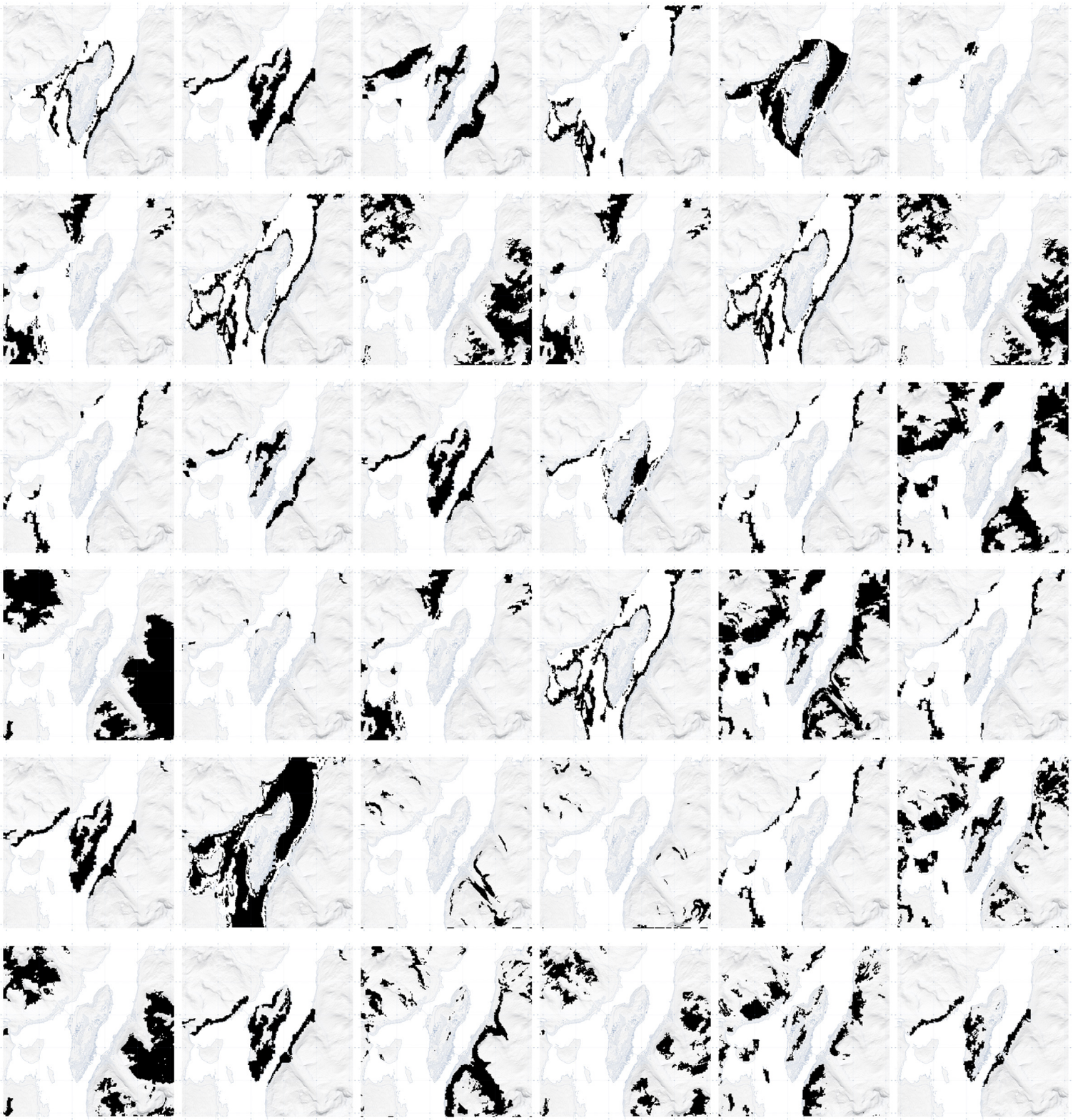
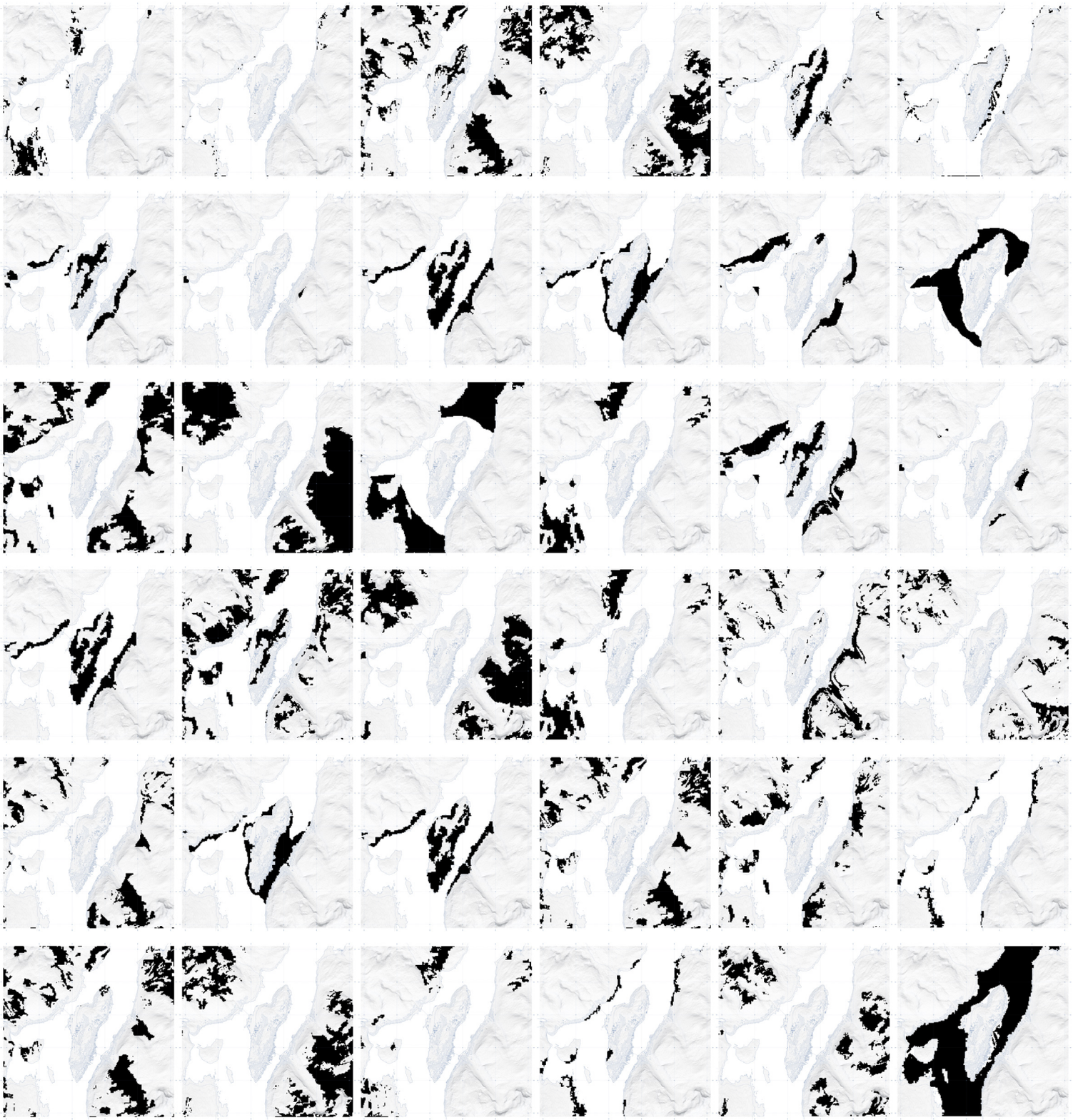


Figure [5.28]. An overview of (a part of) the 360 generated maps. The highlighted areas in black are the areas where the combination of two maps overlap, resulting in different territorial conditions



V.III.2 - HOW TO USE THE ATLAS?

Taken together, the maps provide a broad reading of spatial conditions related to light and darkness. To show how the maps can be read, Figure [5.29] presents a selection of nine combinations as examples of meaningful overlaps.

Rather than representing fixed design interventions, these combinations should be understood as *territorial conditions* that reveal how light behaves, spreads, accumulates, or remains absent within the landscape. The combinations make visible where darkness is vulnerable, where light operates at a regional scale, and where ecosystems depend on prolonged or uninterrupted dark conditions.

The mappings function as an interpretative framework for future spatial decision-making and help to identify territorial conditions through the lens of light and darkness. Finally, three overarching typologies can be identified:

■ *Landscape as Medium*
This typology describes areas in which light actively travels through the landscape. Here, the landscape acts as a medium that transports, amplifies, or projects light across larger distances. Conditions such as open topography, sky view factor, and horizontal light propagation determine the regional impact of light.

● *Light as Emission System*
This typology focuses on areas where artificial light is primarily produced and emitted. It addresses settlements, infrastructure, and human activity as sources. Light is understood here as a form of emission with effects that extend beyond the immediate location of its source.

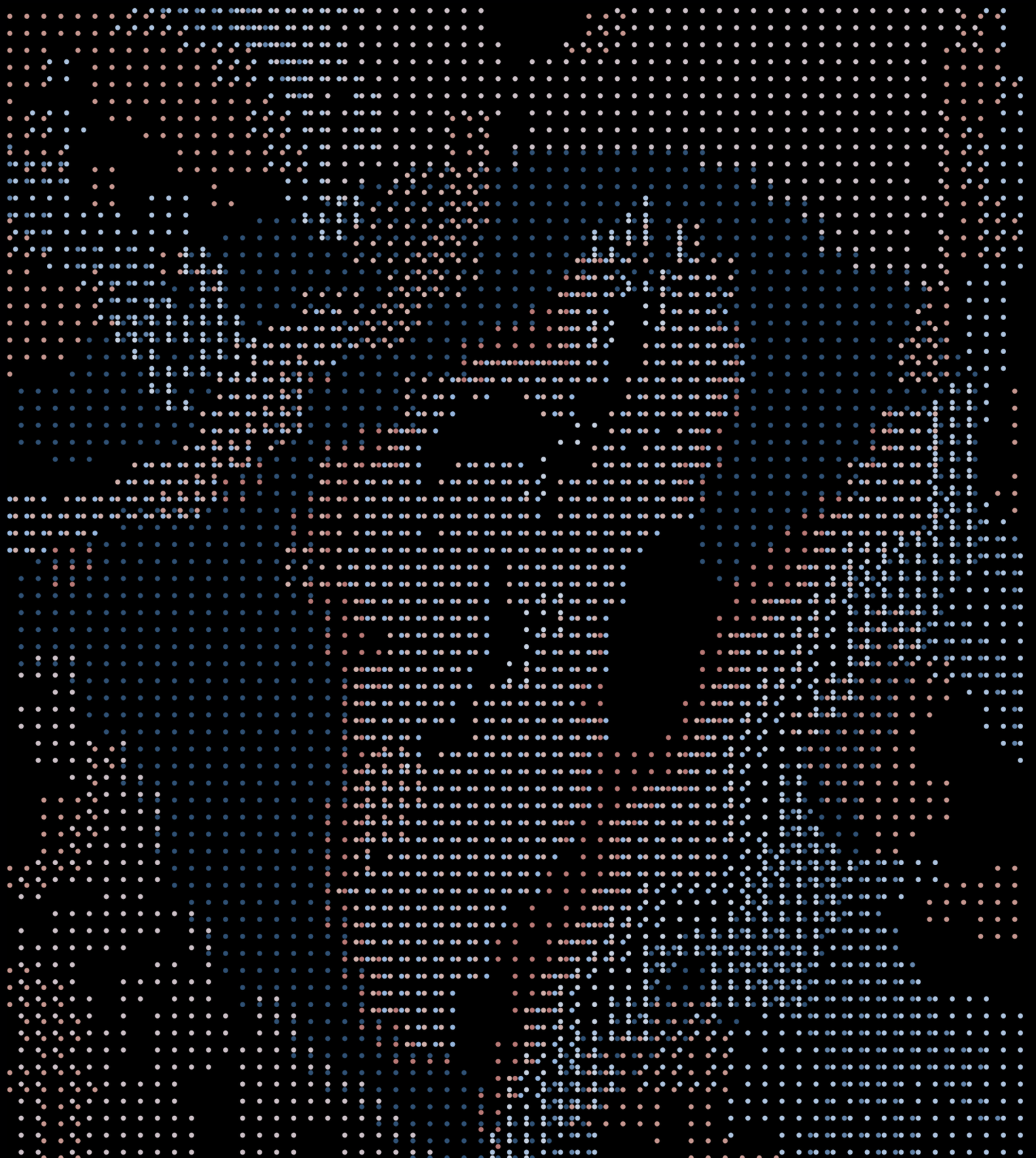
▲ *Darkness as Protected Infrastructure*
This typology approaches darkness not as the absence of activity, but as a spatial condition with intrinsic ecological value. The combinations within this category identify areas where darkness persists, is ecologically necessary, or functions as a continuous environmental infrastructure across terrestrial and marine ecosystems.

Land Cover:
[1] - *Industry / settlement*
[2] - *Agriculture*
[3] - *Forest*
[4] - *Mountain*
[5] - *Wetlands*
[6] - *Water*



→ **Figure [5.29].** An overlay of 9 territorial conditions, derived from the matrix-based atlas.

Territorial Conditions	Combined Layers	Land Cover	Legend
■ *External light contamination of otherwise dark landscape*	low NTLR - high SB	3, 4, 5, 6	
▲ *Natural darkness retention pocket*	low SVF - low NTLR	3, 5	
● *Urban light emission core*	high NTLR - high SB	1, 2	
▲ *Intrinsic darkness dependency ecosystem*	low SH - low NTLR	3, 4, 5, 6	
■ *Artificially extended daylight dominance*	low SH - high SB	3, 4, 5, 6	
▲ *Marine black corridor*	low LFSB - low SB	5, 6	
● *Light-saturated human productivity landscapes*	high SB - high SH	1, 2, 5	
■ *Long-range illumination corridors*	high HLTD - high SVF	2, 4	
● *Coastal light leakage*	high LFSB - high NTLR	5, 6	



V.III.3 - CONTRIBUTION TO RIGHTS OF NATURE

Finally, this thesis contributes to the Rights of Nature discourse by exploring how urbanism and representation shape the way nature is perceived, valued, and acted upon. Rather than understanding the Arctic solely through systems of extraction, efficiency, and continuous operation, the project has shown a more-than-human approach in understanding the landscape. Seasonal darkness, and non-human systems are recognised as active conditions structuring the Arctic's space and time.

By framing darkness as an ecological condition with intrinsic value, the thesis argues for a shift toward practices of care and ecological regeneration. Here, regeneration is not understood as technological repair after damage has occurred, but as the capacity to sustain and restore the relationships between humans, non-humans, and the temporal rhythms of the Polar night.

Practices of care emerge through attention, observation, and the recognition that not all environments should be permanently illuminated, optimised, or controlled.

The project does not claim how to resolve the loss of the night. Rather, it aims to make visible that a form of ecological loss is taking place in the first place. A possible next step would therefore be to ask who, or what, can speak on behalf of darkness as a threatened ecological condition. In this sense, the thesis seeks to enable another way of seeing the Arctic: one in which the loss of darkness is no longer understood as progress, but as a urgent territorial transformation.

To communicate this notion, four tiles have been made with future gestures. These tiles function as open-ended propositions that translate the thesis' conceptual concerns into reflections. Together, they form a constellation of thoughts, inviting reflection on how urbanism could participate in the recognition, protection, and negotiation of darkness within dominant urban, industrial and infrastructural development.

To conclude: development is often seen through growth and expansion. Yet, through removal and degrowth, space is made for darkness to persist.

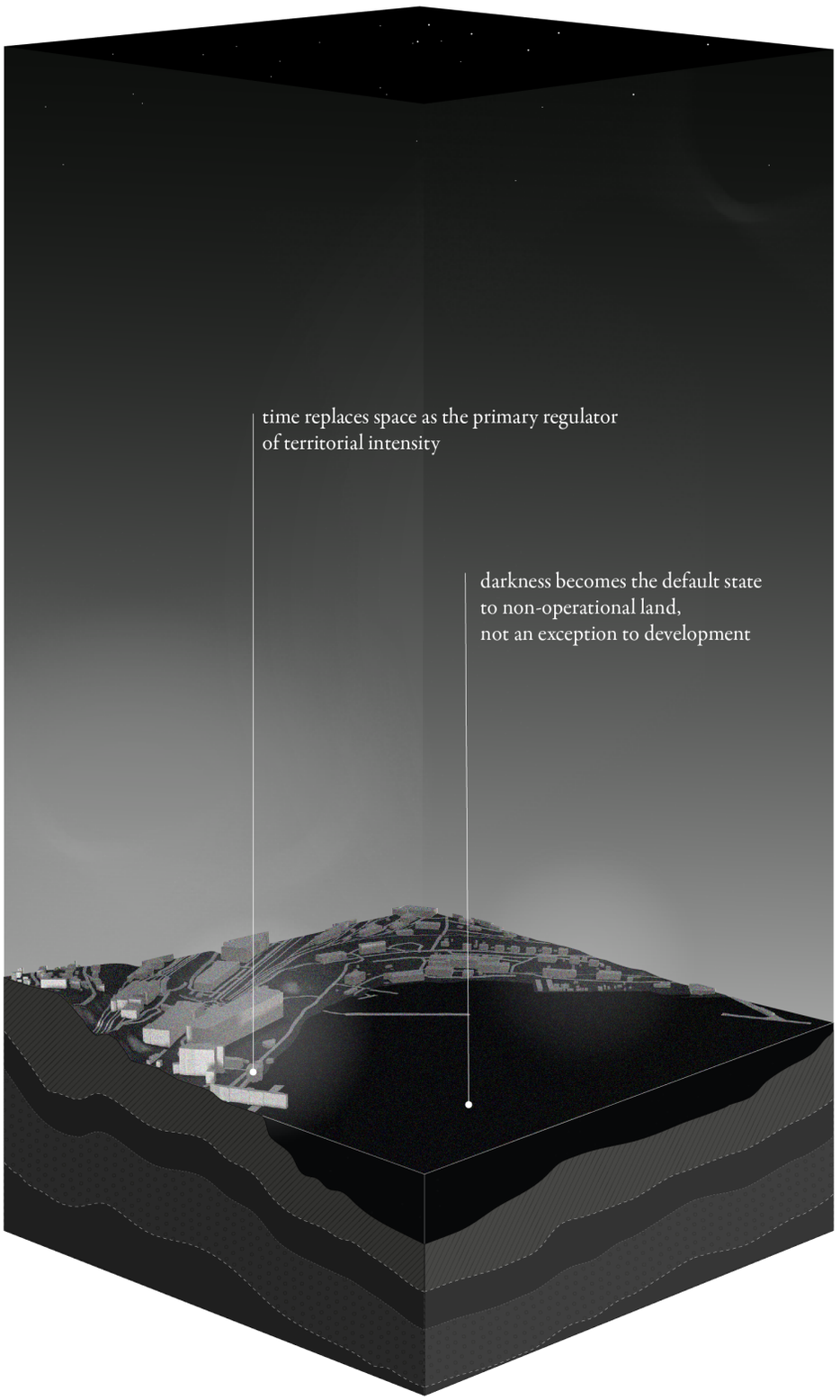
↓ **Figure [5.27] (p. 186)** Tile with future gestures, moving from permanent productivity to cyclical territorial activation.

↓ **Figure [5.28] (p. 187)** Tile with future gestures, moving from coastal emission systems to protected dark zones.

↓ **Figure [5.29] (p. 188)** Tile with future gestures, moving from illuminated maritime corridors to dark seascapes.

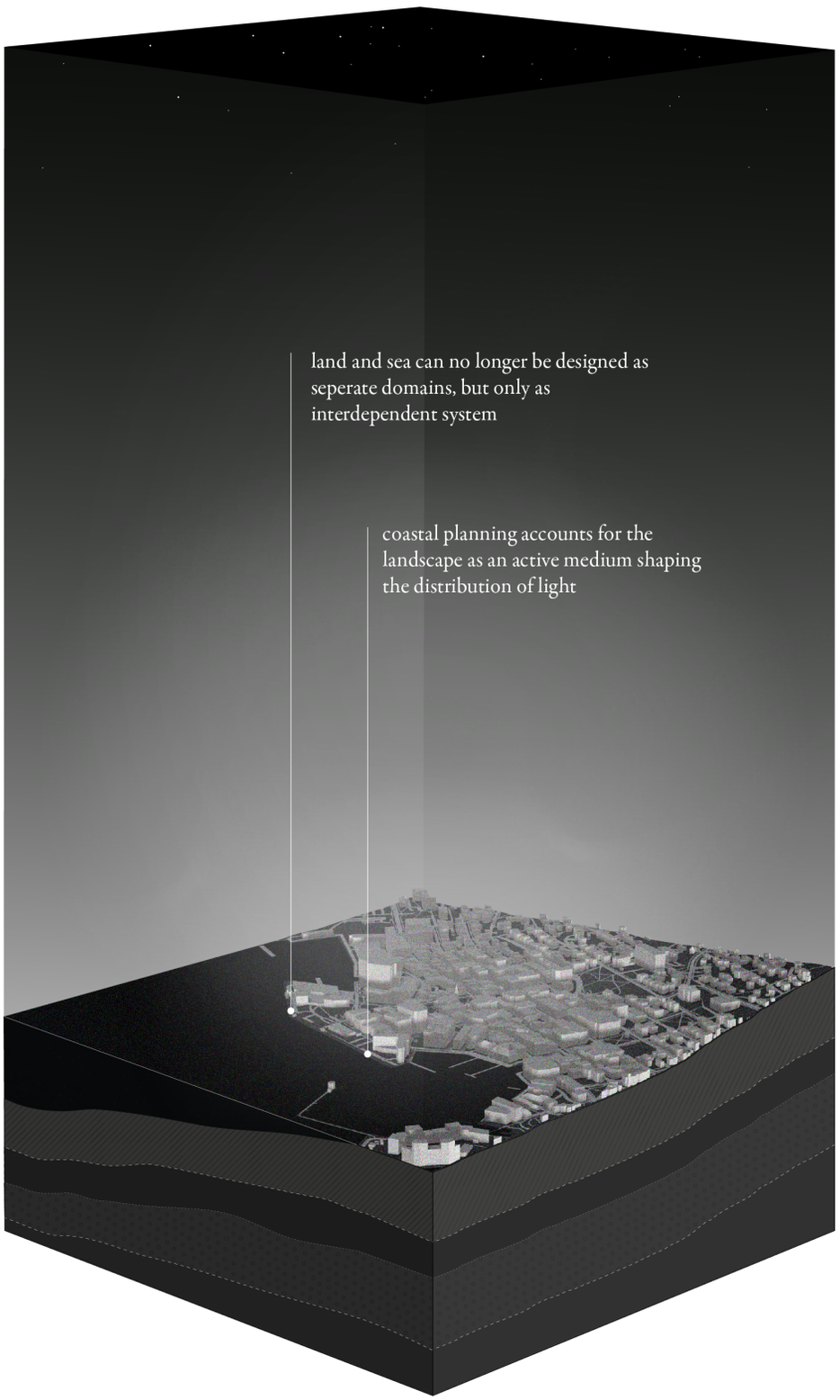
↓ **Figure [5.30] (p. 189)** Tile with future gestures, moving from territorial expansion to strategic withdrawal.

> *"How can a designer be designed to be a provider of care via the designing of things that ontologically care?"*
> (Escobar, 2017)



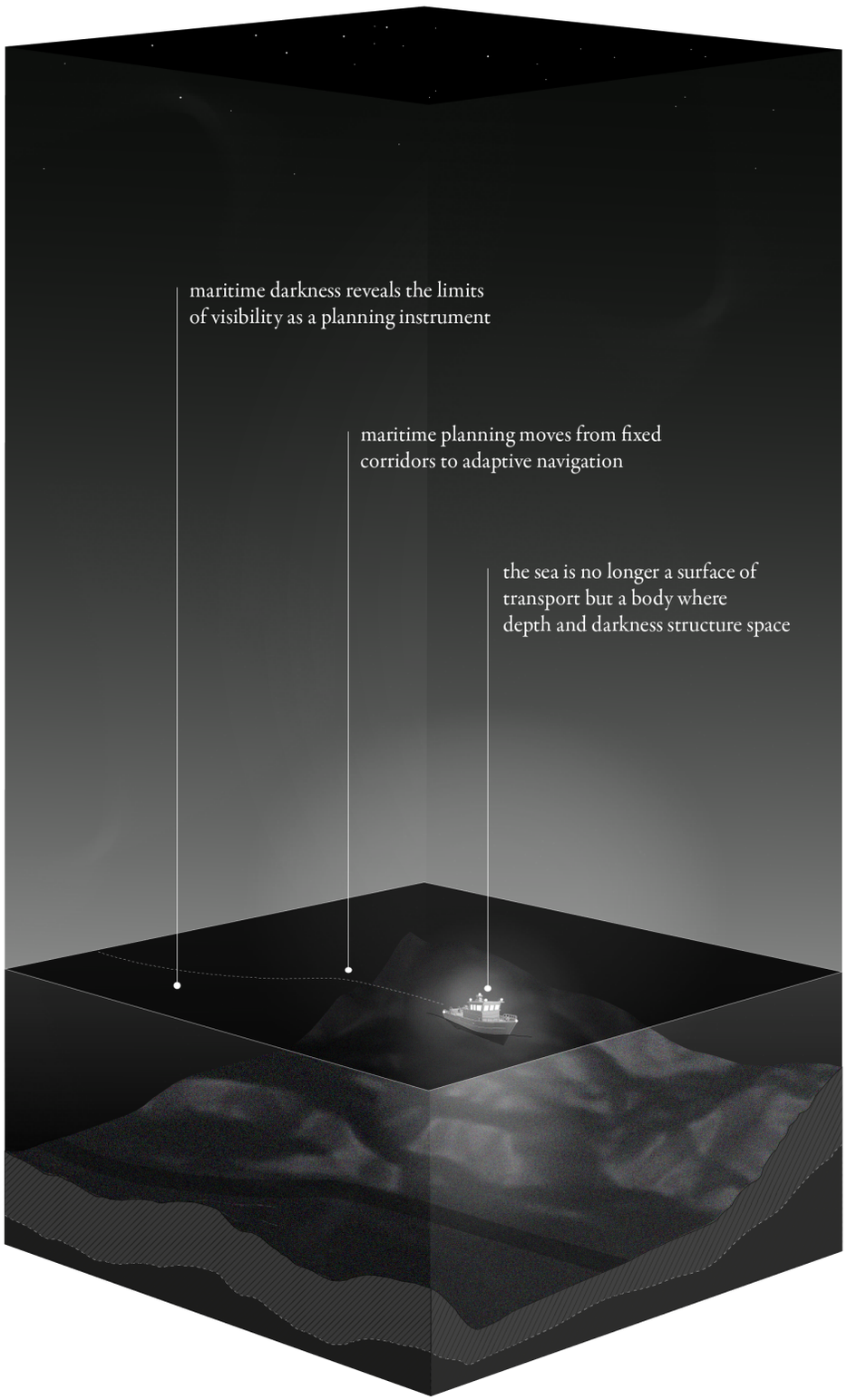
SEASONAL OPERATIONAL RHYTHMS

from permanent productivity to cyclical territorial activation

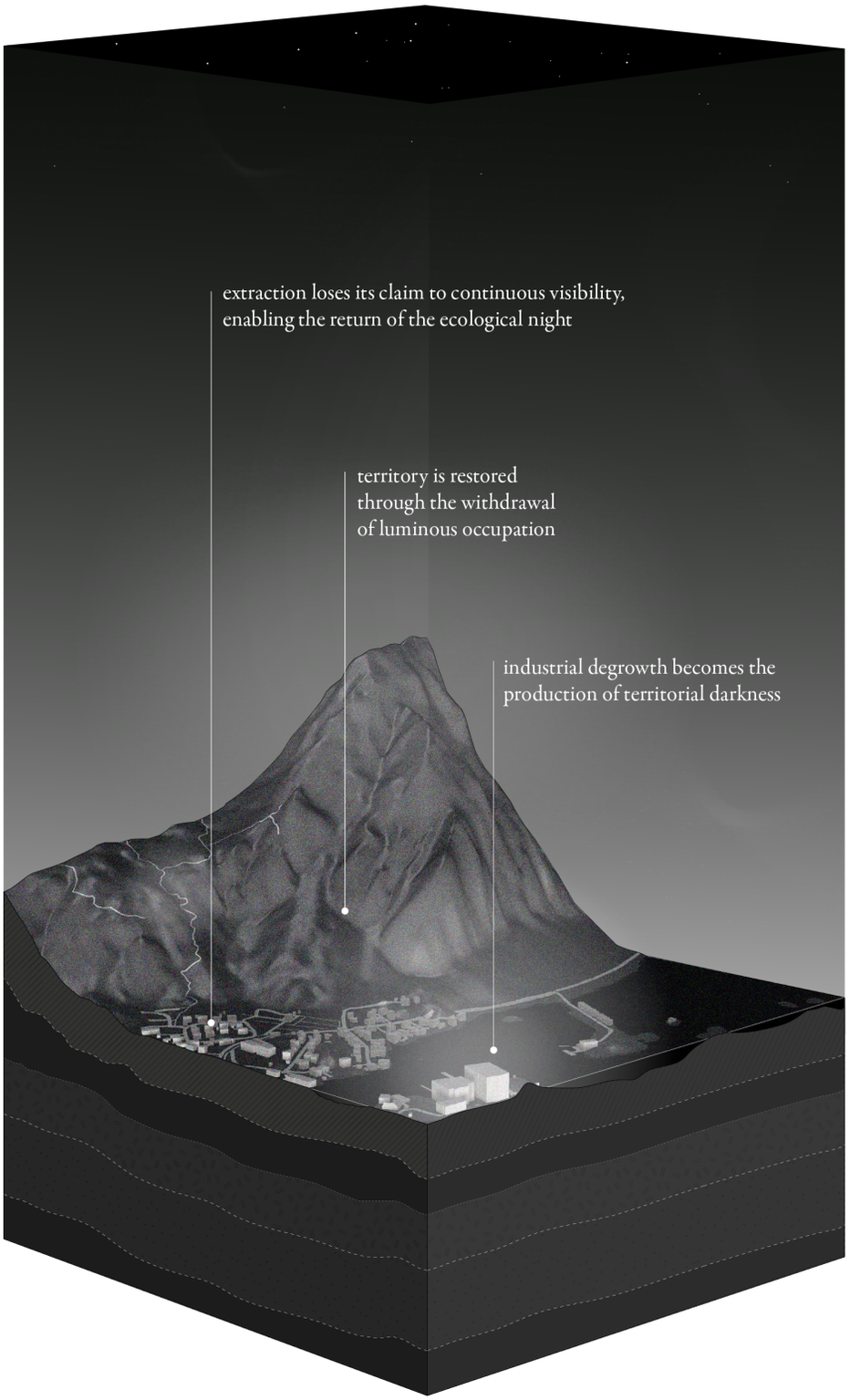


COASTAL DARKNESS BOUNDARIES

from coastal emission systems to protected dark zones



NOCTURNAL MARINE TERRITORIES
from illuminated maritime corridors to dark seascapes



THE RETREAT OF LUMINOUS TERRITORY

from territorial expansion to strategic withdrawal

CONCLUSIONS

CONCLUSION

This thesis understands Arctic darkness during the Polar night not as the absence of light, but as a fundamental ecological, spatial, and temporal condition that structures biological rhythms, ecological processes, and human and non-human relations in high-latitude environments. Through the Rights of Nature framework, darkness is approached as a condition with intrinsic ecological value, rather than a passive environmental condition.

However, increasing infrastructural development and the usage of artificial light at night (ALAN) are threatening Arctic darkness. These systems extend into an environment structured by the cycle of prolonged light and darkness.

Within this context, the research follows a progressive zoom, starting on the mega-regional scale of the Arctic to finally get to the city of Tromsø in Norway. The projected was structured through 7 subquestions, to answer the main research questions:

[Primary] - *How can design mediate the recognition of darkness as a right of nature to support ecological regeneration along the Norwegian Arctic coastline?*

[Secondary] - *How can the Arctic's space and time be reconceptualised through theories that challenge human-centred perspectives?*

• **[SQ1]** *How is the Arctic being reconfigured through planetary processes of environmental change, economic expansion, and geopolitical interest?*
The Arctic is increasingly integrated into global systems of circulation, extraction, and geopolitical governance through accelerating climate change, retreating sea ice, expanding resource extraction, and the emergence of new trans-Arctic shipping routes with significantly reduced travel times. Alongside this, tourism, fisheries, and infrastructural development are increasing, accompanied by intensified geopolitical competition over territory, resources, and strategic infrastructure.

These processes collectively reconfigure the Arctic as a space of planetary urbanisation, where systems of efficiency, connectivity, and extraction extend into environments historically structured by seasonal and multi-temporal ecological rhythms. The region is therefore no longer operating as an isolated environmental system but as a continuous operational territory embedded in global flows. Within this transformation, artificial light at night (ALAN) emerges as a spatial manifestation of these processes. It extends permanent illumination into Arctic territories that are historically defined by prolonged darkness. This reinforces the shift towards infrastructural continuity and operational expansion.

• **[SQ2]** - *How do the phenomena of Polar day and Polar night arise?*
The Polar day and Polar night arise from the axial tilt of the Earth, which produces extreme seasonal variation in solar exposure at high latitudes. The further north one moves, the more pronounced these variations become, resulting in extended periods of continuous daylight in summer and continuous darkness in winter.

However, these phenomena are not only astronomical conditions but also structures ecological behaviour, seasonal rhythms, and spatial perception in Arctic environments. Light and darkness operate as organising principles that actively shape how time and space are experienced and inhabited.
These conditions vary across latitude, producing differentiated temporal regimes throughout the Arctic region. Darkness therefore functions not as a lack of illumination, but as a territorial condition that structures ecological and environmental systems across space and time.

• **[SQ3]** - *How do Arctic ecosystems adapt to the absence of daylight?*
Arctic ecosystems are highly adapted to prolonged periods of darkness during the Polar night. Unlike global ecosystems structured primarily around daily light cycles, Arctic species rely on extremely low levels of natural light to regulate essential biological processes such as migration, feeding, reproduction, and orientation.

These processes are regulated by circadian rhythms, which depend on subtle variations in environmental light as external cues for synchronisation. Even extremely low and often undetectable light levels can function as biological signals during the Polar night. This adaptation is demonstrated through three indicator species representing terrestrial, aerial, and marine ecosystems: reindeer, the little auk, and zooplankton. Together, these species illustrate how ecological systems across different environmental realms depend on darkness as a structuring condition.

The main finding is therefore that darkness functions as a critical ecological infrastructure that enables biological synchronisation and supports biophysical processes during the Polar night.

• **[SQ4]** - *What is artificial light at night, and how are Arctic ecosystems disrupted by it?*
Artificial light at night (ALAN) occurs across multiple scales and originates primarily from anthropogenic infrastructures, such as ports, roads, vessels, industrial sites, and offshore installations. Between 1992 and 2013, more than 600,000 km² of the Arctic transitioned from

dark to lit. Approximately 85% of ALAN in the Arctic originates from industrial infrastructure, producing not only local illumination but it also spreads through skyglow and light trespass. In marine environments, artificial light can penetrate to depths of up to 200 metres, affecting ecological processes below the surface. ALAN disrupts ecological systems that have evolved in relation to prolonged darkness.

[1] In the terrestrial realm, reindeer have adapted their eyes to include ultraviolet sensitivity during winter, but actively avoid infrastructures such as high-voltage power lines due to ultraviolet corona emissions, leading to barrier effects and migration fragmentation.

[2] In the aerial realm, the little auk, dependent on low-light vision for navigation and foraging, is affected by artificial illumination from vessels and offshore infrastructure, resulting in disorientation, increased collision risk, and altered behavioural patterns.

[3] In the marine realm, zooplankton undertake vertical migrations regulated by light variation. ALAN disrupts these movements, altering feeding behaviour and predator avoidance strategies. During winter, zooplankton enter diapause and descend into deeper waters; however, in shallow coastal environments under approximately 200 metres, artificial light may penetrate the full water column, potentially disturbing seasonal cycles, reproduction, and ecosystem dynamics.

These impacts are most concentrated along Arctic coastlines, where terrestrial, marine, and aerial ecosystems intersect with dense human infrastructure. Coastal zones therefore emerge as critical areas of ecological vulnerability under increasing artificial illumination.

• **[SQ5]** - *How is the Norwegian Arctic transformed through the intersection of energy extraction, shipping corridors, and infrastructural development?*
Mapping of shipping activity reveals a strong concentration of human presence along the Norwegian coastline. As sea ice retreats and Arctic waters become more accessible, the coastline is increasingly reorganised into a corridor of economic and logistical activity structured by shipping routes, fisheries, tourism, energy extraction, and transport infrastructure. Norwegian extraction licences continue to extend further north, and night-time light radiance analysis shows a corresponding shift of economic activity towards higher latitudes. This spatial redistribution is accompanied by increasing artificial illumination in previously dark Arctic regions.

This transformation is framed through the Norwegian paradox, where Norway's strong international environmental reputation coexists with an economy largely dependent on oil and gas export. Within this context, light becomes a dual condition: it is both an indicator of economic development and a force that contributes to ecological fragmentation. Darkness, conversely, functions as an ecological condition that is gradually being reduced through infrastructural expansion.

• **[SQ6]** - *What site-specific conditions characterise the Norwegian coastlines under the Polar night?*
Fieldwork along the Norwegian Arctic coastline showed that the Polar night is not uniform, but differs spatially, shaped by terrain enclosure, snow cover, coastal topography, water reflection, and atmospheric conditions. These factors influence visibility, depth perception, and spatial orientation. The field observations and photographic documentation demonstrate that natural darkness is increasingly interrupted by artificial illumination sources. This produces a transitional landscape in which ecological darkness and infrastructural light regimes overlap and interact.

• **[SQ7]** - *How can (the transformation of) Arctic darkness be made spatially visible?*
Conventional satellite-based night-time light datasets are insufficient for understanding how darkness is structured by landscape conditions or how artificial light behaves at a local scale. To address this accuracy gap, maps are designed to gain a more detailed understanding of darkness as a territory.

First, natural darkness is mapped through factors based on terrain and elevation, such as enclosure, sky view factor, horizontal light travel distance, and seasonal variations in daylight. These maps together identify areas of naturally high darkness and therefore (ecological) sensitivity to artificial illumination.

Second, ALAN is modelled as spatial pressure. A method is introduced to assess this pressure: the *coastal light pressure method*, using five main sources of artificial light: airports, road infrastructure, housing, shipping, and industrial sites. These sources are translated into continuous spatial representations of light pressure along the coastline.

Third, a final atlas combines these map layers into three typologies: light as emission system, landscape as a medium and darkness as protected infrastructure. Together, these mappings reframe darkness as an active territorial condition and allow to understand the landscape differently.

CONCLUSION

In this project, design mediates the recognition of darkness as a right of nature by making visible the spatial, temporal, and ecological conditions through which darkness is being transformed.

Through representing a condition that is often overlooked, building on cartographic and analytical methods, design translates abstract ecological processes into spatial relationships that reveal how artificial light restructures Arctic environments.

Furthermore, reading the Arctic through interpretations of the *Critical Zone theory* and *Planetary Urbanisation*, its space and time are reconceptualised beyond human-centred perspectives. This allows to understand darkness from a more-than-human perspective as an ecological commons under threat.

In this research, design operates as a critical and interpretative tool that:

> [A] *reveals* darkness as ecological infrastructure rather than absence;
> [B] *translates* infrastructural activity into spatial pressure;
> [C] *exposes* the overlap between ecological sensitivity and human development;
> [D] *connects* multi-scalar processes from planetary systems to site-specific conditions.

Ultimately, the project communicates through 4 tiles that darkness must be recognised as an ecological, spatial and temporal asset within urban and regional planning. From shipping corridors to the design of coastal infrastructure: spatial interventions directly reshape the ecological integrity of the Arctic nightscape.

SCIENTIFIC REFLECTION, LIMITATIONS AND RECOMMENDATIONS

Rethinking urbanism through research and design
During this graduation project, my understanding of urbanism changed a lot. At the start of the project, I mainly understood urbanism through the physical design of neighbourhoods, cities, regional visions, and spatial strategies. However, throughout the process I discovered that urbanism can also operate through narratives, representation, mapping, and critical reflection. The notion of James Corner on the agency of mapping (Corner, 1999) has been one of the major insights of the graduation process.

Within the master degree of Urbanism, there is a strong focus on climate-related challenges. During my studies at Delft University, it became very clear to me that much of the discussion (both within and outside the faculty), focuses on reducing environmental impact. Design obviously plays an important role in this. At the same time, I started questioning whether 'solving' with technology is enough. The climate crisis is also deeply connected to systems, behaviour, and the way humans position themselves in relation to nature.

With *Darkness as Territory*, I therefore tried to challenge this mindset. Instead of designing a conventional urban intervention, I explored whether theoretical research, urban analysis, mapping, and storytelling could together form a counter-narrative. In that sense, the project became more about revealing an overlooked condition. This also became the main contribution of the project to urbanism: expanding the way spatial transformation can be understood and represented. Rather than focusing only on physical form or technical solutions, the project explores how urbanism can also engage with (invisible) ecological conditions, temporal systems, and more-than-human relationships.
Throughout the project, I also reflected on the boundaries of the discipline itself. I often asked myself: what actually defines urbanism? Exploring those boundaries became an important part of the graduation process. It showed me again how broad the discipline actually is, and how urbanism can also be used to critically analyse systems, territories, and ecological relationships.

The Relationship Between Research and Design
One of the most important moments of the project was the field trip to Northern Norway early in the process. Before visiting the Arctic, I approached any artificial light mainly as a form of pollution. However, experiencing the Polar night changed that assumption almost immediately. I realised that artificial light in the Arctic cannot simply be understood as something negative or harmful. During long periods of darkness, light also becomes essential for wellbeing and mental health to people.

This insight introduced a much more nuanced understanding of the relationship between darkness, ecology, and human presence. It shifted the project away from a purely ecological critique of artificial light towards a broader reflection on coexistence, balance, and the tensions between human and non-human needs within Arctic environments.

This insight introduced a much more nuanced understanding of the topic and changed the tone of the project. Besides the spatial observations themselves, the cultural dimension of light became extremely valuable. Looking back, I think this field trip was one of the most important moments of the graduation process. It taught me how valuable it is to experience a place before fully defining the research direction. I would therefore strongly recommend planning fieldwork early within research projects, because it can fundamentally sharpen the research questions and its scope.

Reflection on Methodology and Working Process
One of the most valuable aspects of this graduation project was the combination between theoretical research and the design-oriented way of working. The project continuously moved between literature, spatial analysis, field observations, mapping, photography, and visualisation. Designing the narrative itself became part of the research process.

I wanted to learn how to translate theory and spatial data into visual representation. This became one of the most enjoyable parts of the process. It showed me that design can also function as an analytical method and not only as the production of spatial interventions. At the start of the project, one of my personal goals was to improve my technical skills in QGIS and spatial visualisation. Initially, I had relatively little experience with these tools, and I found it difficult to work with large datasets and geospatial analysis. Throughout the process, however, these visualisations became an essential part of the project. I am satisfied with how the final mappings helped communicate relationships that are otherwise difficult to see or explain.

A large part of the project also relied on literature review. In order to understand the ecological impact of artificial light at night, it was necessary to study ecological systems, circadian rhythms and Arctic ecosystems in depth. This taught me that projects dealing with rights of nature or ecological ethics require a real understanding of the systems they discuss.

At the same time, I also became aware of the limits of my own disciplinary background. Although I approached the topic from an urbanism perspective, I often felt that collaboration with ecologists or environmental scientists could have strengthened the project significantly. Especially when

dealing with ecological impact, interdisciplinary collaboration would have been very valuable. If the project were to continue further, I would definitely approach it in a more interdisciplinary way.

Interestingly, the lack of data also became an important part of the project itself. Especially within the Arctic context, there was often very limited information available about habitats, light sources, or ecological impacts. At several moments in the project, this slowed the research down considerably. Sometimes I felt stuck because I simply could not find the information I was looking for.

In retrospect, however, this absence of data also shaped the project in a meaningful way. The fact that so little is documented about these transformations actually reinforces the argument of the thesis itself. The project ultimately became a story about something that is still largely overlooked and underrepresented.

Ethical Reflection

One of the most important ethical reflections within the project relates to representation and positionality. The Rights of Nature movement raises important questions about who is able to represent nature and speak on behalf of ecosystems. These questions also became relevant within my own project, because I was researching and representing a place that is not my own.

As an outsider working in the Arctic context, I became increasingly aware of how difficult it is to represent a place that is not your own. This is especially relevant in a region where Indigenous communities live and where relationships with the landscape are very different from my own. Throughout the project, I often reflected on the risk of oversimplifying the region or unintentionally projecting my own perspective onto it. At the same time, I do not think this means that outsiders should avoid engaging with these territories. On the contrary, I believe we should become more involved with the environments that are actively put under pressure. However, doing so requires a high level of self-awareness, humility, and sensitivity towards local perspectives and relationships with the landscape.

Limitations

The project has clear limitations. Due to the broad theoretical scope, it was not always possible to investigate every ecological or social dimension in depth. The project primarily approaches the Arctic from an urbanism perspective, which means that certain ecological processes could only be understood through existing literature rather than through direct interdisciplinary collaboration.

In addition, the project focuses strongly on representation and critical reflection rather than implementation. While this allowed space for conceptual exploration, it also raises questions about how these insights could translate into policy or governance.

Another limitation of the project is the lack of detailed data on artificial light in the Arctic. Because of this data gap, the project had to rely on several approximations in order to analyse and visualise light pressure across the landscape. For example, within the coastal light pressure method, light sources were generalised and simplified. The method does not distinguish between continuous and intermittent light sources, nor does it account for movement through the landscape or differences in light emission direction and timing.

As a result, the method should not be understood as a fully accurate representation of light impact, but rather as a first step towards understanding spatial patterns of artificial light in the Arctic context. With more detailed and site-specific data, the assessment could become significantly more precise. Further refinement of the methodology would therefore be an important recommendation for future research.

In terms of governance, the project does not go into depth on the active stakeholders in the Arctic. This means that the question of how nature is currently represented and by whom remains largely open within the scope of this research. From a Rights of Nature perspective, this would be an important next step: to further investigate which actors could potentially act as representatives of darkness, and how this could contribute to a shift towards more explicit protection of it.

More importantly, the project changed my own understanding of what urbanism can be. Before starting this graduation studio, I mainly saw urbanism as the design of physical space. Now I understand it much more as a way of thinking critically about relationships between humans, non-humans and territory. That shift in perspective has probably been the most valuable outcome of the entire graduation process.

APPENDICES

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APPENDIX I

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APPENDIX I

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PYTHON CODING

APPENDIX II

The script below has been made and employed for production of the atlas maps. The thresholds in the script define the high and low values. By changing these values, specific characteristics can be prioritised.

```
import os
import numpy as np
import rasterio
from rasterio.warp import reproject, Resampling
from itertools import combinations

rasters = [
    "/Users/allardvanengelenhoven/Desktop/Fractionlightseabednormalized.tif",
    "/Users/allardvanengelenhoven/Desktop/Viewdistancenormalized.tif",
    "/Users/allardvanengelenhoven/Documents/TU Delft/Graduation/Datasets/Skyviewfactornormalised2.tif",
    "/Users/allardvanengelenhoven/Documents/TU Delft/Graduation/Datasets/Sunhoursnormalised2.tif",
    "/Users/allardvanengelenhoven/Documents/TU Delft/Graduation/Datasets/NormalisedSkybrightness.tif",
    "/Users/allardvanengelenhoven/Documents/TU Delft/Graduation/Datasets/normalisedVIIRS.tif"
]

thresholds = {
    "Fractionlightseabednormalized": 0.1,
    "Viewdistancenormalized": 0.3,
    "Skyviewfactornormalised2": 0.7,
    "Sunhoursnormalised2": 0.7,
    "NormalisedSkybrightness": 0.2,
    "normalisedVIIRS": 0.2
}

landuse_path = "/Users/allardvanengelenhoven/Documents/TU Delft/Graduation/Datasets/Tromsolandusee.tif"

landuse_classes = {
    1: "settlements_industry",
    2: "agriculture",
    3: "forest",
    4: "mountain",
    5: "wetlands",
    6: "water"
}

out_dir = "/Users/allardvanengelenhoven/Desktop/raster_combinations"
os.makedirs(out_dir, exist_ok=True)

def get_valid_crs():
    for p in rasters:
        with rasterio.open(p) as src:
            if src.crs is not None:
                return src.crs
    raise Exception("No valid CRS found")

fallback_crs = get_valid_crs()

with rasterio.open(rasters[0]) as ref:
    ref_shape = (ref.height, ref.width)
    ref_transform = ref.transform
    ref_crs = ref.crs if ref.crs is not None else fallback_crs

def align(path, categorical=False):

    with rasterio.open(path) as src:

        arr = src.read(1)

        if not categorical:
            arr = arr.astype("float32")

        dst = np.zeros(ref_shape, dtype=arr.dtype)

        src_crs = src.crs if src.crs is not None else ref_crs

        reproject(
            source=arr,
            destination=dst,
            src_transform=src.transform,
            src_crs=src_crs,
            dst_transform=ref_transform,
            dst_crs=ref_crs,
            resampling=Resampling.nearest if categorical else Resampling.bilinear
        )

        return dst

arrays = [align(p) for p in rasters]

names = [
    os.path.splitext(os.path.basename(p))[0]
    for p in rasters
]

landuse = align(landuse_path, categorical=True)

def low(arr, t):
    return arr < t

def high(arr, t):
    return arr >= t

for i, j in combinations(range(len(rasters)), 2):

    a = arrays[i]
    b = arrays[j]

    name_a = names[i]
    name_b = names[j]

    ta = thresholds[name_a]
    tb = thresholds[name_b]

    a_low = low(a, ta)
    a_high = high(a, ta)

    b_low = low(b, tb)
    b_high = high(b, tb)

    combos = {
        "low_low": a_low & b_low,
        "high_high": a_high & b_high,
        "low_high": a_low & b_high,
        "high_low": a_high & b_low
    }

    for combo_name, combo_mask in combos.items():

        for class_value, class_name in landuse_classes.items():

            final_mask = combo_mask & (landuse == class_value)

            out_path = os.path.join(
                out_dir,
                f"{name_a}_{name_b}_{combo_name}_{class_name}.tif"
            )

            with rasterio.open(
                out_path,
                "w",
                driver="GTiff",
                height=ref_shape[0],
                width=ref_shape[1],
                count=1,
                dtype="uint8",
                nodata=0,
                crs=ref_crs,
                transform=ref_transform,
                compress="lzw"
            ) as dst:

                dst.write(final_mask.astype("uint8"), 1)

    print(f"Done: {name_a} + {name_b}")

print("Finished all combinations")
```

Darkness as Territory

master thesis by Allard van Engelenhoven

June, 2026

