DARKNESS AS TERRITORY

a spatio-temporal understanding of light in the Arctic

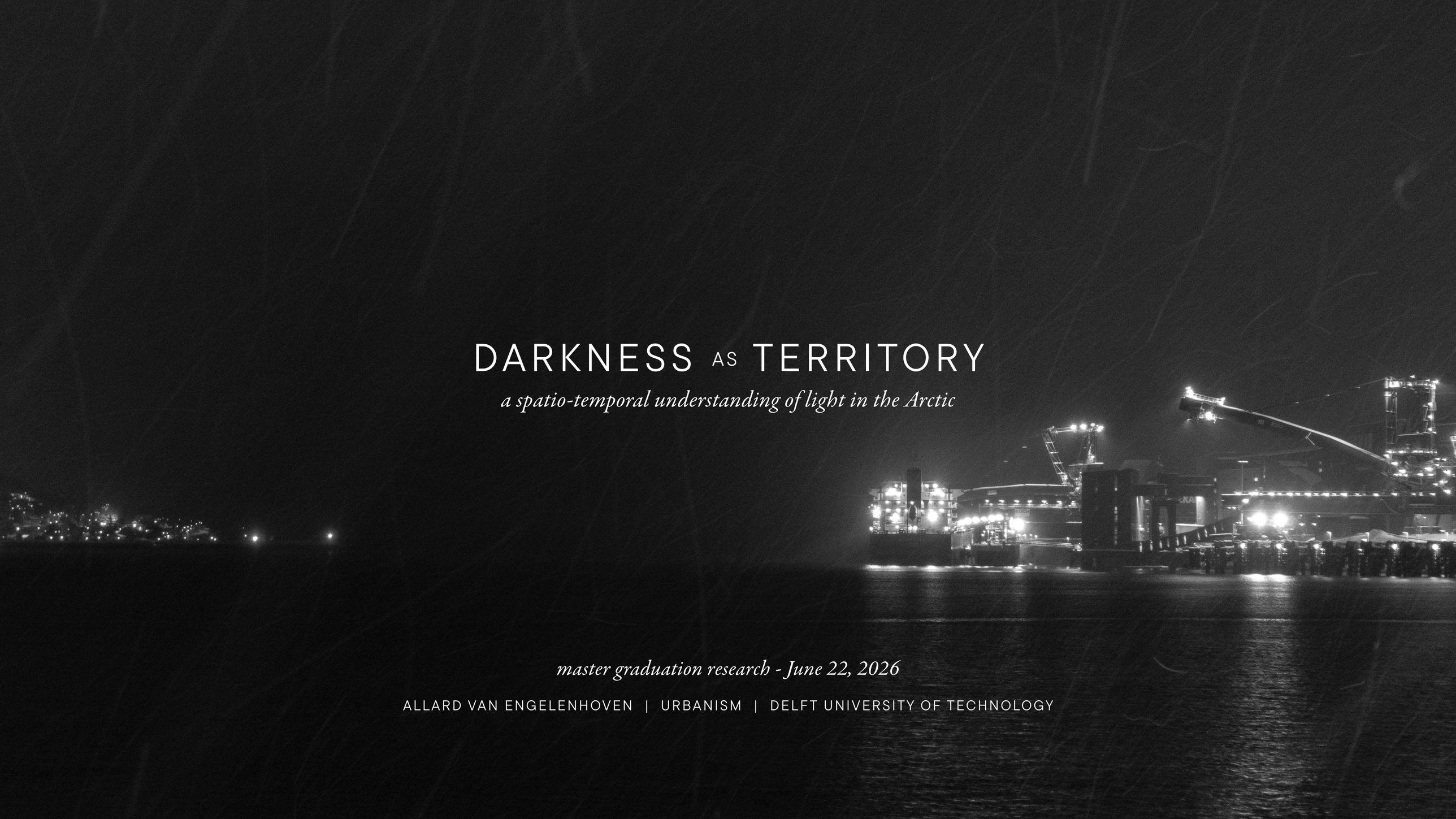
master graduation research - June 22, 2026

ALLARD VAN ENGELENHOVEN | URBANISM | DELFT UNIVERSITY OF TECHNOLOGY

JUNE 22ND

JUNE 21ST - JUNE 22ND

shortest night on the Northern hemisphere



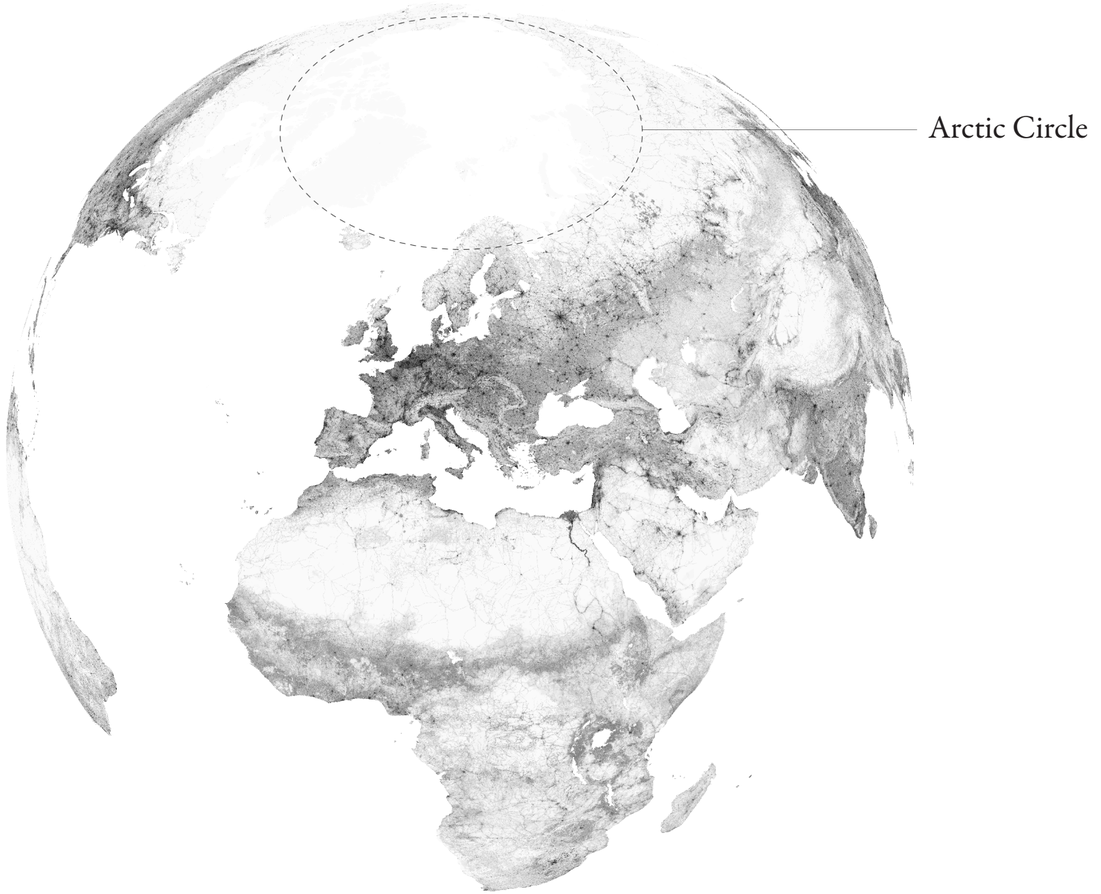
DARKNESS AS TERRITORY

a spatio-temporal understanding of light in the Arctic

master graduation research - June 22, 2026

ALLARD VAN ENGELENHOVEN | URBANISM | DELFT UNIVERSITY OF TECHNOLOGY

HUMAN ACTIVITY

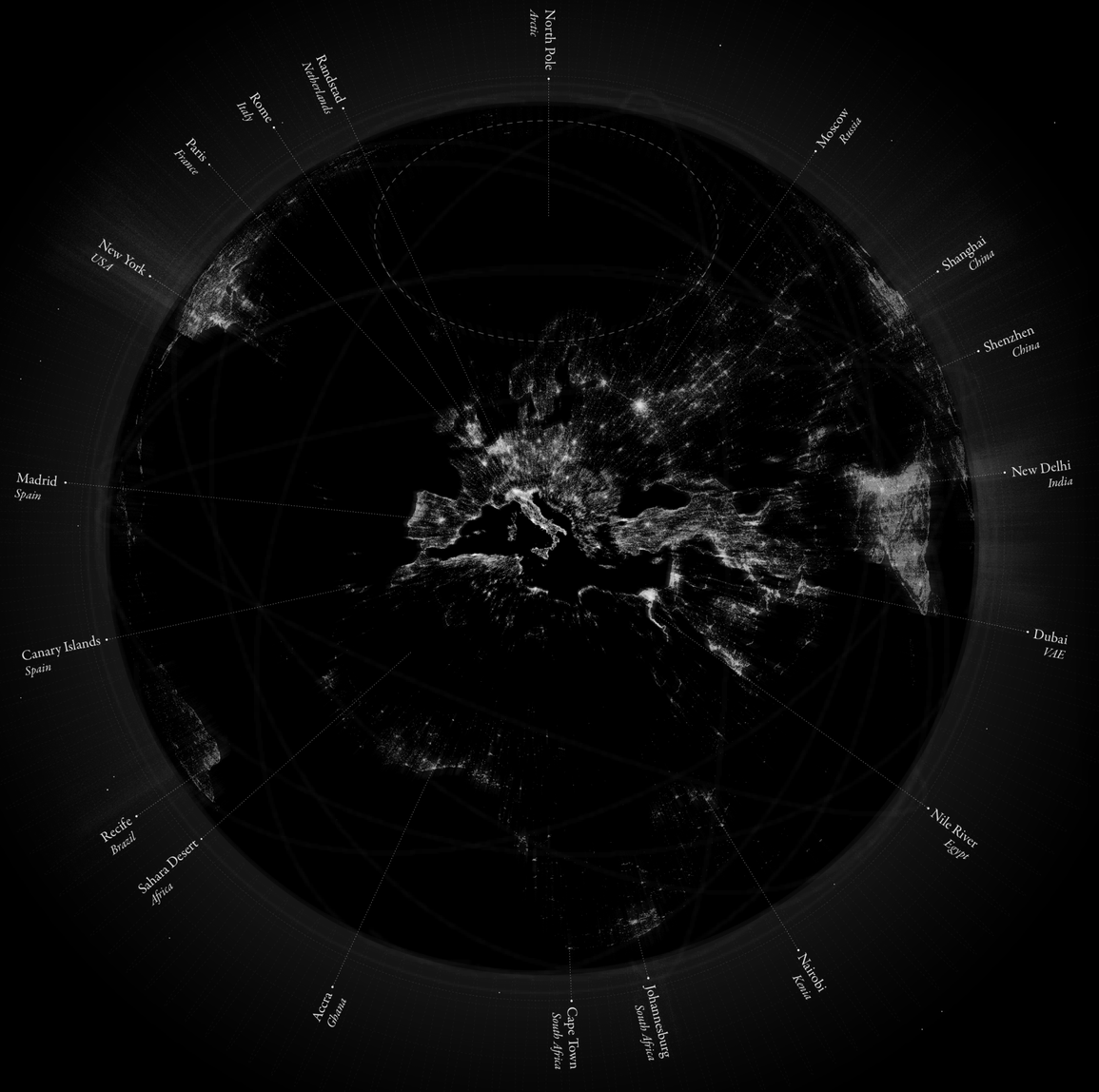


Human Footprint (%)

100

0

ARTIFICIAL LIGHT AT NIGHT (ALAN)

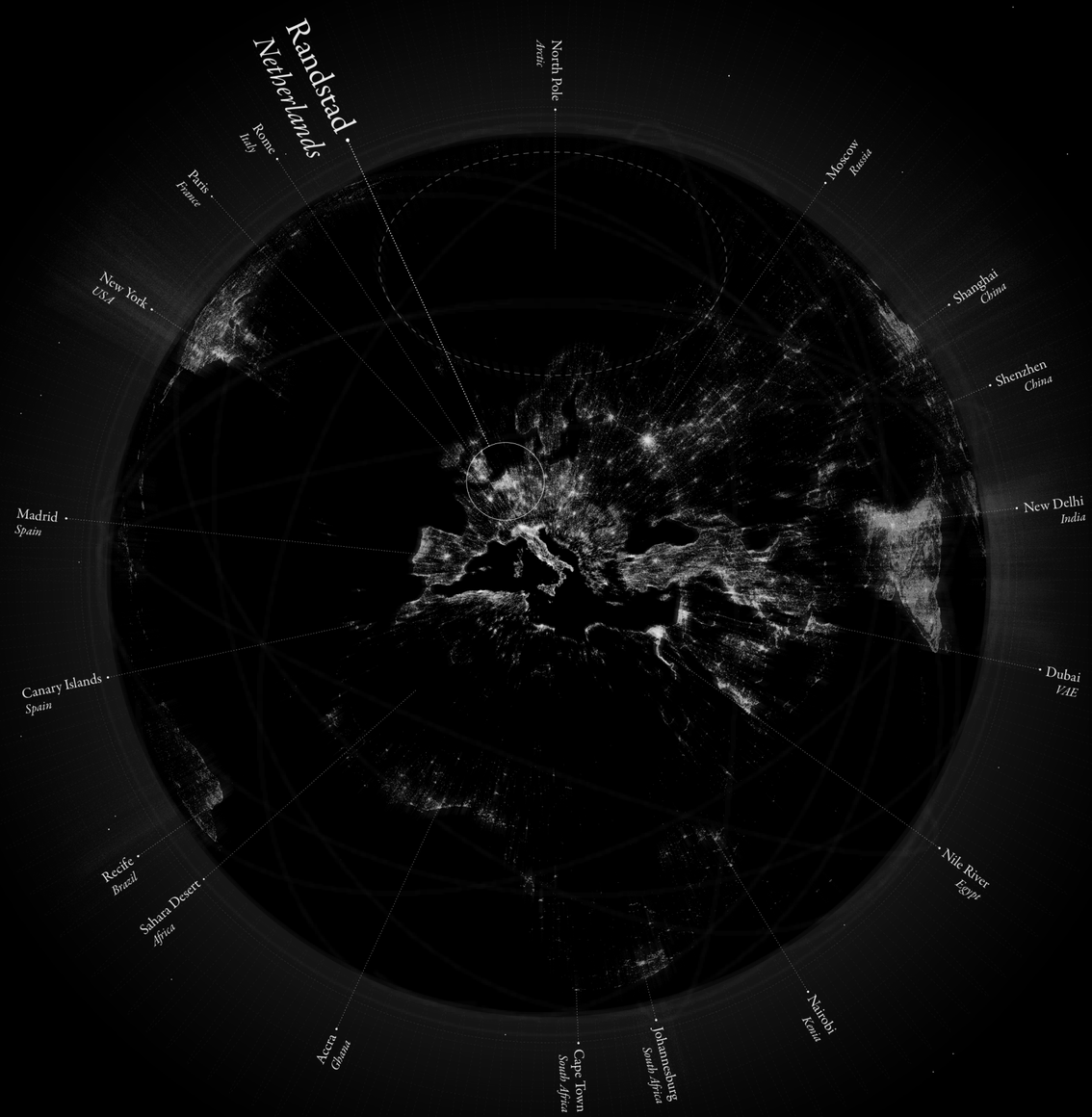


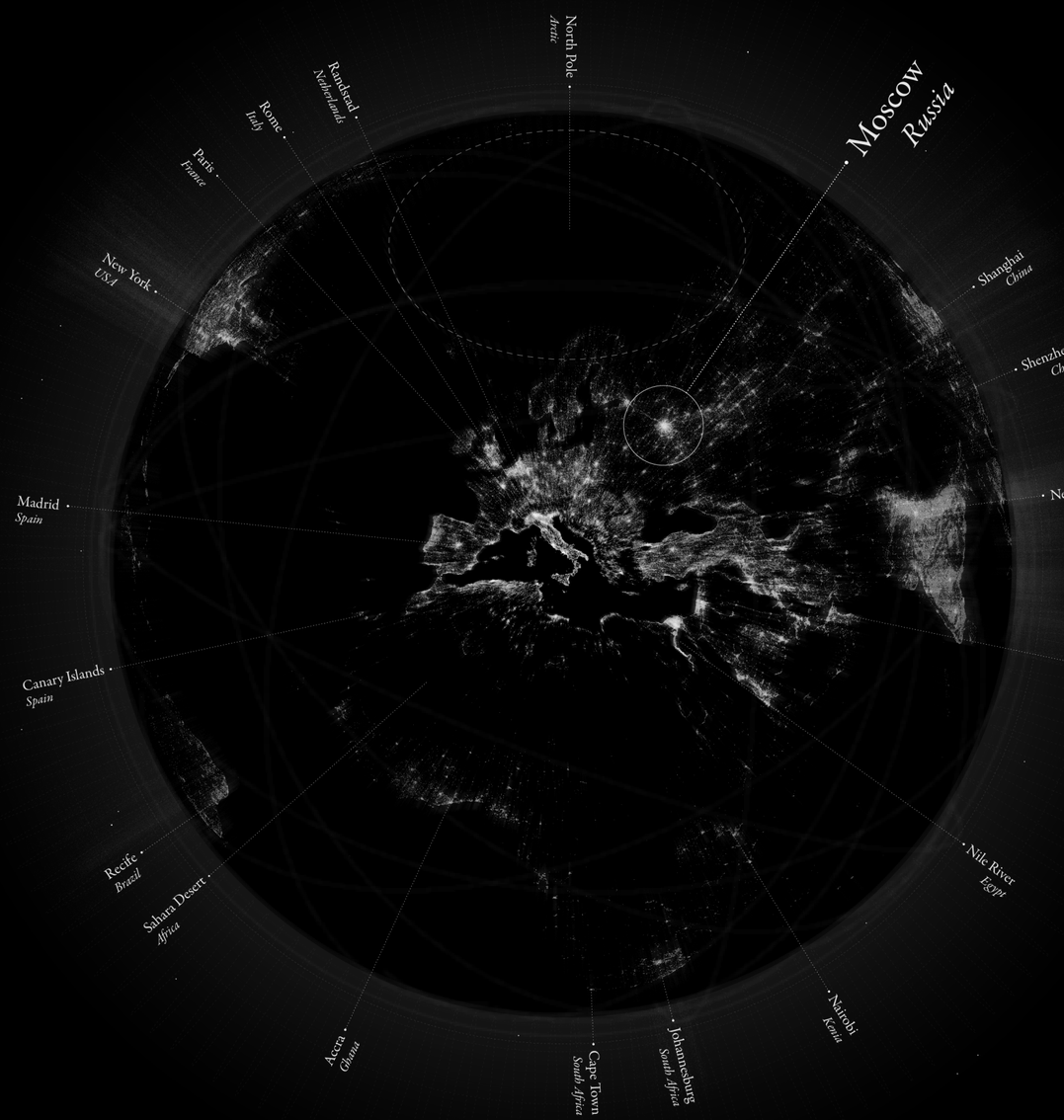
Night Time Lights (nW/cm²/sr)

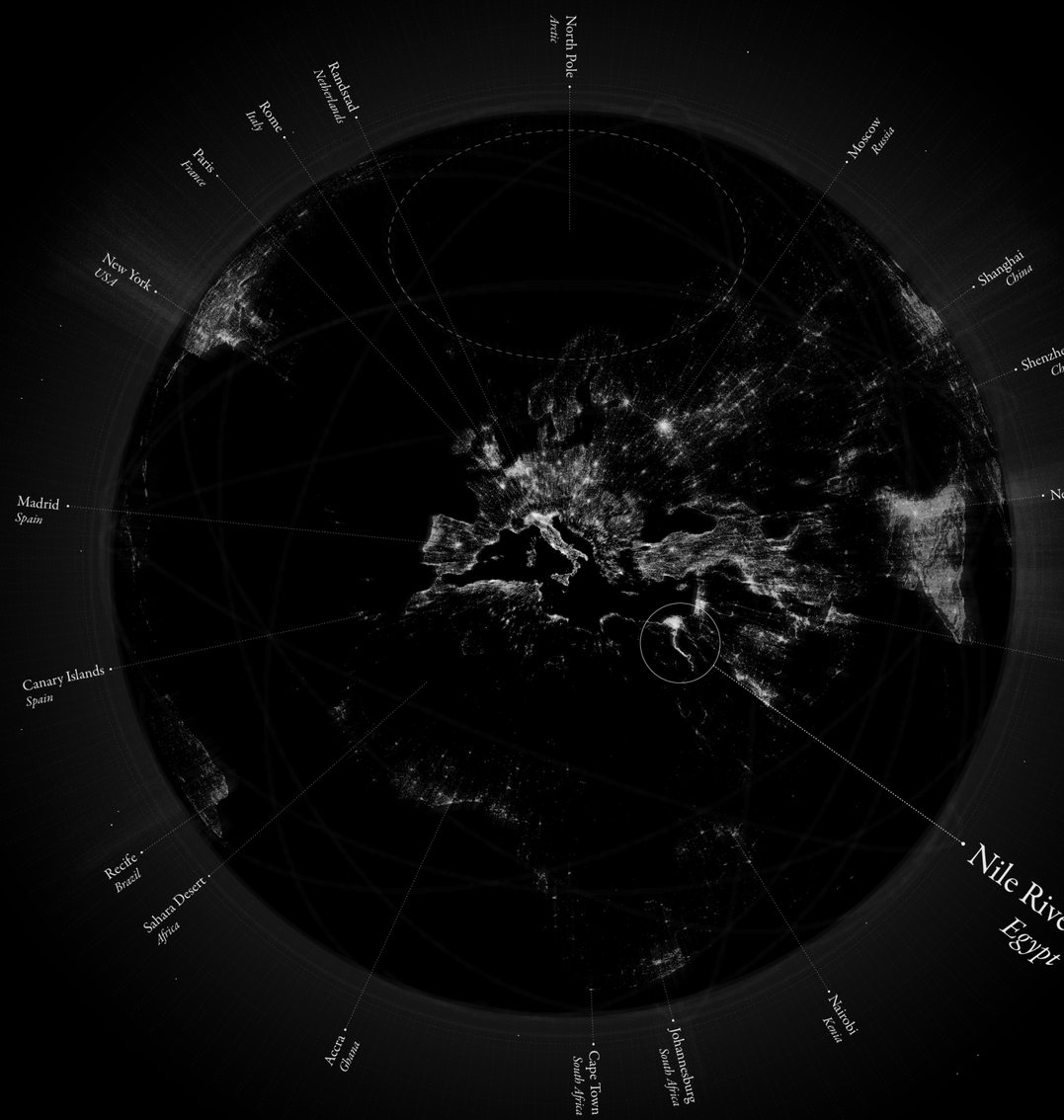
660

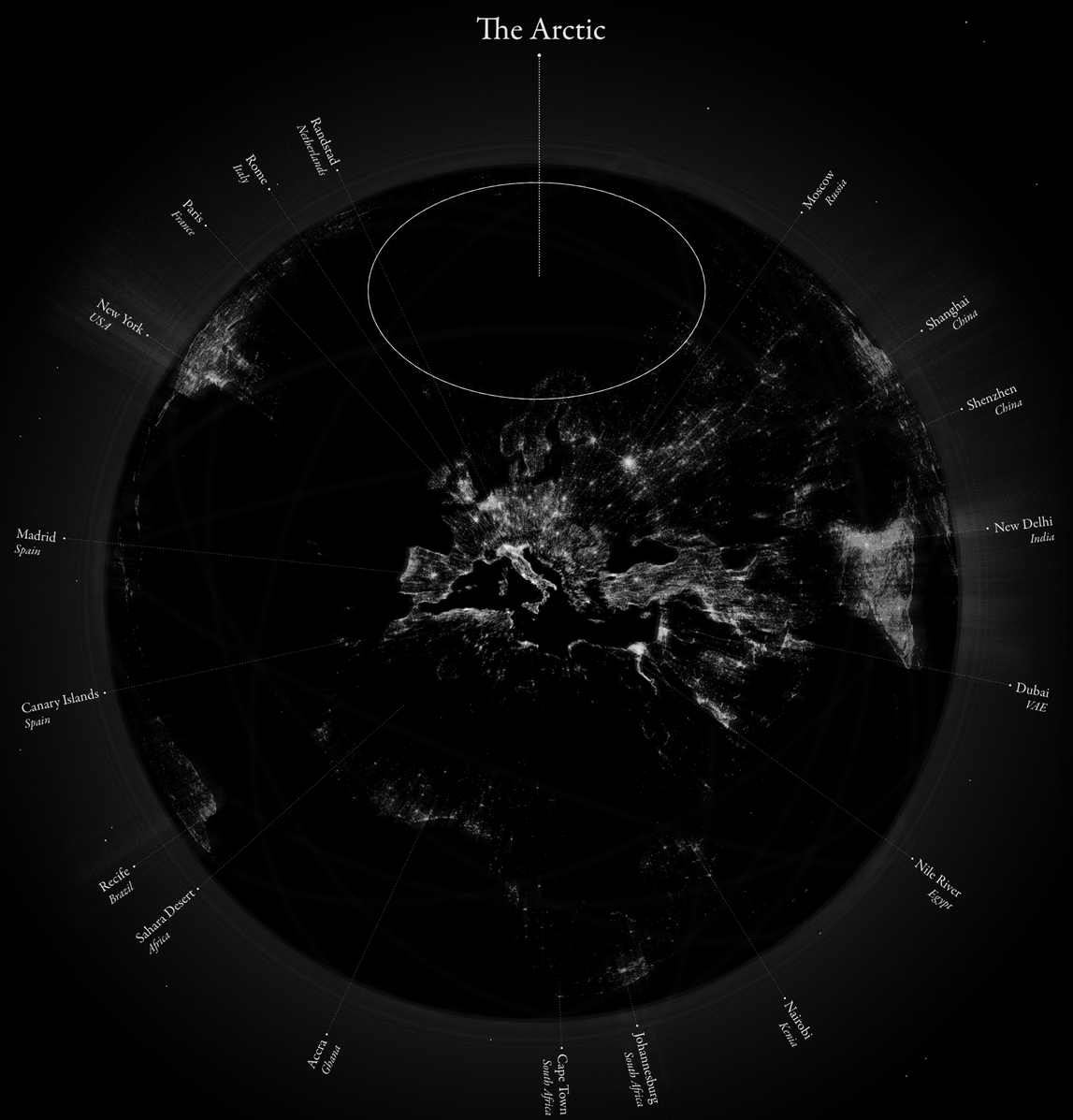
0


HUMAN ACTIVITY = ARTIFICIAL LIGHT AT NIGHT (ALAN)


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


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

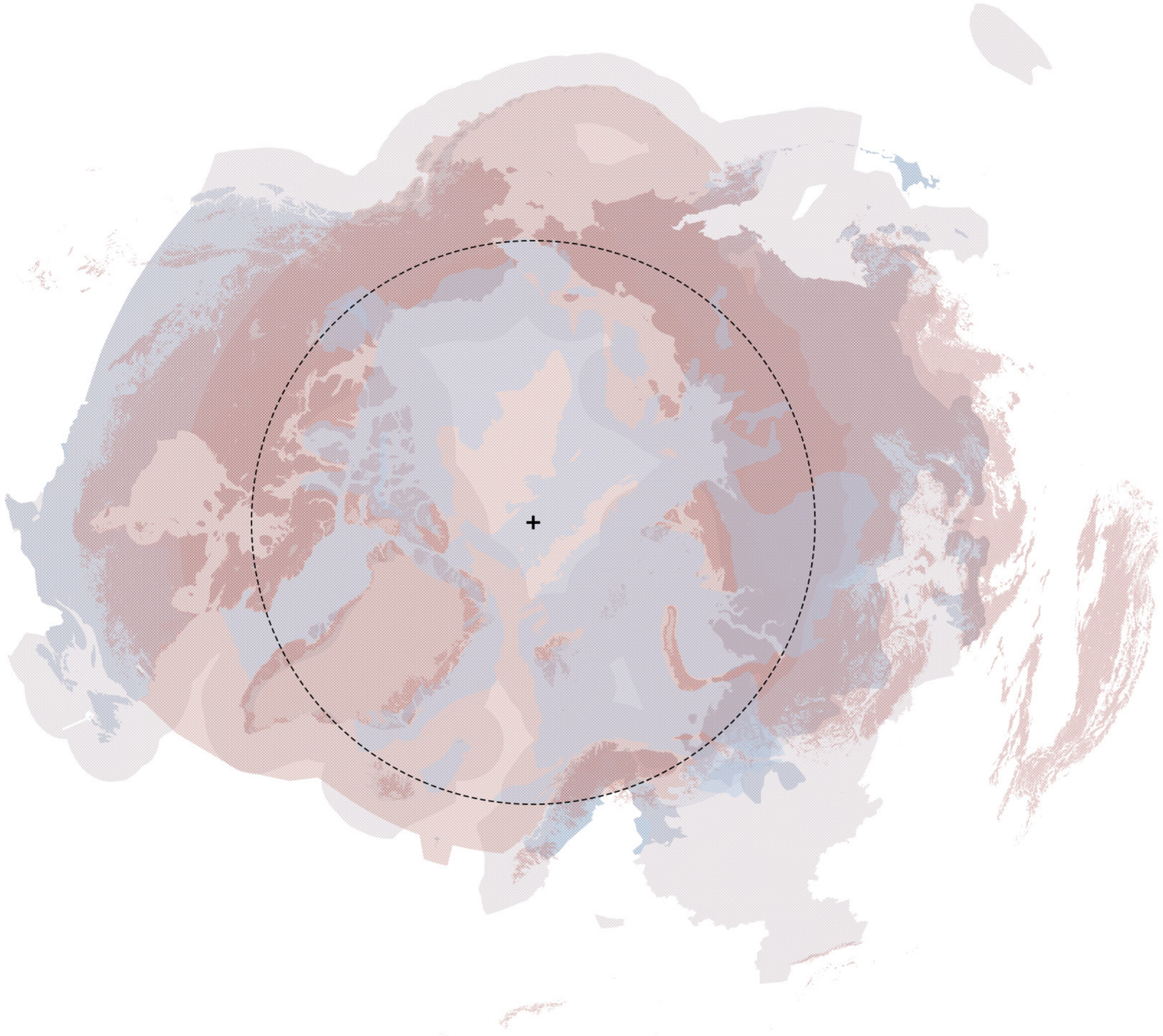

North Pole
Arctic
Moscow
Russia
Shanghai
China
Shenzhen
China
New Delhi
India
Dubai
UAE
Nile River
Egypt
Nairobi
Kenia
Johannesburg
South Africa
Cape Town
South Africa
Accra
Ghana
Sahara Desert
Africa
Recife
Brazil
Canary Islands
Spain
Madrid
Spain
New York
USA
Paris
France
Rome
Italy
Randstad
Netherlands


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

WHAT IF?

66°33’45.9”N

THE ARCTIC DEFINITION



8 ARCTIC STATES

GREENLAND (DENMARK)

UNITED STATES OF AMERICA

NORWAY

FINLAND

SWEDEN

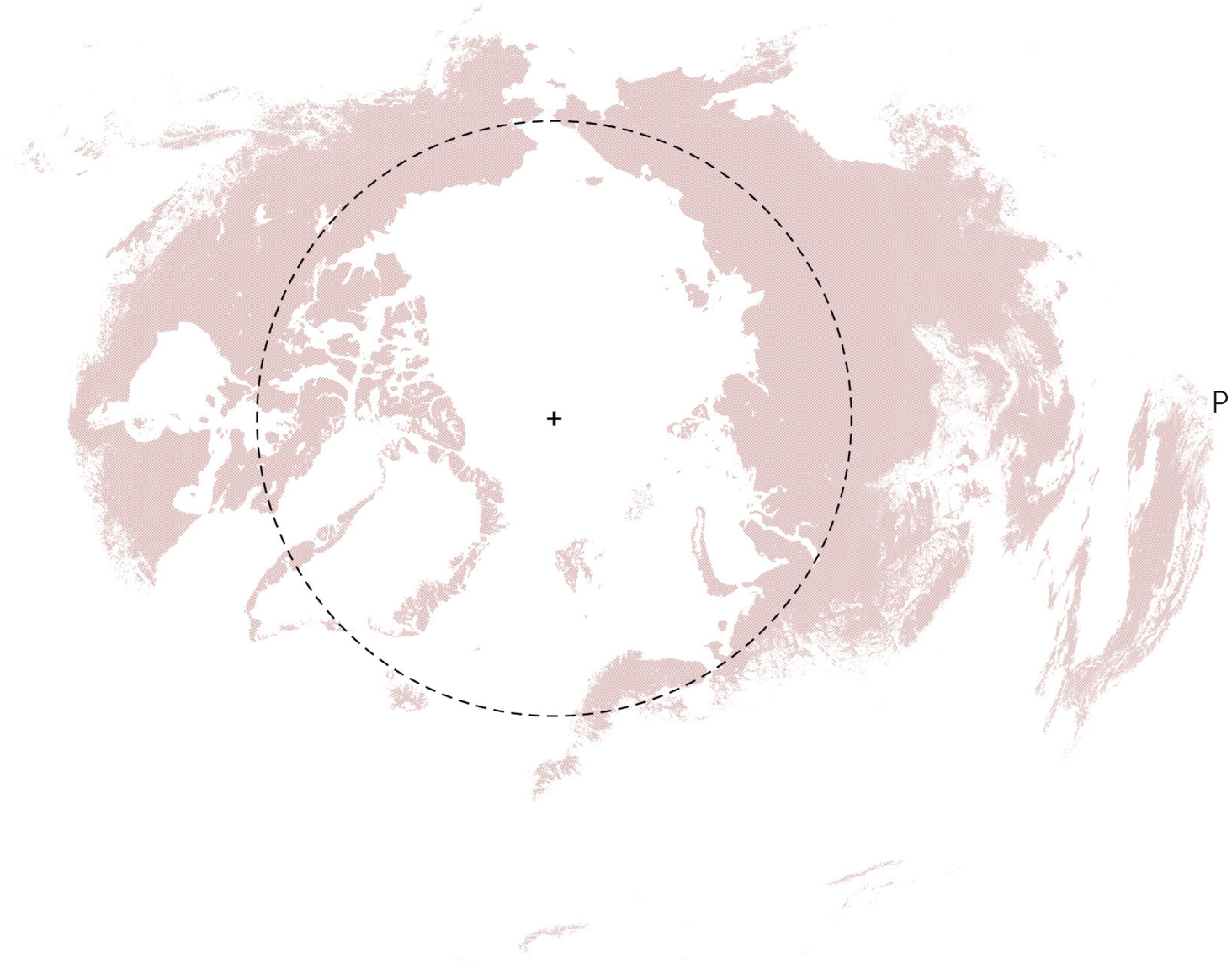
RUSSIA

CANADA

ICELAND

BEYOND 66°33’45.9”N

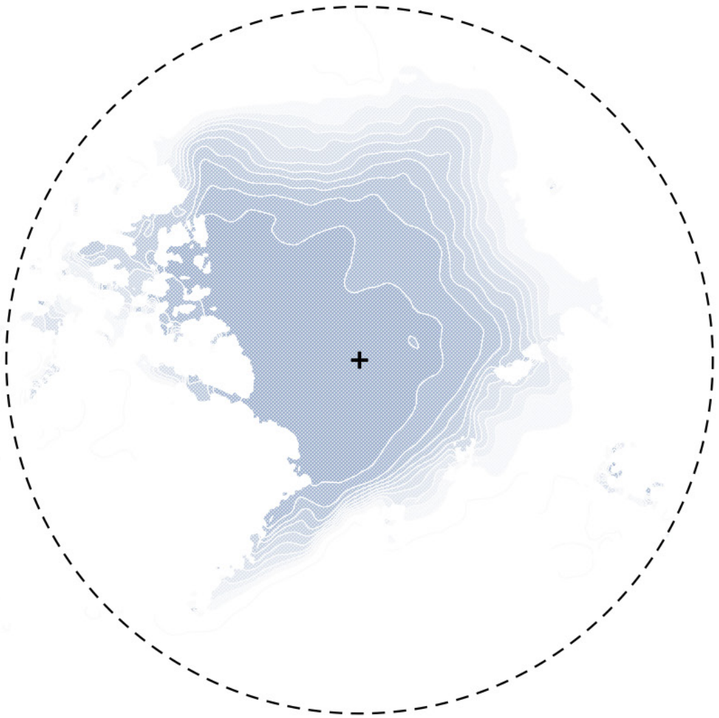
THE ARCTIC DEFINITION



PERMAFROST EXTENT

BEYOND 66°33’45.9”N

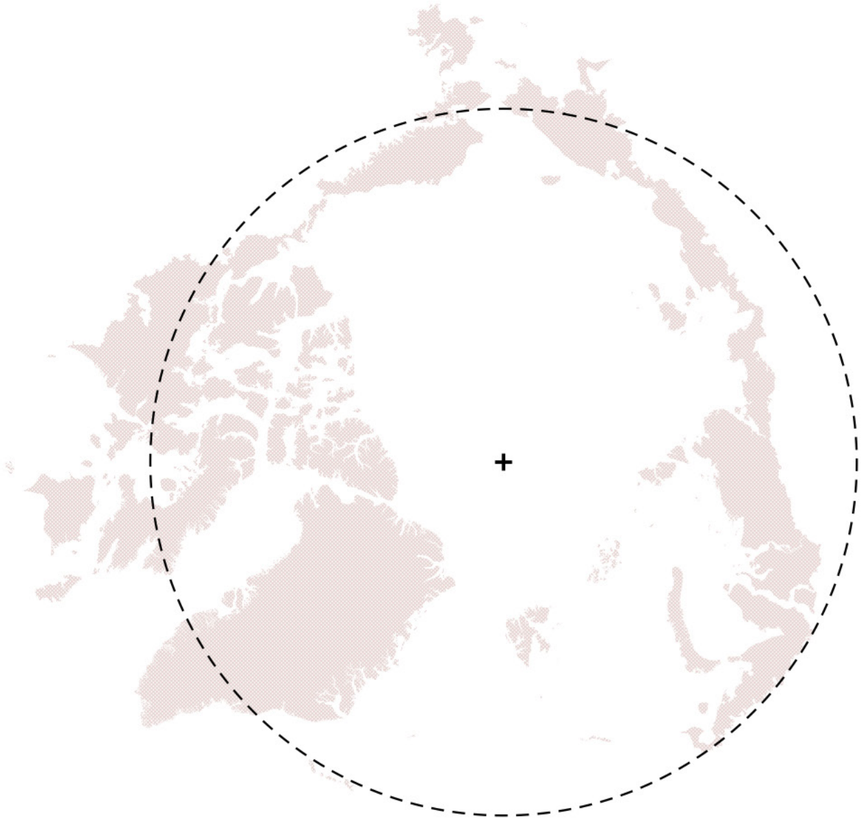
THE ARCTIC DEFINITION



ICE SHEET EXTENT

BEYOND 66°33’45.9”N

THE ARCTIC DEFINITION



TREE LINE BOUNDARY

BEYOND 66°33’45.9”N

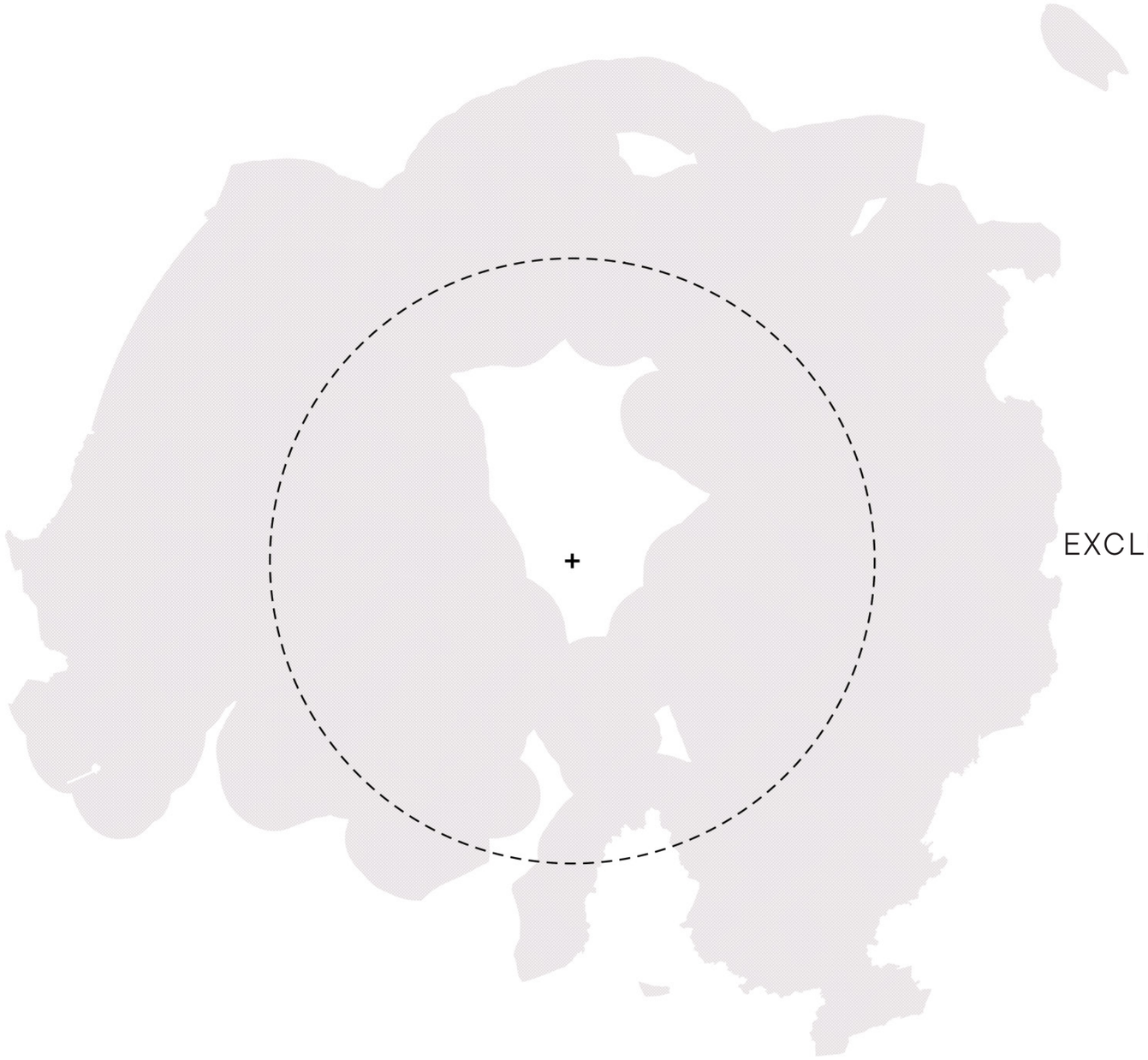
THE ARCTIC DEFINITION



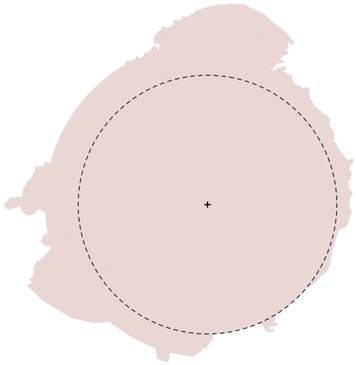
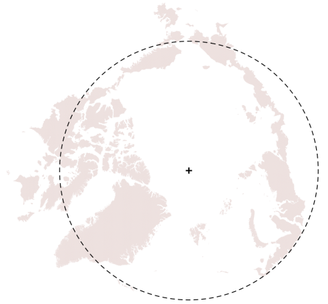
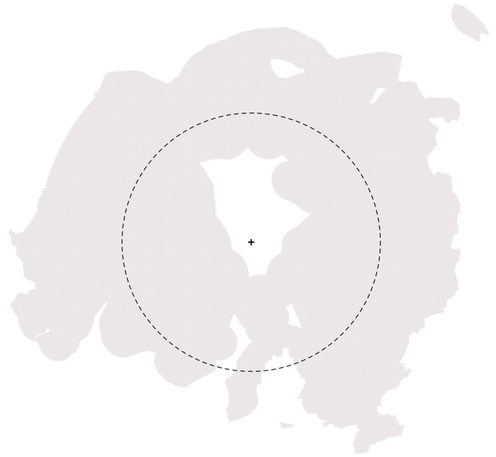
INDIGENOUS LANGUAGE REGIONS

BEYOND 66°33’45.9”N

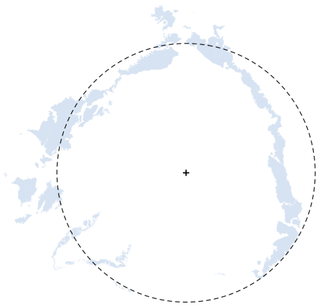
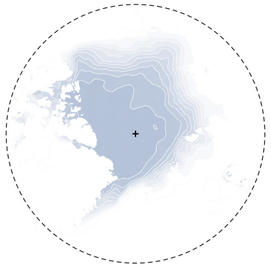
THE ARCTIC DEFINITION



EXCLUSIVE ECONOMICAL ZONES

EVERY REPRESENTATION PRODUCES A SPECIFIC READING OF SPACE

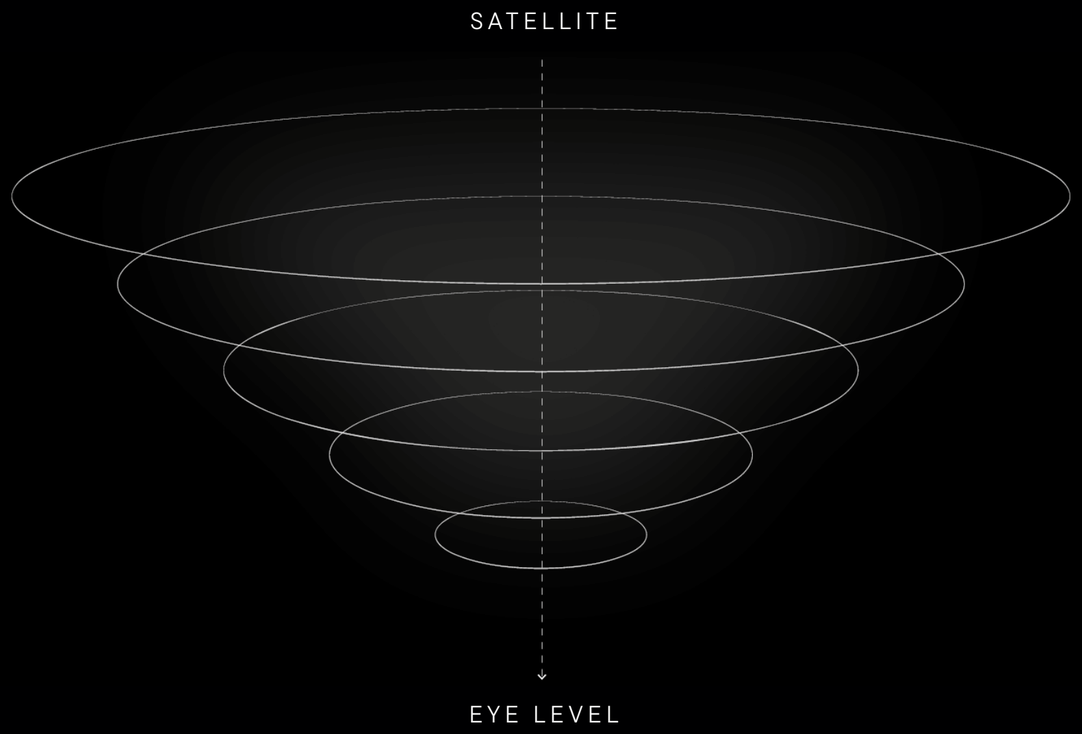





OBSERVE + LISTEN

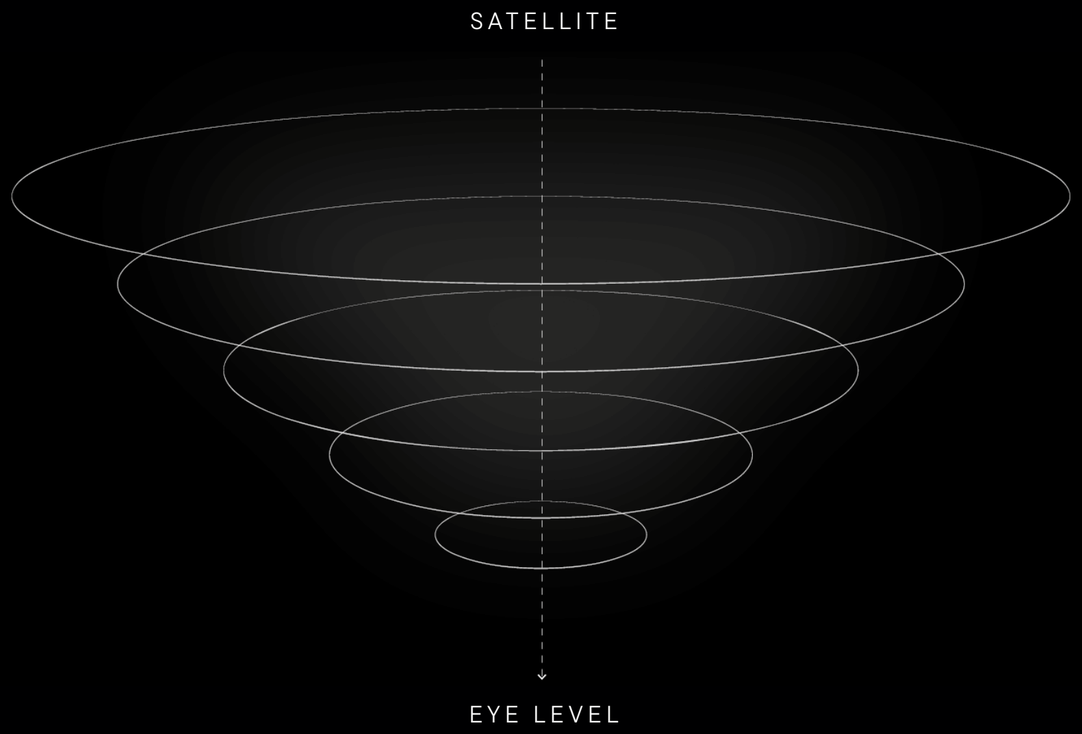
CONTENTS

MULTI-SCALAR APPROACH



CONTENTS

MULTI-SCALAR APPROACH



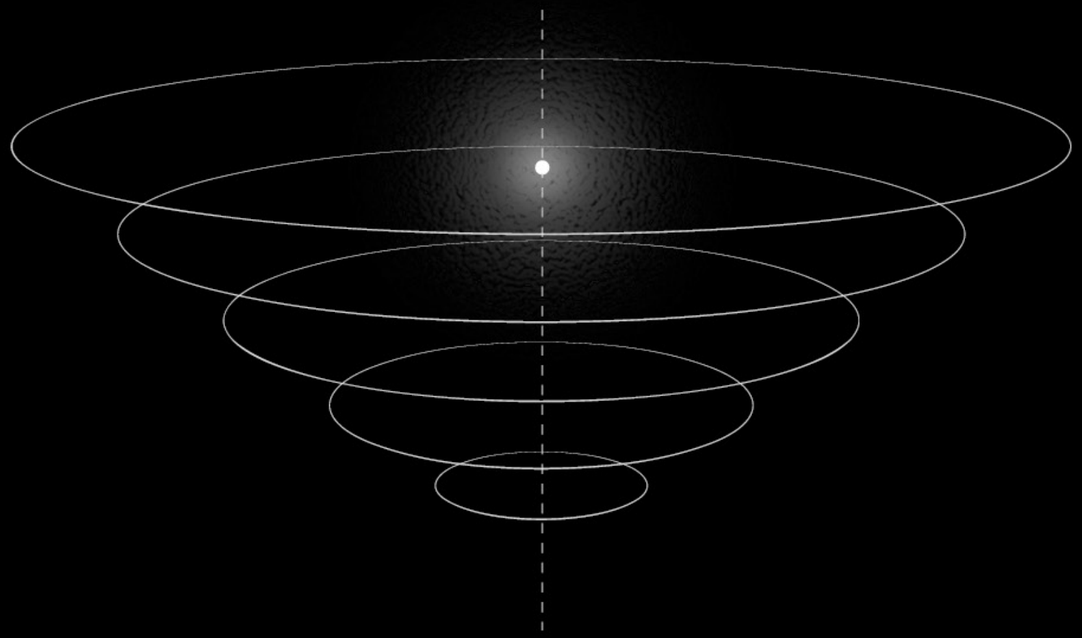
ACT I: ARCTIC CONTEXT

ACT II: ECOLOGICAL IMPACT OF ARTIFICIAL LIGHT

ACT III: THE NORWEGIAN PARADOXES

ACT IV: FIELDTRIP

ACT V: REPRESENTING THE UNSEEN



ACT I

THE OPENING OF A FRONTIER

GLOBAL TRENDS

SURFACE TEMPERATURE INCREASE



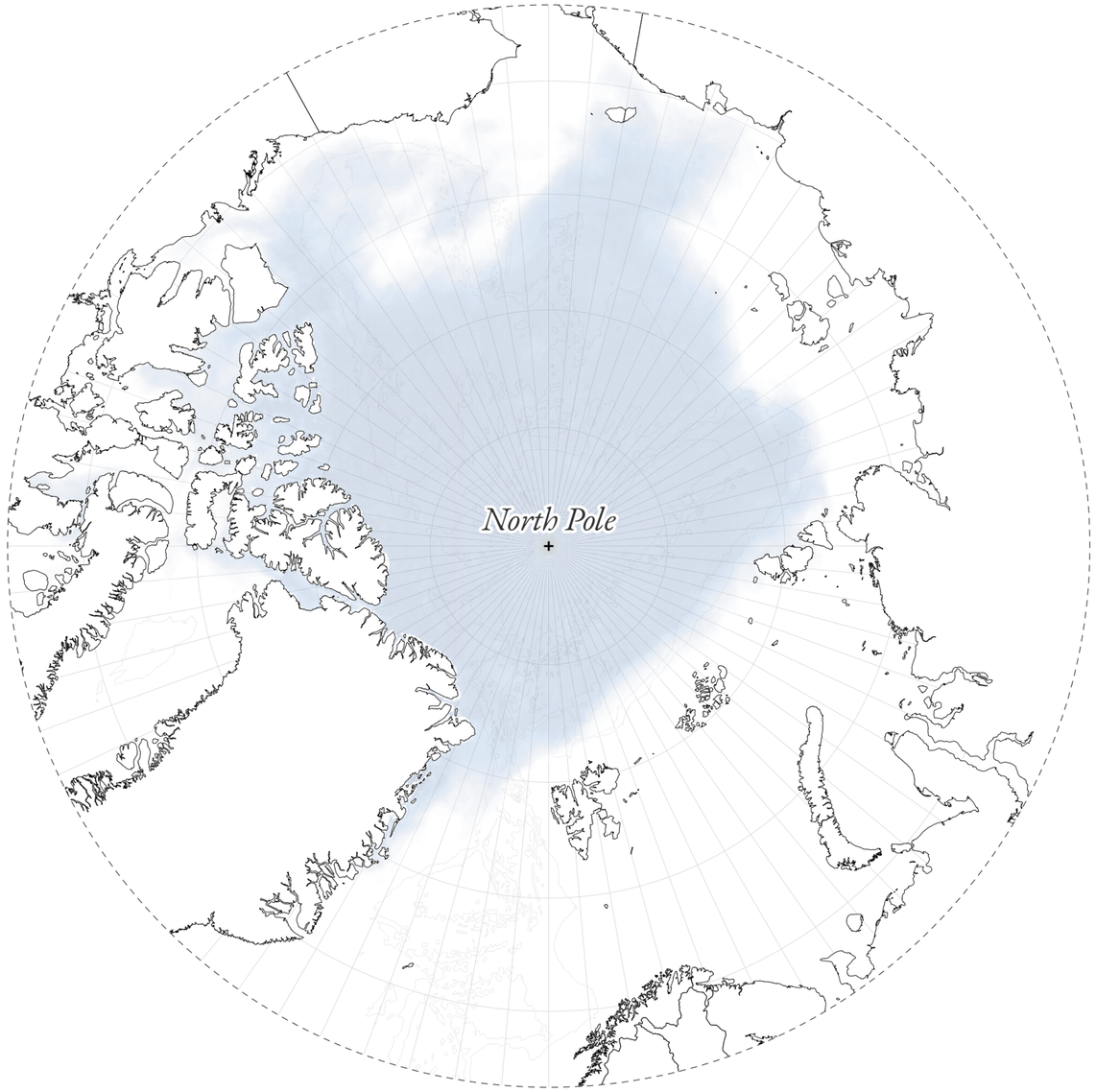
Temperature Increase (°C)

- 0,0 - 0,2
- 0,2 - 0,4
- 0,4 - 0,6
- 0,6 - 0,8
- 0,8 - 1,0
- 1,0 - 1,2
- 1,2 - 1,4
- 1,4 - 1,6
- 1,6 - 1,8
- 1,8 - 2,0
- 2,0 - 2,2
- 2,2 - 2,4
- 2,4 - 2,6
- 2,6 - 2,8
- 2,8 - 3,0
- 3,0 - 3,2
- 3,2 - 3,4
- 3,4 - 3,6

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

ARCTIC SEA ICE

EXTENT IN SEPTEMBER 2025



- **ACT I**
- ACT II
- ACT III
- ACT IV
- ACT V

Sea Ice Extent September 2025

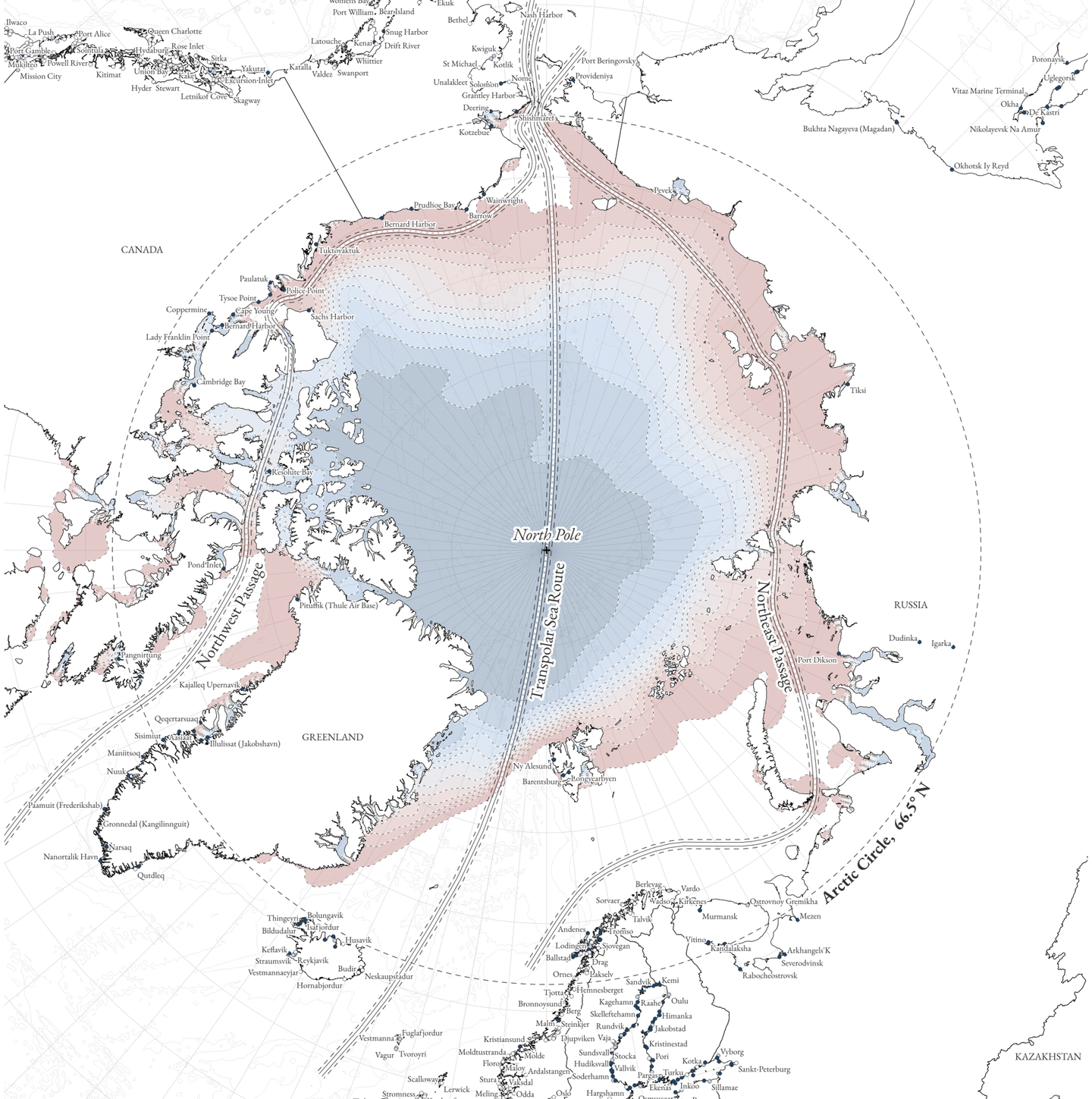


2035

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

POLAR ROUTES

INCREASED ACCESSIBILITY



Emerging Polar sea route

Ports

- Year-round ice-free entrance
- Seasonally ice-covered entrance
- No ice data available

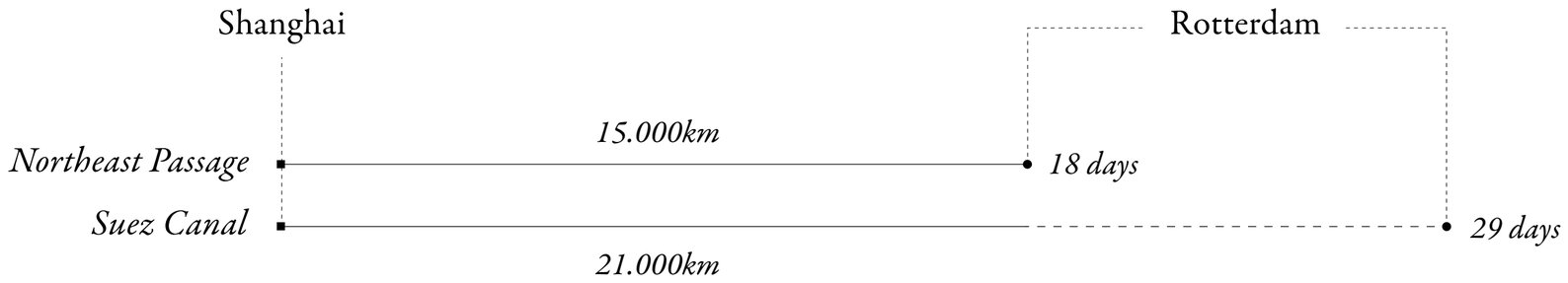
Sea Ice Extent in September (Frequency in %)

- 0,5
- 10
- 20
- 30
- 40
- 50
- 60
- 70
- 80
- 90
- 99,5

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

POLAR ROUTES

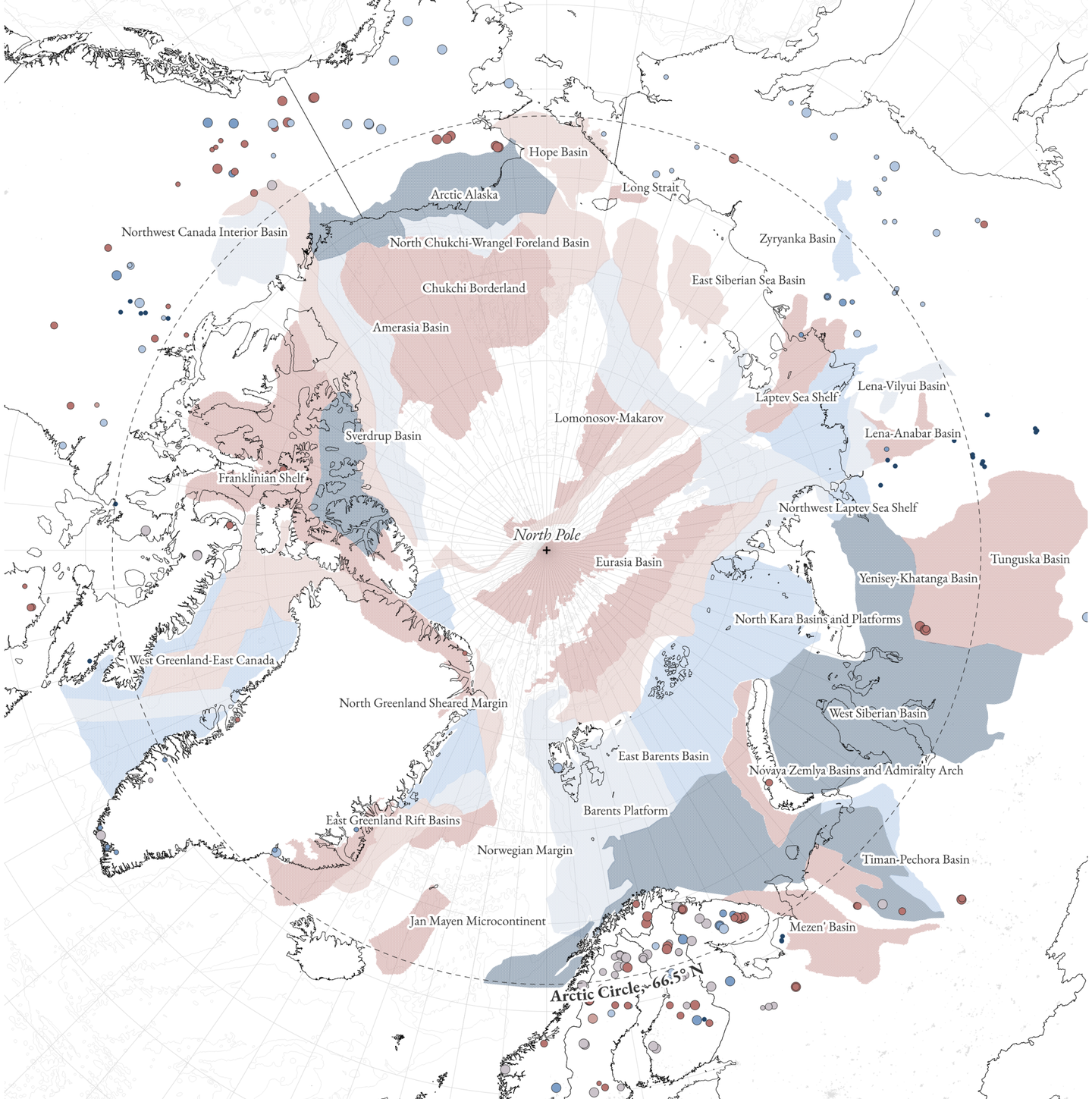
INCREASED ACCESSIBILITY



• **ACT I**
ACT II
ACT III
ACT IV
ACT V

RESOURCE POTENTIALS

OIL, GAS, METALS, DIAMONDS



Diamond deposit

Metal Deposits

- Base metals
- Energy metals
- Ferrous metals
- Precious metals
- Special metals

Metal Deposit - Total Tonnage (MT)

- 0 - 15
- 15 - 150
- 150+

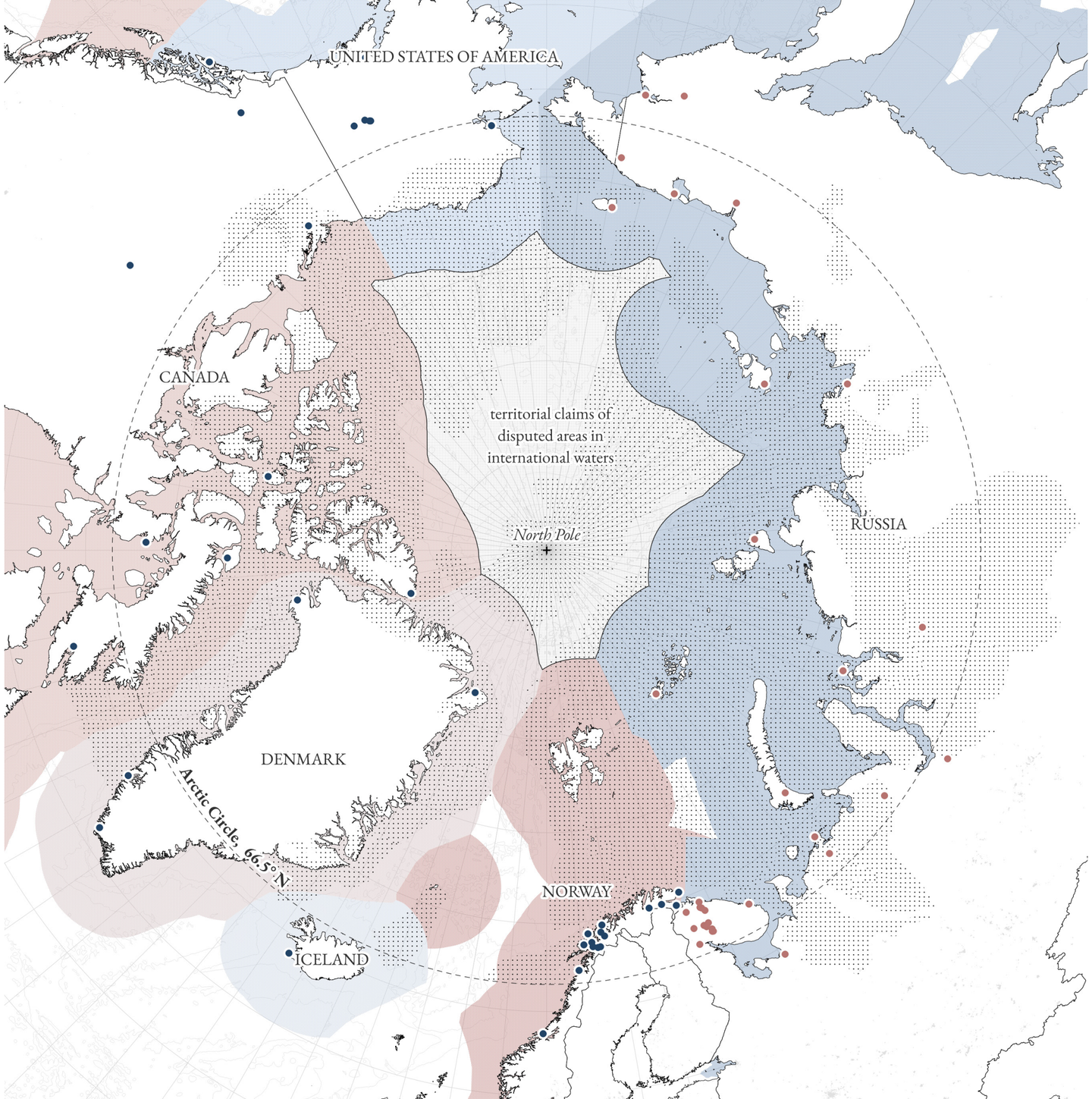
Oil and Gas Potentials (%)

- 0 - 10
- 10 - 30
- 30 - 50
- 50 - 75
- 75 - 100

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

GEOPOLITICAL INTEREST

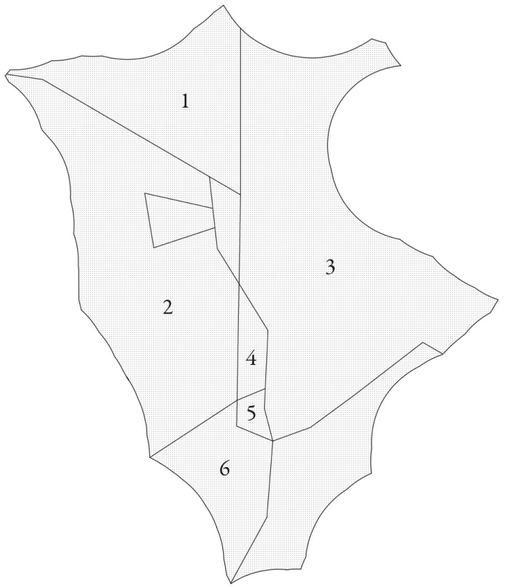
INCREASING MILITARY ACTIVITY



• **ACT I**
ACT II
ACT III
ACT IV
ACT V

TERRITORIAL CLAIMS

OF INTERNATIONAL WATERS



1. UNITED STATES OF AMERICA

2. CANADA

3. RUSSIA

4. CANADA & RUSSIA

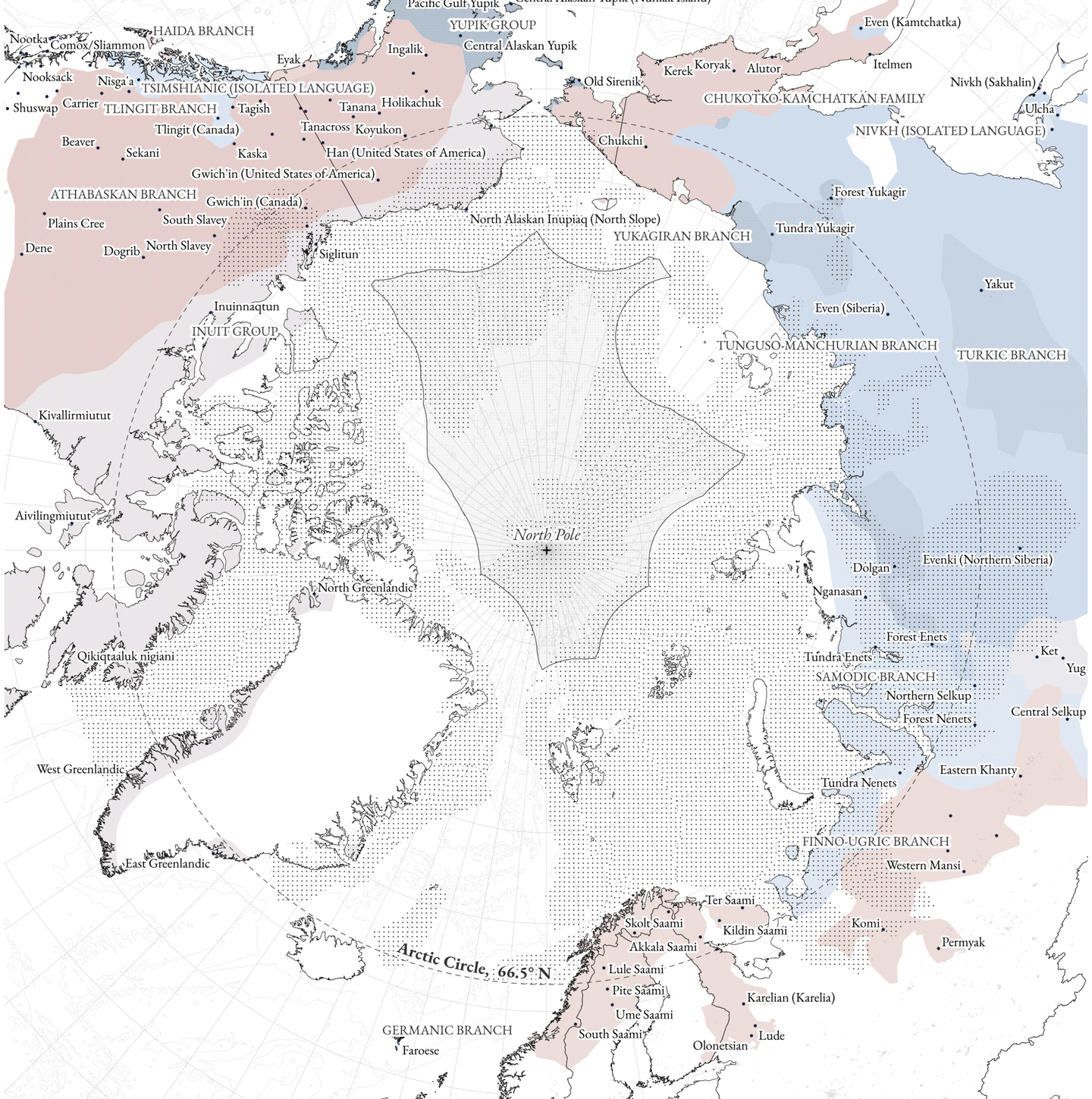
5. DENMARK & RUSSIA

6. DENMARK

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

INDIGENOUS PEOPLES

LANGUAGE, KNOWLEDGE, CULTURE



Territorial claims

Oil & gas resource potential

Indigenous Language Families

- Aleut group
- Athabaskan branch
- Chukotko-Kamchatkan family
- Eyak branch
- Finno-Ugric branch
- Germanic branch
- Haida branch
- Inuit group
- Ket (isolated language)
- Mongolic branch
- Nivkh (isolated language)
- Samodic branch
- Tlingit branch
- Tsimshianic (isolated language)
- Tunguso-Manchurian branch
- Turkic branch
- Yukagiran branch
- Yupik group

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

THE OPENING OF A FRONTIER

ACCESSIBILITY, PRODUCTIVITY, CONTINUITY



• **ACT I**
ACT II
ACT III
ACT IV
ACT V

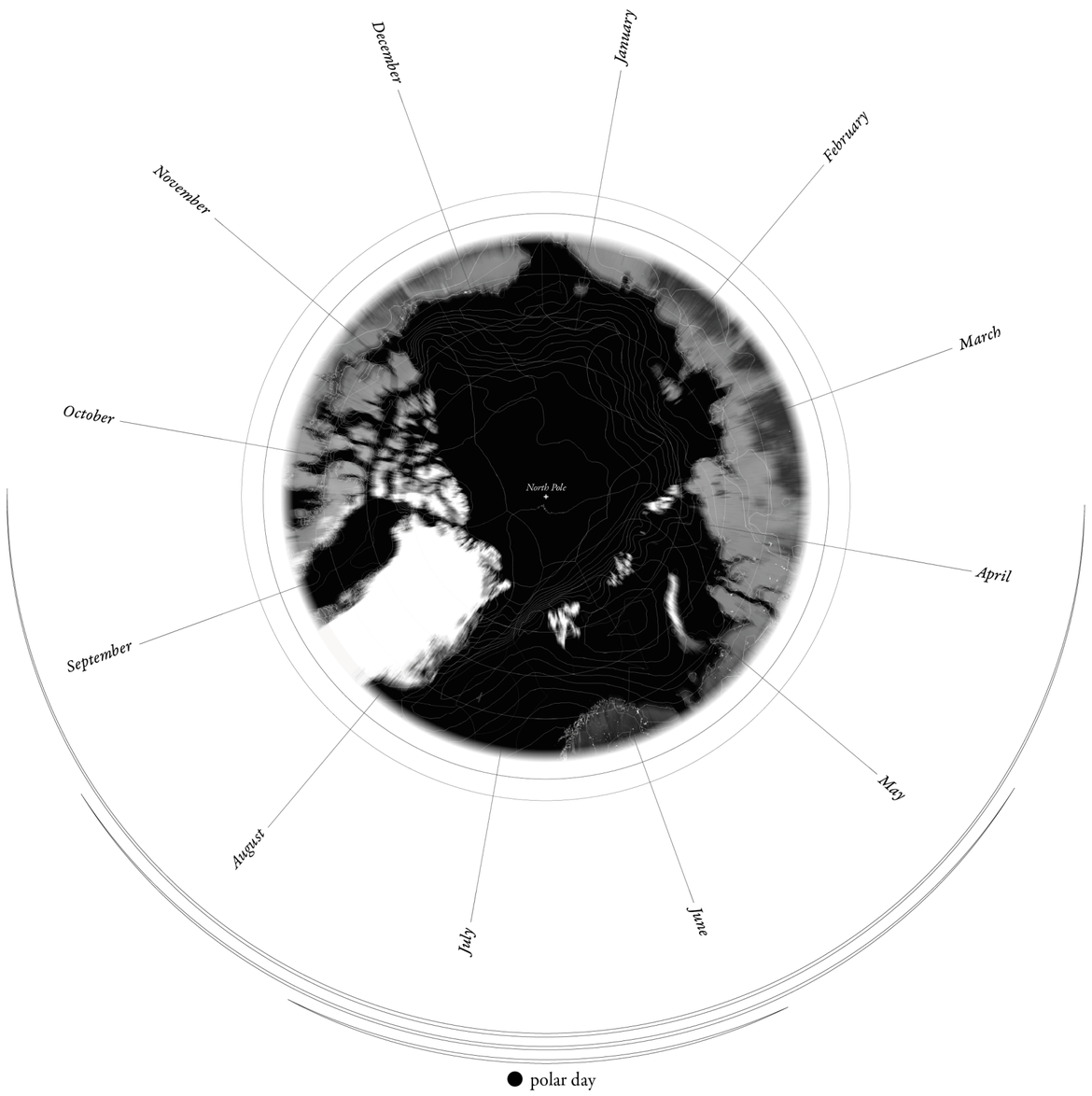

24/7

RHYTHMS OF THE ARCTIC

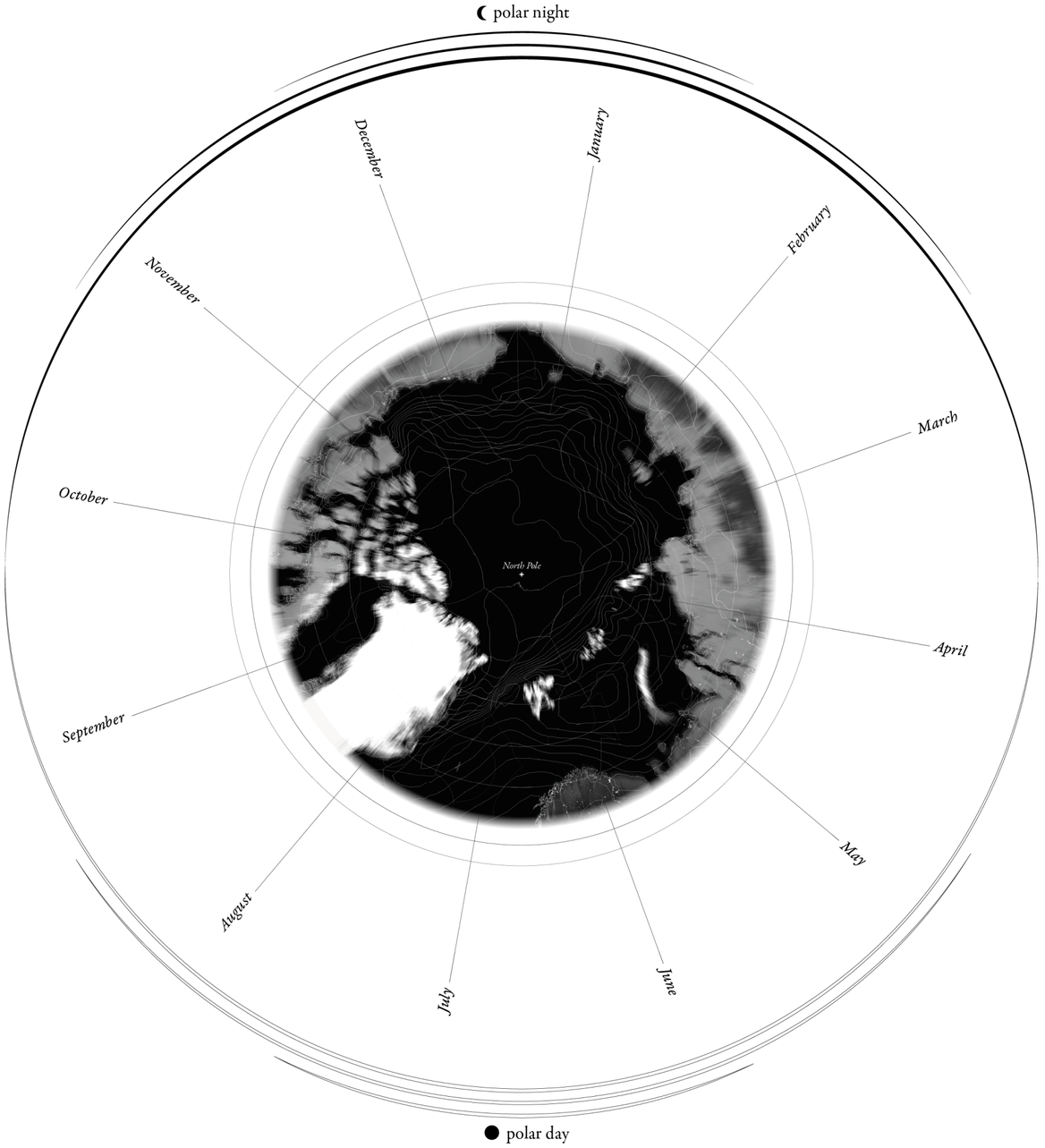


• **ACT I**
ACT II
ACT III
ACT IV
ACT V

POLAR DAY



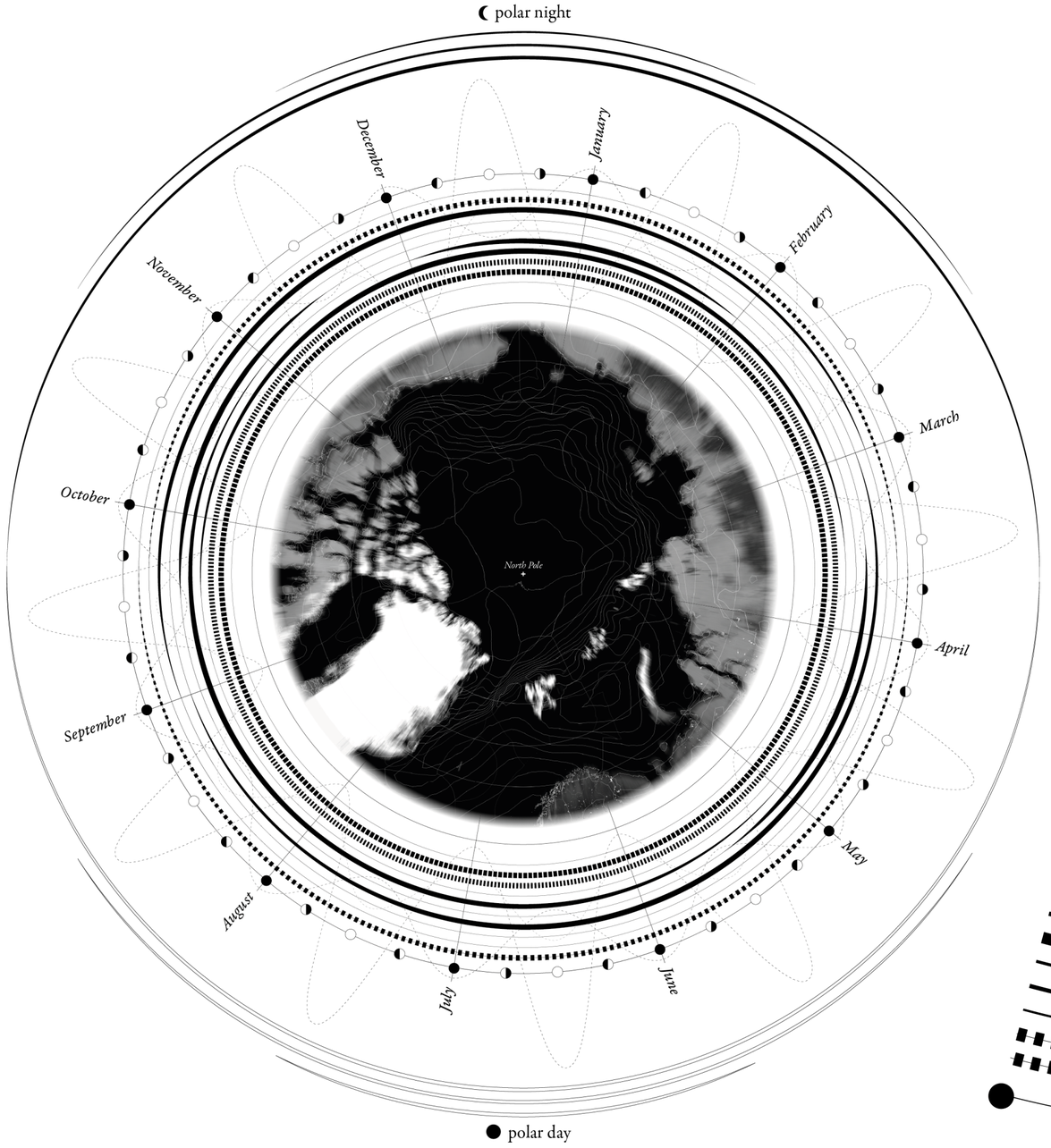
• **ACT I**
ACT II
ACT III
ACT IV
ACT V

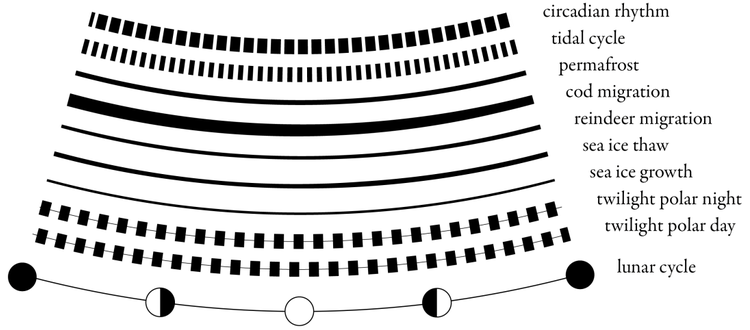


POLAR NIGHT

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

RHYTHMS OF THE ARCTIC





• **ACT I**
ACT II
ACT III
ACT IV
ACT V



ECOLOGICAL ADAPTATION

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

THE DARKNESS OF THE POLAR NIGHT

ecological adaptation & regulation

ARTIFICIAL LIGHT AT NIGHT (ALAN)

24/7 continuity

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

THE DARKNESS OF THE POLAR NIGHT

ecological adaptation & regulation

ARTIFICIAL LIGHT AT NIGHT (ALAN)

24/7 continuity

THE DARKNESS OF THE POLAR NIGHT
ecological adaptation & regulation

+

ARTIFICIAL LIGHT AT NIGHT (ALAN)
24/7 continuity

EROSION OF DARKNESS,
ESSENTIAL TO ARCTIC ECOSYSTEMS

DARKNESS AS A RIGHT OF NATURE?

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

HOW CAN DESIGN MEDIATE THE RECOGNITION OF DARKNESS AS A RIGHT OF NATURE TO SUPPORT ECOLOGICAL REGENERATION IN THE ARCTIC?

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

HOW CAN DESIGN MEDIATE THE RECOGNITION OF DARKNESS AS A RIGHT OF NATURE TO SUPPORT ECOLOGICAL REGENERATION IN THE ARCTIC?

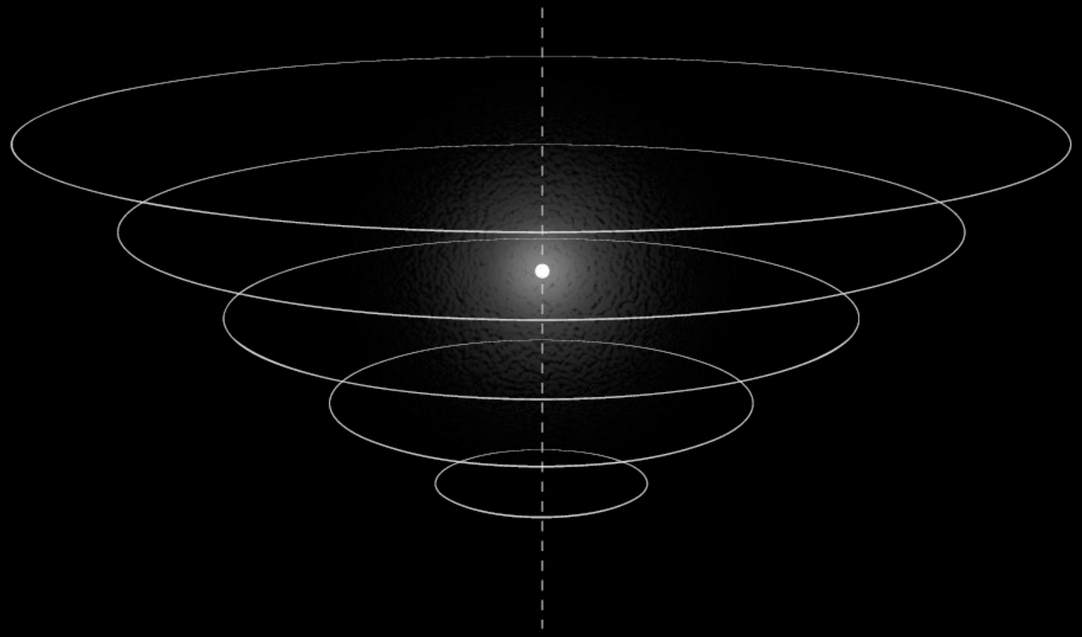
• **ACT I**
ACT II
ACT III
ACT IV
ACT V

HOW CAN DESIGN MEDIATE THE RECOGNITION OF DARKNESS AS A RIGHT OF NATURE TO SUPPORT ECOLOGICAL REGENERATION IN THE ARCTIC?

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

HOW CAN DESIGN MEDIATE THE RECOGNITION OF DARKNESS AS A RIGHT OF NATURE TO SUPPORT ECOLOGICAL REGENERATION IN THE ARCTIC?

• **ACT I**
ACT II
ACT III
ACT IV
ACT V

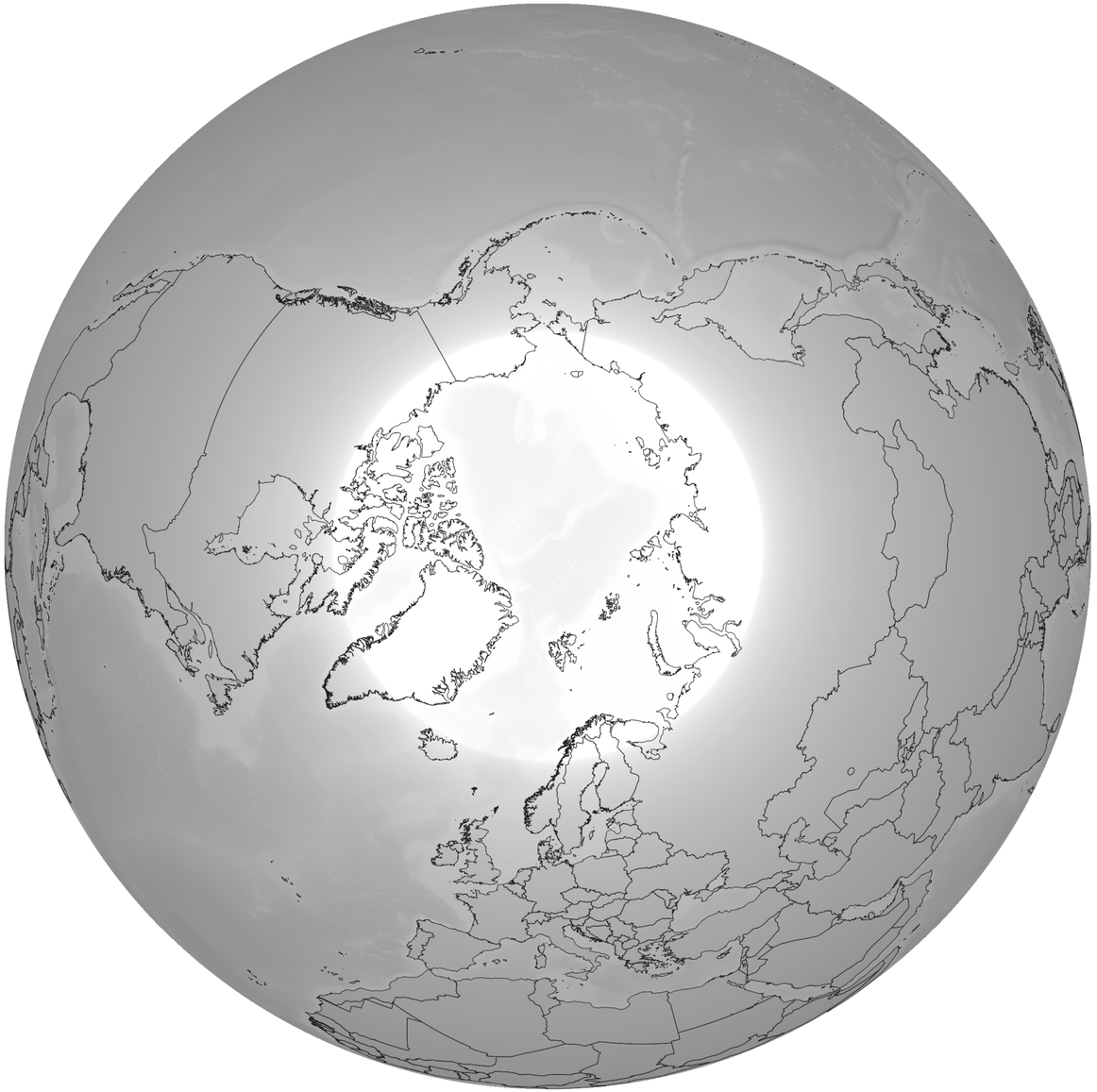


ACT II

A GEOGRAPHY OF DARKNESS

THE POLAR DAY

DUE TO THE TILT AXIS OF THE EARTH



JUNE SOLSTICE

0 24

hours of sunlight

ACT I
• **ACT II**
ACT III
ACT IV
ACT V

THE POLAR NIGHT

DUE TO THE TILT AXIS OF THE EARTH



DECEMBER SOLSTICE

0 24

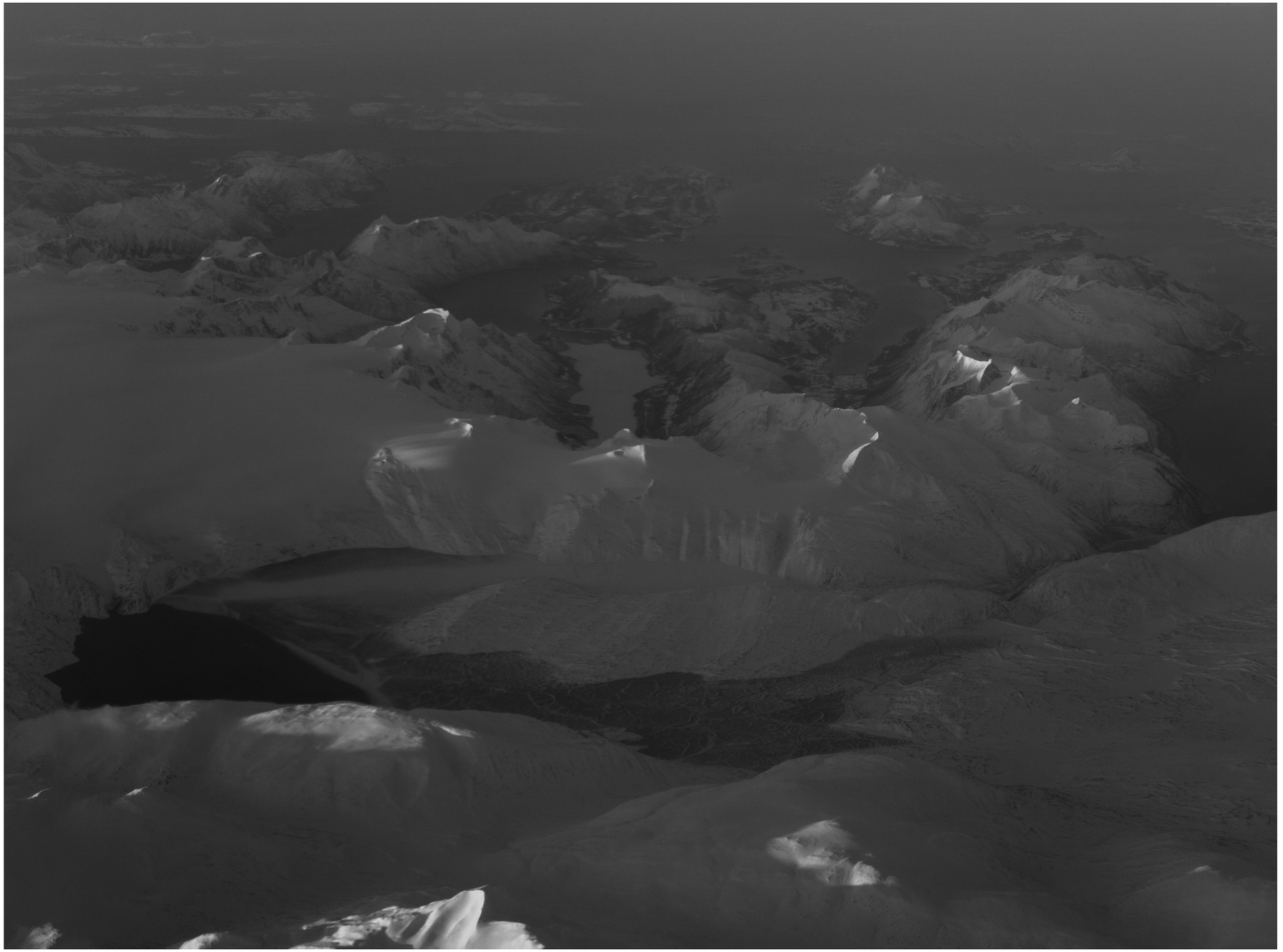
hours of sunlight

ACT I
• **ACT II**
ACT III
ACT IV
ACT V

STRUCTURING SPACE AND TIME

THE CHANGE OF PERCEPTION

ACT I
• **ACT II**
ACT III
ACT IV
ACT V



BIOLOGICAL SYNCHRONISATION WITH NATURAL LIGHT

ZEITGEBER

ECOLOGICAL FUNCTIONS

BIOPHYSICAL BEHAVIOUR

BIOLOGICAL SYNCHRONISATION WITH NATURAL LIGHT

ZEITGEBER

ECOLOGICAL FUNCTIONS

BIOPHYSICAL BEHAVIOUR

COMMUNICATION
MIGRATION
PREY-PREDATOR INTERACTION
REPRODUCTION

ECOSYSTEM PROTECTION



Heightened ecological signficance

Protected Areas

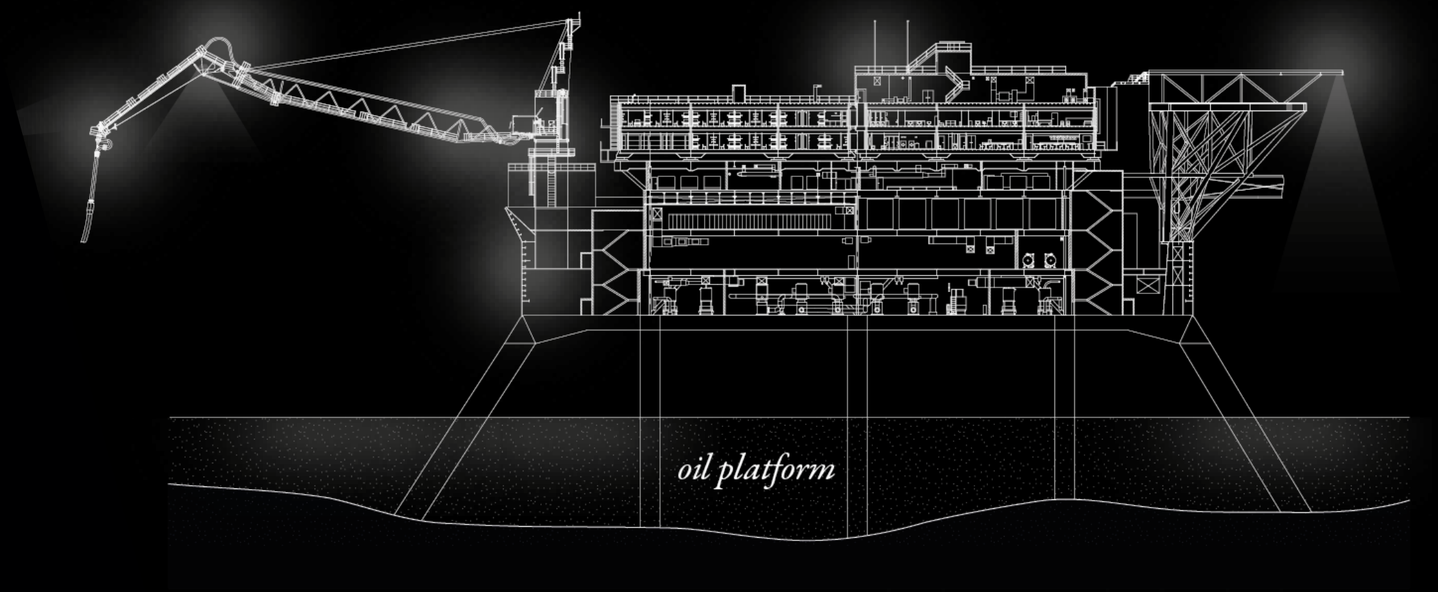
Terrestrial

Marine

ACT I
• **ACT II**
ACT III
ACT IV
ACT V

LIGHT SOURCES

ARTIFICIAL LIGHT AT NIGHT



LIGHT SOURCES

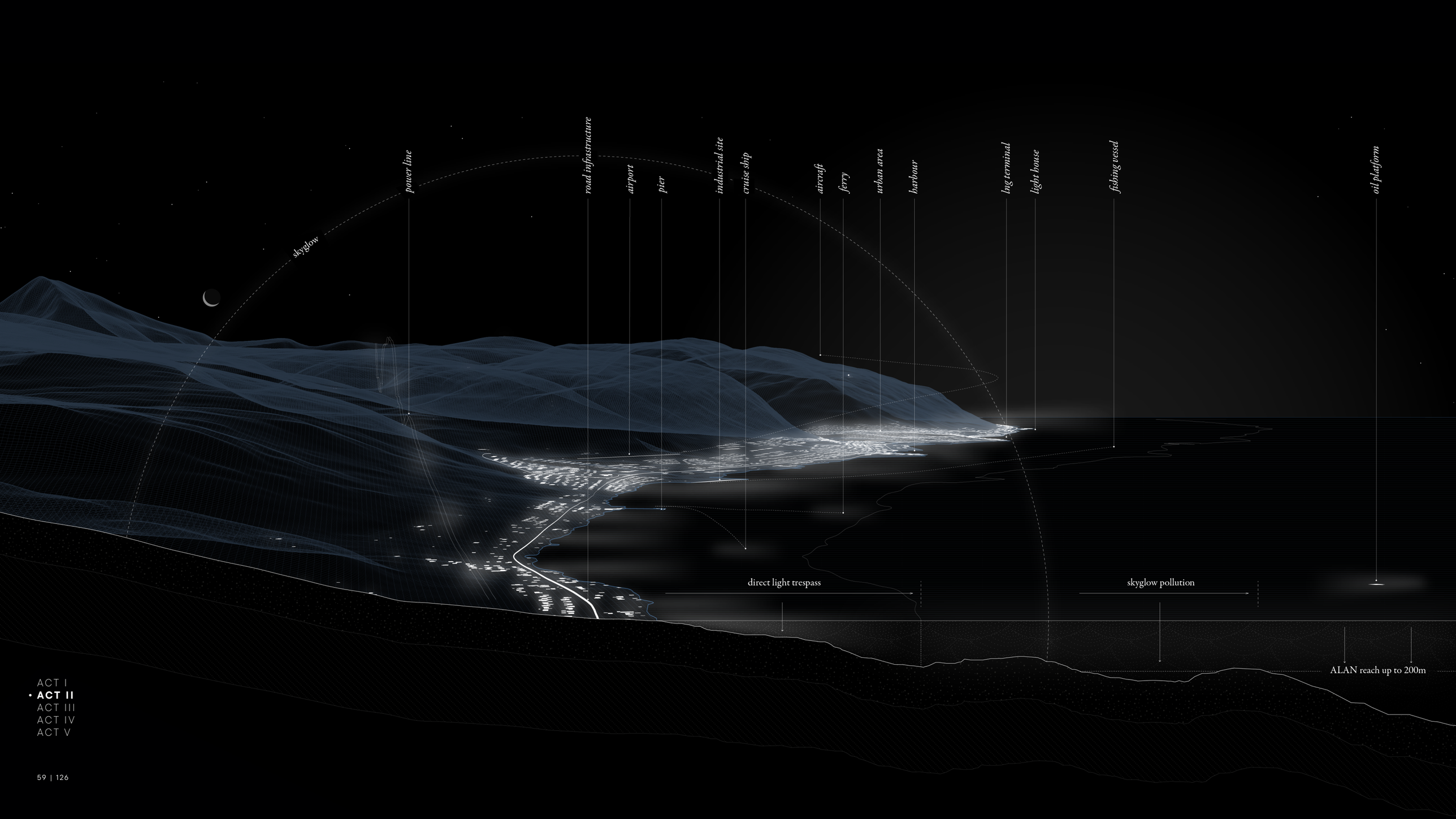
ARTIFICIAL LIGHT AT NIGHT



ACT I
• **ACT II**
ACT III
ACT IV
ACT V

600,000 KM²

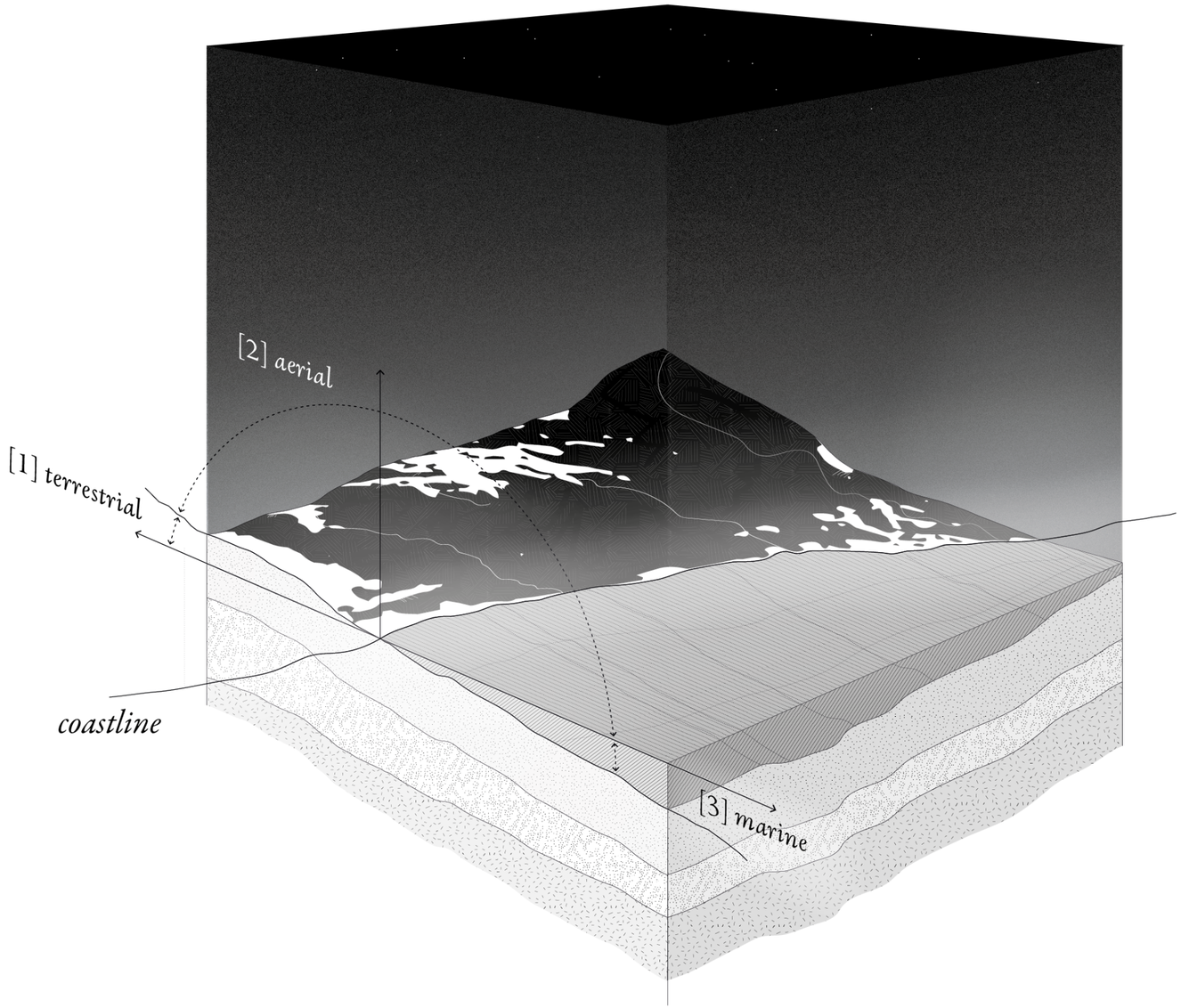

600,000 KM²



ACT I
• **ACT II**
ACT III
ACT IV
ACT V

COASTAL ZONE OF CONVERGENCE

SYSTEMIC APPROACH



ACT I
• **ACT II**
ACT III
ACT IV
ACT V

WARNING SPECIES

IMPACTED BY ARTIFICIAL LIGHT AT NIGHT

[1] TERRESTRIAL REALM: REINDEER

[2] AERIAL REALM: LITTLE AUK

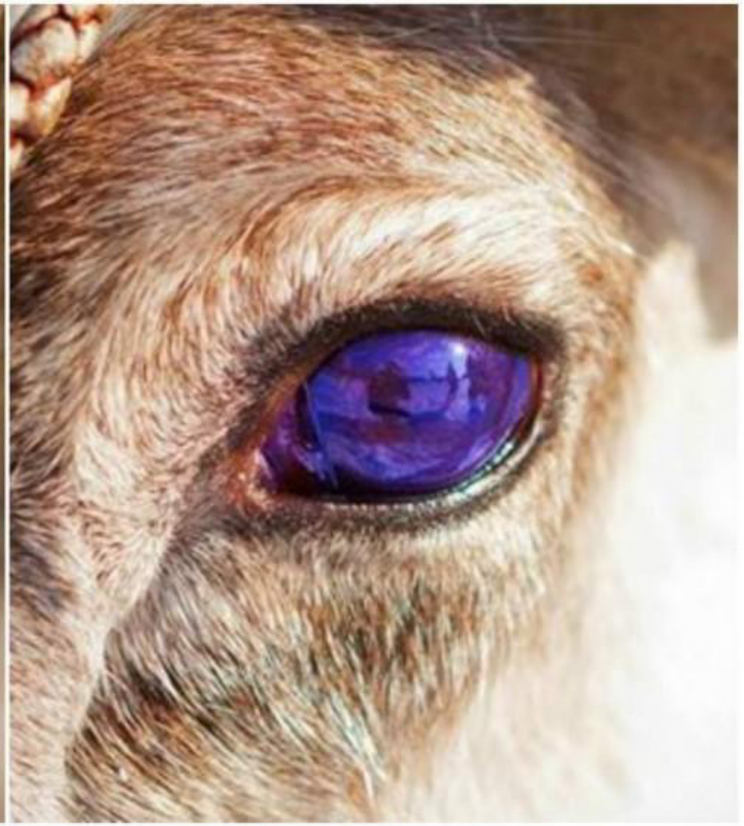
[3] MARINE REALM: ZOOPLANKTON

TERRESTRIAL REALM: REINDEER

ADAPTATION TO THE POLAR NIGHT



SPRING, SUMMER, AUTUMN

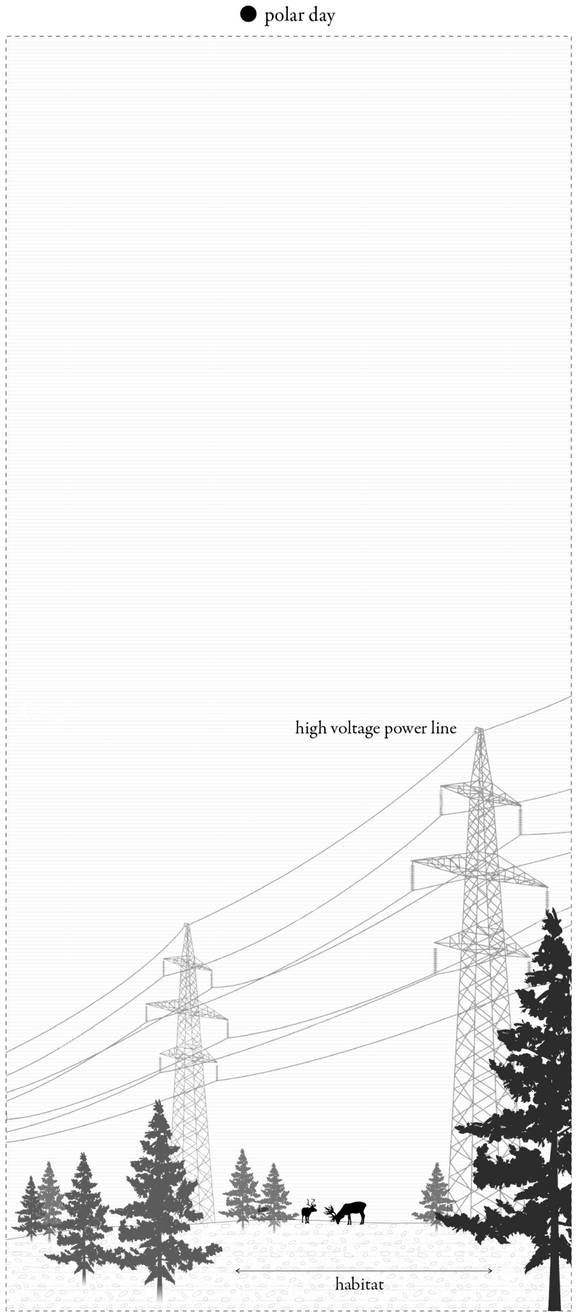


WINTER

PHOTO: PADDY KALISH

REINDEER

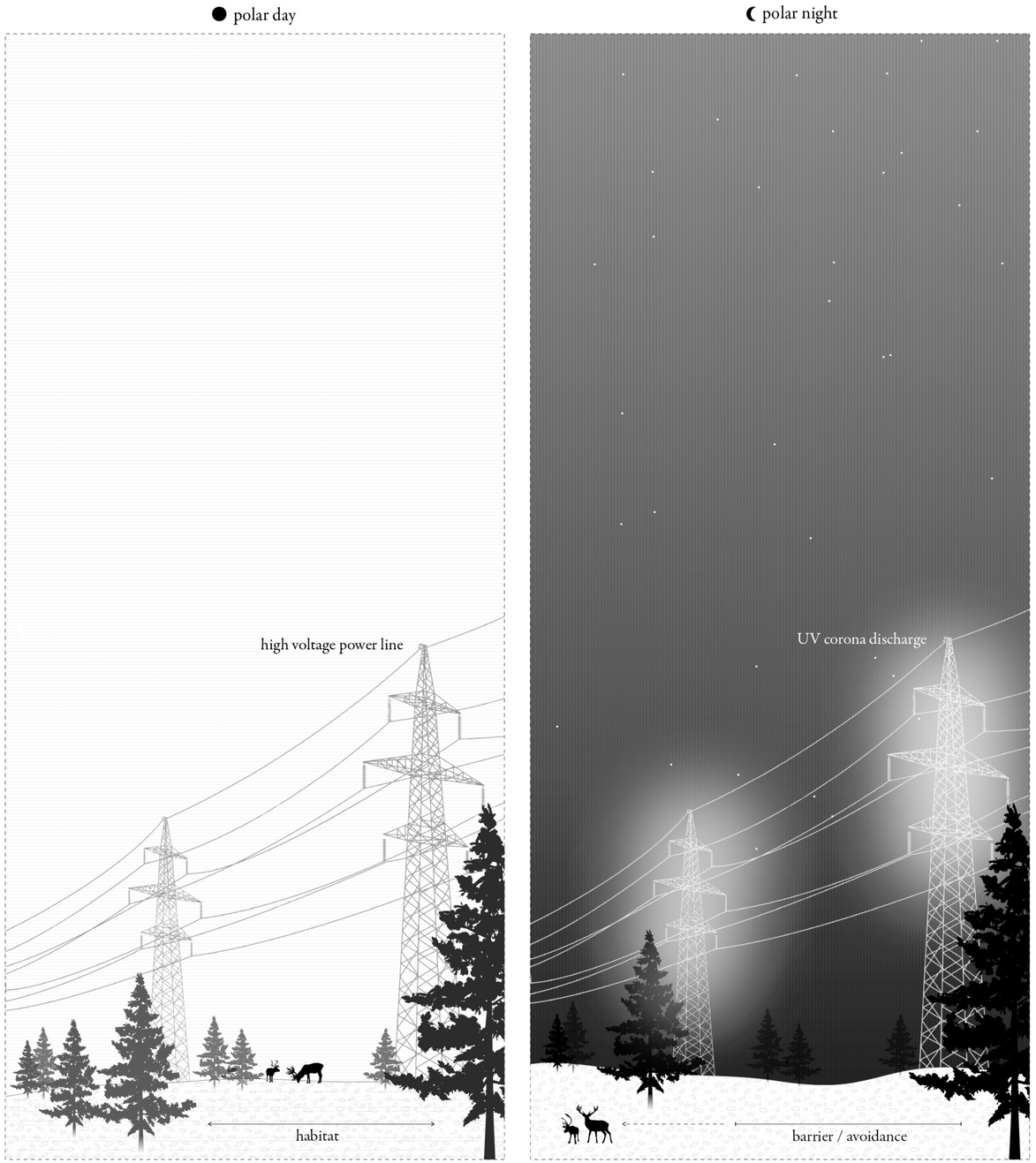
ADAPTATION TO THE POLAR NIGHT



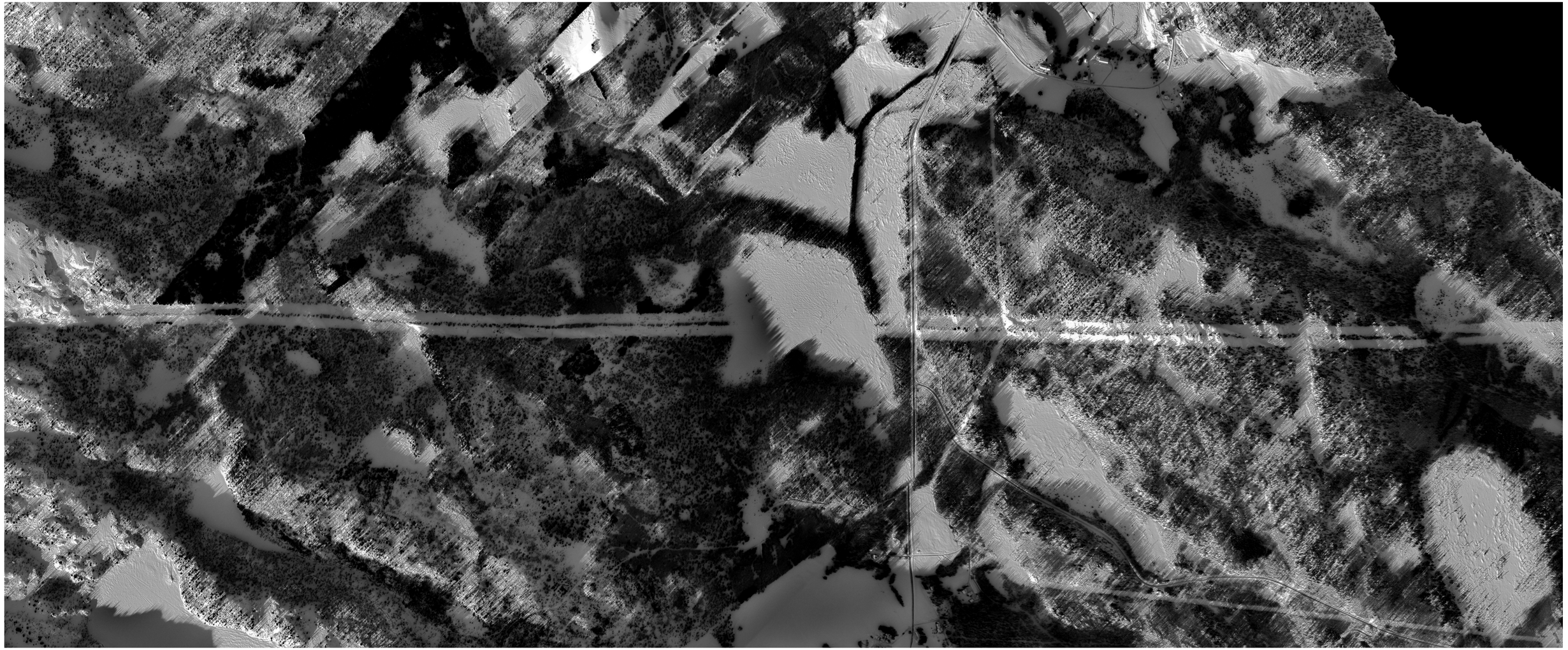
ACT I
• **ACT II**
ACT III
ACT IV
ACT V

REINDEER

ADAPTATION TO THE POLAR NIGHT



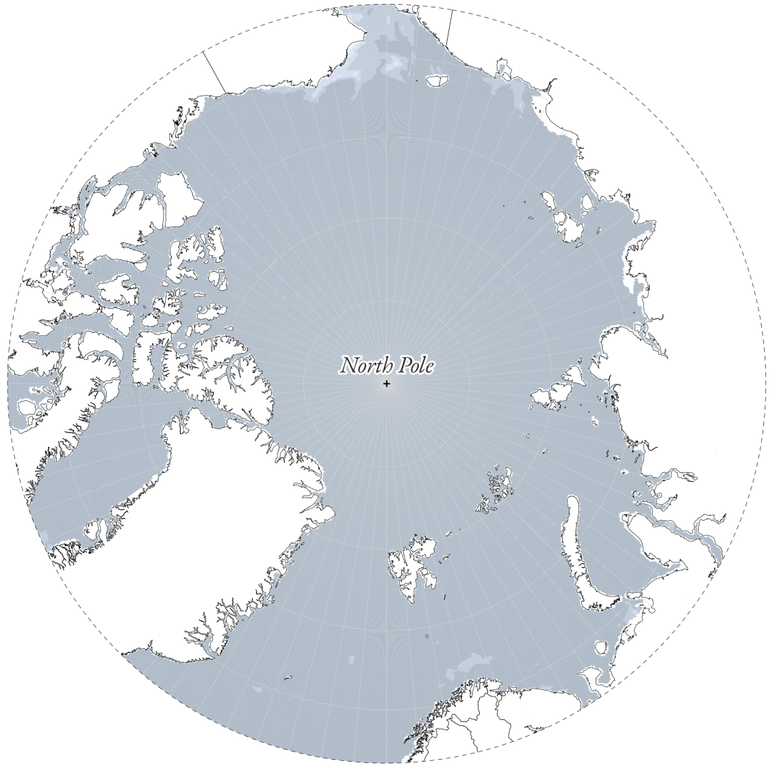
ACT I
• **ACT II**
ACT III
ACT IV
ACT V



ACT I
• **ACT II**
ACT III
ACT IV
ACT V

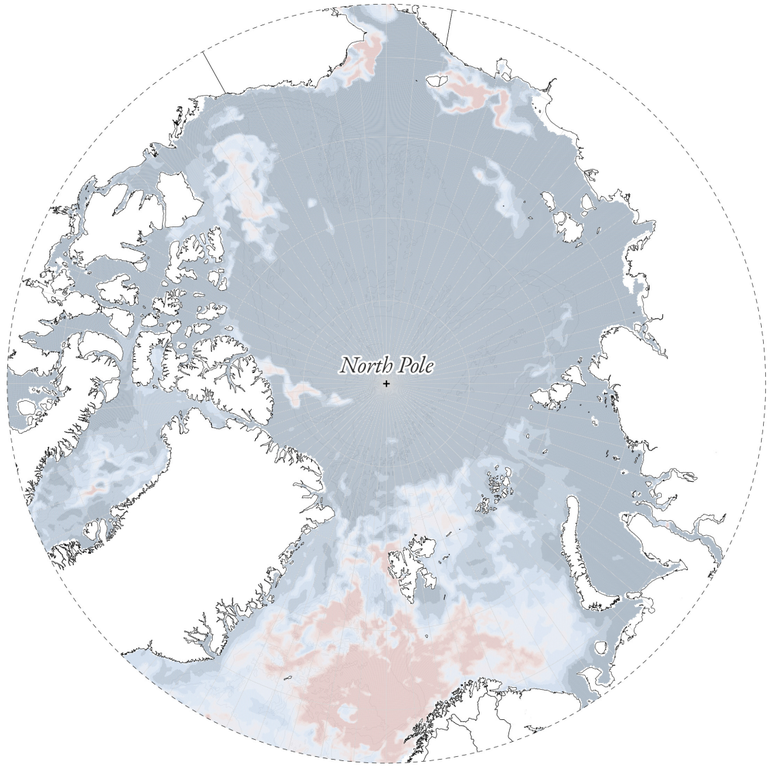
MARINE REALM: ZOOPLANKTON

CONCENTRATION AT SURFACE WATERS



WINTER

Polar night



SUMMER

Polar day

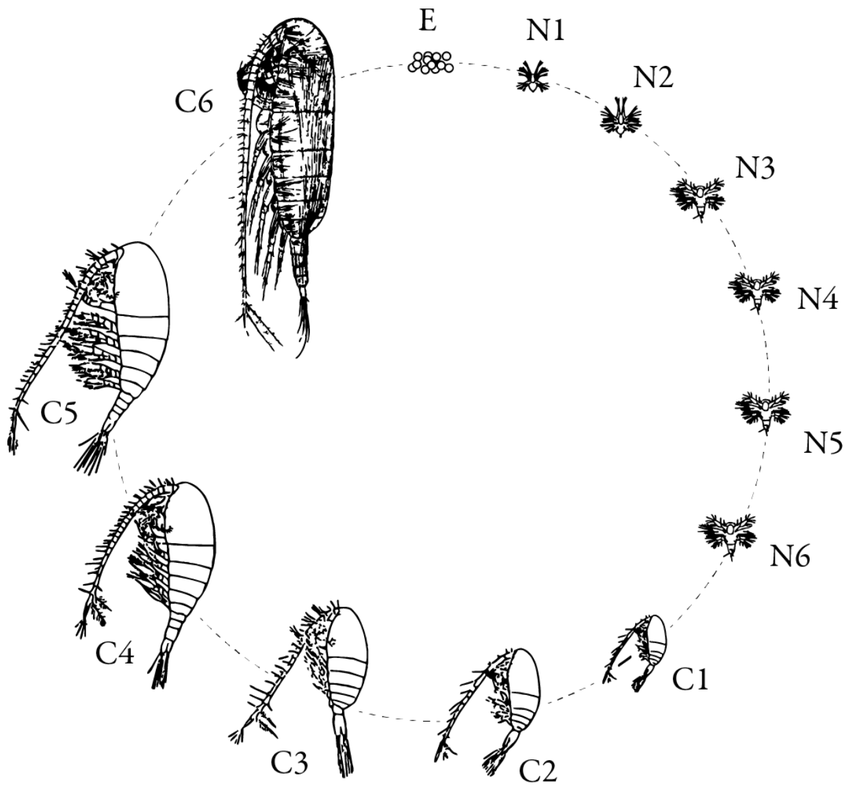
Mole Concentration of Zooplankton (mmol/m³)

- 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+

ACT I
• **ACT II**
ACT III
ACT IV
ACT V

ZOOPLANKTON

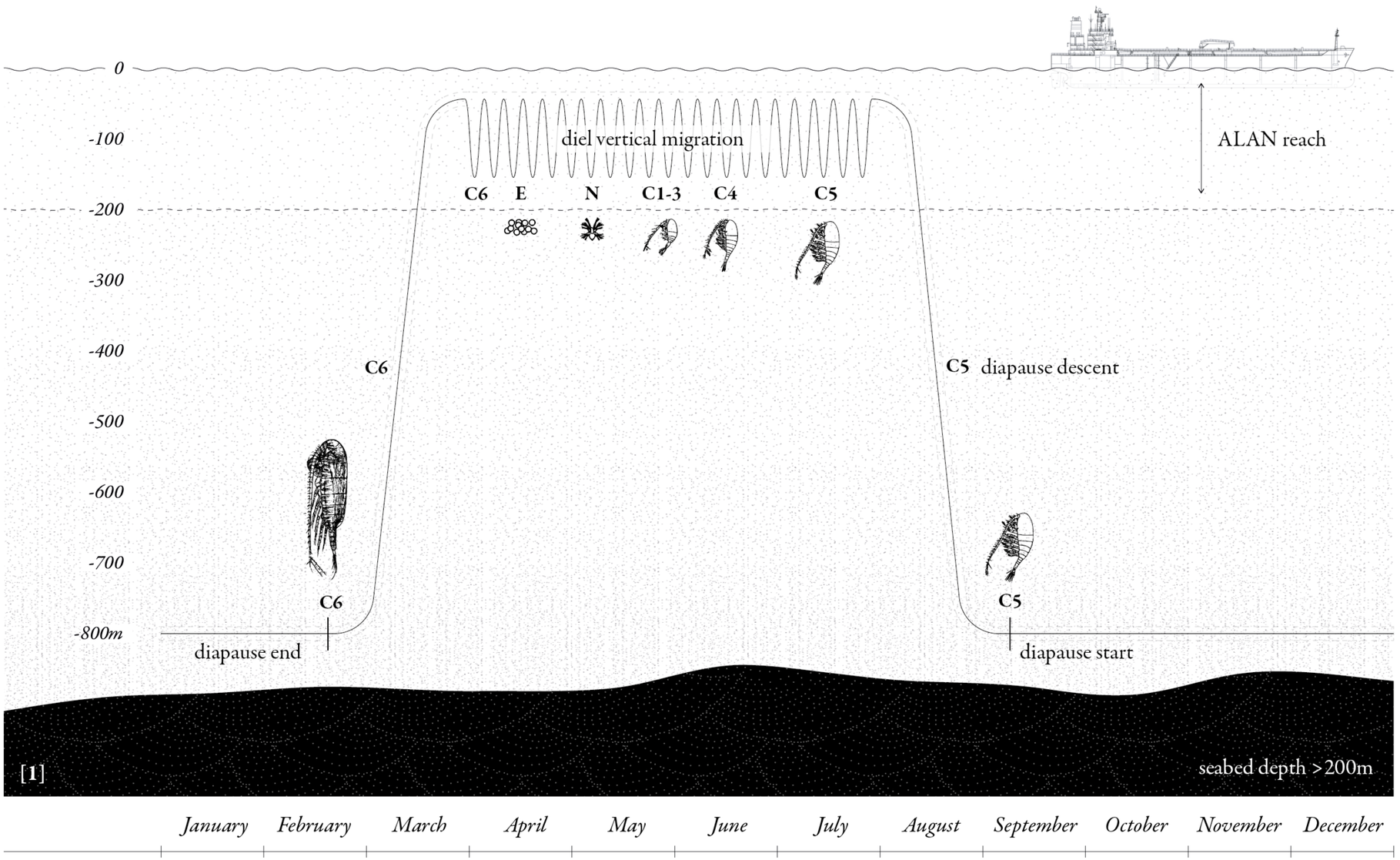
LIFE STAGES



ACT I
• **ACT II**
ACT III
ACT IV
ACT V

ZOOPLANKTON

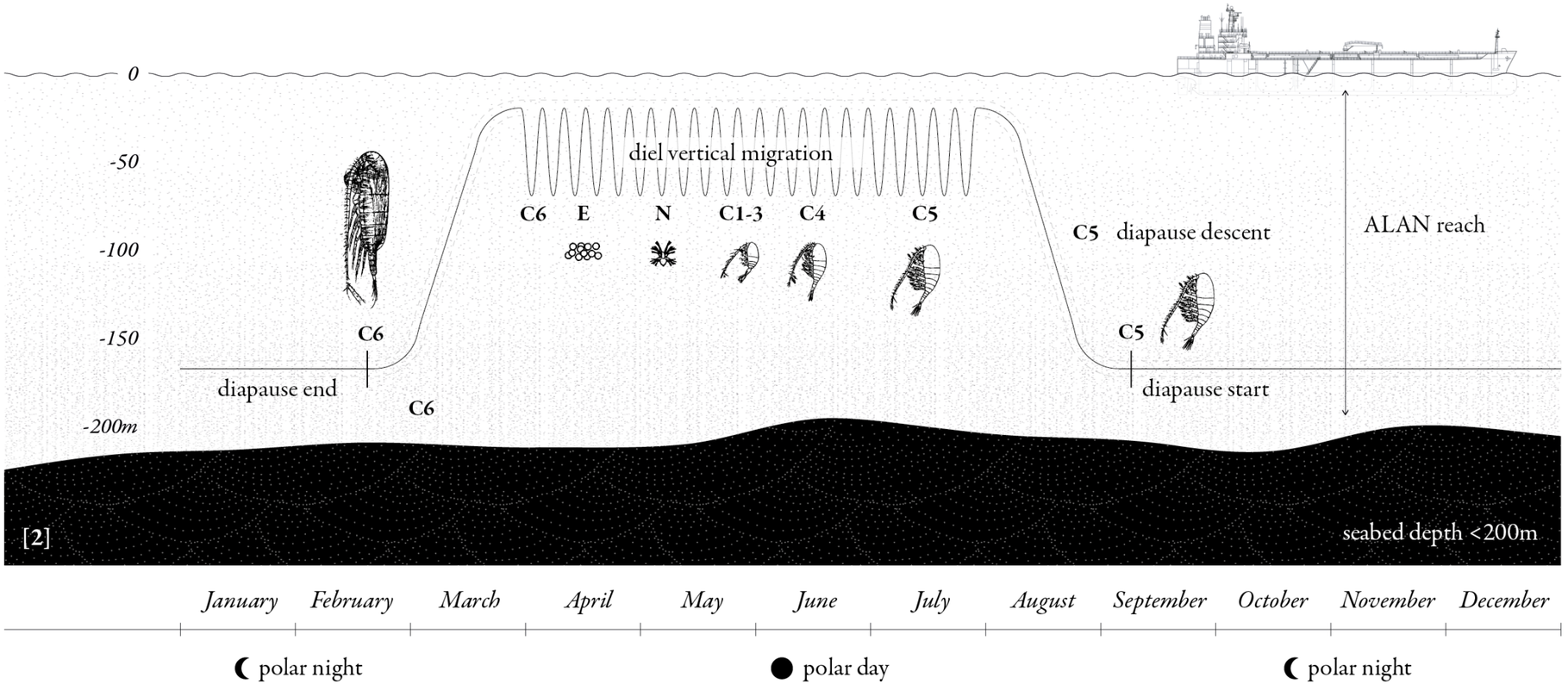
DIEL VERTICAL MIGRATION



ACT I
• **ACT II**
ACT III
ACT IV
ACT V

ZOOPLANKTON

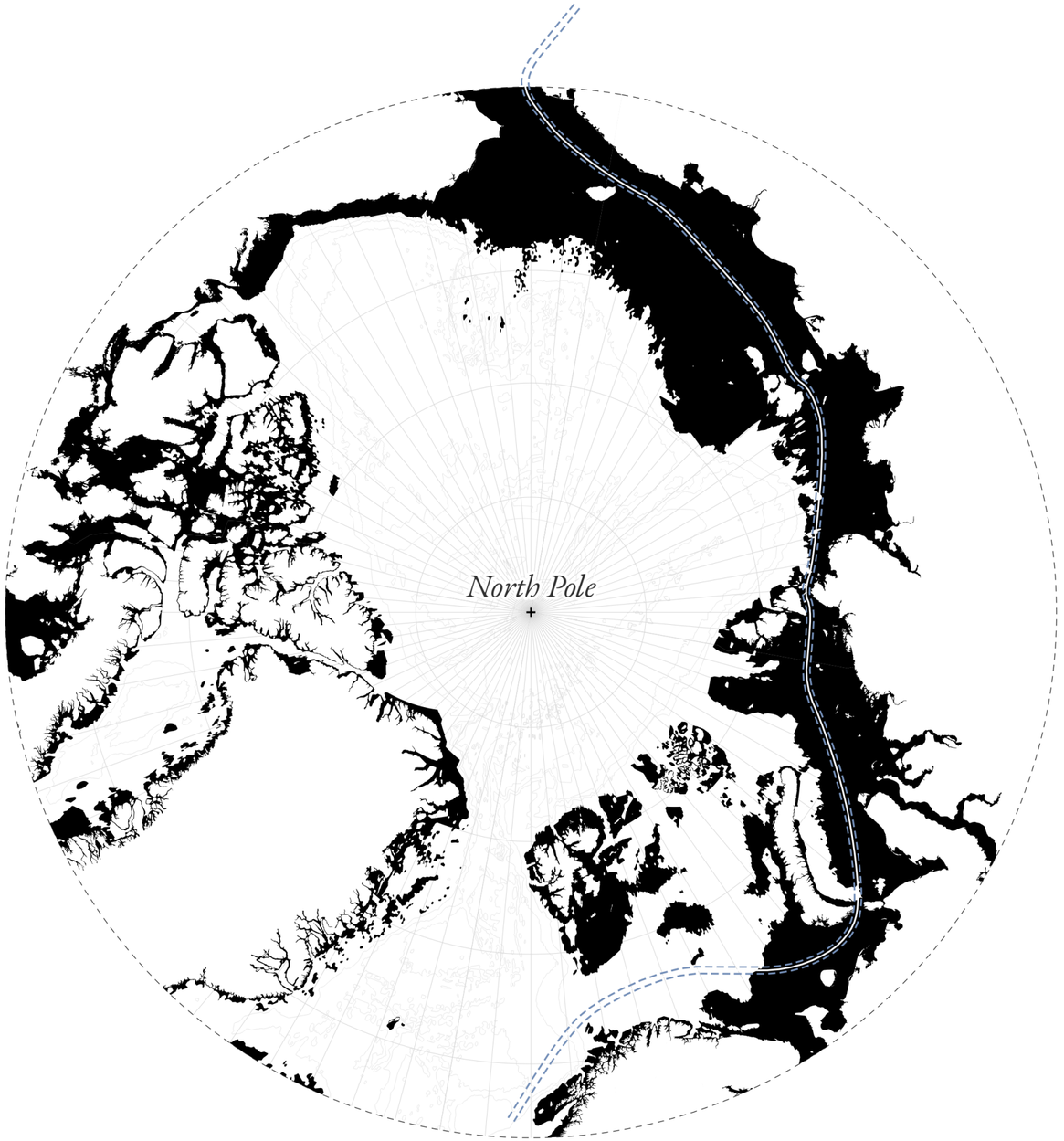
DIEL VERTICAL MIGRATION



SEA BED <200M

OVERLAPPING WITH

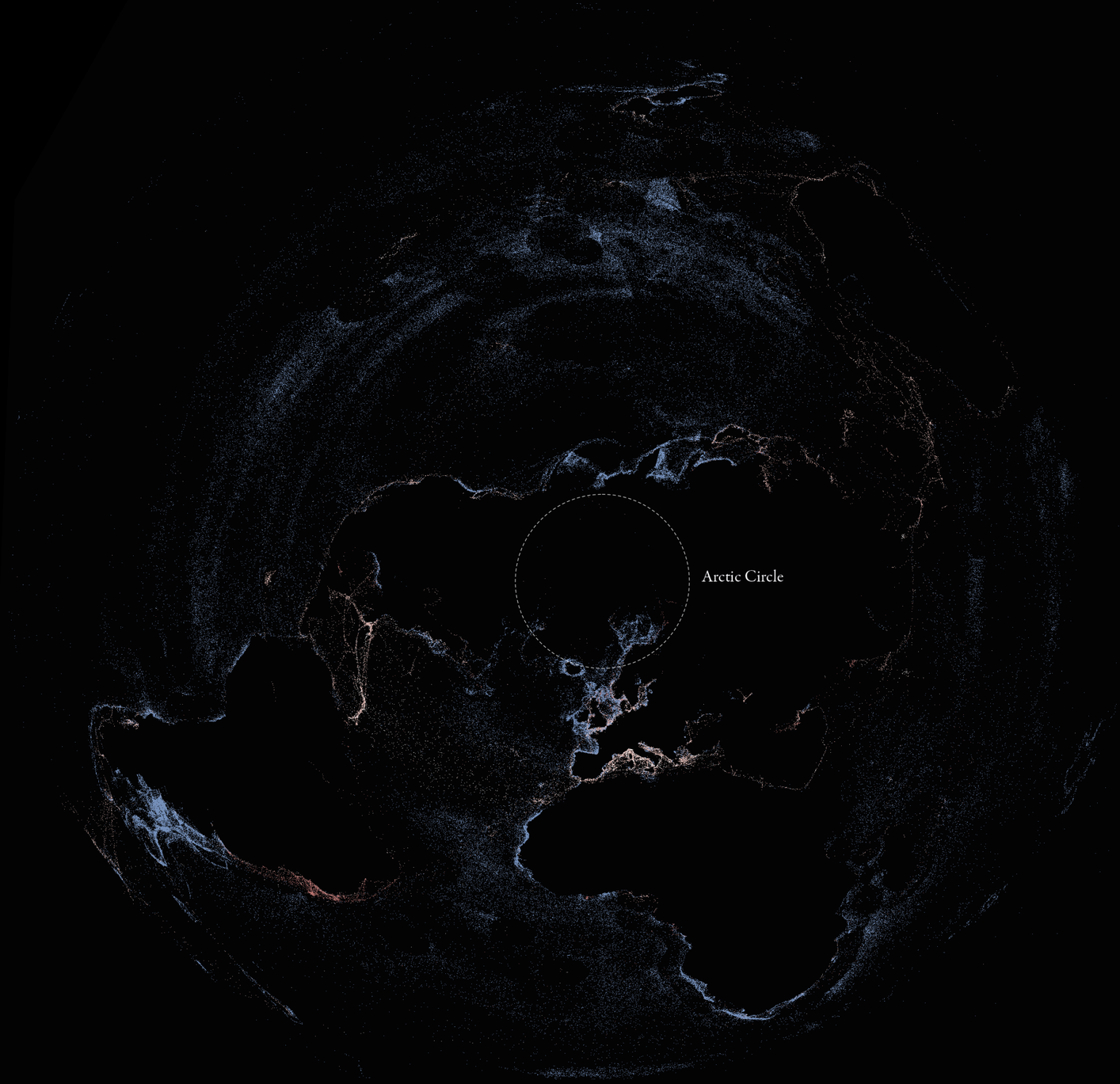
NORTH EAST PASSAGE



ACT I
• **ACT II**
ACT III
ACT IV
ACT V

GLOBAL SHIPPING

HUMAN ACTIVITY AT SEA

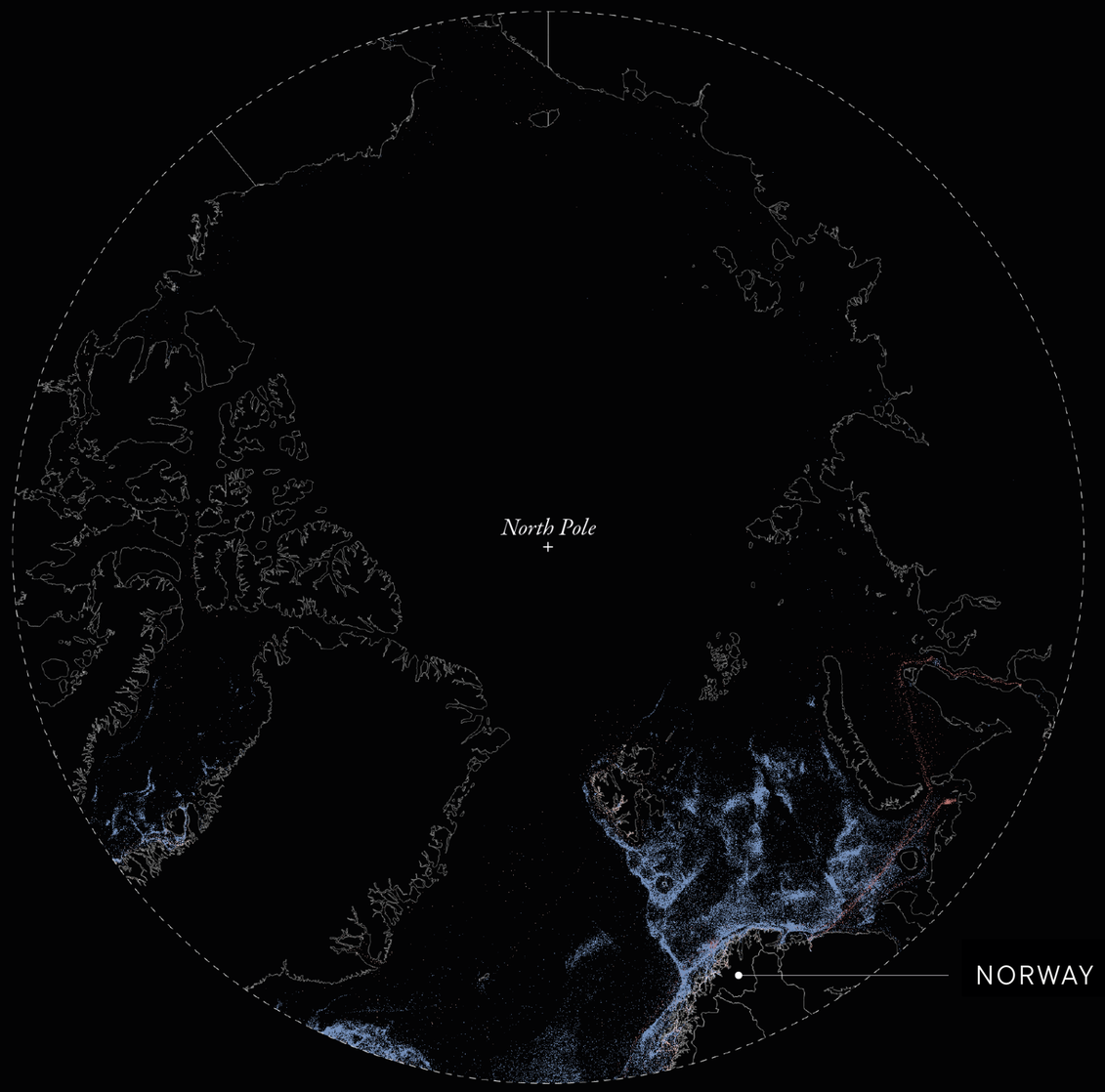


[A] LEISURE VESSELS
[B] PASSENGER VESSELS
[C] OIL & GAS VESSELS
[D] FISHING VESSELS

ACT I
• **ACT II**
ACT III
ACT IV
ACT V

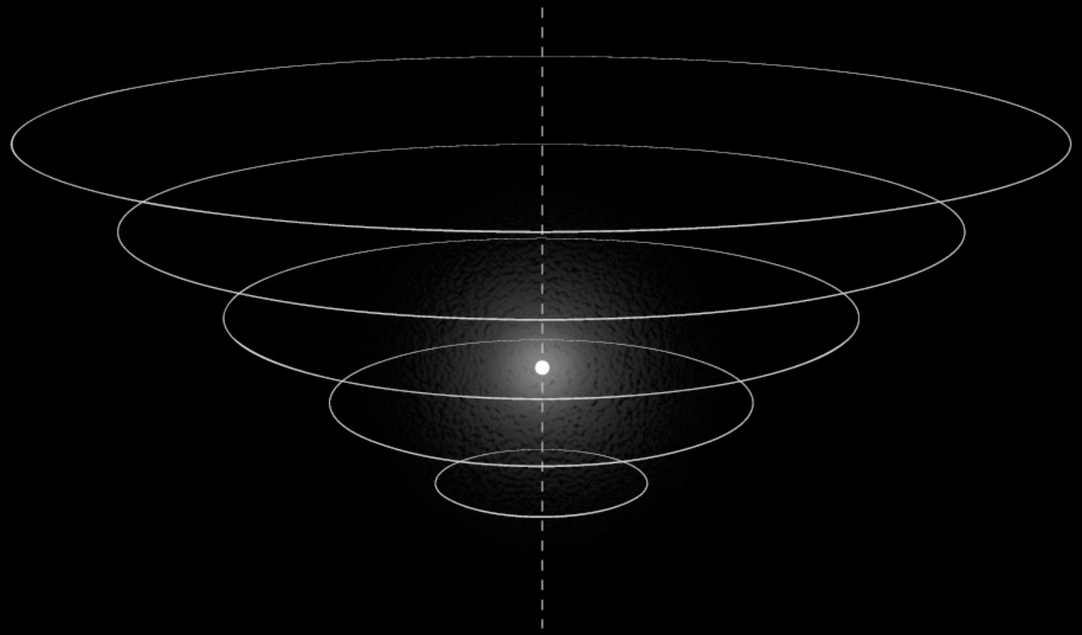
GLOBAL SHIPPING

HUMAN ACTIVITY AT SEA



[A] LEISURE VESSELS
[B] PASSENGER VESSELS
[C] OIL & GAS VESSELS
[D] FISHING VESSELS

ACT I
• **ACT II**
ACT III
ACT IV
ACT V



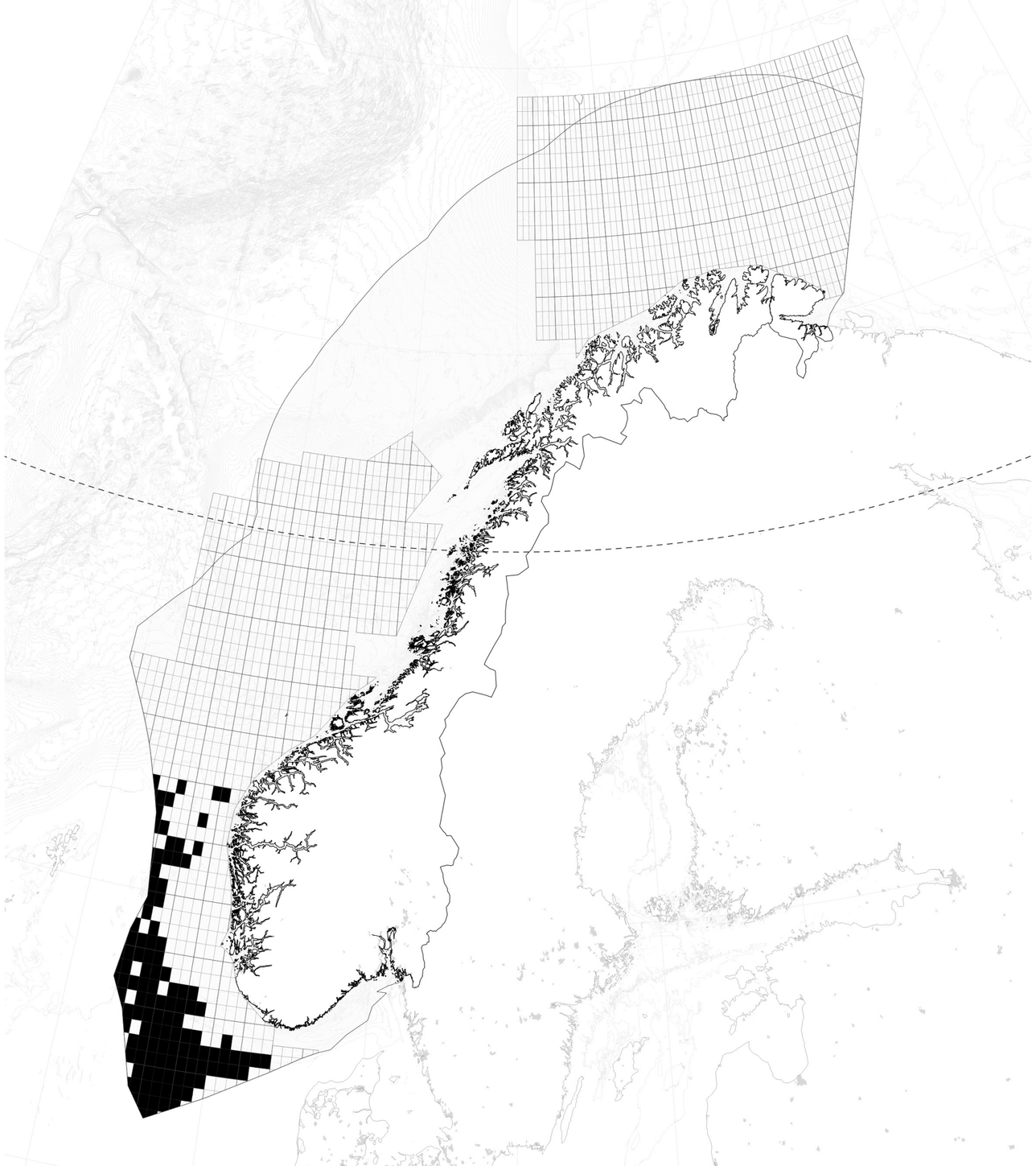
ACT III

THE NORWEGIAN PARADOX - REVISITED

NORWEGIAN OIL

LICENCED EXTRACTION AREAS

1969 - 1980



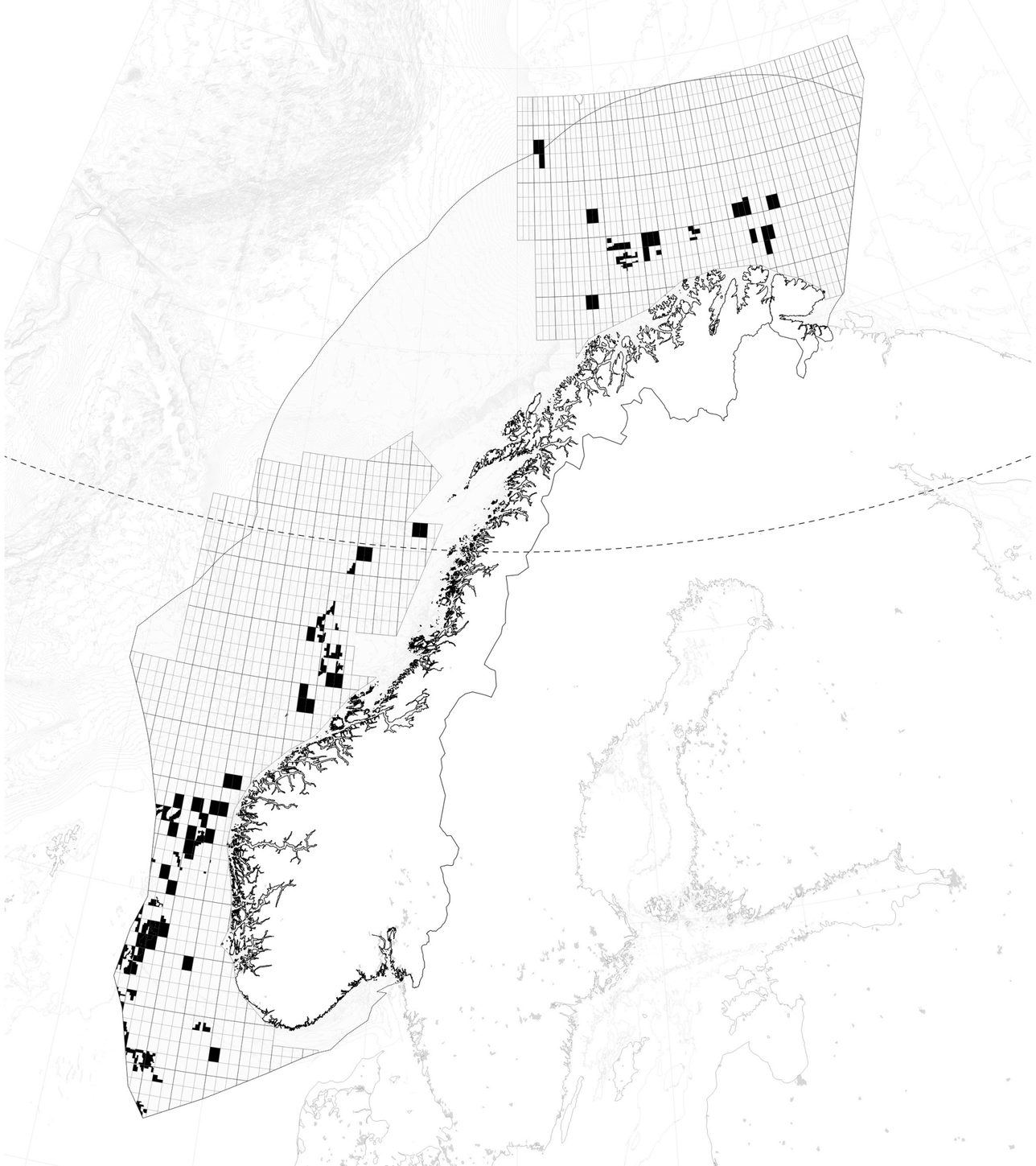
100 200 300 km

ACT I
ACT II
• **ACT III**
ACT IV
ACT V

NORWEGIAN OIL

LICENCED EXTRACTION AREAS

1980 - 1995



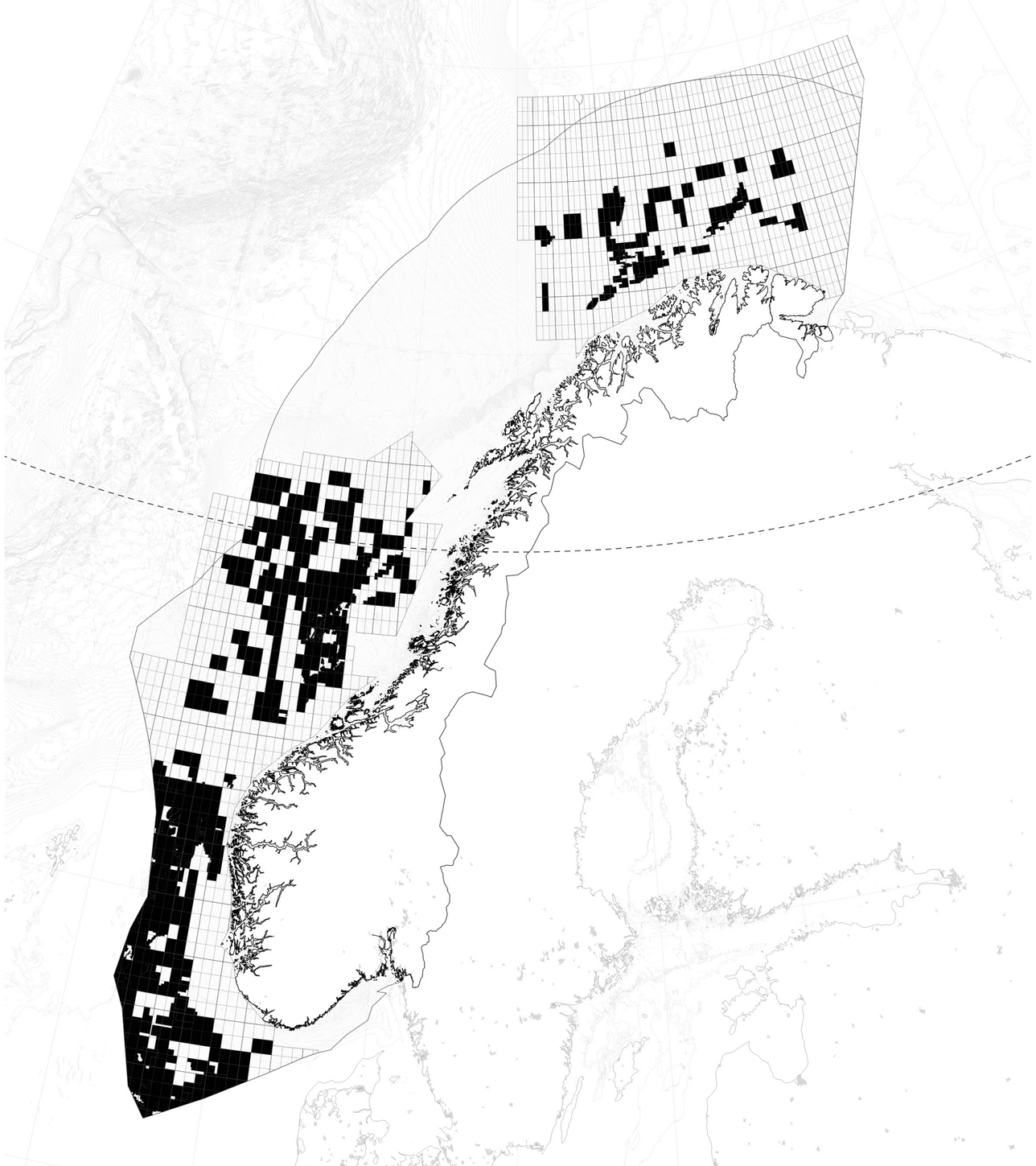
100 200 300 km

ACT I
ACT II
• **ACT III**
ACT IV
ACT V

NORWEGIAN OIL

LICENCED EXTRACTION AREAS

1995 - 2010



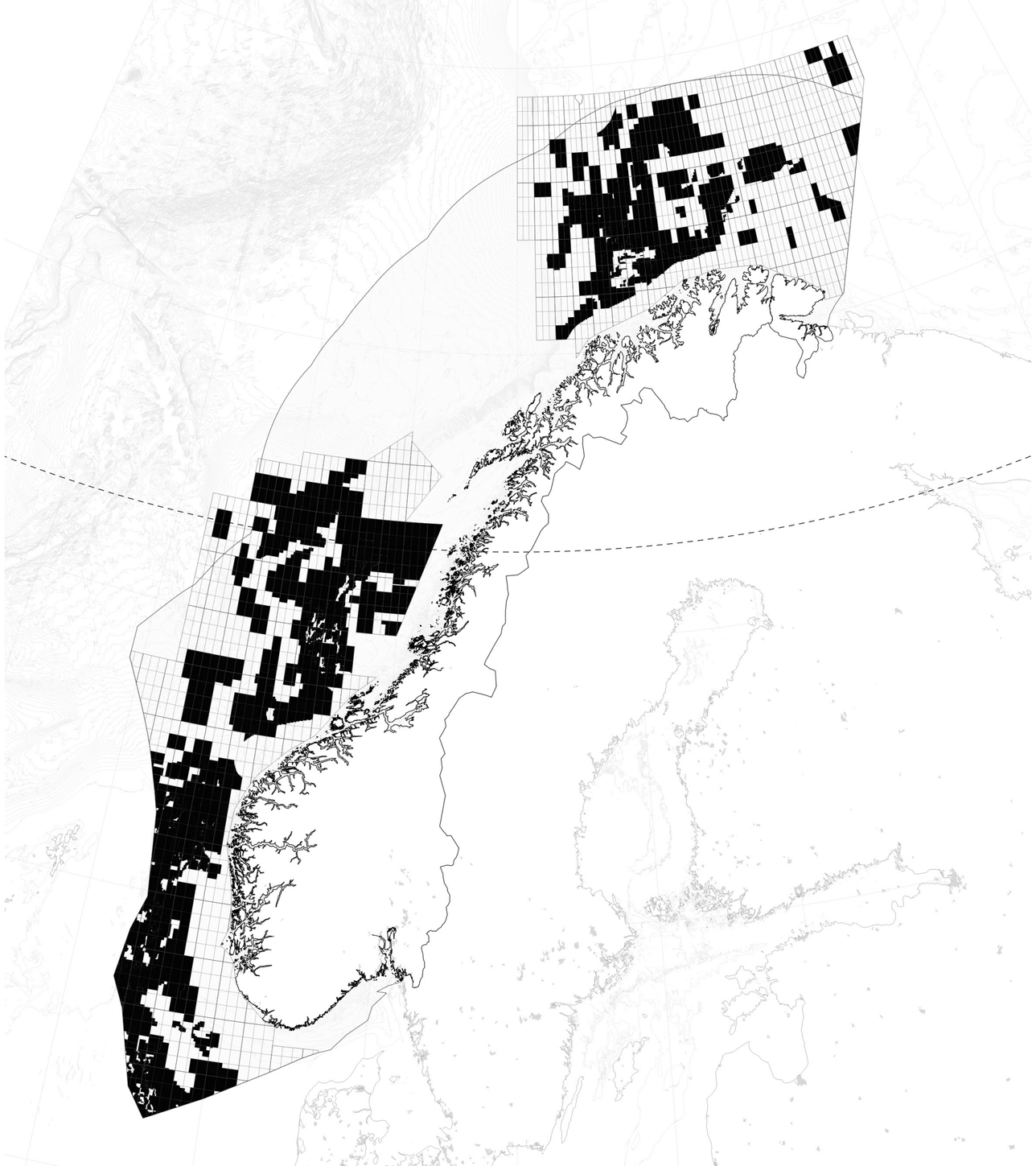
100 200 300 km

ACT I
ACT II
• **ACT III**
ACT IV
ACT V

NORWEGIAN OIL

LICENCED EXTRACTION AREAS

2010 - 2026



ACT I
ACT II
• **ACT III**
ACT IV
ACT V

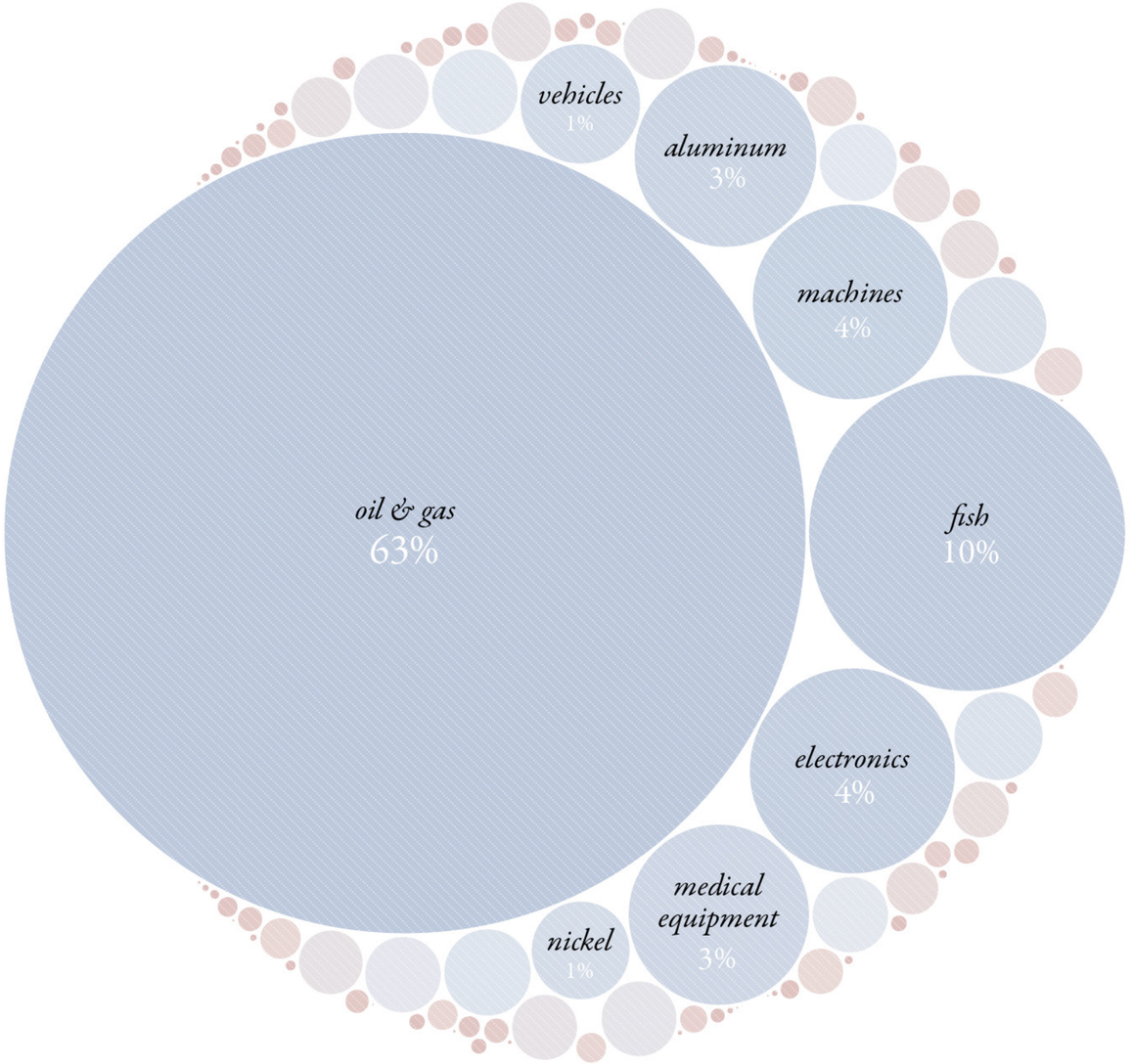
100 200 300 km



ACT I
ACT II
• **ACT III**
ACT IV
ACT V

NORWEGIAN EXPORT

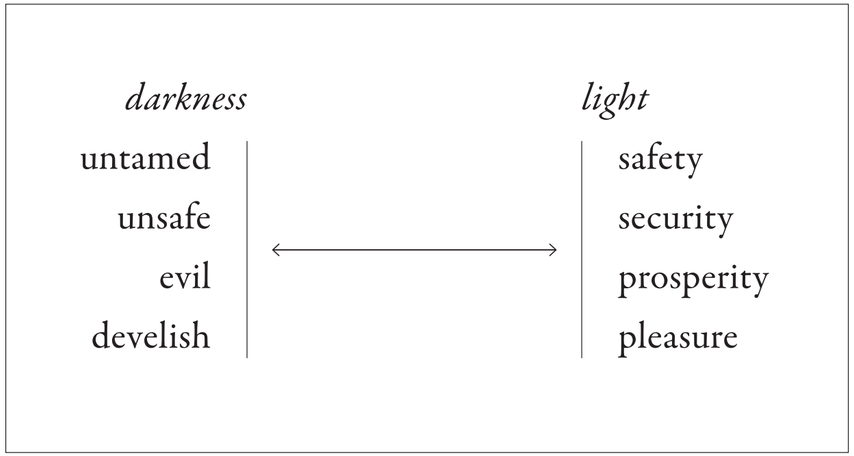
IN 2025



NORWEGIAN PARADOX

ACT I
ACT II
• **ACT III**
ACT IV
ACT V

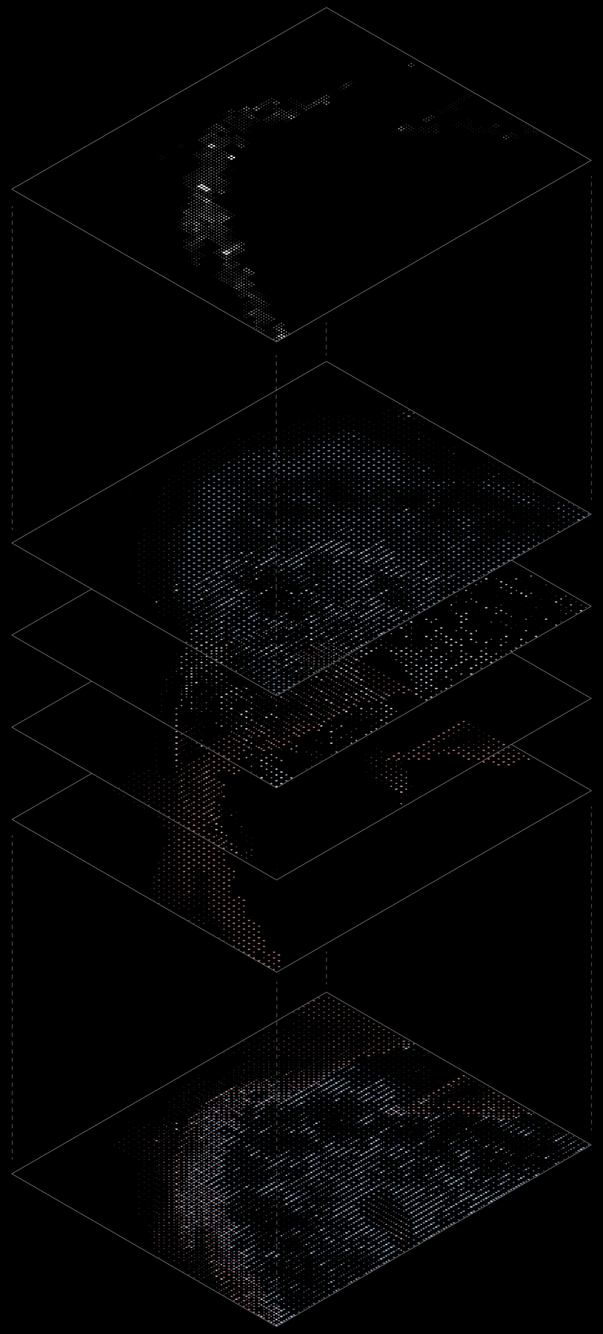
INTRODUCING THE LIGHT PARADOX



ACT I
ACT II
• **ACT III**
ACT IV
ACT V

HOTSPOT ANALYSIS

NORWEGIAN COASTAL ARCTIC



HOTSPOTS

ARTIFICIAL SKY BRIGHTNESS

NIGHT TIME LIGHT RADIANCE

SHIPPING DENSITY

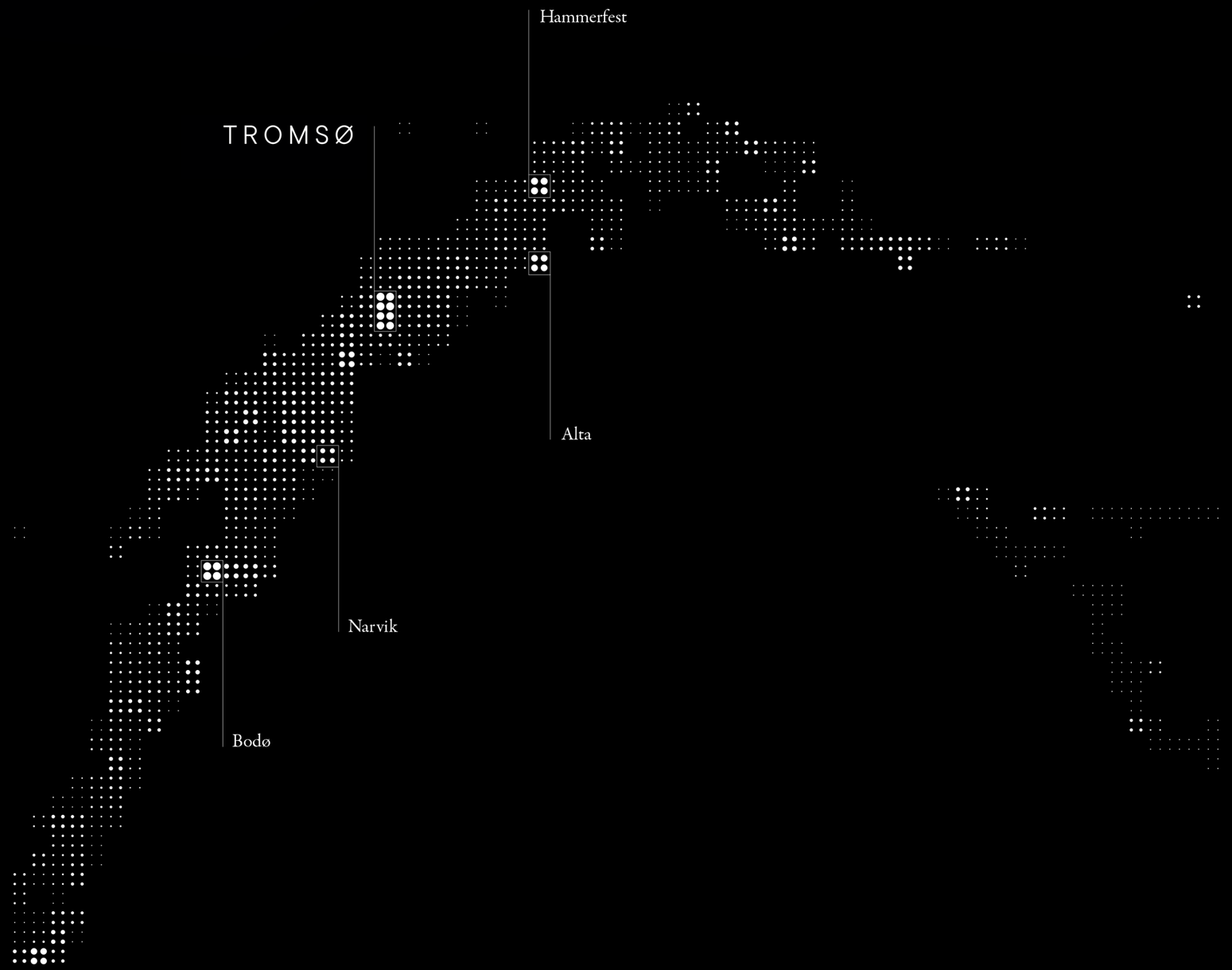
LIGHT FRACTION REACHING SEA BED

ZONAL STATISTICS

ACT I
ACT II
• **ACT III**
ACT IV
ACT V

HOTSPOT ANALYSIS

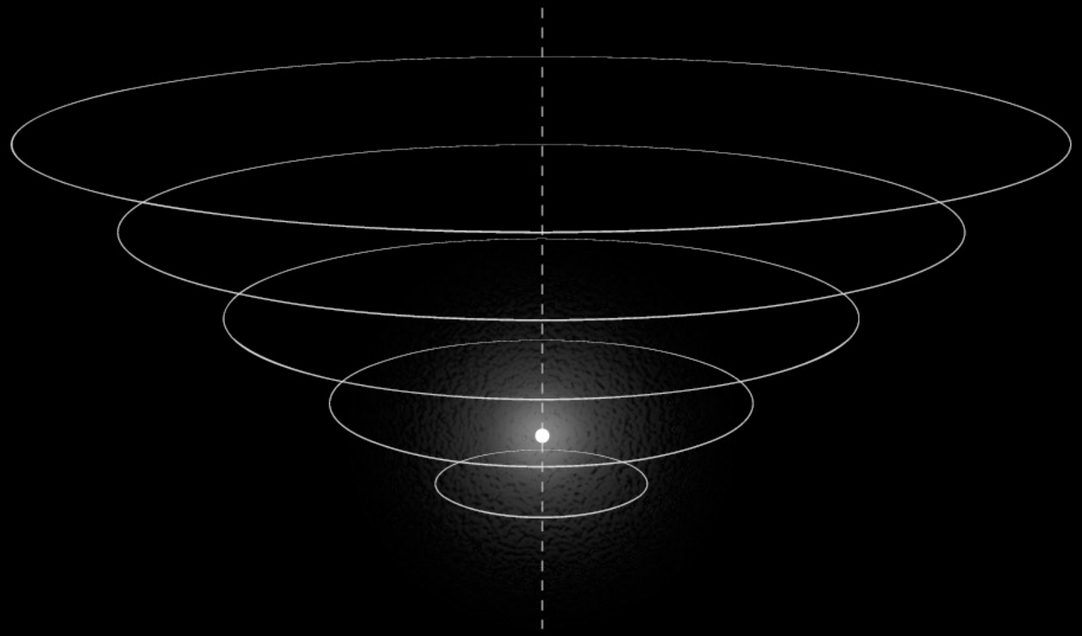
NORWEGIAN COASTAL ARCTIC



ACT I
ACT II
• **ACT III**
ACT IV
ACT V

hotspot concentration

low · • • • • high

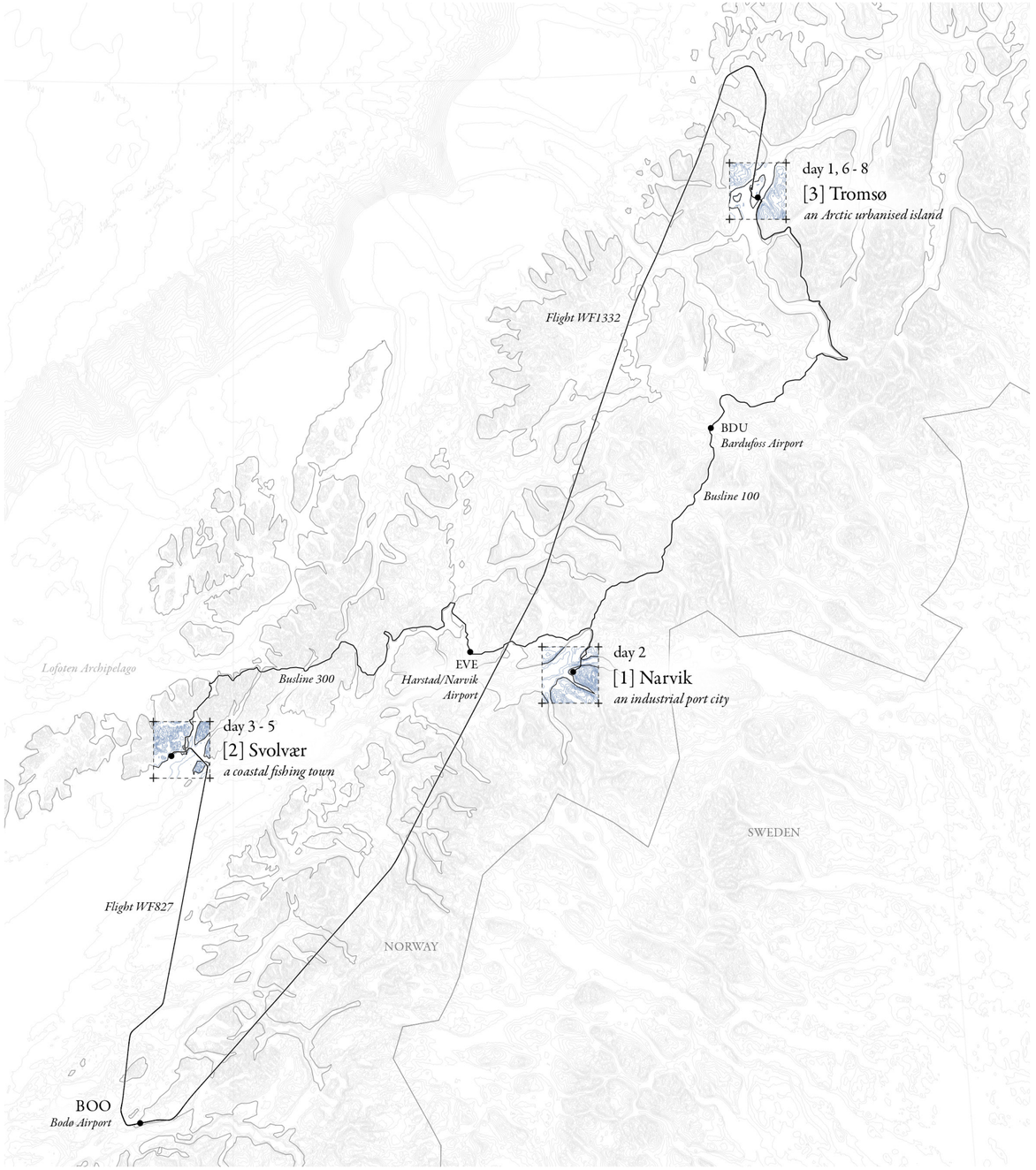


ACT IV

THE FIELD CONDITION

FIELDTRIP

TROMSØ, NARVIK, SVOLVÆR



ACT I
ACT II
ACT III
• **ACT IV**
ACT V


Lofoten
Sveiseindustri


HILLERSØY
FLORØ


HURTIGRUTEN
NORDLYS






N-55
SAGA 5
DO NOT TOUCH

MAIN CONCLUSION

FROM FIELDTRIP

ARTIFICIAL LIGHT ≠ LIGHT POLLUTION

HUMAN ARE PART OF ARCTIC ECOSYSTEM

MAIN CONCLUSION

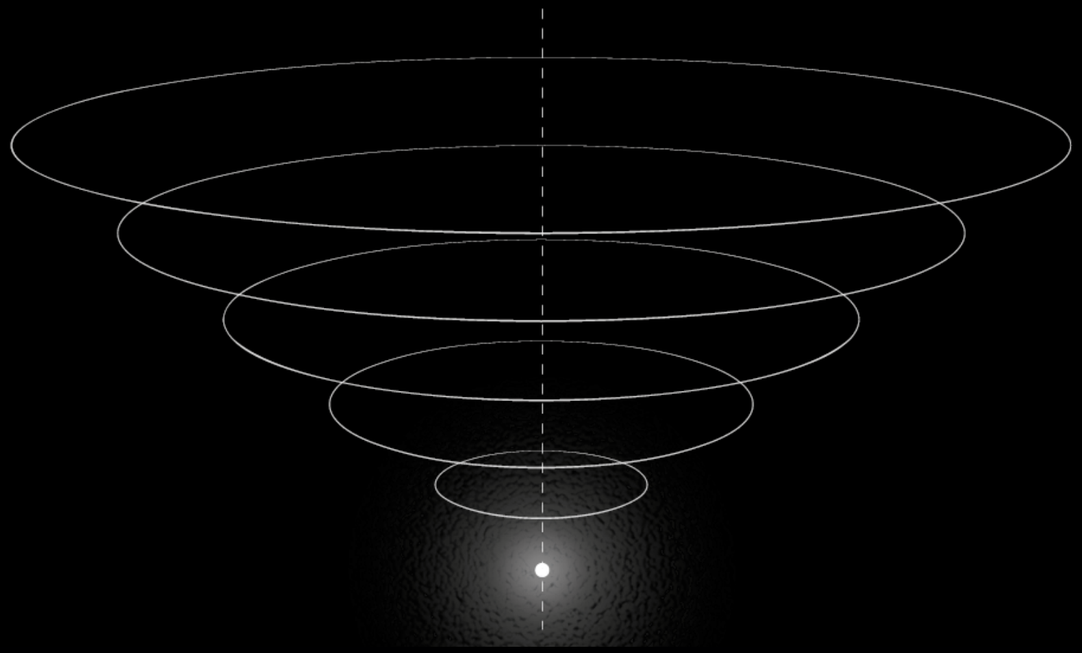
FROM FIELDTRIP

ARTIFICIAL LIGHT PER SECTOR

85% INDUSTRIES

15% HUMAN SETTLEMENTS

ACT I
ACT II
ACT III
• **ACT IV**
ACT V



ACT V

REPRESENTING THE UNSEEN

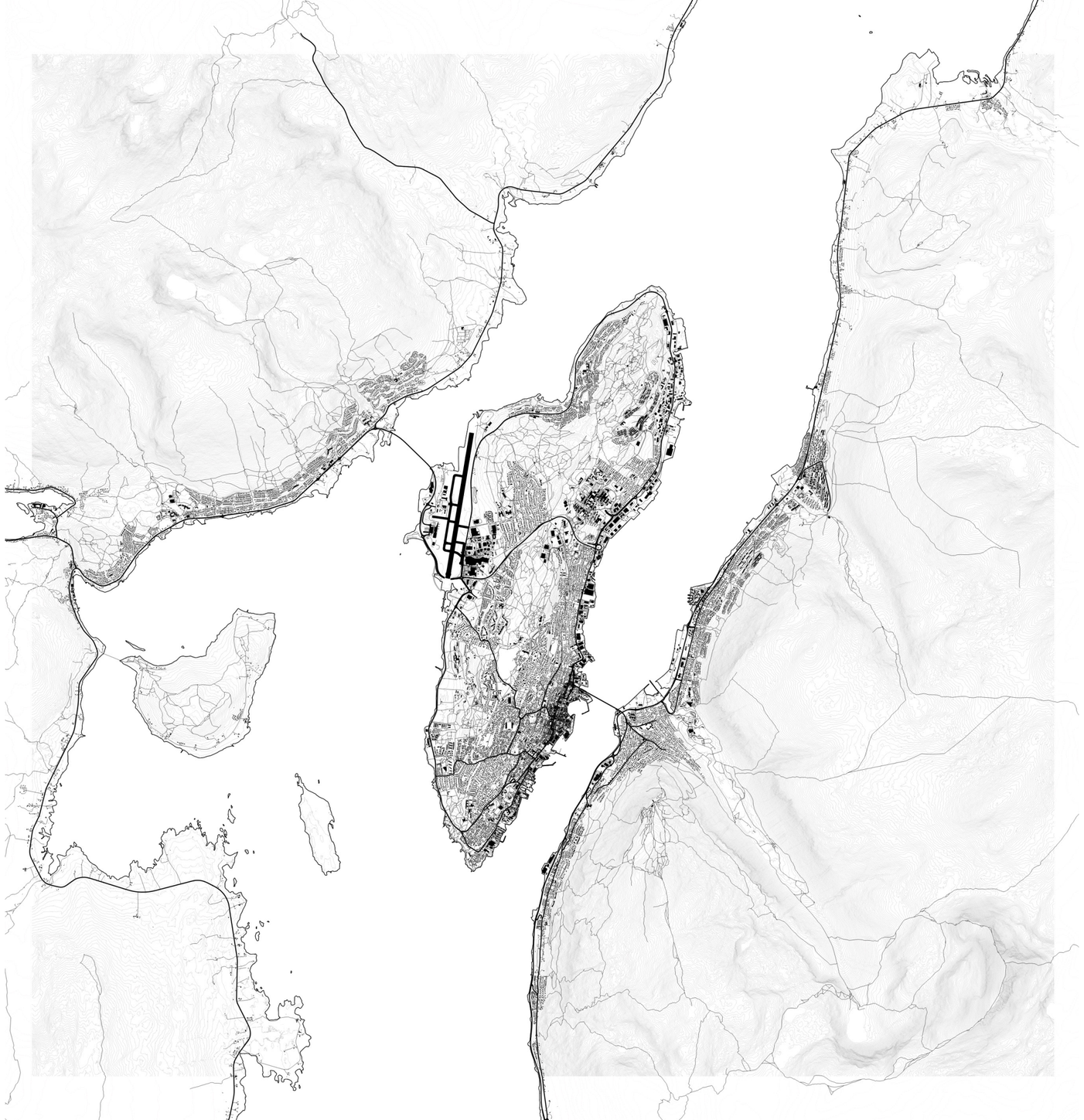
TROMSØ



ACT I
ACT II
ACT III
ACT IV
• **ACT V**

TROMSØ

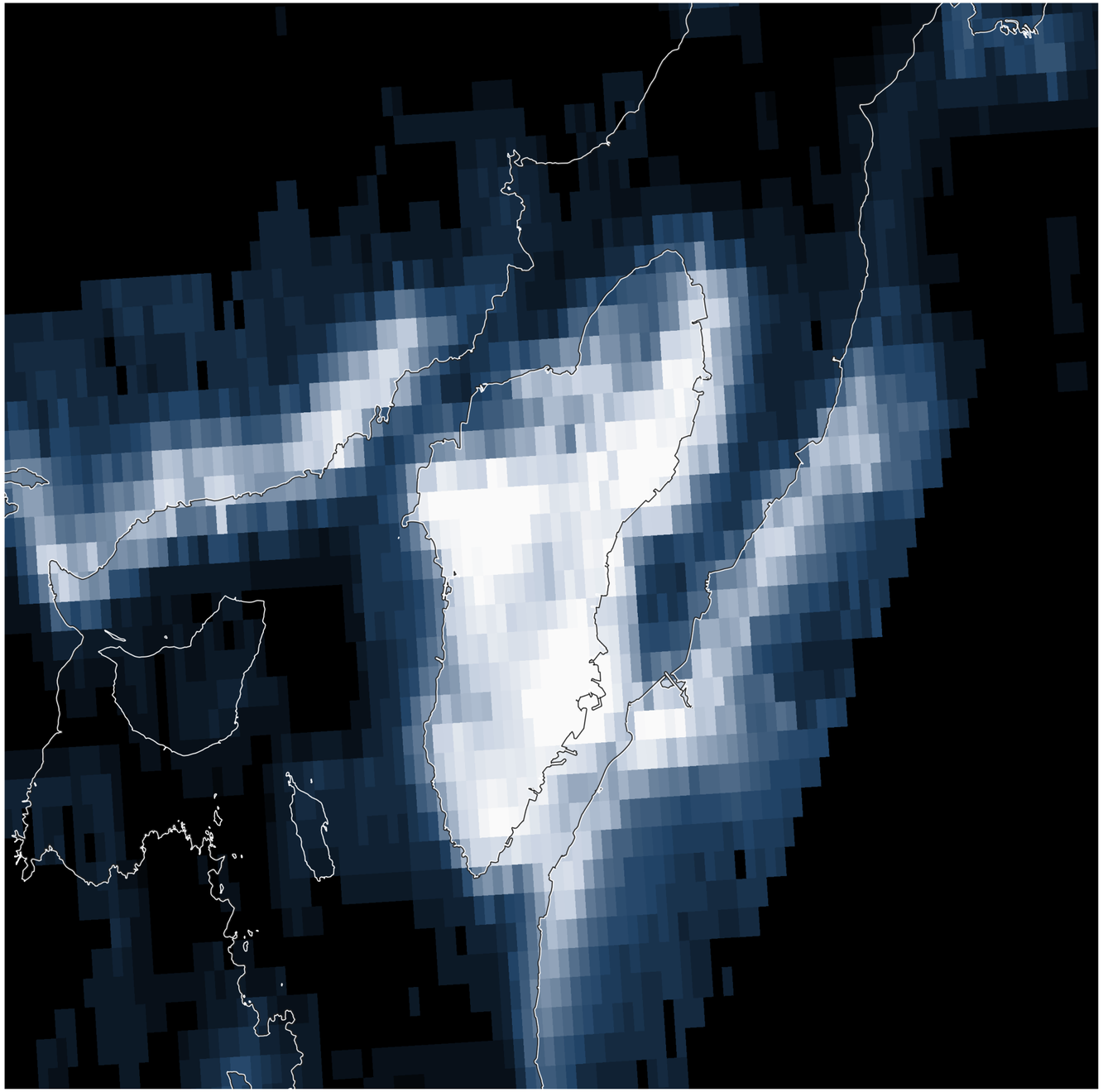
AS CASE STUDY



ACT I
ACT II
ACT III
ACT IV
• **ACT V**

1 2 km

NIGHT TIME LIGHTS



Night Time Light Radiance
(nW/cm²/sr)

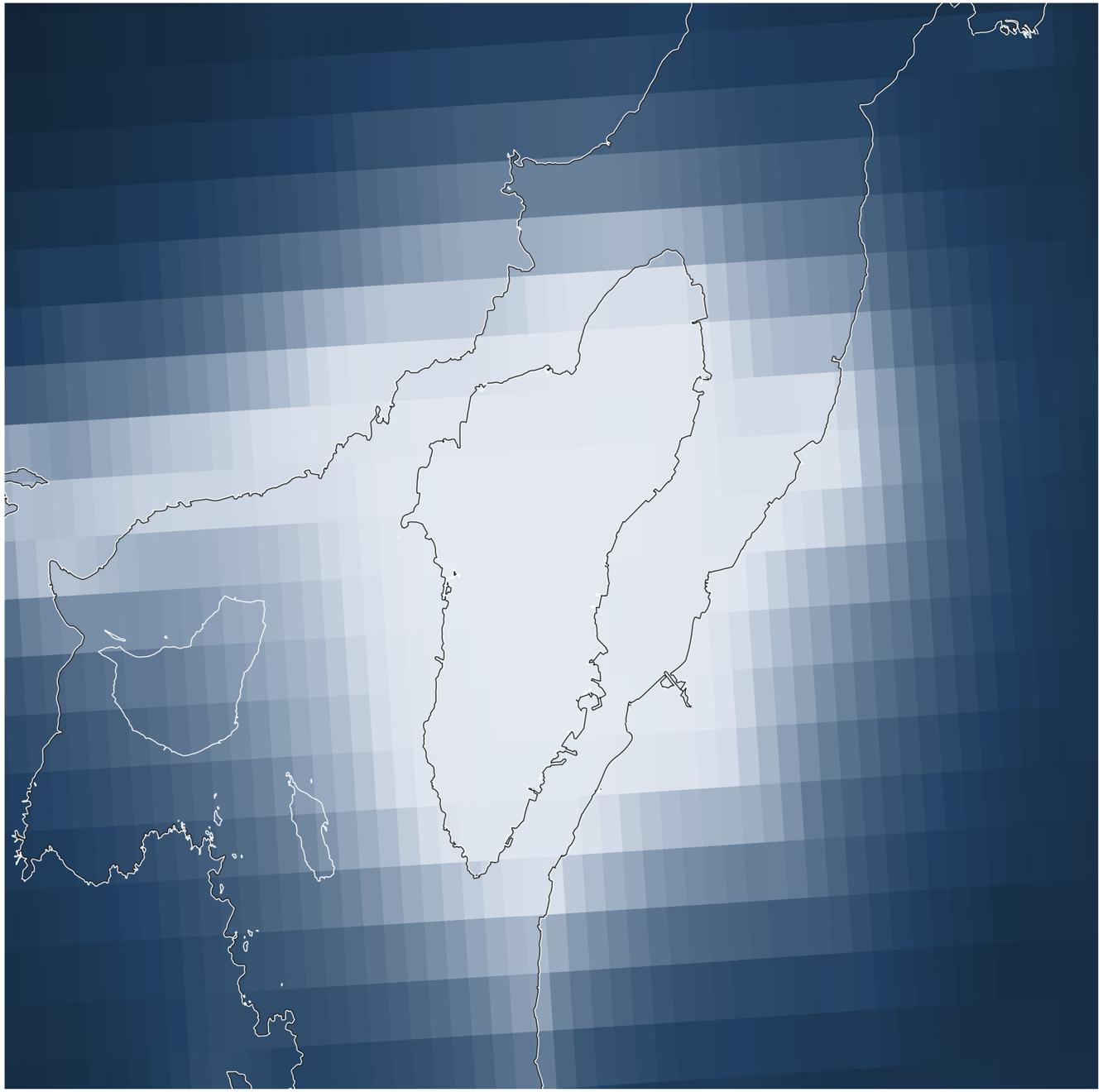
660

0

1 2 km

ACT I
ACT II
ACT III
ACT IV
• **ACT V**

SKY BRIGHTNESS



Sky Brightness
(ratio artificial/natural)

55

0

1 2 km

ACT I
ACT II
ACT III
ACT IV
• **ACT V**

REPRESENTING THE UNSEEN

IN THREE PARTS

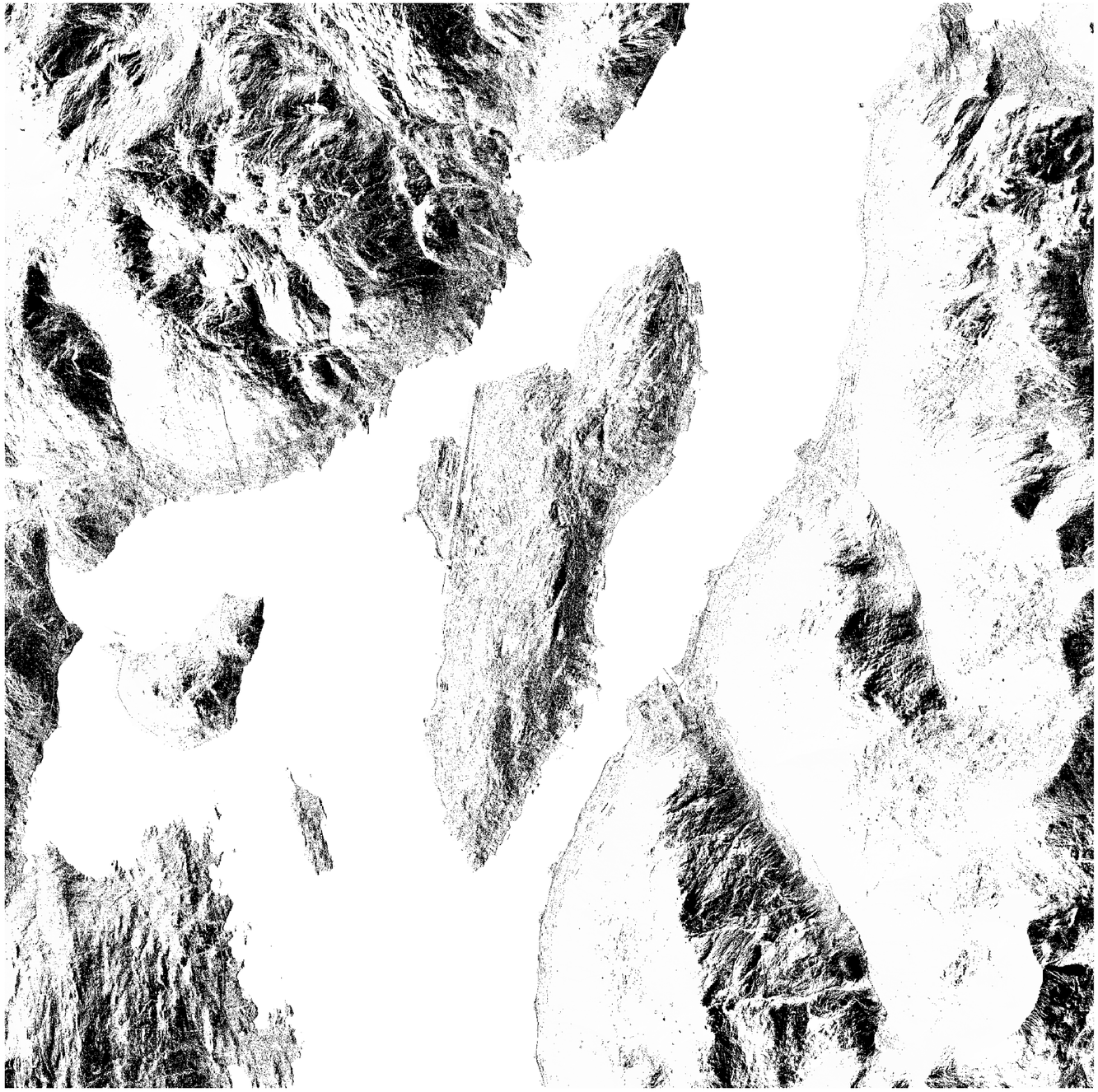
PART I - NATURAL LIGHT

PART II - ARTIFICIAL LIGHT

PART III - ATLAS: DARKNESS AS TERRITORY

TERRAIN

ASPECT MAPS



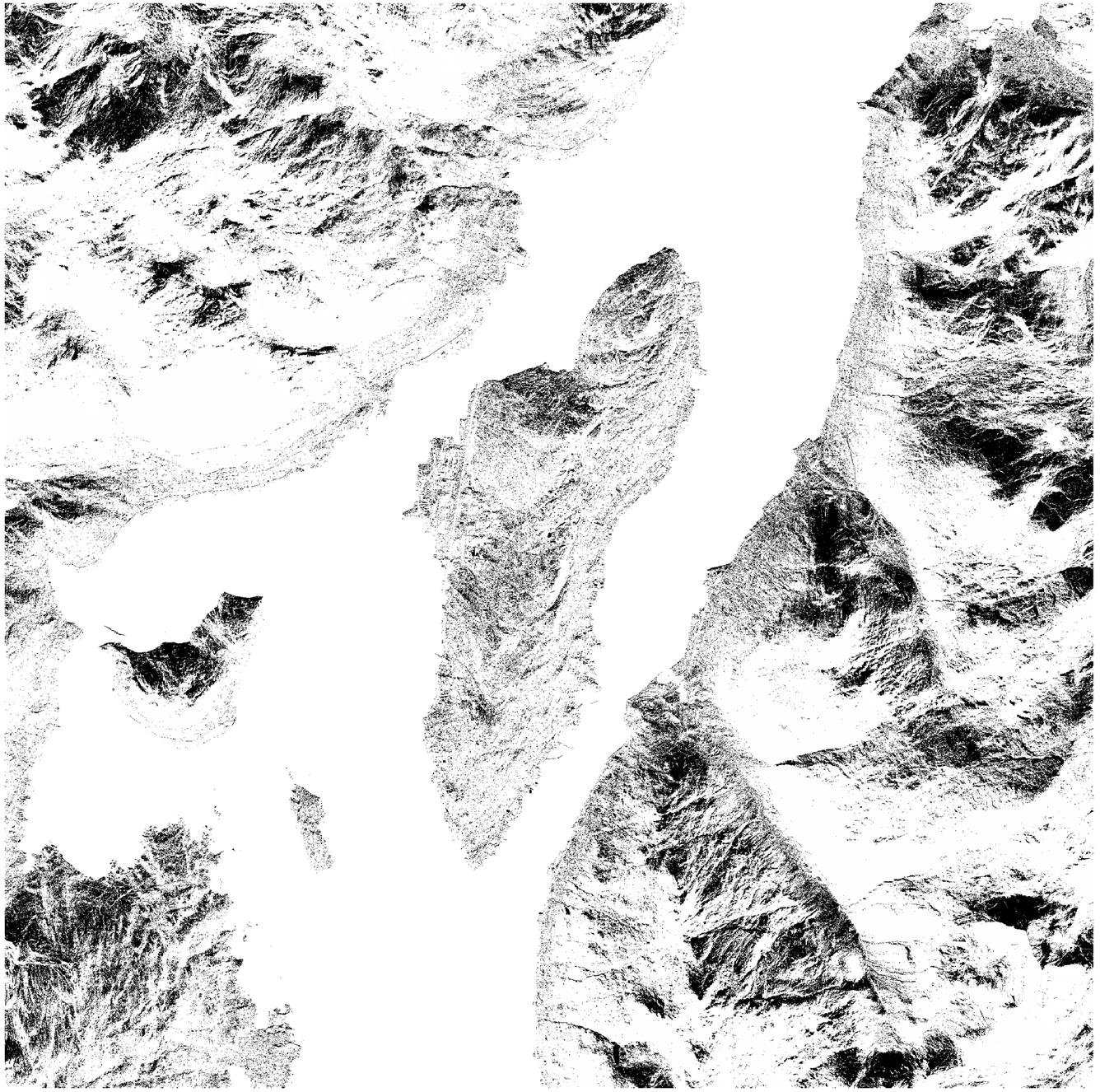
EAST

ACT I
ACT II
ACT III
ACT IV
• **ACT V**

1 2 km

TERRAIN

ASPECT MAPS



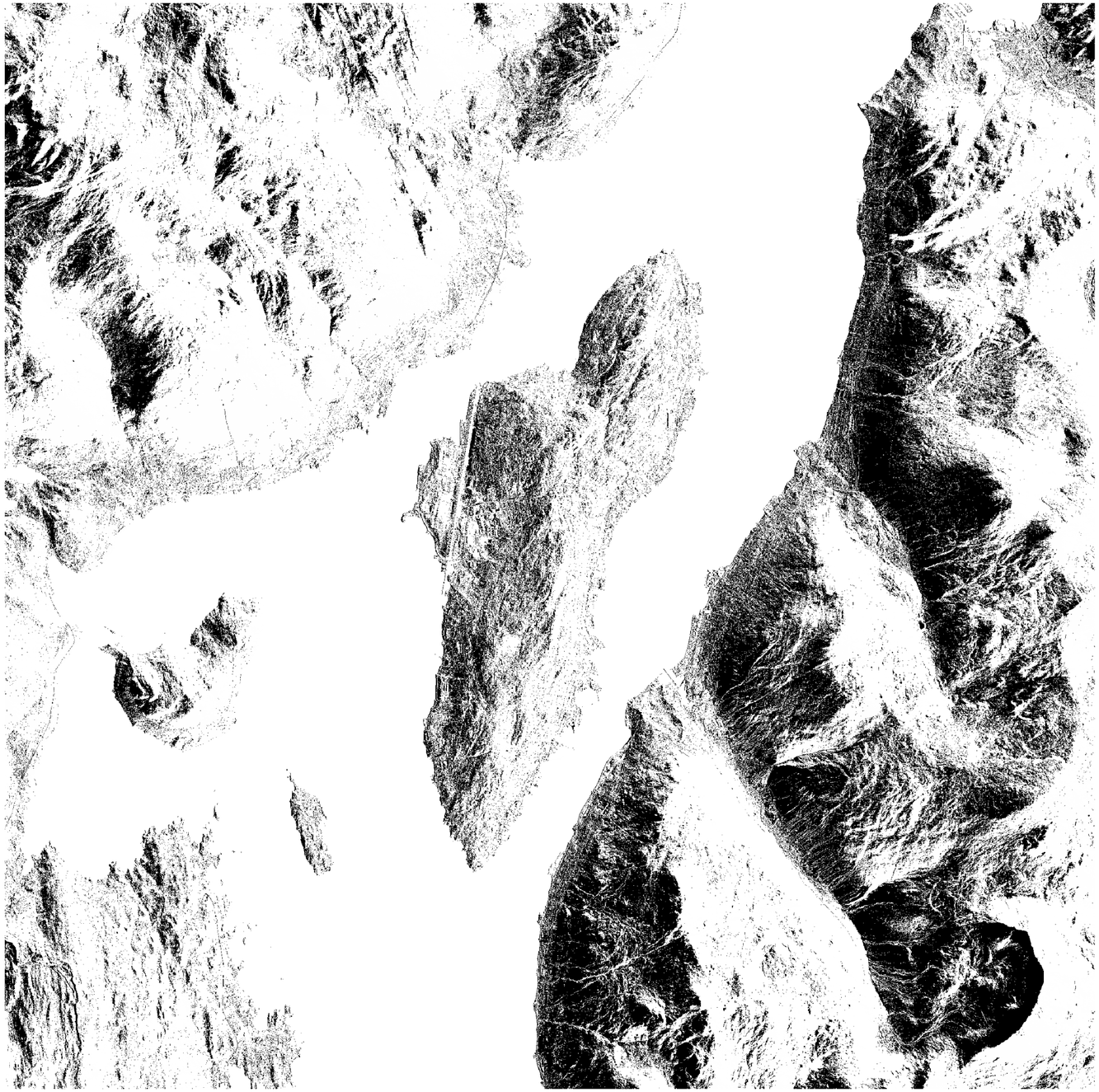
NORTH

1 2 km

ACT I
ACT II
ACT III
ACT IV
• **ACT V**

TERRAIN

ASPECT MAPS



WEST

ACT I
ACT II
ACT III
ACT IV
• **ACT V**

1 2 km

TERRAIN

ASPECT MAPS



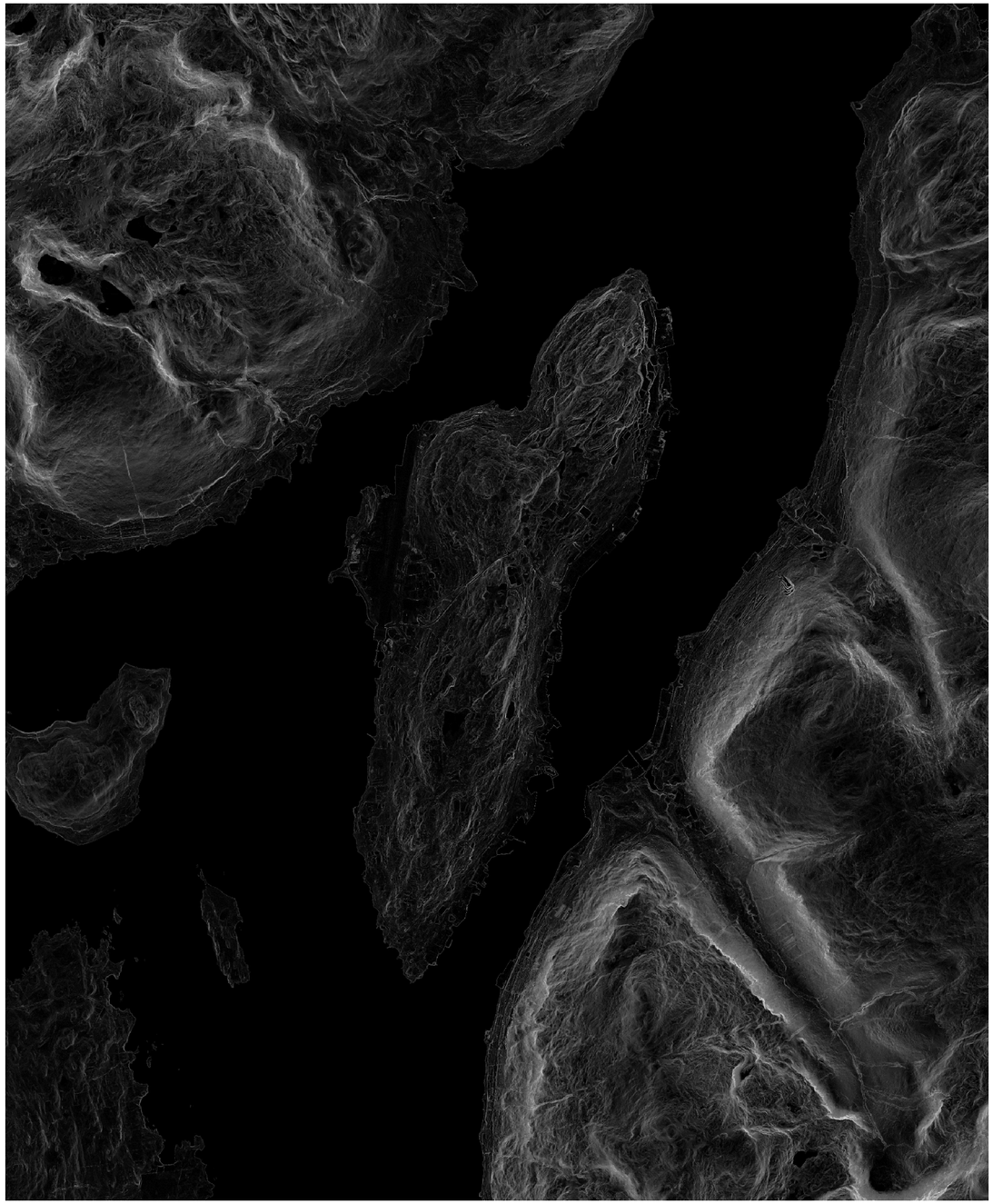
SOUTH

ACT I
ACT II
ACT III
ACT IV
• **ACT V**

1 2 km

TERRAIN

TERRAIN SLOPE



Terrain Slope (degrees)

85

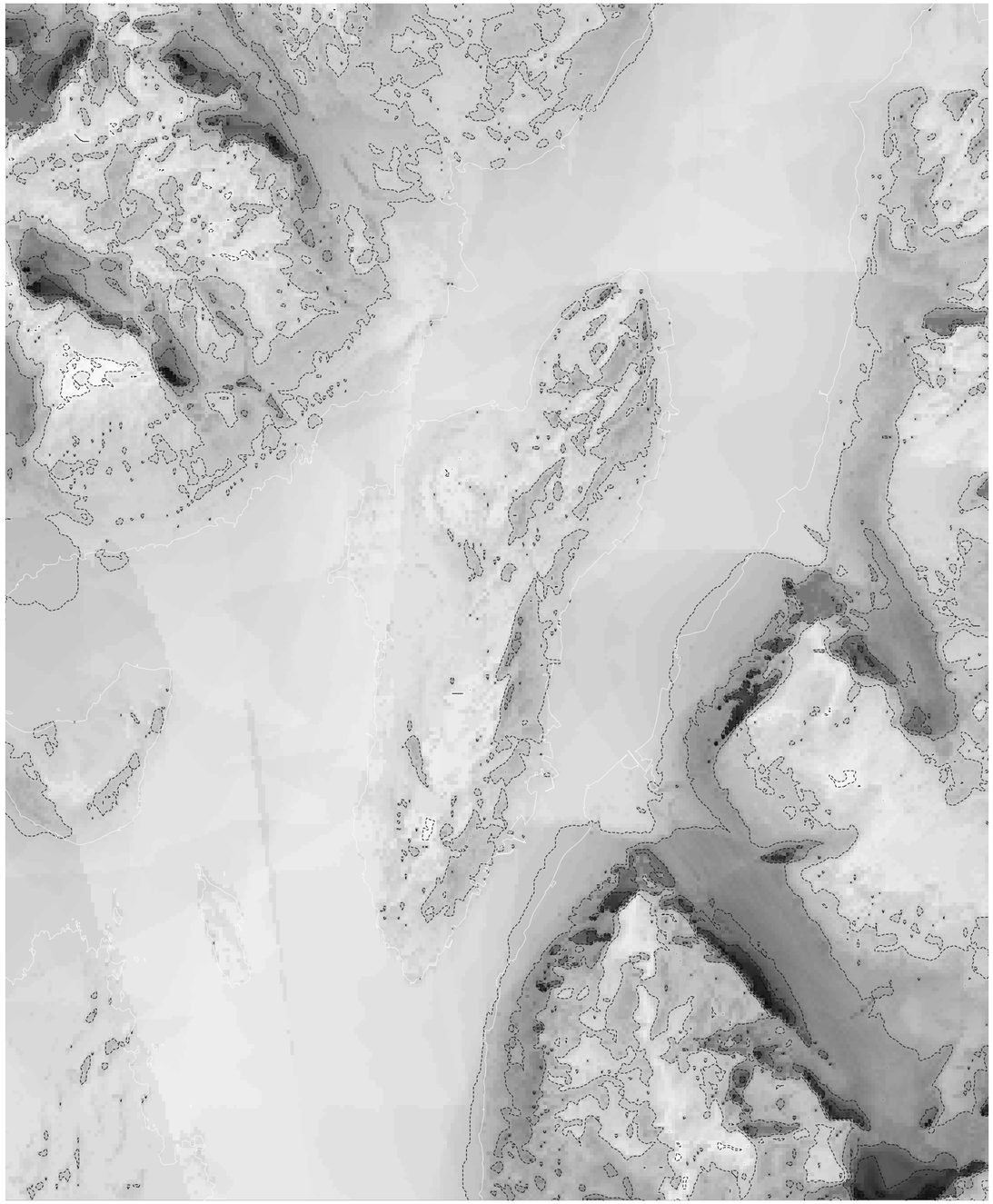
0

1 2 km

ACT I
ACT II
ACT III
ACT IV
• **ACT V**

NATURAL DARKNESS

AVERAGE HOURS OF SUNLIGHT PER DAY



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

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

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

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

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

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

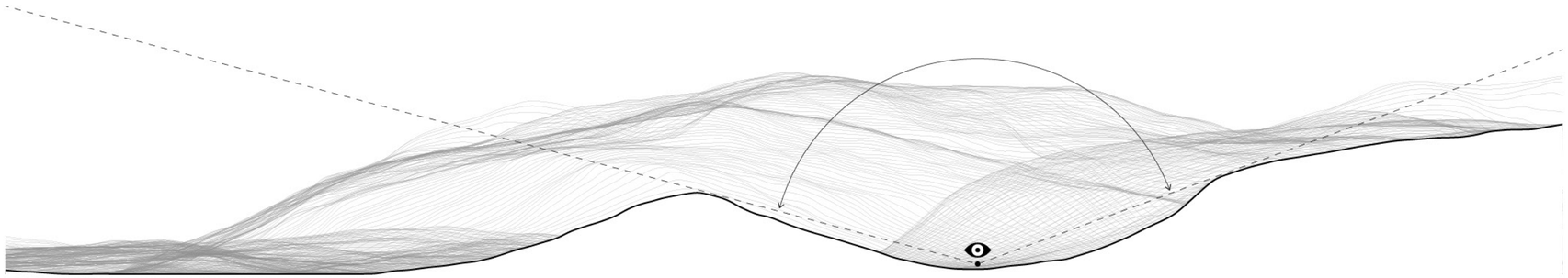
Yearly average of direct sunlight
hours per day (24h)

12

0

1 2 km

ACT I
ACT II
ACT III
ACT IV
• **ACT V**



[A]

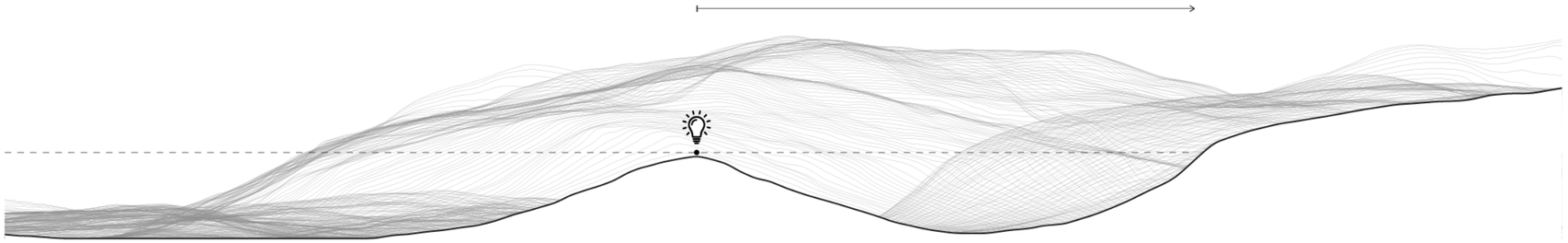
NATURAL DARKNESS

THROUGH OTHER CONDITIONS

SKY VIEW FACTOR



ACT I
ACT II
ACT III
ACT IV
• **ACT V**

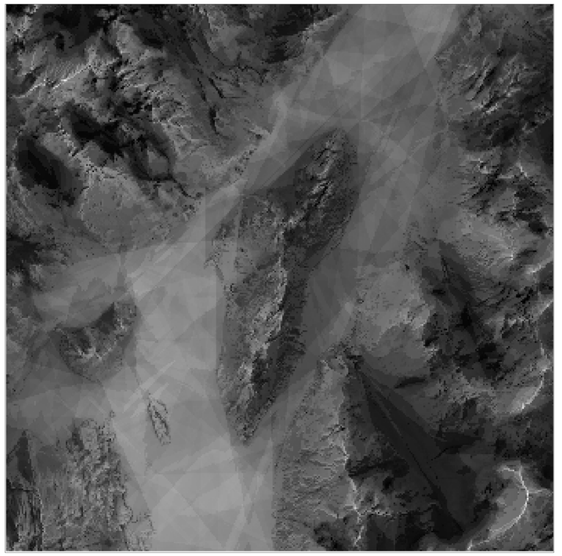


[B]

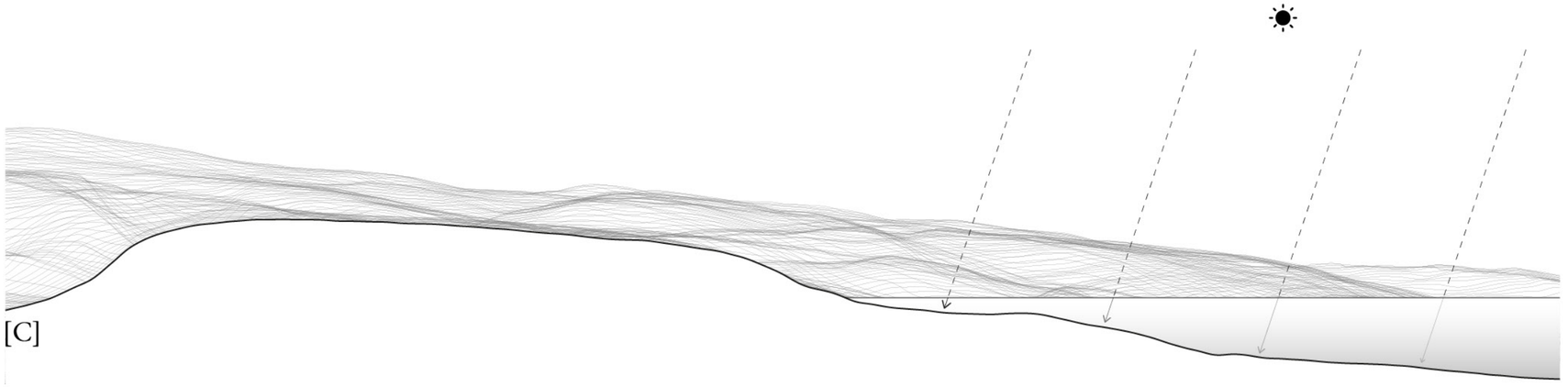
NATURAL DARKNESS

THROUGH OTHER CONDITIONS

HORIZONTAL LIGHT TRAVEL DISTANCE



ACT I
ACT II
ACT III
ACT IV
• **ACT V**

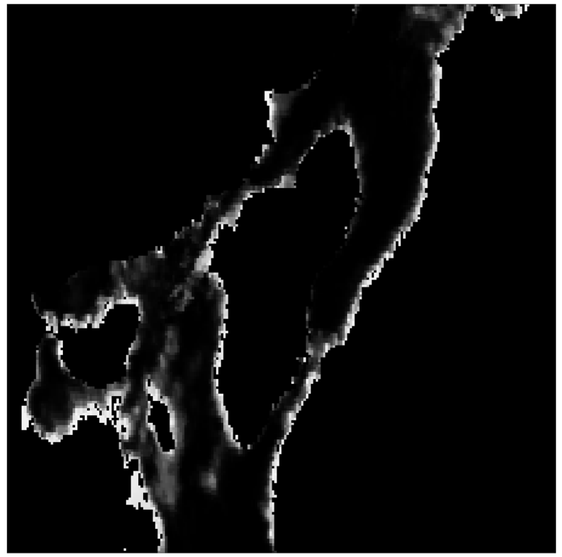


[C]

NATURAL DARKNESS

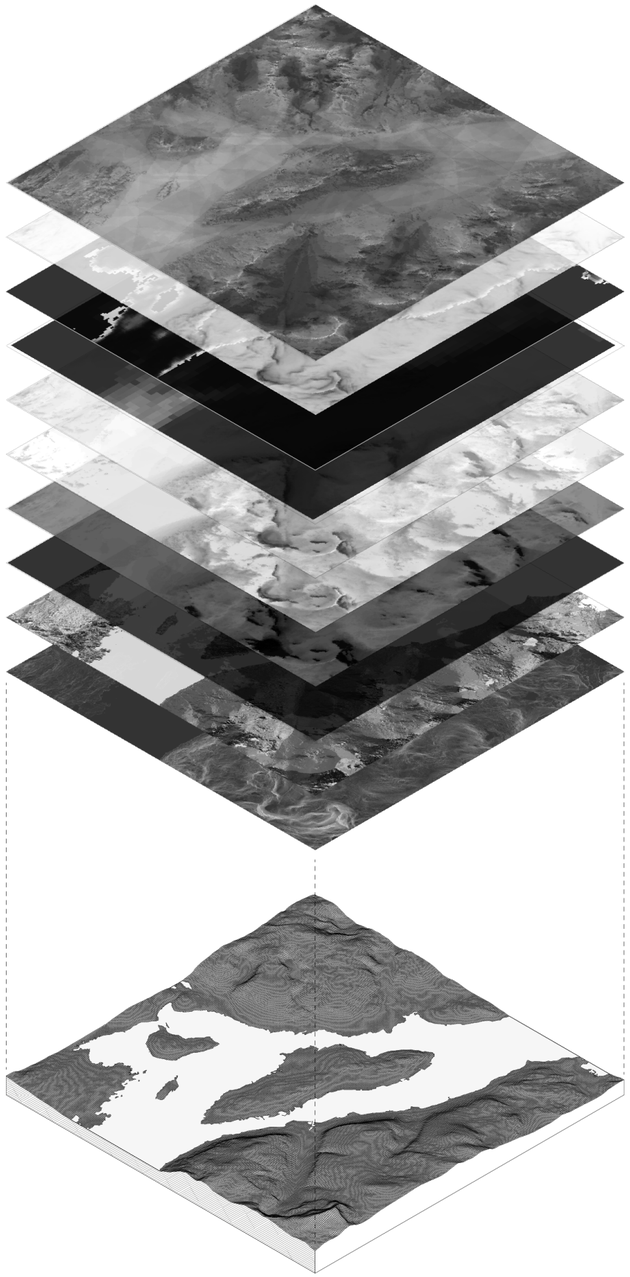
THROUGH OTHER CONDITIONS

LIGHT FRACTION REACHING SEABED



ACT I
ACT II
ACT III
ACT IV
• **ACT V**

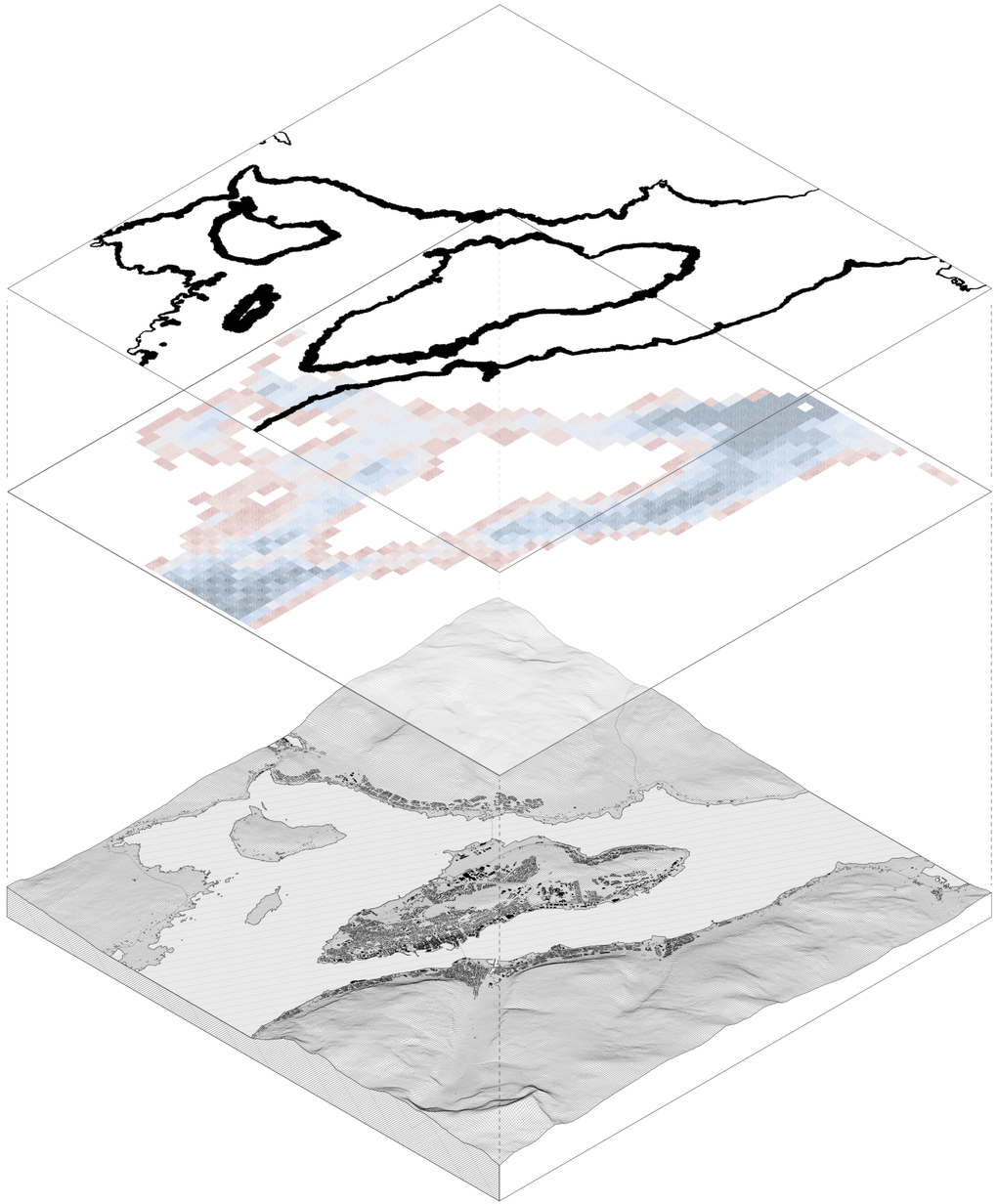
COMBINING NATURAL DARKNESS



ACT I
ACT II
ACT III
ACT IV
• **ACT V**

SENSITIVITY TO ALAN

OF WATER SURROUNDING TROMSØ



Coastal ALAN Sensitivity

low

high

low

high

ACT I
ACT II
ACT III
ACT IV
• **ACT V**

PART II: ARTIFICIAL PERSPECTIVE

LIGHT SOURCES

ACT I
ACT II
ACT III
ACT IV
• **ACT V**

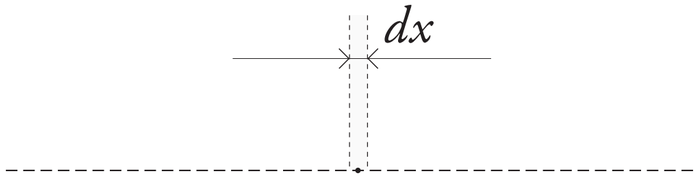
COASTAL LIGHT PRESSURE

DESIGNING A METHOD

ACT I
ACT II
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• **ACT V**

COASTAL LIGHT PRESSURE

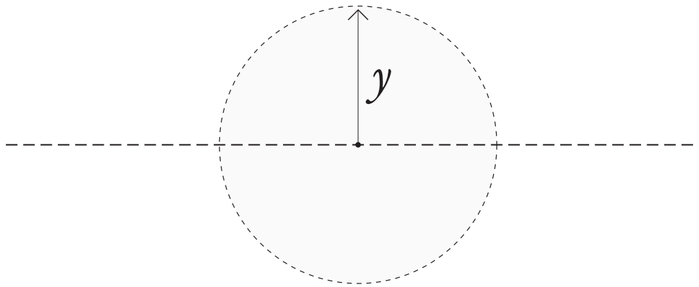
DESIGNING A METHOD



ACT I
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COASTAL LIGHT PRESSURE

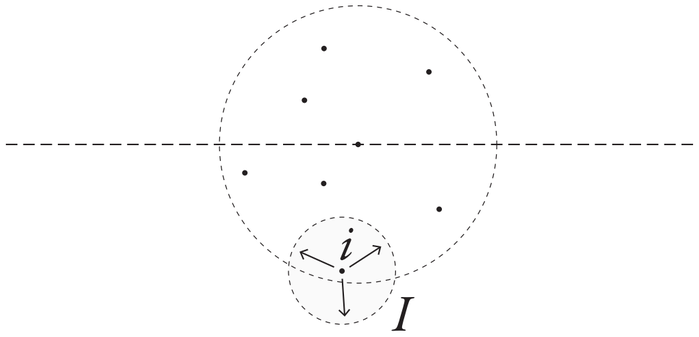
DESIGNING A METHOD



ACT I
ACT II
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• **ACT V**

COASTAL LIGHT PRESSURE

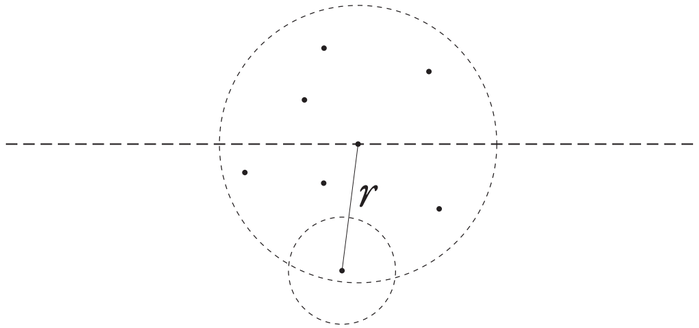
DESIGNING A METHOD



ACT I
ACT II
ACT III
ACT IV
• **ACT V**

COASTAL LIGHT PRESSURE

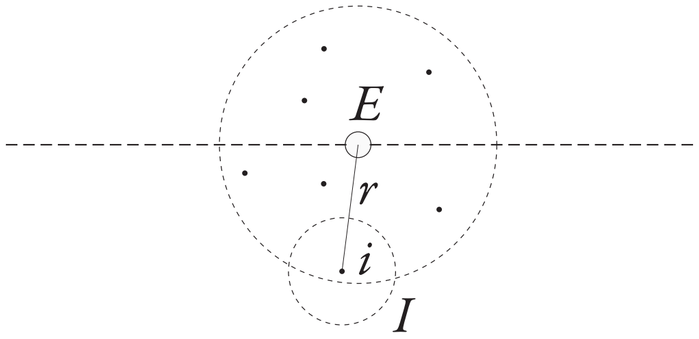
DESIGNING A METHOD



ACT I
ACT II
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• **ACT V**

COASTAL LIGHT PRESSURE

DESIGNING A METHOD

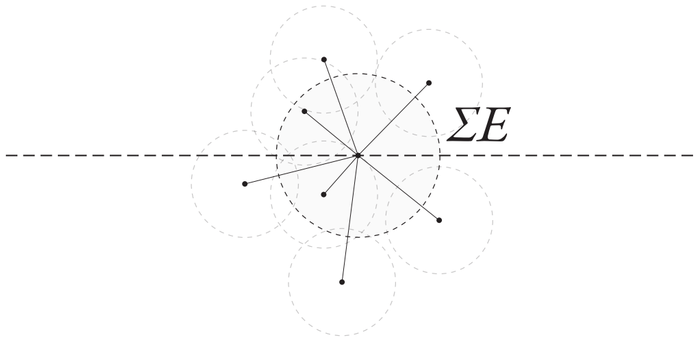


$$\mathrm{E_i(x)} = \frac{\mathrm{I_i}}{4\pi \mathrm{r_i(x)}^2}$$

ACT I
ACT II
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• **ACT V**

COASTAL LIGHT PRESSURE

DESIGNING A METHOD

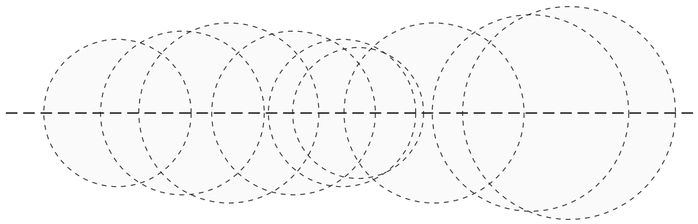


$$E(x) = \sum_{i} \frac{I_i}{4\pi r_i(x)^2}$$

ACT I
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• **ACT V**

COASTAL LIGHT PRESSURE

DESIGNING A METHOD



$$E_{tot} = \int_{coastline} \left(\sum_{i} \frac{I_i}{4\pi r_i(x)^2} \right) dx$$

ACT I
ACT II
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• **ACT V**

COASTAL LIGHT PRESSURE

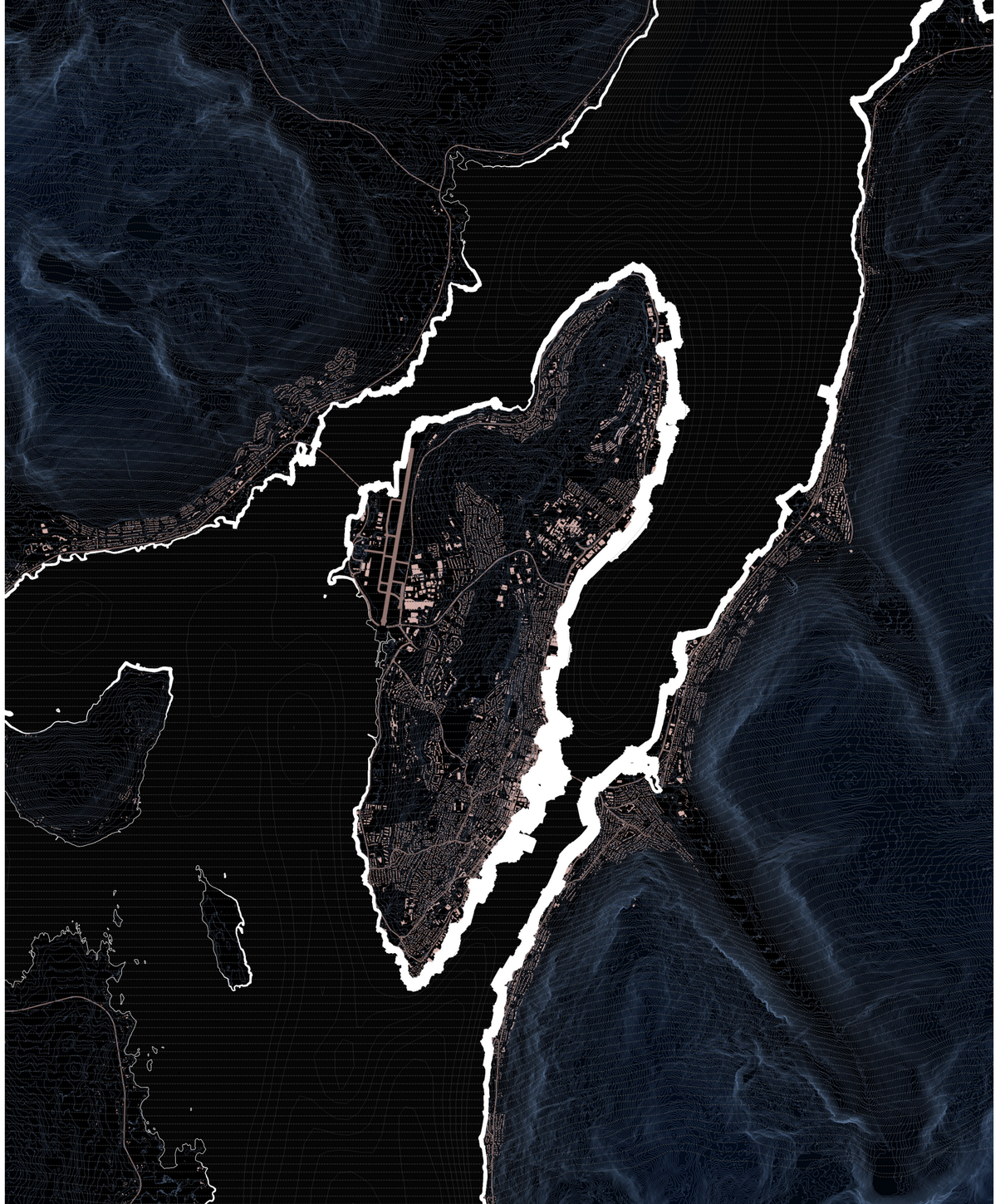
DESIGNING A METHOD



ACT I
ACT II
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• **ACT V**

COASTAL LIGHT PRESSURE

DESIGNING A METHOD



Coastal Light Pressure

high

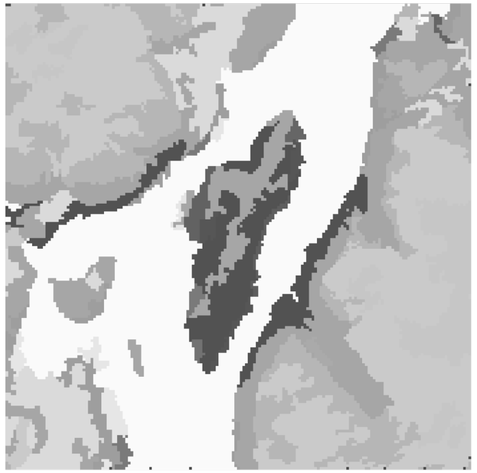
low

1 2 km

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• **ACT V**

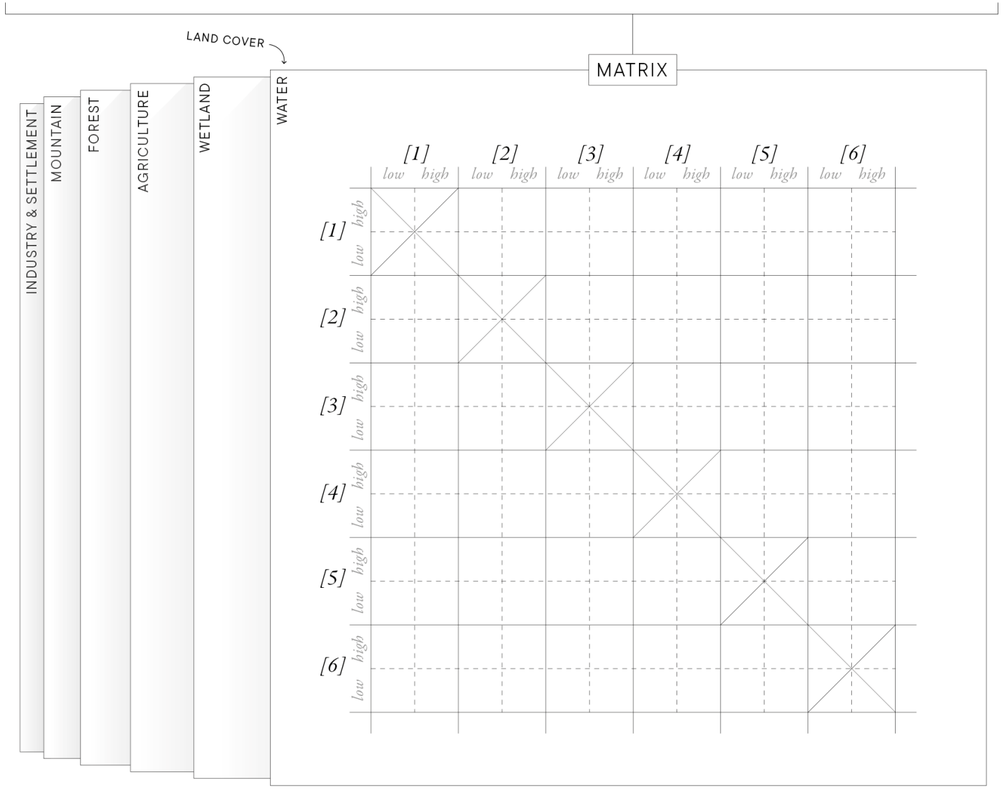
PART III: ATLAS - DARKNESS AS TERRITORY

TERRITORIAL CONDITIONS



[1] industry / settlement
[2] agriculture
[3] forest
[4] mountain
[5] wetlands
[6] water

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*



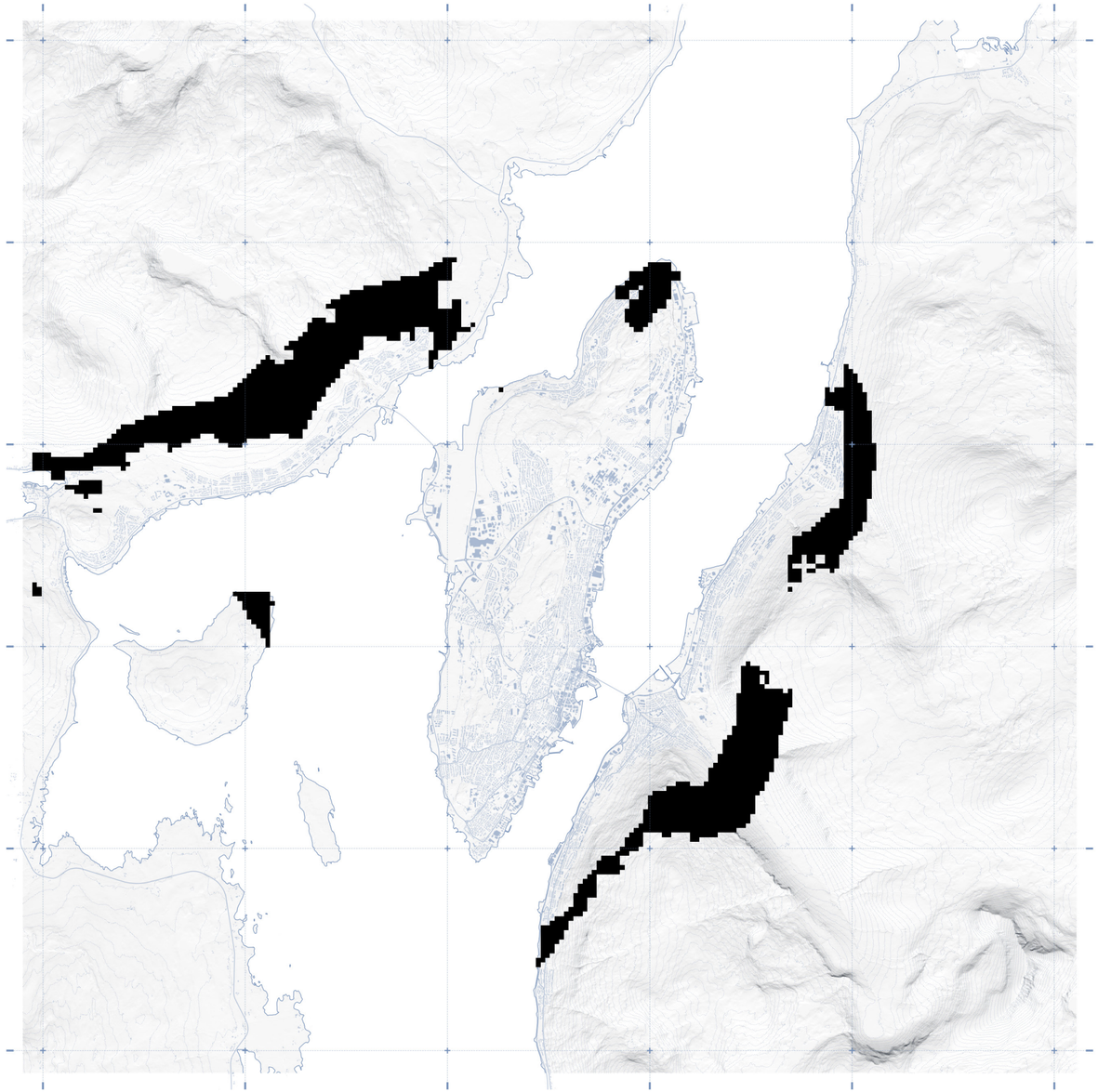
ACT I
ACT II
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ACT IV
• **ACT V**

EXTERNAL LIGHT CONTAMINATION OF OTHERWISE DARK FORESTS

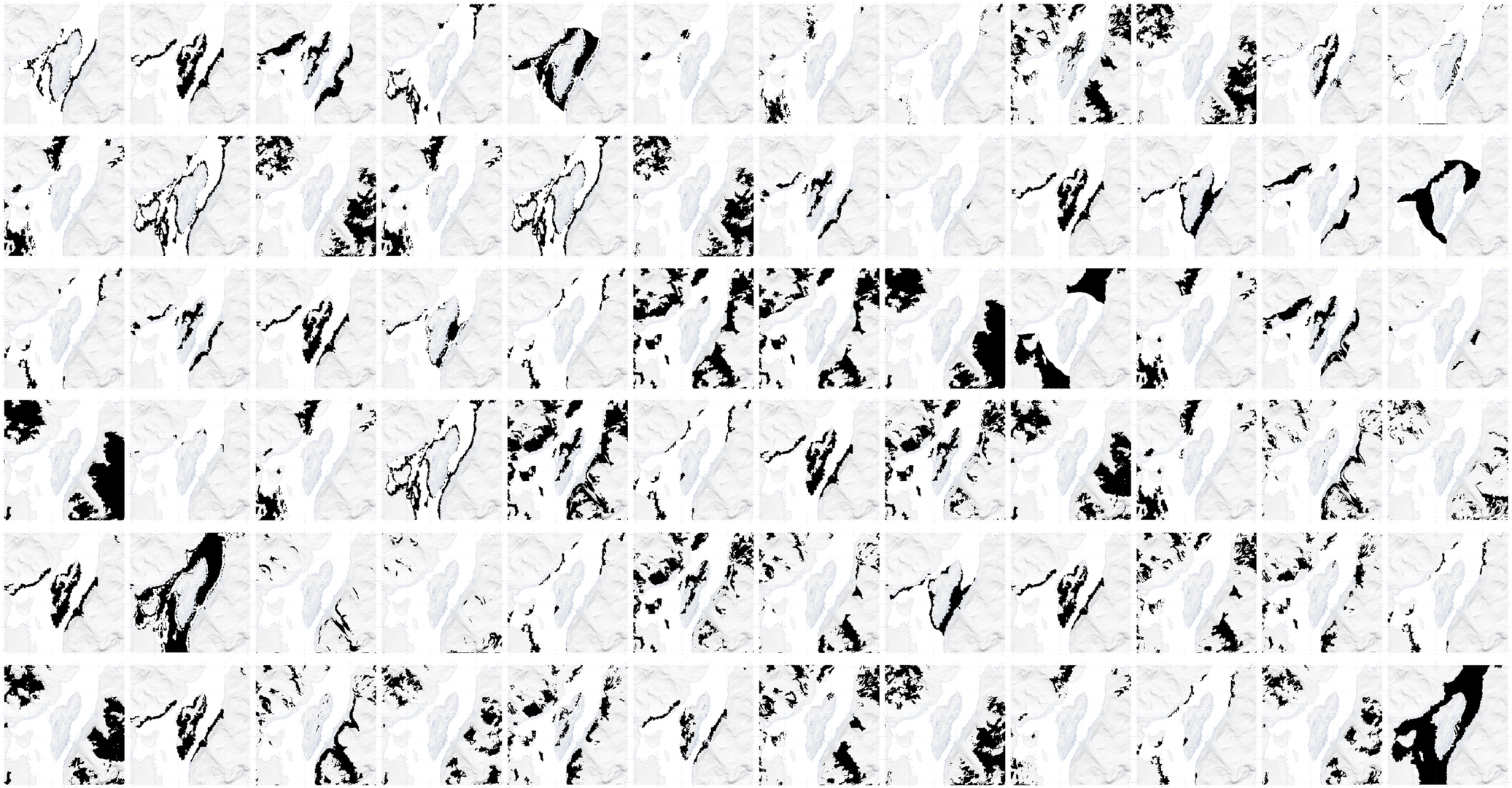
LOW NIGHT TIME LIGHT RADIANCE

HIGH SKY BRIGHTNESS

FORESTS



ACT I
ACT II
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• **ACT V**



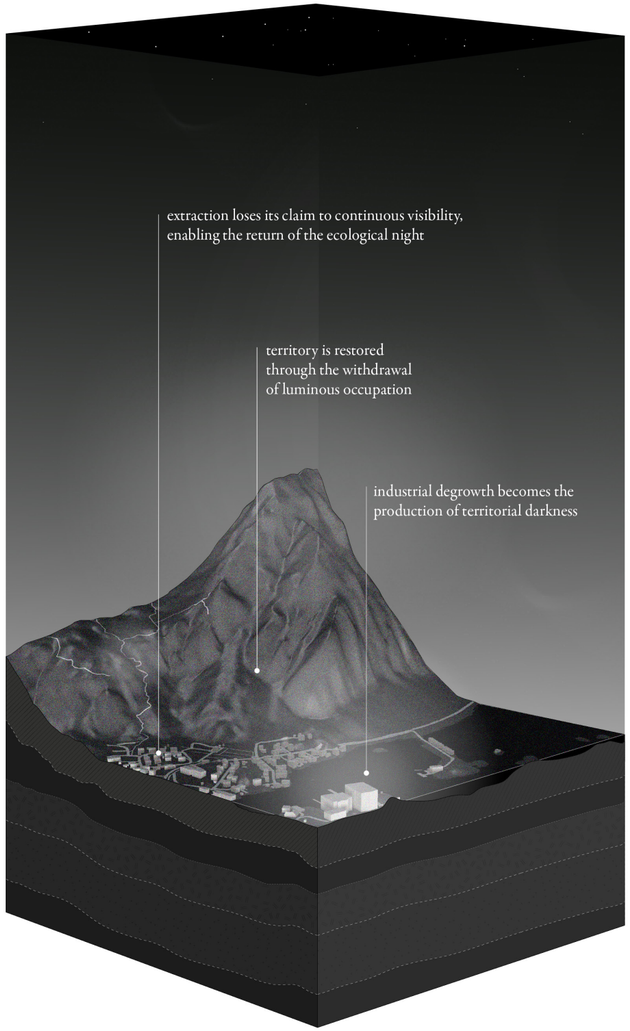
INTERPRETATIVE FRAMEWORK IDENTIFYING TERRITORIAL CONDITIONS

CONCLUSION

HOW CAN DESIGN MEDIATE THE RECOGNITION OF DARKNESS AS A RIGHT OF NATURE TO SUPPORT ECOLOGICAL REGENERATION IN THE ARCTIC?

CONCLUSION

CONTRIBUTION TO RIGHTS OF NATURE



OPEN ENDED PROPOSITIONS

FROM CONCERNS TO REFLECTIONS

ACT I
ACT II
ACT III
ACT IV
• **ACT V**

FOR SOURCES, SEE THESIS AND BIBLIOGRAPHY