Atlas of Knowledge
Exploring the Landscape

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Fluid Soils

(Co)Designing for the Wadden Sea Landscapes

edited by Laura Cipriani

TU Delft OPEN

Colophon

Fluid Soils
(Co)Designing for the Wadden Sea Landscapes

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Exploring the Landscape

Laura Cipriani | TU Delft

The first part of the work—'Atlas of Knowledge'—intends to investigate the territories of the Wadden Sea through the development of territorial maps that range from their historical development to current issues: from the geological system of the soil to the water systems, from agriculture to ecological networks, from terrestrial and marine environmental systems to energy networks, from the historical remains of raised villages (terps) to the urban fabric and infrastructure systems of cities. The presented maps constitute a critical operation of data and cartography collections and interpretations from different sources.

What emerges is that the Wadden Sea territory is partly the product of a lengthy geological process of interchange between sediments and water and a relatively recent anthropic process of defense and reclamation when the land is reclaimed from the sea. It is a territory that has long been dominated by a dynamic interchange between land, sea, and sediments, which, starting from the 13th century with the construction of the first dams, transformed into a static landscape due to man's hydraulic defense works. Historical maps have represented a fundamental step in imagining the future territory since many of these lands, today below hygrometric zero, could be reconquered by water in the future.

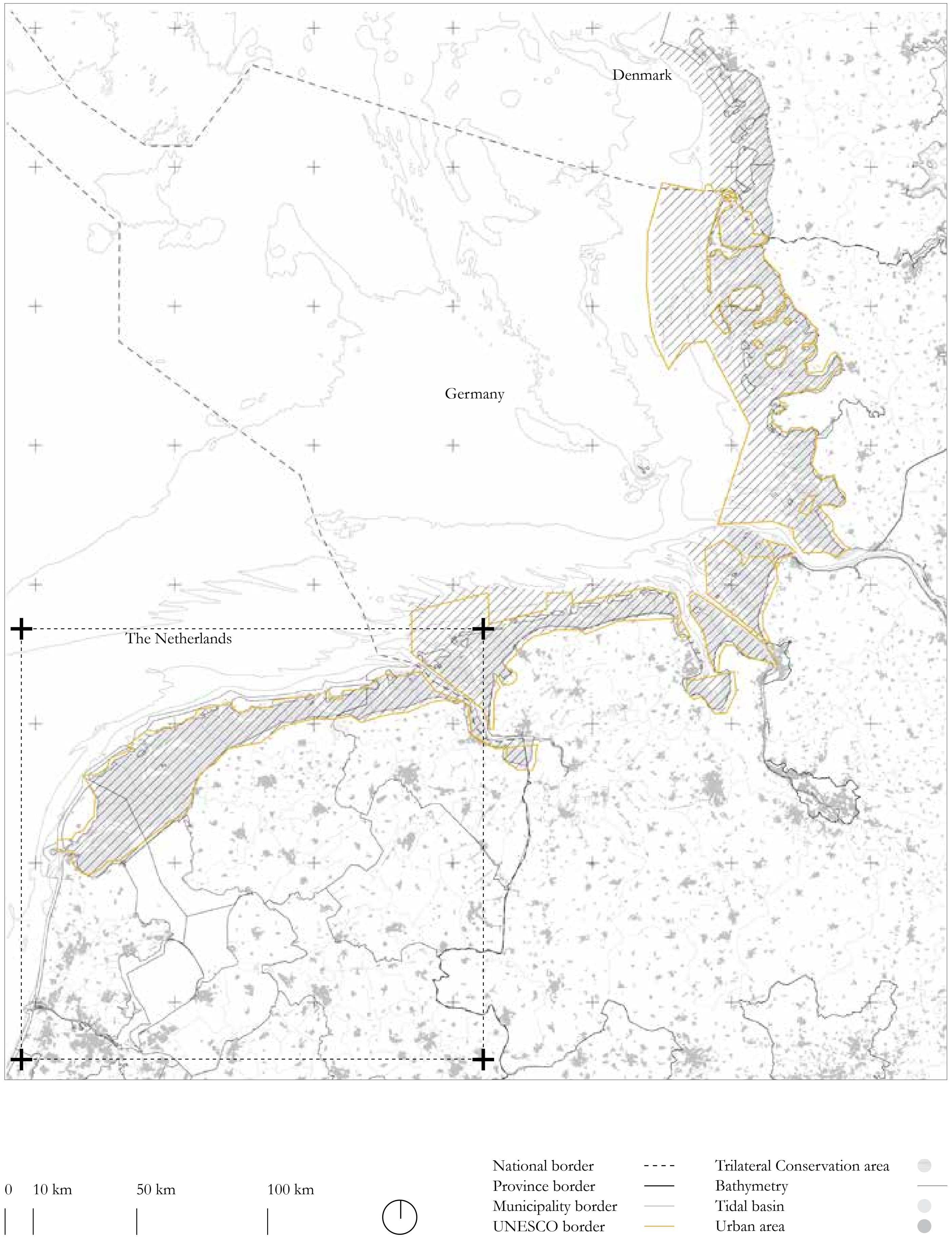
Beyond the rich remains of the villages built on the mounds, the present territory presents significant challenges: rising sea levels, soil salinization, subsidence due to gas extraction and drainage practices lowering the water table, sediment dredging, and dumping. These factors have modified the natural dynamic processes of coastal morphology and ecosystems, the urbanization of marine-based energy infrastructure, and the coming and going of ships, which threatens one of the most delicate ecological ecosystems—the agricultural industry—with its internal water pollution and indifference to ecological networks.

The authors of the images and texts from page 36 to page 110 are the following students: Anna Gorokhova, Xinjian Jiang, Zhaolei Li, Hanneke Wander, and Heather Wong. Texts and images were revised and edited by Laura Cipriani.

Administration and Protection Borders

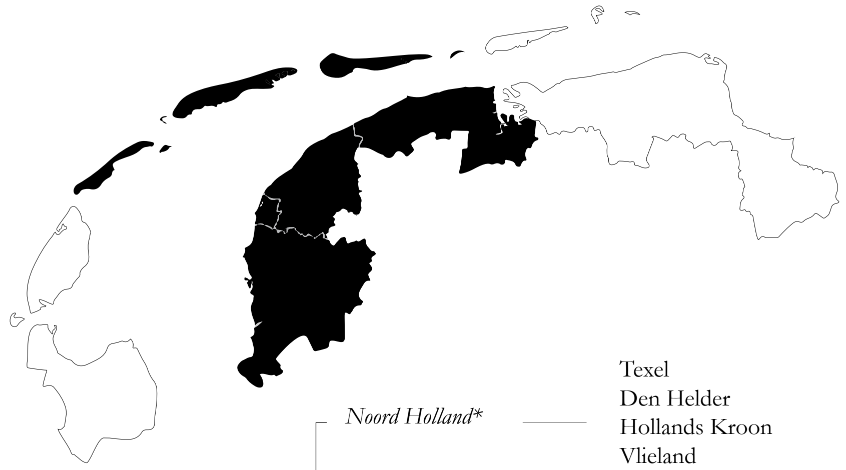
Data: General Bathymetric Chart of the Oceans, 2021.
Image: Heather Wong, 2022.

The Wadden Sea is over 500 km long, has a width of 20 km, and stretches over three countries: the Netherlands, Germany, and Denmark. The continuous tidal system of the Wadden Sea has 39 tidal basins, whose intricate interactions facilitate a multitude of habitats.



Provinces and Dutch Stakeholders

The Dutch Wadden Sea region encloses three provinces (Noord-Holland, Friesland, and Groningen) and 14 Wadden municipalities. Represented in the Wadden Region Regional Council, they coordinate policy and management with different ministries and water boards to manage the entire region. To protect this nature reserve, they have made agreements on nature conservation, recreation, tourism, and mudflat hiking. Four water boards are responsible for flood protection and water management on the islands and the mainland of the Wadden Sea Region. They ensure that the sea-retaining dikes and the retaining sandy coastline remain in good condition. Dike reinforcement along the Wadden coast is a task for the Wetterskip. The Ministry of Infrastructure and Water Management is the initiator and formal client for the process of the Agenda for the Wadden Region 2050.
More recently, in 2019, the Wadden Sea Management Authority (Beheerautoriteit Waddenzee) was established to enhance cooperation and mutual consultation among the various authorities involved in managing the Wadden Sea (Lamboy, Venis and Stokkermans, 2019).



Wadden Sea Region
The Netherlands

- 3 Provinces / 14 Wadden Municipalities
  - *Noord Holland**
    - Texel
    - Den Helder
    - Hollands Kroon
    - Vlieland
  - *Friesland**
    - Terschelling
    - Ameland
    - Schiermonnikoog
    - Súdwest-Fryslân
    - Harlingen
    - Waadhoeke
    - Noardeast-Fryslân
  - *Groningen**
    - Het Hogeland
    - Eemsdelta
    - Oldambt
- 4 Water boards
  - Wetterskip Fryslân
  - Noorderzijlvest
  - Hunze en Aa's
  - Hollands Noorderkwartier
- 3 National Parks
  - Texel Dunelands National Park
  - Lauwersmeer National Park
  - Schiermonnikoog National Park
- Ministries
  - The Ministry of Economic Affairs
  - The Ministry of Infrastructure and Water Management*
  - The Ministry of Agriculture, Nature and Food Quality*
  - The Ministries of Education
  - The Ministries of Culture and Science
  - The Ministry of Defense
  - Rijkswaterstaat
- Wadden Sea Management Authority
  - Wadden Sea Administrators Collective
  - Wadden Region Regional Council
  - *Clients of the Managing Authority
- Organizations
  - Wadden Academy
  - Young Wadden Academy
  - Rich Wadden Sea (PRW)

Old sea dikes.
Photo: Heather Wong, 2022.

Territorial Site Model and Sea Bathymetry

Data: General Bathymetric Chart of the Oceans, 2021.
Photo: Keyan Tang, 2021.

This model of the Dutch, German, and Danish Wadden Sea is entitled *Altitudes of Flatness*. It conveys the Wadden Sea's unbroken natural system in relation to elevations and juristic boundaries. The vertical scale is intentionally exaggerated to emphasize bathymetries, topographies, and micro-topographies.

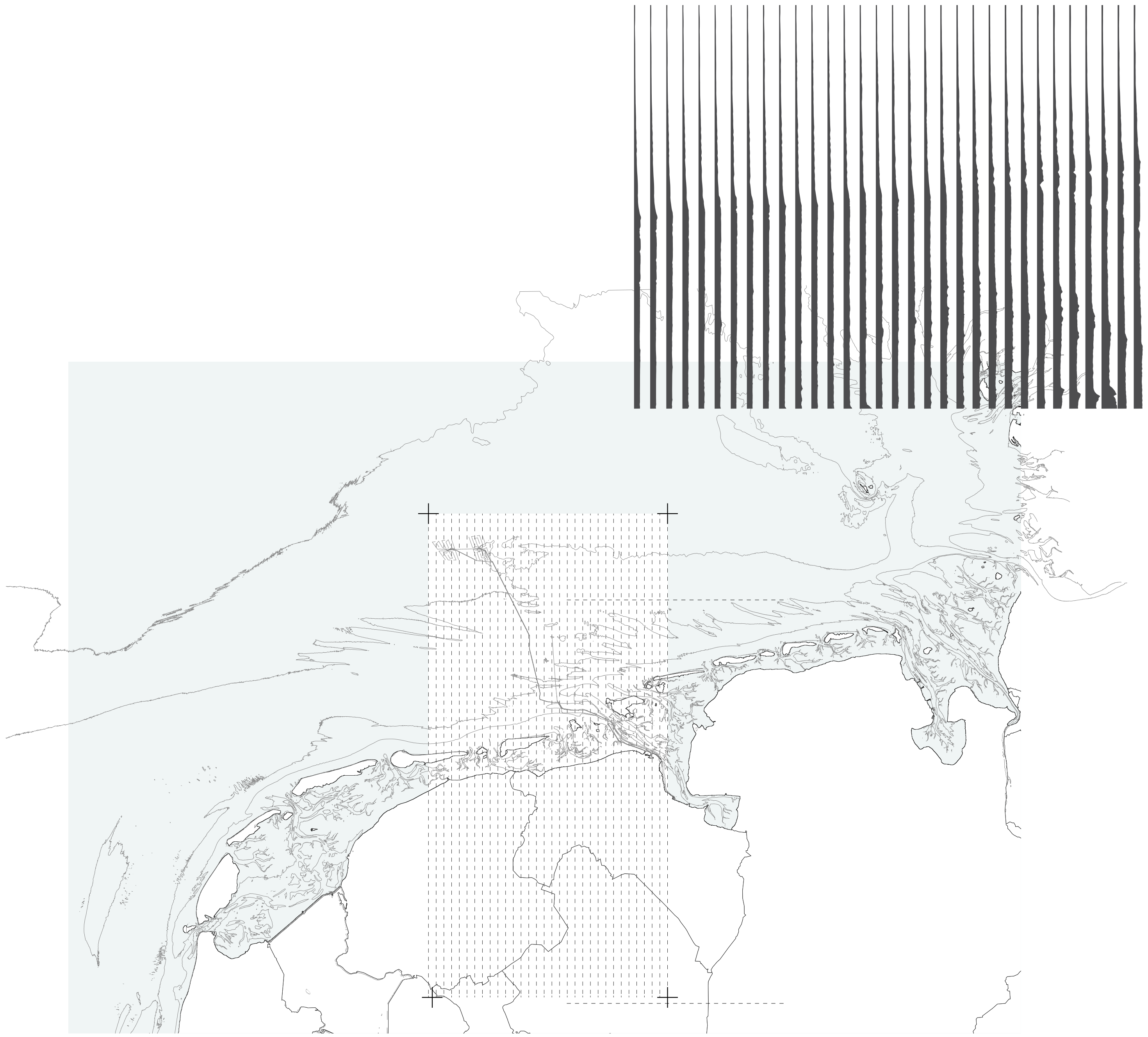
Students: Keyan Tang, Hanneke Wander, Madelief Dekker, Wong Yin Wah, Suihui Kuo.
Docent: Laura Cipriani

The Altitudes of Flatness, Thinking with Sections and Models Course, Year 2020-21.
Horizontal scale (x) 1:750.000. Vertical scale (y) 1:7500. Model size 500 x 500 mm.

Territorial Sea Bathymetry and Sections

Data: General Bathymetric Chart of the Oceans, 2021.
Image: Xinjian Jiang, 2023.

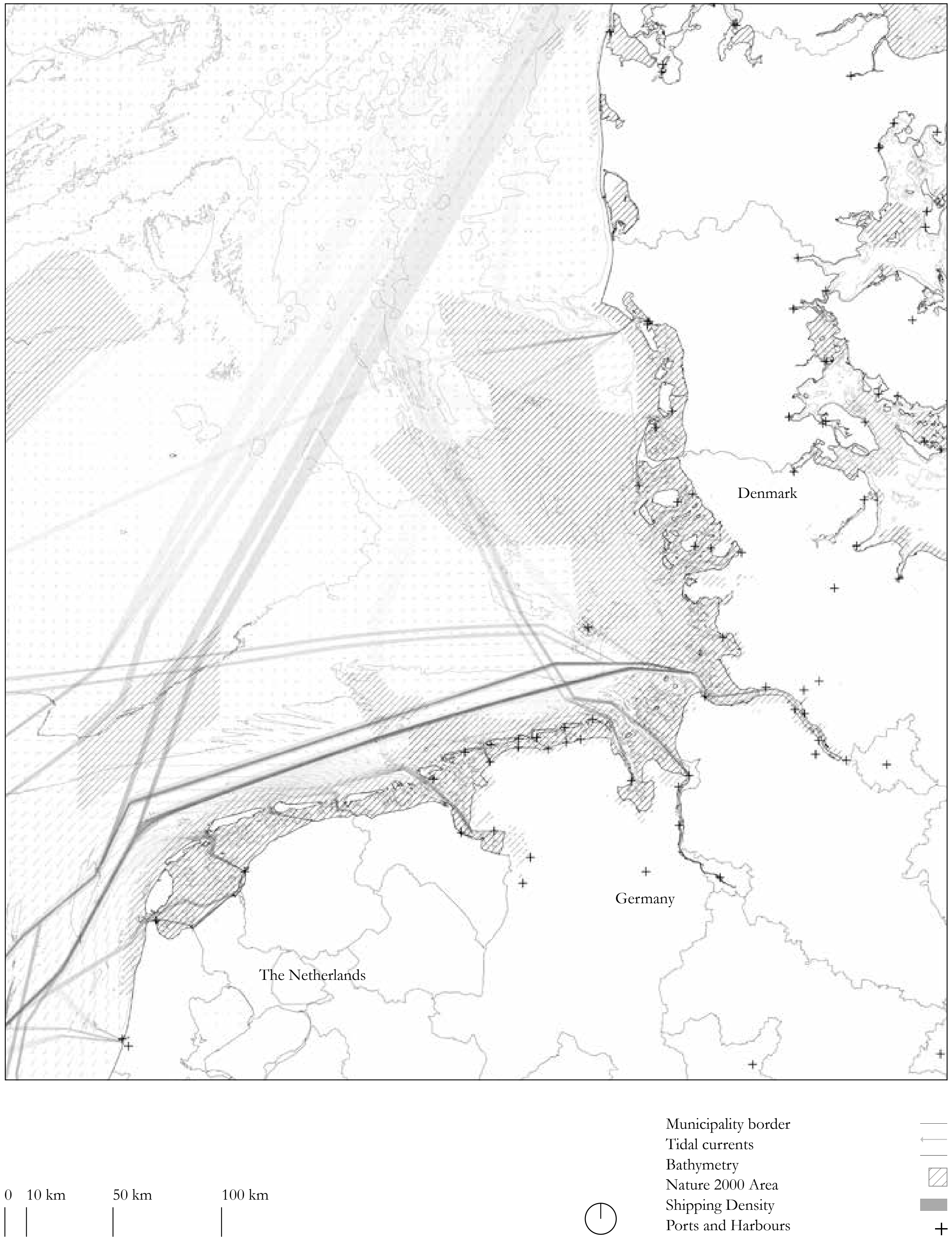
Territorial sea bathymetries and sections of the Wadden Sea show the topographical relationships between the sea, land, and islands.



Shipping, Infrastructures and Nature Area

Data: The European Marine Observation and Data Network, 2022.
Image: Xinjian Jiang, 2023.

This map represents shipping routes and infrastructure in relation to—and in contrast to—the Nature 2000 areas. The Wadden Sea is near some of the busiest shipping routes of the North Sea. The area is home to some of Northern Europe's most important ports, including Hamburg, Bremen-Bremerhaven, Wilhelmshaven, Esbjerg, and Delfzijl, which hold significant economic importance both regionally and internationally. Additionally, the ports provide a connection to the Baltic Sea via the Kiel channel, which connects to ports worldwide. Offshore wind parks are now being installed in the area seaward of the Wadden Sea, leading to increased ship traffic for maintenance purposes.
Due to the region's vulnerability and ecological significance, it was declared a Particularly Sensitive Sea Area (PSSA) in 1994. This designation allows the states adjacent to it to implement measures to provide improved protection against marine pollution. The area also benefits from stronger shipping laws and initiatives such as BE-AWARE, which aim to reduce the risk of marine pollution in the broader region.

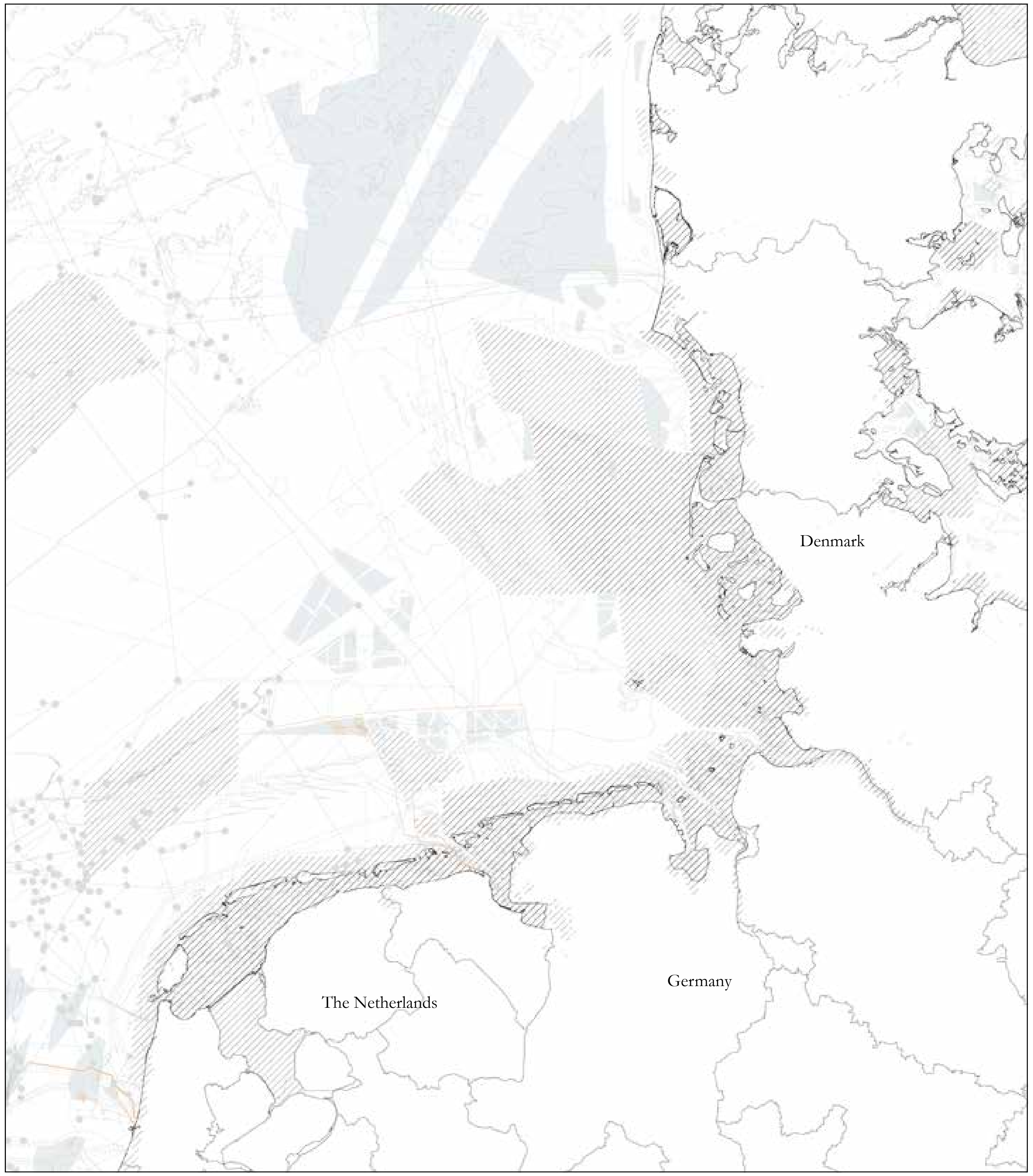


Turbines.
Photo: Irfan Alijagic, 2018.

Energy Infrastructure and Nature

Data: The European Marine Observation and Data Network, 2022.
Image: Xinjian Jiang, 2023.

This map represents energy infrastructure in relation to—and in contrast to—the Nature 2000 areas. Wind farms, offshore platforms, pipelines, telecom, and power cables traverse the Wadden Sea and its protected areas.



0 10 km 50 km 100 km

Municipality border
Bathymetry
Wind farms
Pipelines
Nature 2000
Telecom cables
Offshore platforms
Power cables

Wind Energy

Images: Xinjian Jiang, 2023.

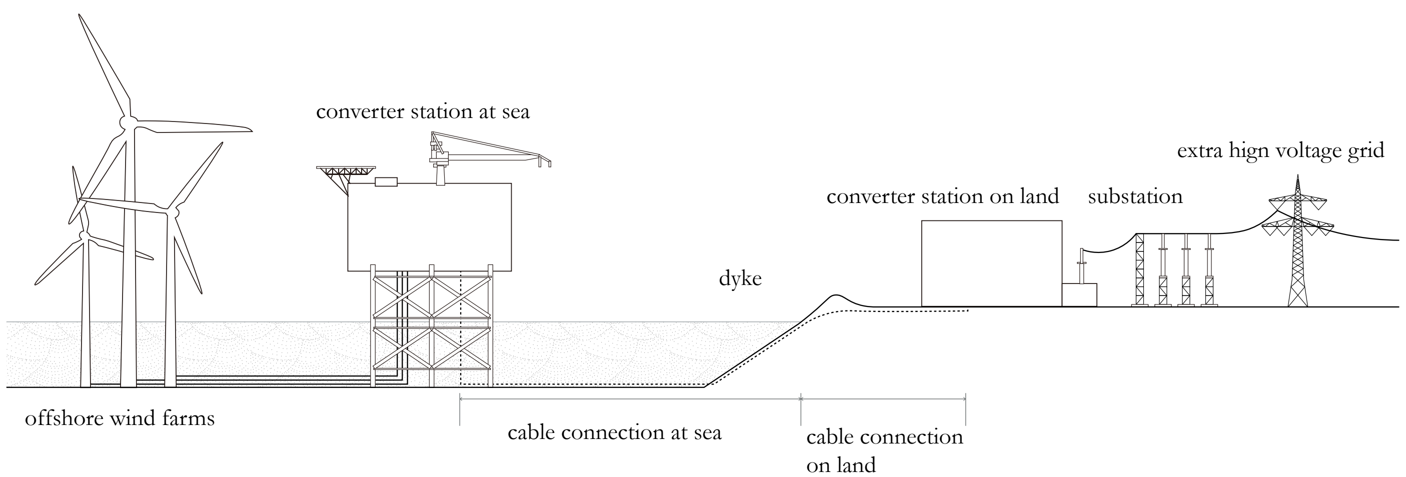
Onshore and offshore wind farms positively and negatively impact nature and the seabed.

Positive Impacts
Offshore wind farms contribute to reducing greenhouse gas emissions by generating clean, renewable electricity, thus mitigating climate change impacts.
Artificial reefs formed by wind turbine foundations can create habitats for marine life. These structures can attract fish and other marine species, effectively acting as artificial reefs.
Offshore wind farms can stimulate local economies through job creation, investment, and revenue generation for coastal communities.

Negative Impacts
Construction activities, such as pile driving and cable laying, can disrupt marine habitats and ecosystems. Noise pollution from construction and operation can also impact marine life, including marine mammals and fish. There is also a risk of collision between marine animals (e.g., birds, marine mammals, fish) and wind turbine structures, especially during migration or feeding.
Furthermore, installing turbine foundations and cables can cause physical disturbance to the seabed, potentially affecting benthic communities and habitats and the electromagnetic fields generated by underwater cables can disrupt the behavior and migration patterns of certain marine species, such as sharks and rays.
Finally, the presence of large wind farms can potentially alter local ocean currents and sediment transport patterns, which may have downstream effects on coastal erosion and sedimentation.

Wind Farms in the Wadden Sea
Currently, the Wadden Sea Plan states that '*the increasing energy production in the Wadden Sea Region, both onshore and offshore, will have several side-effects, such as increasing ship traffic in the coastal sea and cable crossing through the conservation area. Air pollution may increase, as well as interference with bird flyways. The increasing ship traffic in general results in increased dredging and harbor extension*' (Common Wadden Sea Secretariat, 2010).

Offshore Wind Farm

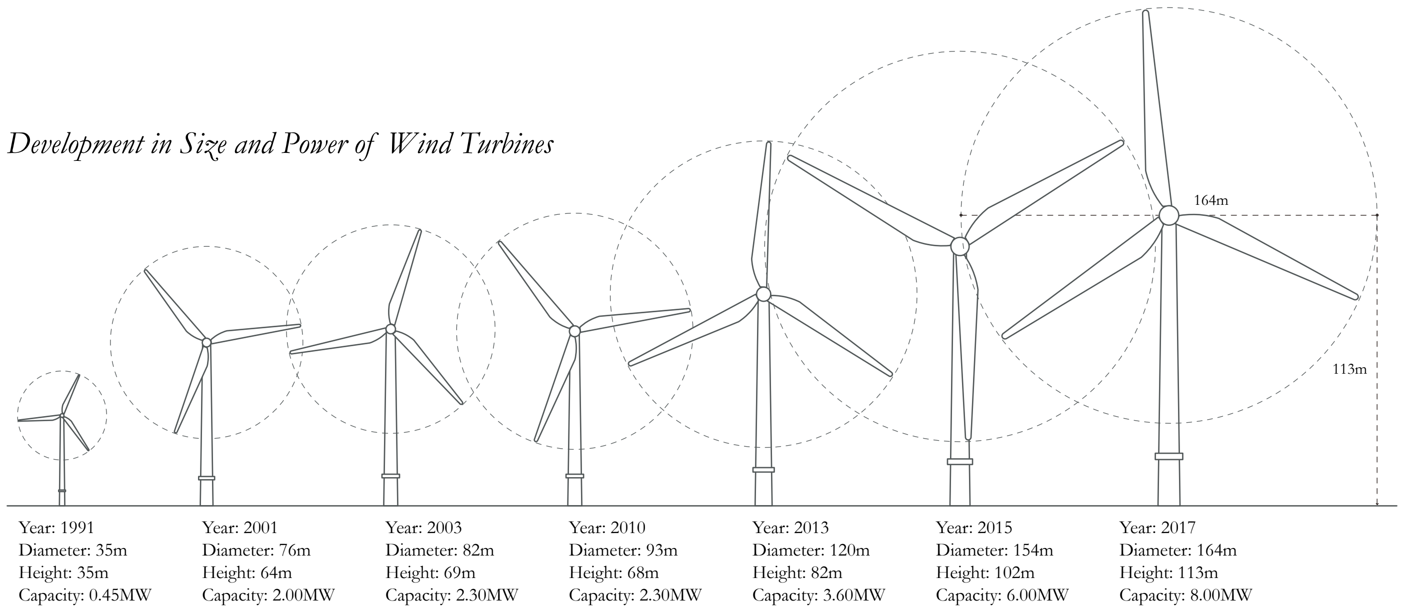


Impacts of Energy Infrastructure

Impact	*Activities causing the impact*	*Construction-related*	*Operation*	*Plant-related*
Underwater noise	wind energy	X	X	
Reef effect	wind energy, gas and oil			X
Physical disturbance of the seafloor	cables and pipelines	X		
Turbidity and Sedimentation	cables and pipelines	X		
Sealing/ habitat loss	wind energy, gas and oil	X	X	X
Heat dissipation	cables and pipelines		X	
Electromagnetic fields	cables		X	
Spills	oil, ships, pipelines		X	
Ground surface subsidence	gas		X	
Collision	wind energy, gas and oil	X	X	X
Scaring	wind energy, gas and oil, ships	X	X	X
Pollution	wind energy, gas and oil, ships	X	X	

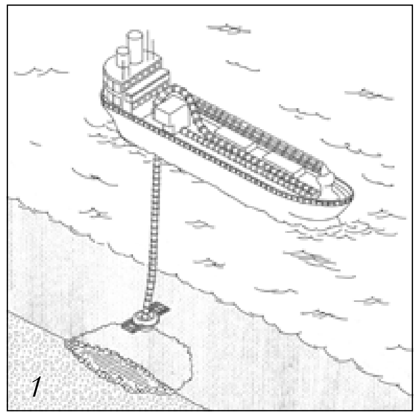
Table 1. Overview about possible impacts of renewable and fossil energy infrastructure, which might affect the Wadden Sea area during the construction and operation phase and plant-related (indicated with X).

Development in Size and Power of Wind Turbines

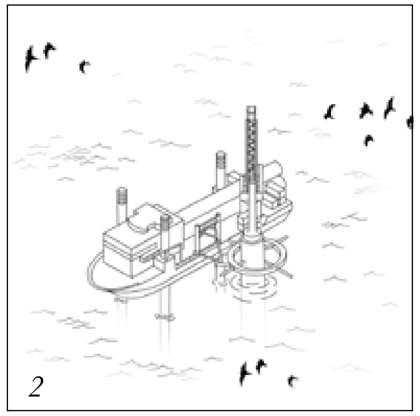


Wind Turbine Installation Steps

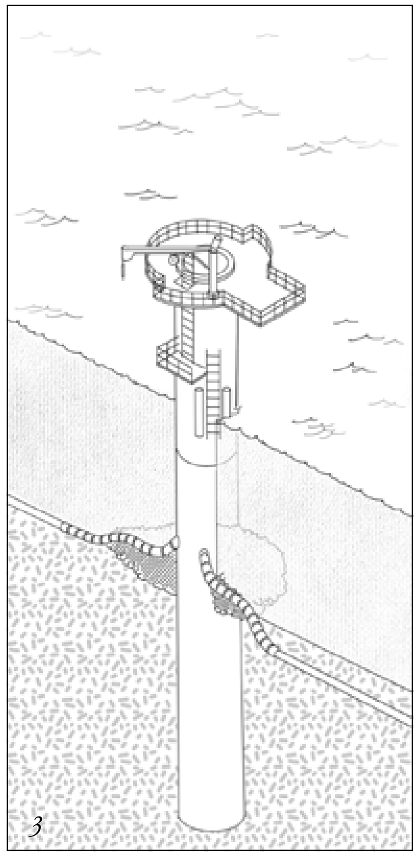
Data: The Gemini Offshore Wind Park, 2017.
Images: Xinjian Jiang, 2023.



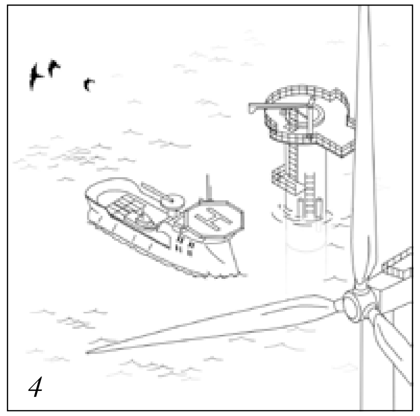
Protection material is deposited by a flexible fallpipe vessel onto the seabed before each monopile is installed.



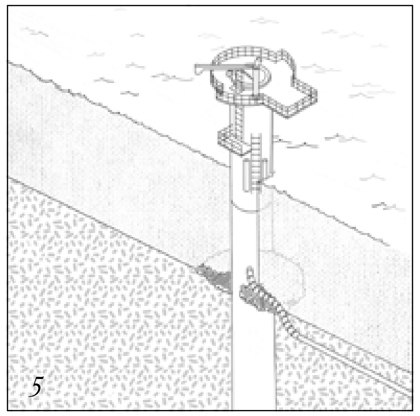
An offshore installation vessel is used to transport and install the monopile.



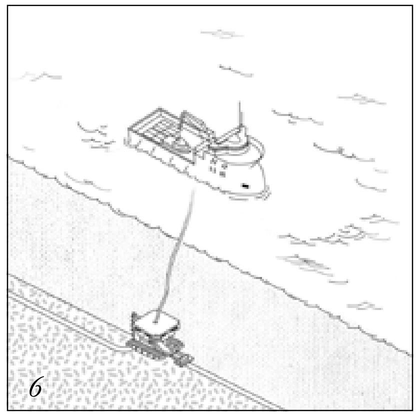
Monopile installation
The monopile is installed.



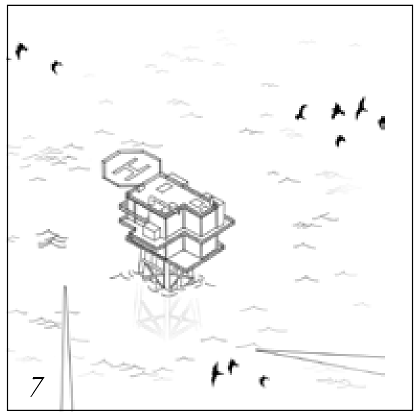
Transition piece installation
The transition piece is installed.



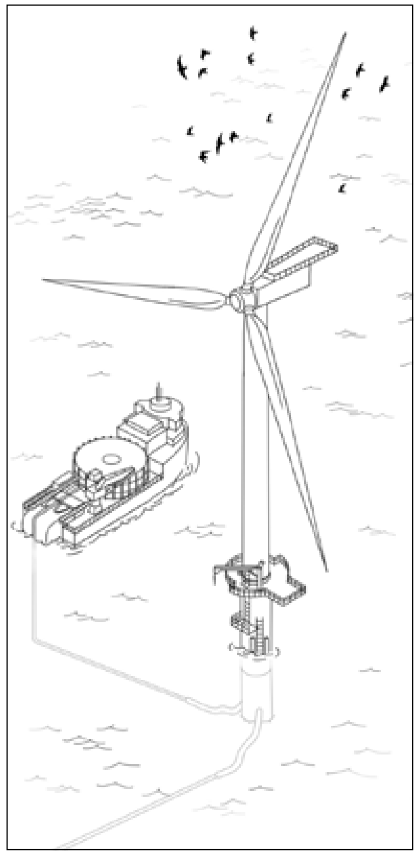
The electrical interconnection cable is laid.



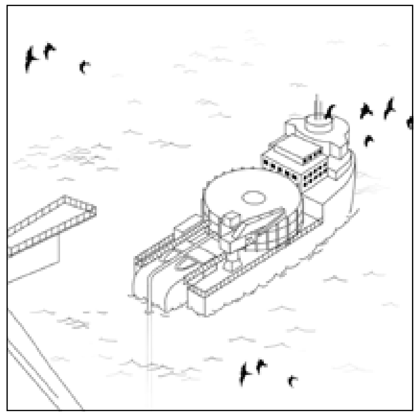
The cables are placed and buried on the seabed.



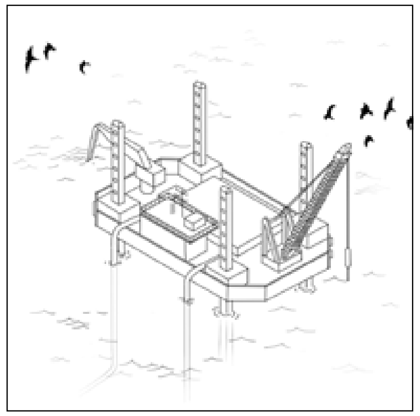
Offshore high-voltage substations are positioned in the wind park.



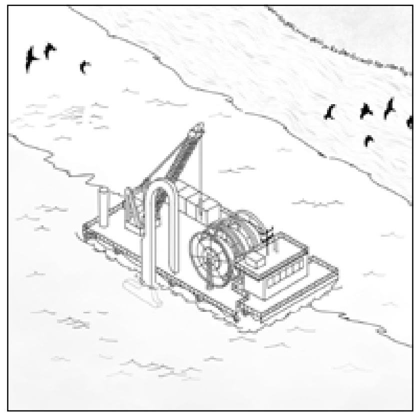
Wind turbine generator
The tower is lifted on and bolted to the Transition piece. The electrical cables are connected.



The electrical cable is laid onto the seabed.

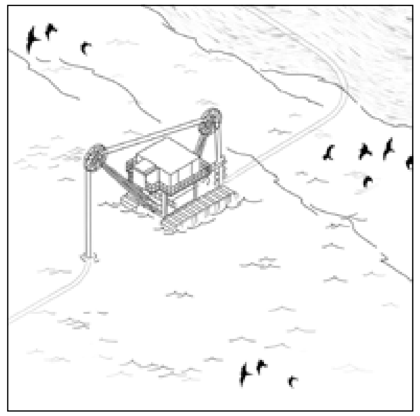


The cable sections are connected.

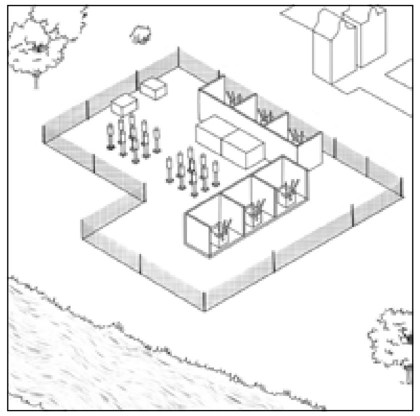


The cable is laid in tidal flats.

The cable is laid in tidal flats.



This is a trencher typically used in intertidal areas to minimize impact on coastal areas.



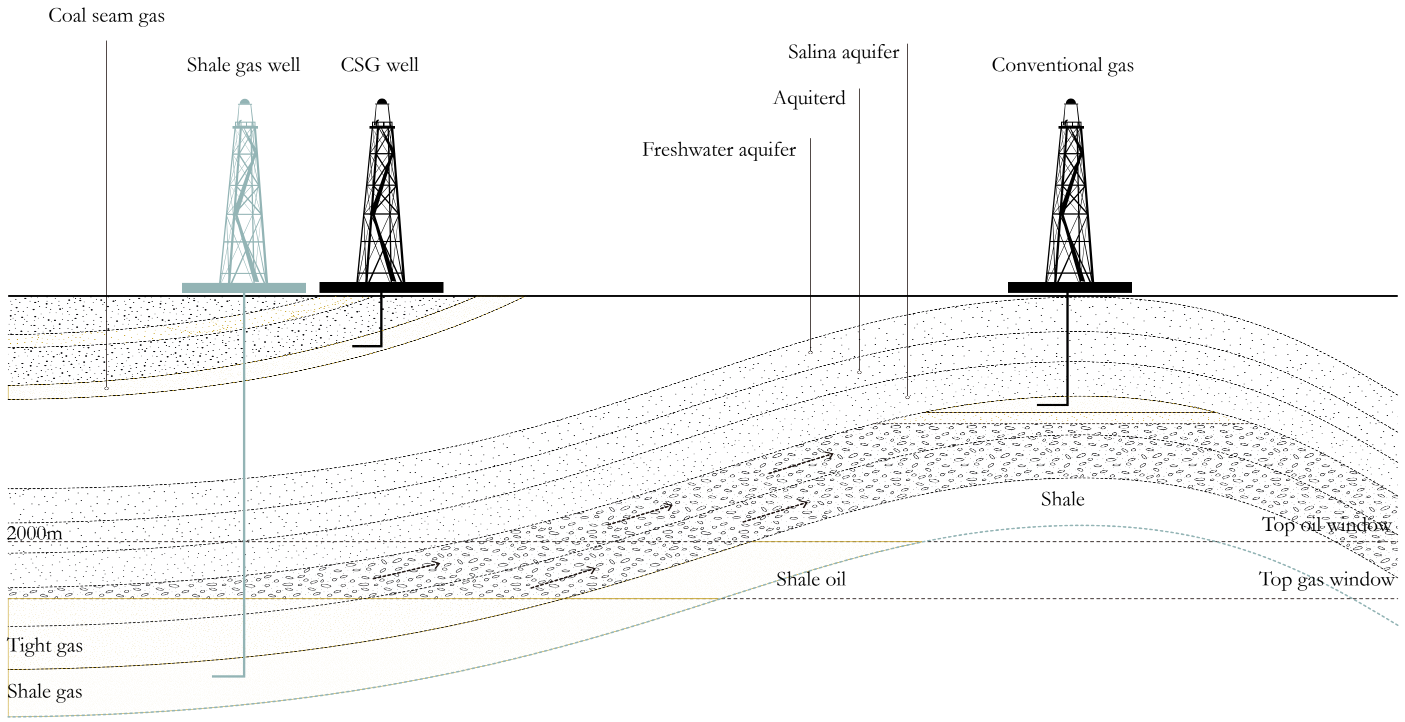
The wind park is connected to the high-voltage grid. The land station transforms the electricity from the export cables to a higher voltage.

Onshore and Offshore Gas Infrastructure

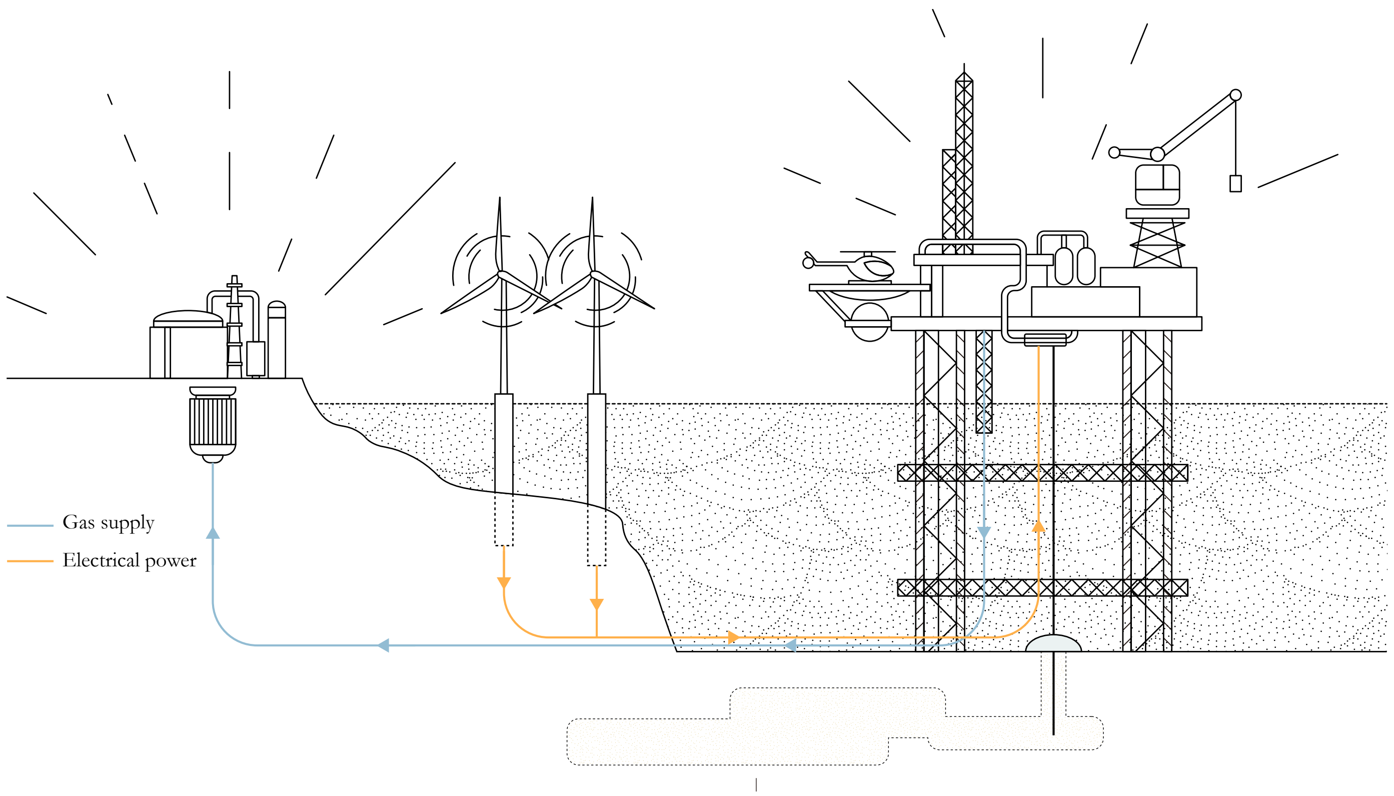
Images: Xinjian Jiang, 2023.

The diagrams below show onshore and offshore gas infrastructure. There are currently more than 100 active mining projects in the Netherlands, and the Wadden Sea is one of the most sensitive areas. Both onshore and offshore gas infrastructure have contributed to subsidence. For example, the Ameland gas field on the island of Ameland has been producing gas since 1986 and caused up to 35 cm of subsidence in 2018.

Conventional/Unconventional Gas



Offshore Gas and Oil Sector



Elevations and Sea Level Rise

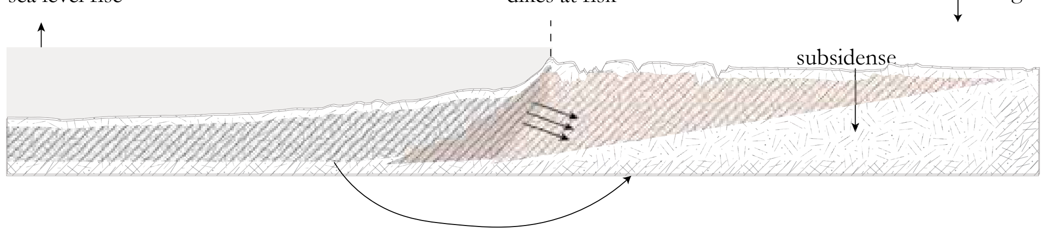
Data: National Aeronautics and Space Administration, 2015.
Image: Zhaolei Li, 2023.

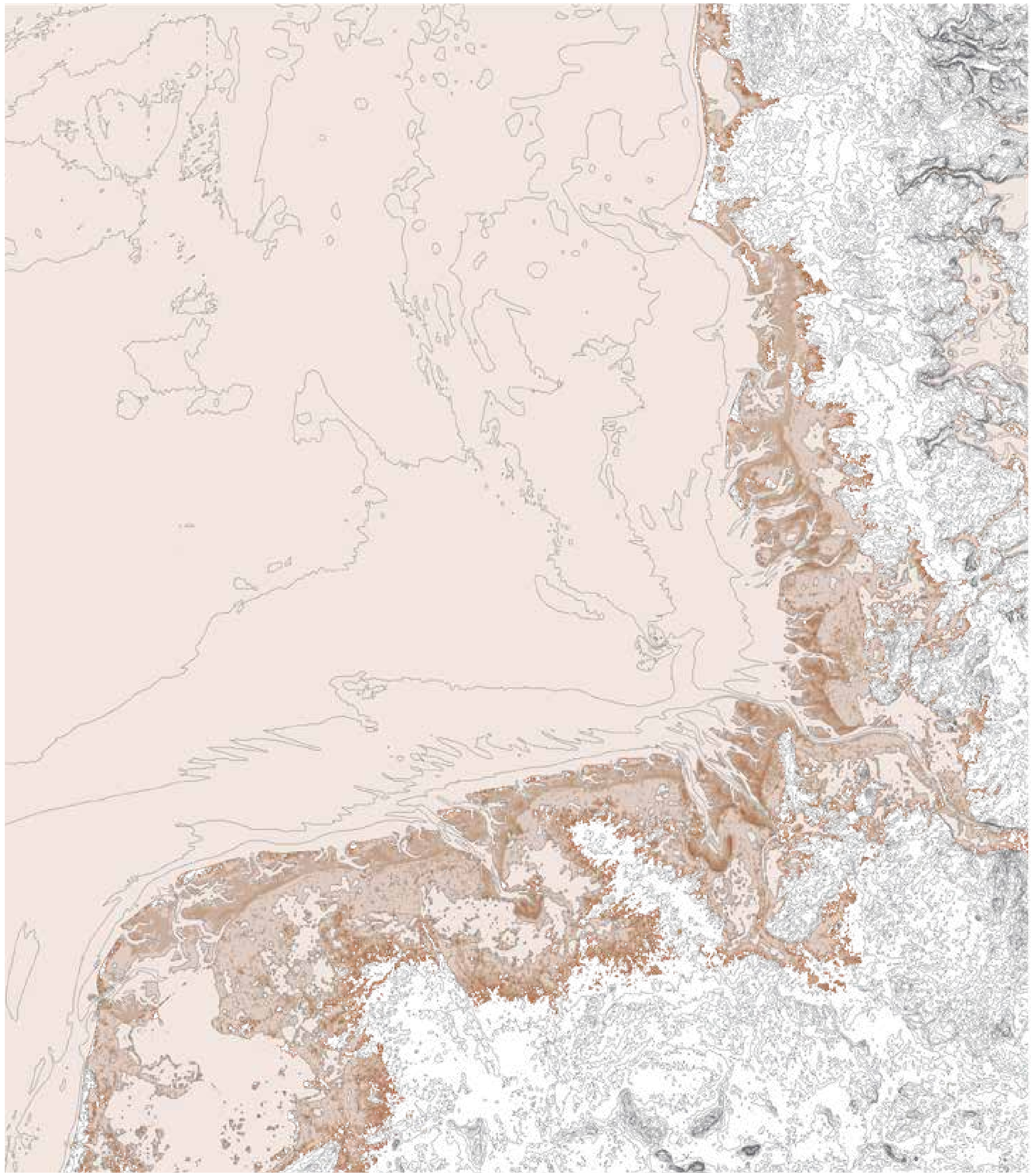
The greenhouse effect has led to a variety of climate problems, including rising sea levels. This map shows sea level rise in relation to elevations of 1, 2, 3, 4, and 5 meters. Temperature extremes, storms, and flooding are still listed as the greatest threats to the Wadden Sea region. The IPCC (2014) concluded that '*Global mean sea level rise will continue during the 21st century, very likely faster than observed from 1971 to 2010. For the 2081–2100 period relative to 1986–2005, the rise will likely be in the ranges of 0.26 to 0.55 m for* RCP2.6*, and 0.45 to 0.82 m for* RCP8.5 *(medium confidence). Sea level rise will not be uniform across regions*' (IPCC, 2014).

Sea Level Rise and Salinization

Salinization is a global issue threatening agricultural activities accelerated by rising sea water levels. Apart from rising sea levels, land subsidence and increasing temperatures also result in groundwater salinization. Groningen, Friesland, and Northern Holland are all at risk of salinization. In Friesland, since the elevation is below mean sea level, salinization of the polders occurs by the lateral intrusion of seawater (Tzemi et al, 2021). The salinization risk is constantly increasing due to rising sea levels—a process that will likely intensify after 2050. Seawater intrusion processes are expected to influence croplands along the Wadden coast.

Sea Level Rise Risk



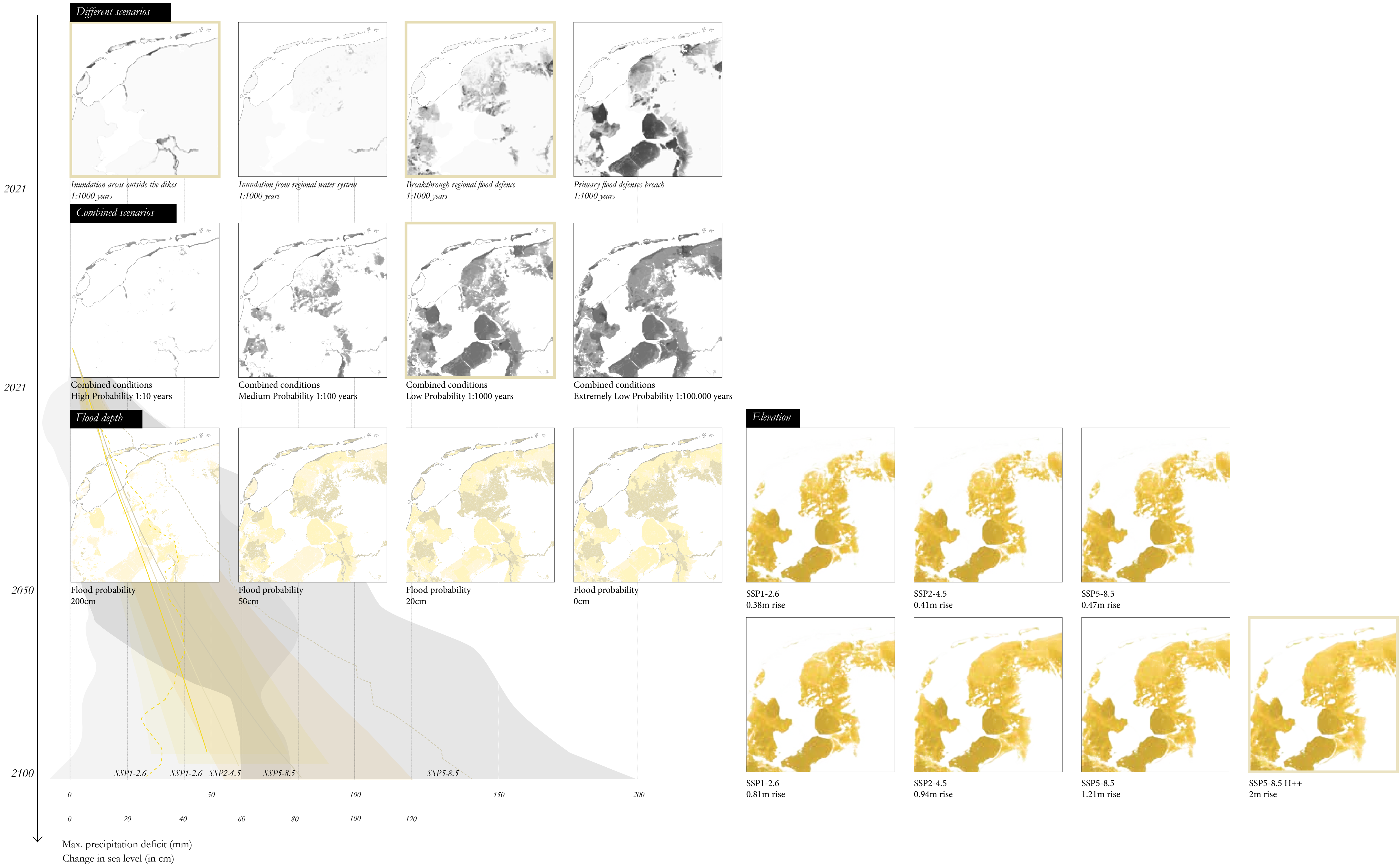


0 10 km 50 km 100 km

Height of sea level rise-0m
Height of sea level rise-1m
Height of sea level rise-2m
Height of sea level rise-3m
Height of sea level rise-4m
Height of sea level rise-5m

Future Uncertainties

Data: Climate Impact Atlas, 2021.
Photo: Heather Wong, 2022.



This image merges all the national maps of flooding caused by the sea and rivers from the Water and Floods Information System (LIWO) and was prepared by Deltares on behalf of Rijkswaterstaat (RWS). The first row of maps is the water depth map of 2021, showing different flood conditions up to approximately once every 1000 years. The dark color represents the high flood depth. The second row is the maximum flood depth of 2021, with a combined condition showing the flood area with different probabilities. The maps combine the four aforementioned flood conditions along the primary and regional water systems. These maps depict possible flooding that, in reality, will not all co-occur. The map showing the highest flood depth and the lowest probability reflects the most extreme flooding scenario.
Prepared by RWS, the third row is the flood probabilities with various water depths in 2050 caused by a breach in the flood defense along the main or regional water system, or by the flooding of unprotected areas. Therefore, this map shows the probability of all possible flooding regardless of the resulting flood depth. All primary flood defenses precisely comply with the flood probability standard in the Water Act. The provincial exceedance probability standard has been used for regional flood defenses as the probability of flooding. The failure probability of primary flood defenses has been assumed independently. The failure probability of primary flood defenses has been estimated based on the current failure definition and without emergency measures (Deltares, 2015). The darker yellow area represents a higher probability of flooding.
There is no spatial flood data on the Netherlands for 2100. Therefore, the elevation maps shown indicate the possible flood level regardless of the flood defense systems. The graph at the back suggests the future sea level rise projection and the maximum precipitation deficit under various emission scenarios.

Wooden lifeguard house on Terschelling beach.
Photo: Bas van Breukelen, 2020.

Timeline and Major Flood Events

Data: Zijlstra et al, 2017.
Timeline: Heather Wong, 2022.

Infrastructure and policy development are closely related to historical flood events. Protection and conservation work specific to the Wadden Sea began in 1978.

Natural processes

Natural disaster

1219
The Saint Marcellus' Flood

1703
Great Storm

1717
Christmas Flood

1730
Dike damage by shipworm

1825
February Flood

1916
Storm Flood

1953
North Sea Flood

Cultural processes

Infrastructures

1200-1500
1st large-scale building of dikes

1505
Reclamation of Bildtdijken & polder

1500-1650
large-scale land reclamation, polders and large-scale peat extraction

1700s
Villages linked to marine network of canels

1800-1950
Modernization of the dikes and dike management

1933
Afsluitdijk

1958
Delta Act

1969
Lauwersmeer

2009-15
Dike reinforcement

Policies

1975
1st International Scientific Wadden Sea Symposium (ISWSS)

1978
1st Trilateral Governmental Conference between Denmark, Germany and the Netherlands

1982
"Joint Declaration on the Protection of the Wadden Sea"

1987
Common Wadden Sea Secretariat (CWSS)

1996-2001
Lancewad

1997
1st Trilateral Wadden Sea plan

1998
Nature Conservation Act

2002
Designated as PSSA under IMO
Establishment of Wadden Sea Forum

2003
International Wadden Sea School (IWSS)

2005
Overleg Orgaan Waddeneilanden (OOW)

2007
LancewadPlan (LWP)
Framework Vision on the Wadden Sea

2008
1st National Water Plan

2009
UNESCO World Heritage
The Dutch and German parts of the Wadden Sea were inscribed on UNESCO's World Heritage List

2010
Revised Wadden Sea plan & Joint Declaration

2015
Second National Water Plan
Delta Programme "Nieuwbouw en herstructurering"

2018
Leeuwarden Declaration

2019
Wadden Sea Management Authority

2020
Agenda for the Wadden Region 2050

2022
14th Trilateral Governmental Council Meeting in 2022
Single integrated management plan (SIMP) Meeting in 2022

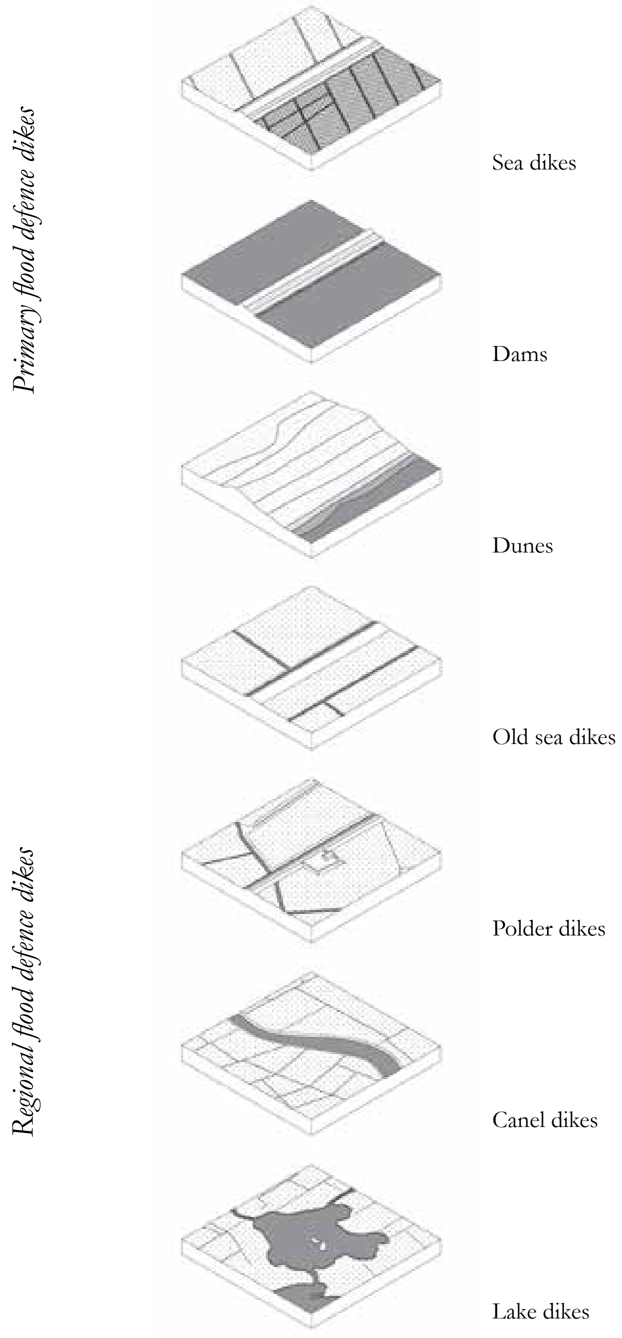
Flood Defense Systems

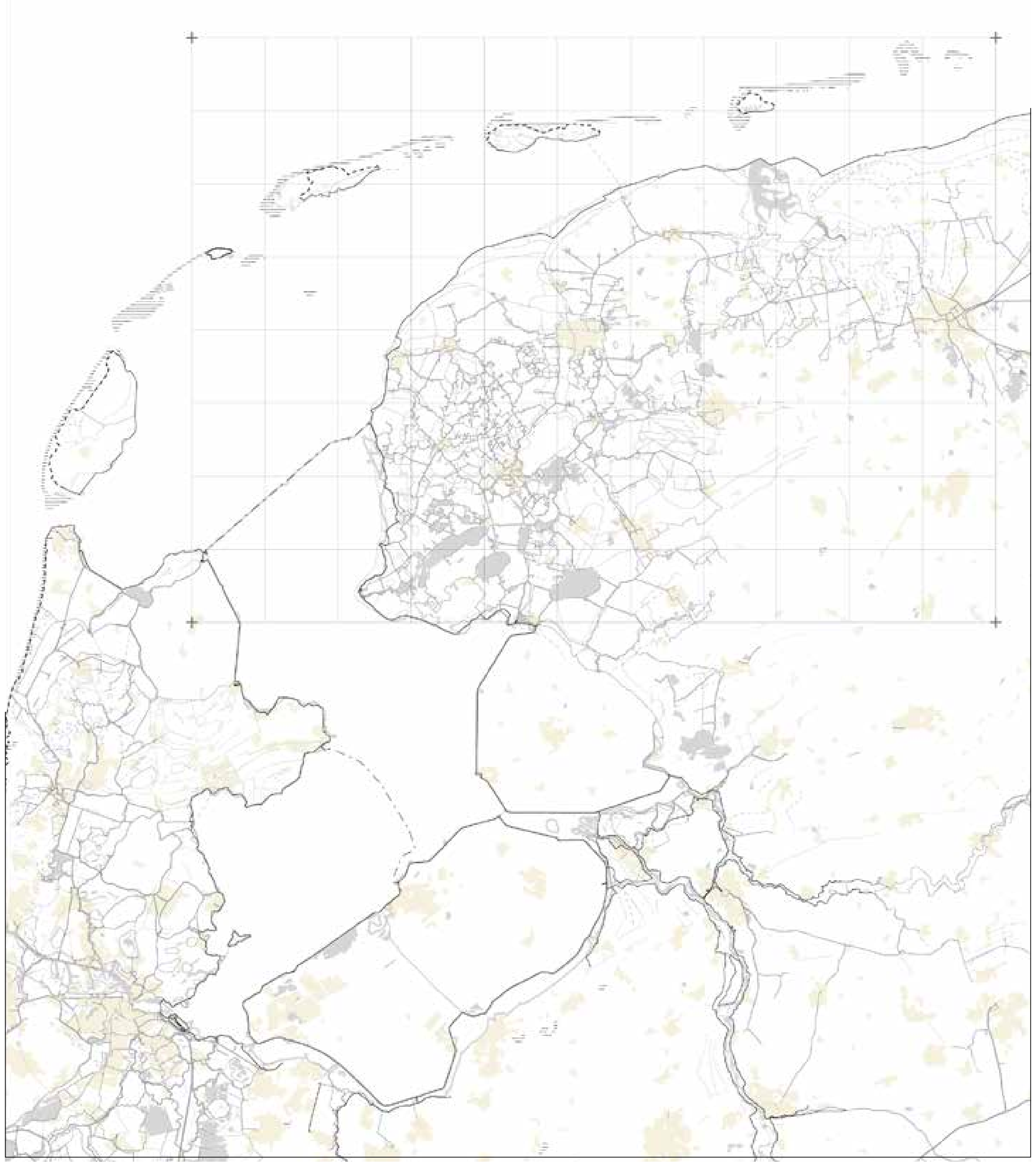
Data: National Georegister, 2021.
Images: Heather Wong, 2022.

Primary flood defenses are the first barriers protecting the country from high sea levels. The primary defense system in the Wadden Sea region consists of sea dikes, dams, and dunes. Sea dikes are relatively high (about 8 meters above ground level), with an asphalt revetment at the lower part of the outer slope. The 32-kilometer Afsluitdijk was built in 1932 to close off the former Zuider Zee from the North Sea to protect the north and central regions of the Netherlands from storm surges from the sea (Pleijster and Veeken, 2014). Dunes are mainly present on the Wadden Islands to prevent water intrusion from the North Sea.

Regional flood defenses refer to all flood defenses with a set standard constructed to protect areas inside or outside of a dike ring (Pleijster and Veeken, 2014). The regional flood defense system includes the former sea dikes, polder dikes, canal dikes, lake dikes, forelands, and summer dikes. Since the water level in the Boezem is higher than the land in the polder, regional dams are crucial to protecting the land in the polders from flooding. In the northern part of Friesland, forelands are present along the coast to accelerate the silting up of the land.

In Friesland, there are approximately 3,200 km of dikes.

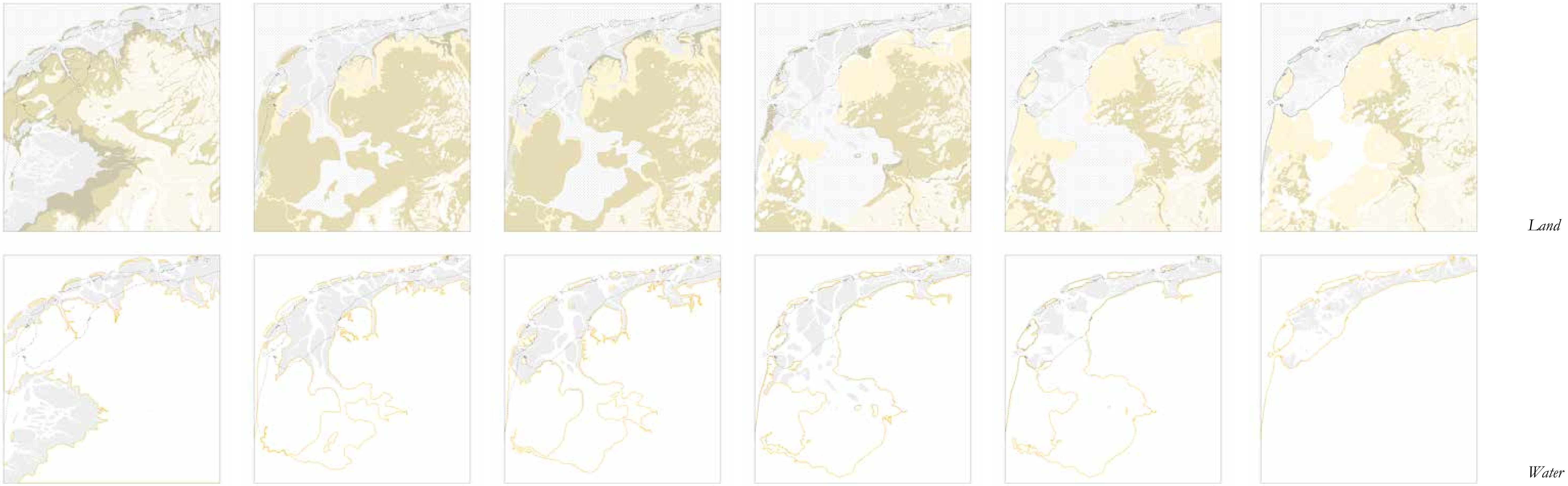




Primary flood defence dikes
Primary dams, storm barriers
Primary dune dikes
Regional flood defence dikes
Disappeared dikes
Other dikes
Sand dunes
Urban area

Geomorphological Evolution

Data: Vos et al, 2020.
Images: Heather Wong, 2022.



3850BC	100AD	800AD	1500	1850	2000
Bronze Age	Iron Age	Middle Age	Middle Age	Modern Age	Anthropocene

- Open water
- Intertidal zone
- Salt marshes
- Dryed salt marshes & river plains
- Peatland
- Reclaimed land
- Coastline
- Current coastline

0 10 km 50 km 100 km

Cultural Heritage

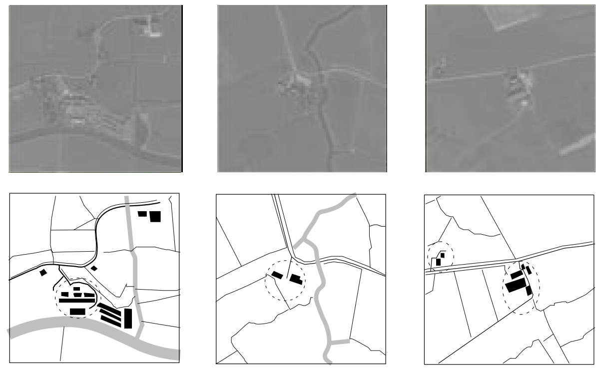
Images: Anna Gorokhova, 2023.

The eternal battle against the sea required significant landscape amendments, in which terps-pioneer settlements, dikes, ditches, canals, mills, etc. all served a role in the process. Historical traces of the past can still be clearly seen in the landscape, forming a unique cultural heritage (Vollmer et al, 2001).

Infrascape

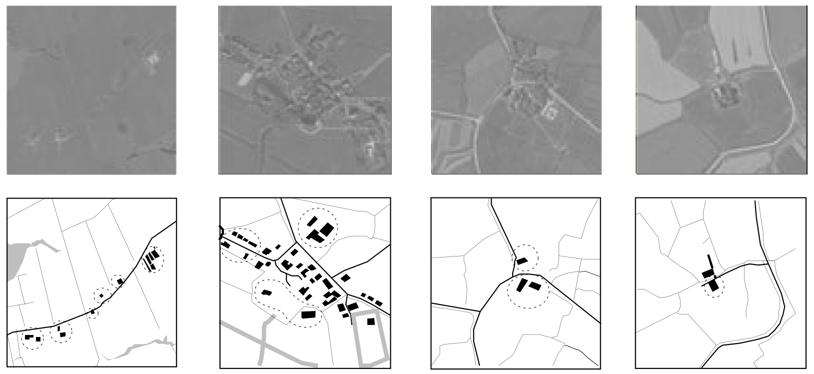
Wind Mill | Old Sea Dike

Waterscape



Major Canal | Secondary Canal | Minor Waterway

Terpscape



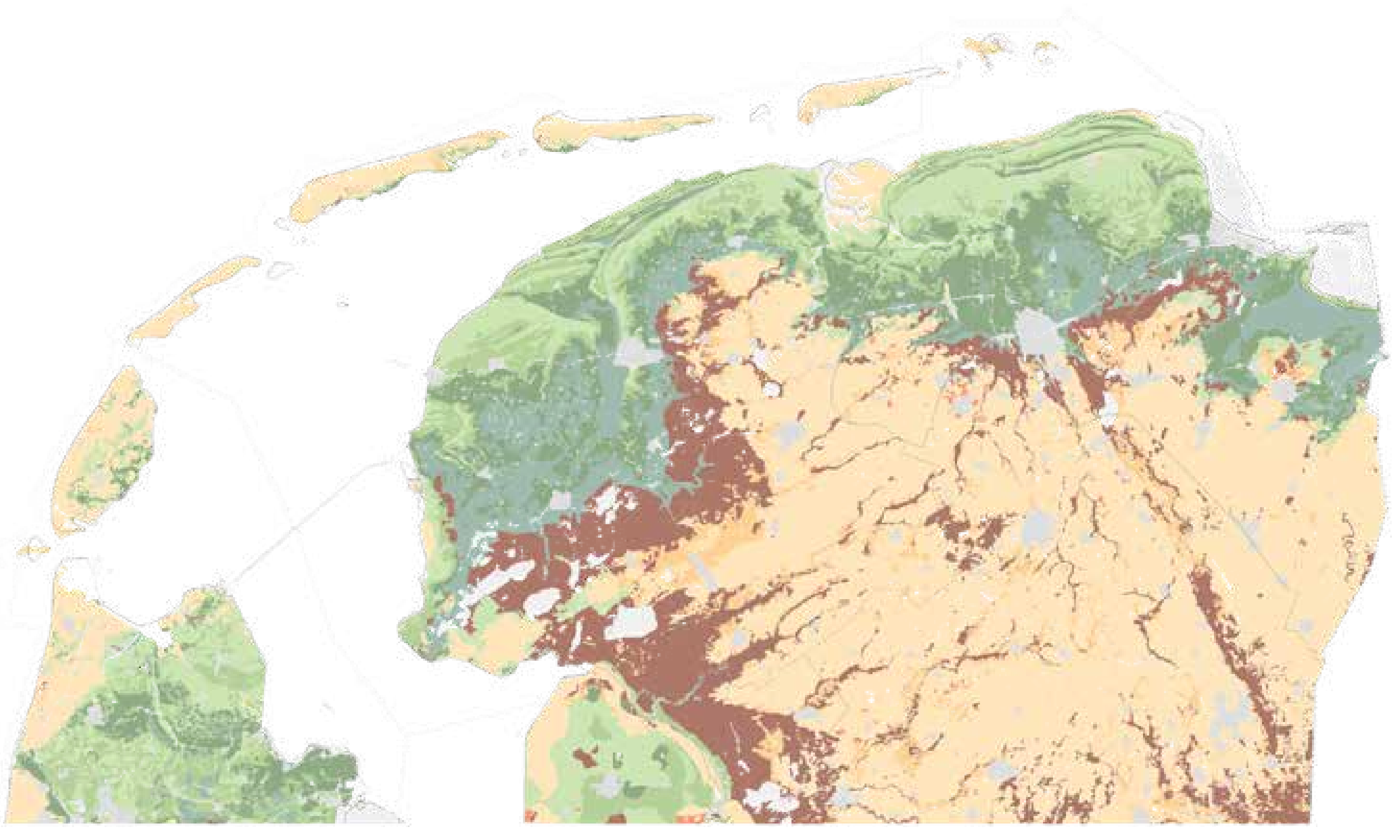
Terpichelago | Multi Isle | Double Isle | Isle

Terp Jannum.
Photo: Hanneke Wander, 2022.

Friesland Peatscapes.
Photo: Anna Gorokhova, 2023.

Soil Structure

Data: Wageningen University, 2006.
Image: Hanneke Wander, 2022.



Sabulous clay
Light clay
Heavy Clay
Peat
Sand

0 10 km 30 km

The marine clay soil belt spans the Wadden coast and is much higher than the subsided Wadden hinterlands.

As a result of geomorphological development and natural anthropogenic causes, the soil structure of Friesland and Groningen corresponds to that of the Wadden Sea due to the '*penetration of tidal creeks, which drained and lowered the peat, leading to further subsidence, while the marine clay soils deposited at the coast created a naturally elevated coastal clay belt*' (Oost al, 2017).

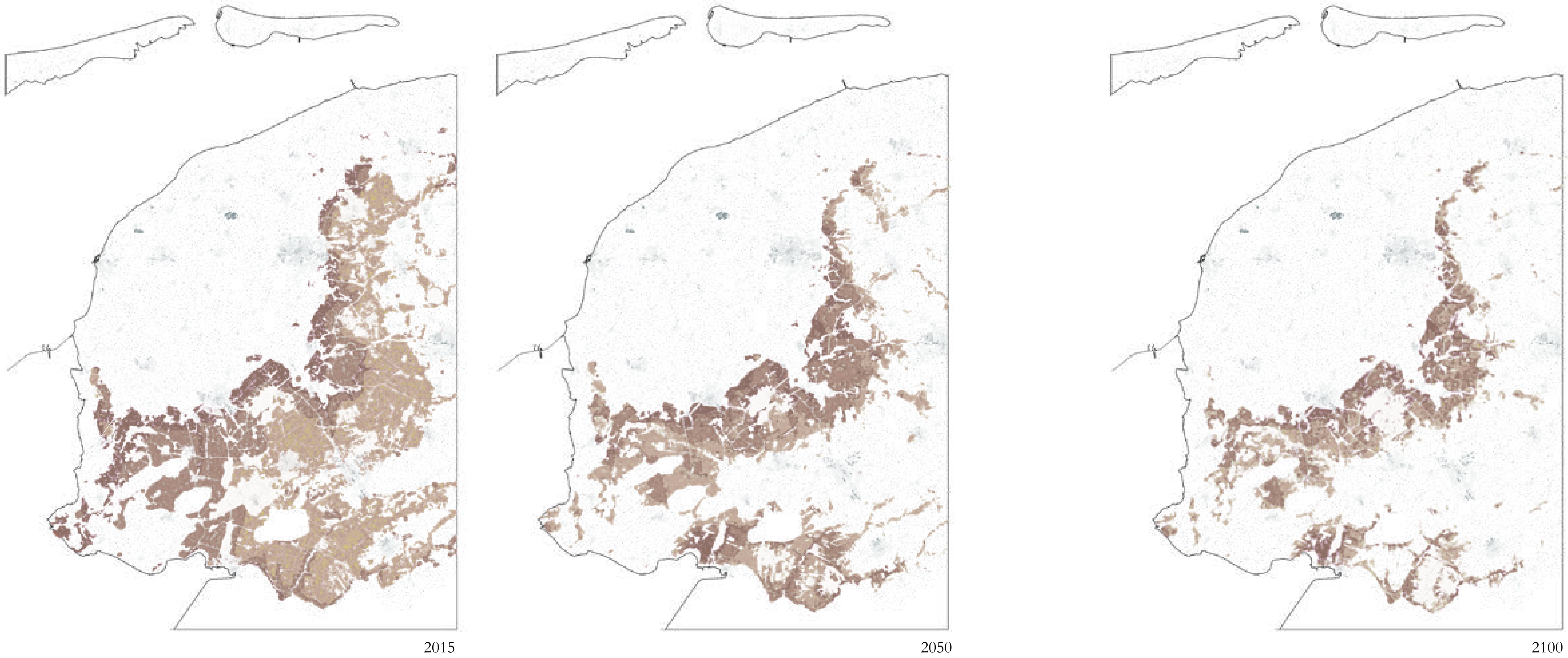
The Dutch geomorphological development and soil structure reveal the Frisian cultural history. As people settled in the salt marshes of Friesland and Groningen in 600 BC, they would inhabit the area temporarily, only during summers. They would retreat to their old villages in the elevated sandy soils during winter to avoid storm surges (Vollmer et al, 2001). Arable farming was complicated as salty storm surges would be disastrous for arable crops. The settlers relied on livestock that they would bring with them and temporarily grew crops until the next storm surge would destroy the harvest (Vollmer et al, 2001). With the embankment of salt marshes, arable agriculture was no longer in danger, and people started to settle permanently. To fight the increasing sea level rise and the threats of storm surges and flooding, the settlers raised their settlements, which are now surrounded by vast agricultural landscapes (Vollmer et al, 2001).

Peat Oxidation

Data: Wetterskip Friesland, Province of Friesland, 2021.
Images: Anna Gorokhova, 2023.

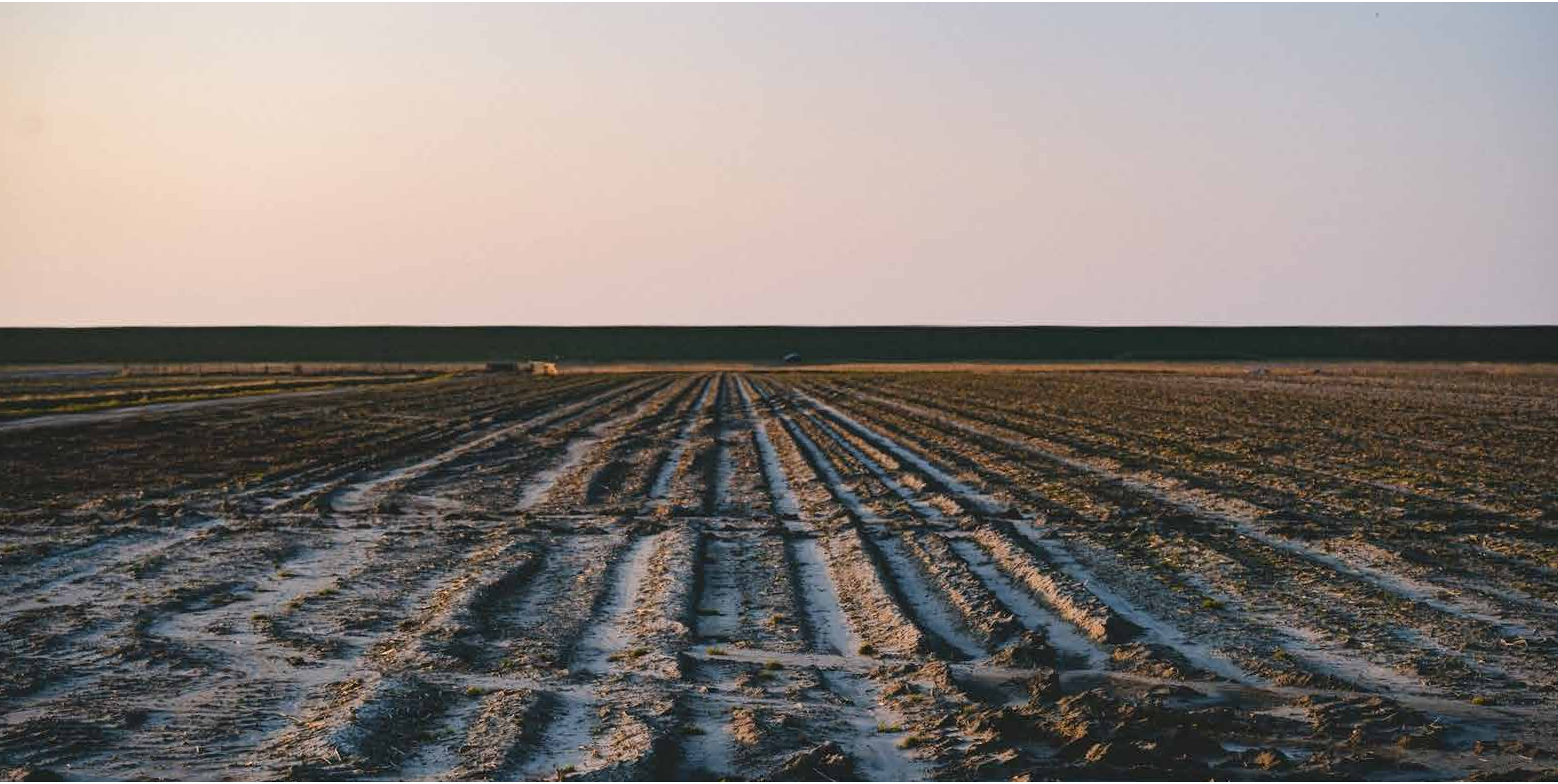
One of the most significant climatic impacts of agriculture due to the draining of excess water is peat oxidation. '*Peat soils cover only 3% of the world's land surface but store one-third of the world's soil carbon*' (de Jong et al, 2021). As '*the water table is lowered for making peat more suitable for cultivation, drainage exposes peat to oxygen, which causes it to decompose and reduce in volume rapidly*' (de Jong et al, 2021). The loss of the peatscape is expected to impact climate change through peat oxidation, during which CO2 emissions are released into the atmosphere. The Dutch government predicts that the unsustainable process of draining excess water in peat landscapes will most likely result in the massive loss of the peatscape (Wetterskip Friesland, Province of Friesland, 2021). '*Drained peat soils emit, on average, 19 tons of CO2/ha/year*' (Brouns et al, 2015). The government has attempted to tackle peat oxidation by raising groundwater levels and other strategic activities (Wetterskip Friesland, Province of Friesland, 2021).

'*Peat subsidence and change in peat properties have been widely observed after drainage, which further accelerates microbial decomposition and carbon loss*' (Zhong, Jiang and Middleton, 2020). '*It has been predicted that the peat areas will subside between 40 and 60 cm between 1999 and 2050*' and is very likely to significantly reduce in size and disappear in the coming 100 to 200 years (Brouns et al, 2015).



0 | 10 km | 30 km

Water
Urban
Peat
Peat with Clay Layer <40cm
Peat with Clay Layer 40-50cm

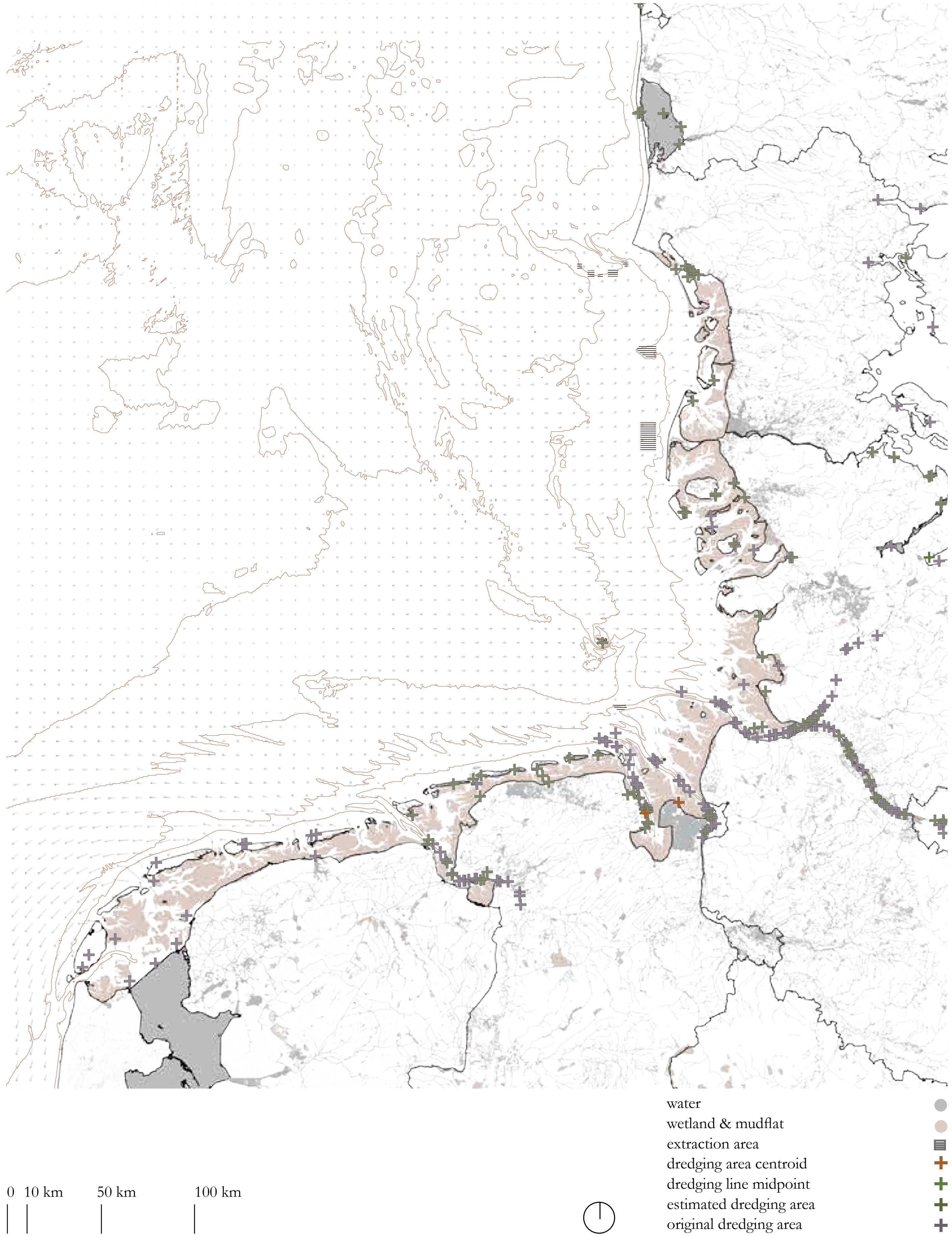


View of sea dike from the farmland.
Photo: Heather Wong, 2022.

Dredging and Dumping

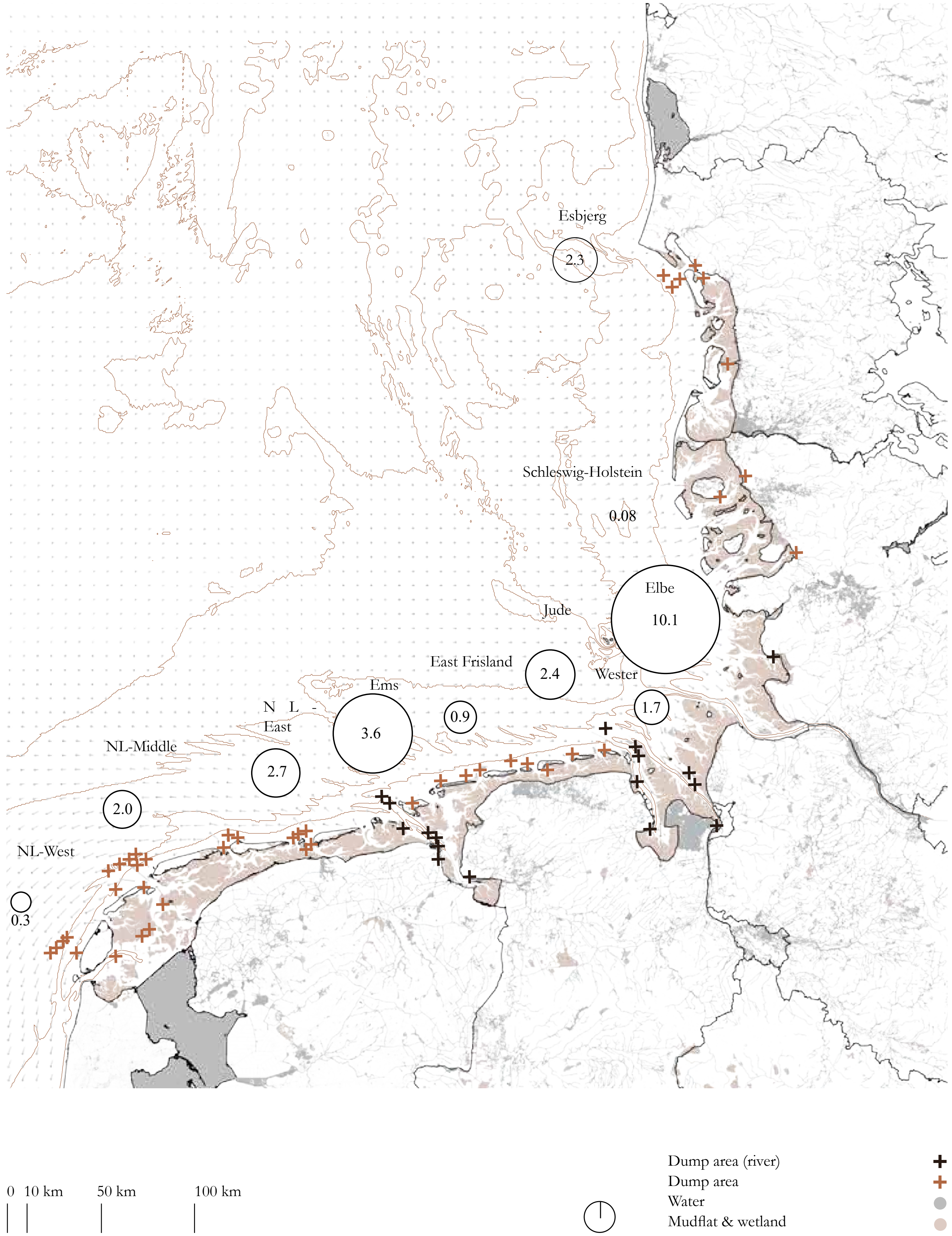
Data: pdok.nl, 2022.
Image: Zhaolei Li, 2023.

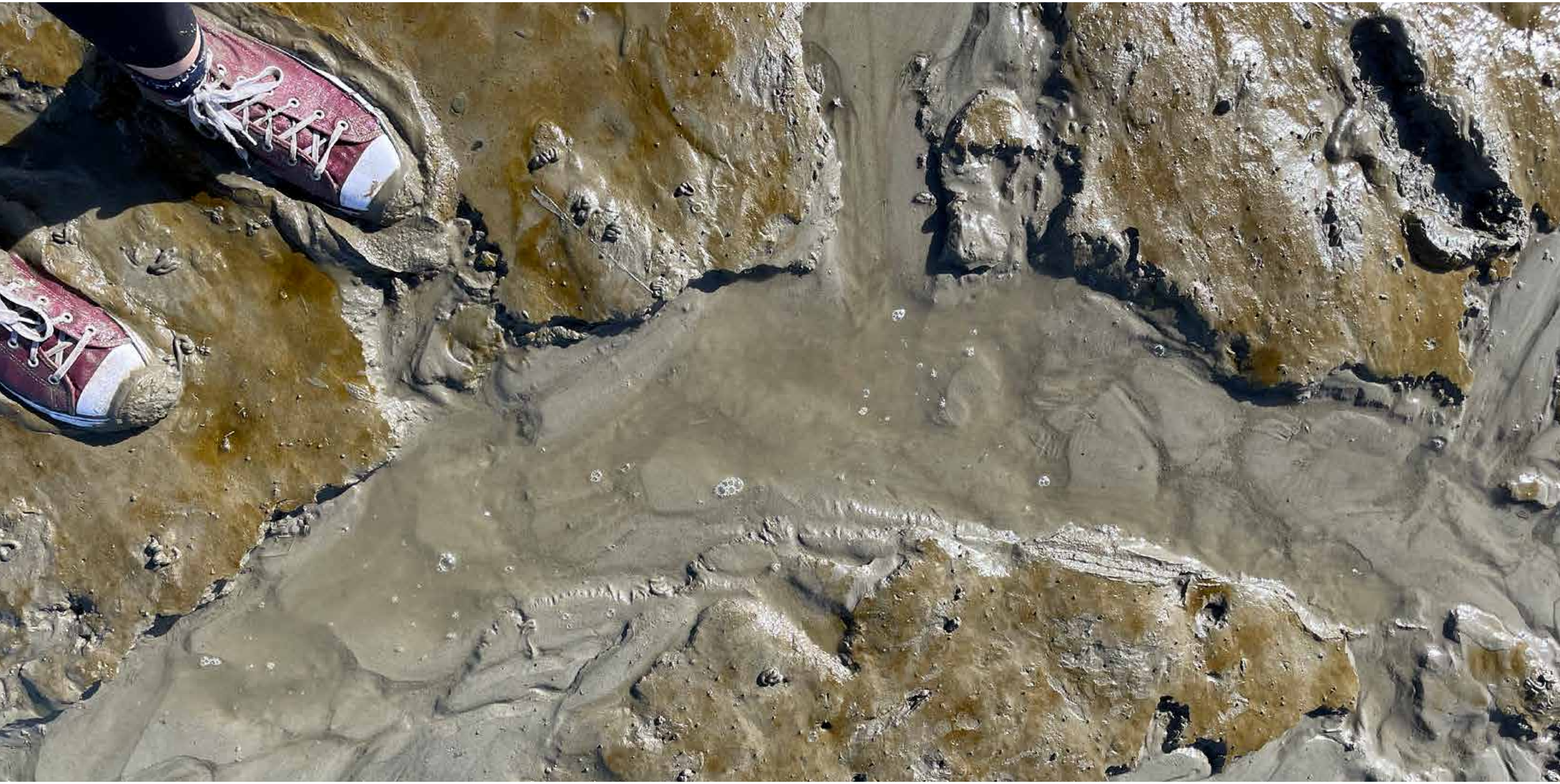
In 2009, the dredged material dumped into the Wadden Sea was 23. 900,000 t/yr, of which 18.5000,000 t/yr was dumped into the German part, 3.4000,000 t/yr into the Dutch part, and 2.9000,000 t/yr into the Danish part (Marencic and Vlas, 2009).
The traditional method of dredging involved using a bucket dredger equipped with a large bucket or scoop that excavates the underwater sediment and deposits it elsewhere. Since the 1970s, dredging operations have been performed by a suction dredger that employs powerful pumps and suction pipes to remove sediment from the bottom. Both dredging methods have impacts on ecological quality: they disrupt habitat, harm benthic organisms, and stir up sediment, which can affect water clarity and quality. Today, dredging and dumping are decreasing, new technologies are being used, and people stir mud in the water without digging it out. However, this also leads to too much soil being suspended in the water, resulting in the water body becoming increasingly turbid and ecological conditions being affected.



Dredging and Dumping

Data: Nehls and Witte, 2009; pdok.nl, 2022.
Image: Zhaolei Li, 2023.

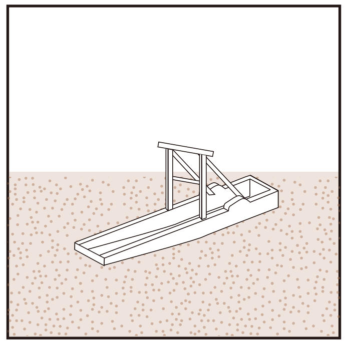




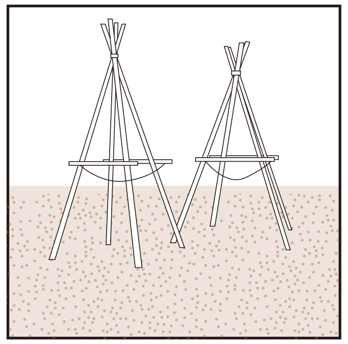
The Wadden Sea at Ebb.
Photo: Hanneke Wander, 2022.

Mud Recreation and Perception

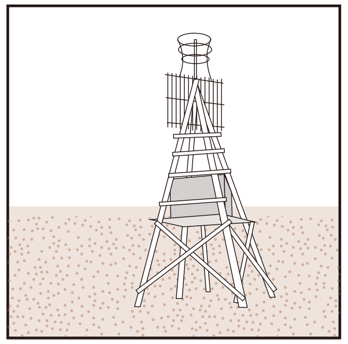
Data:Wadgidsenweb, 2020.
Image: Zhaolei Li, 2023.



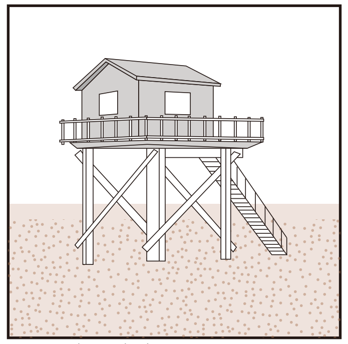
Mud Sled



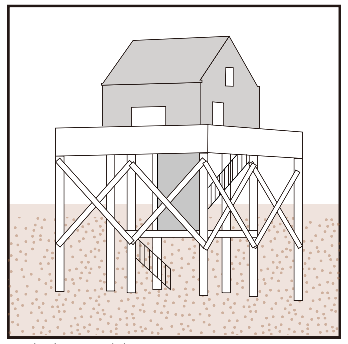
Wad stool (Wadstoel)



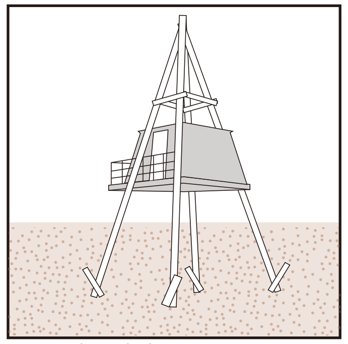
Cape with Shelter



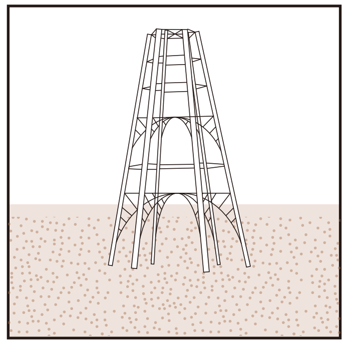
Drowning Shelter



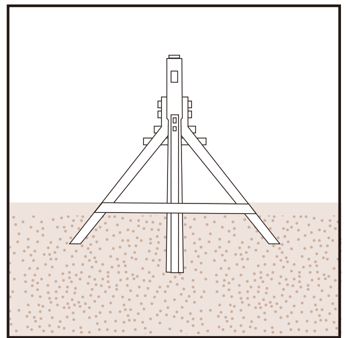
Bird Watching House



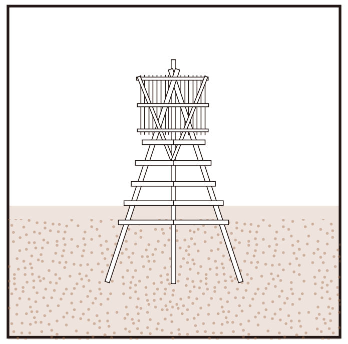
Drowning Shelter



Emder Kaap van Rottumeroog



Boundary Post



Cape

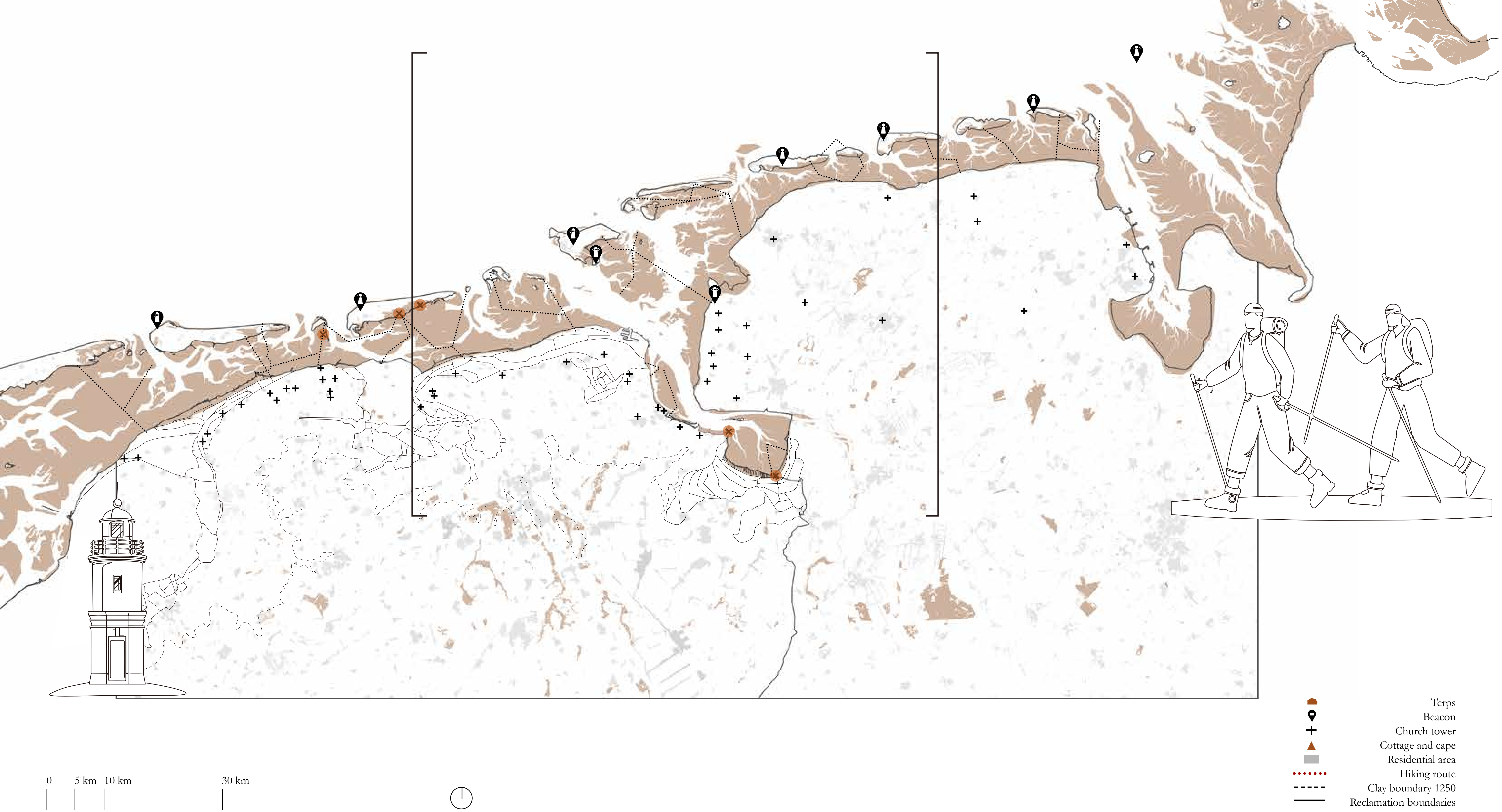
Many multiple mud routes and related facilities are present in the Wadden Sea for recreational purposes.

0 10 km 25 km 50 km

Hiking route

Mud Recreation and Perception

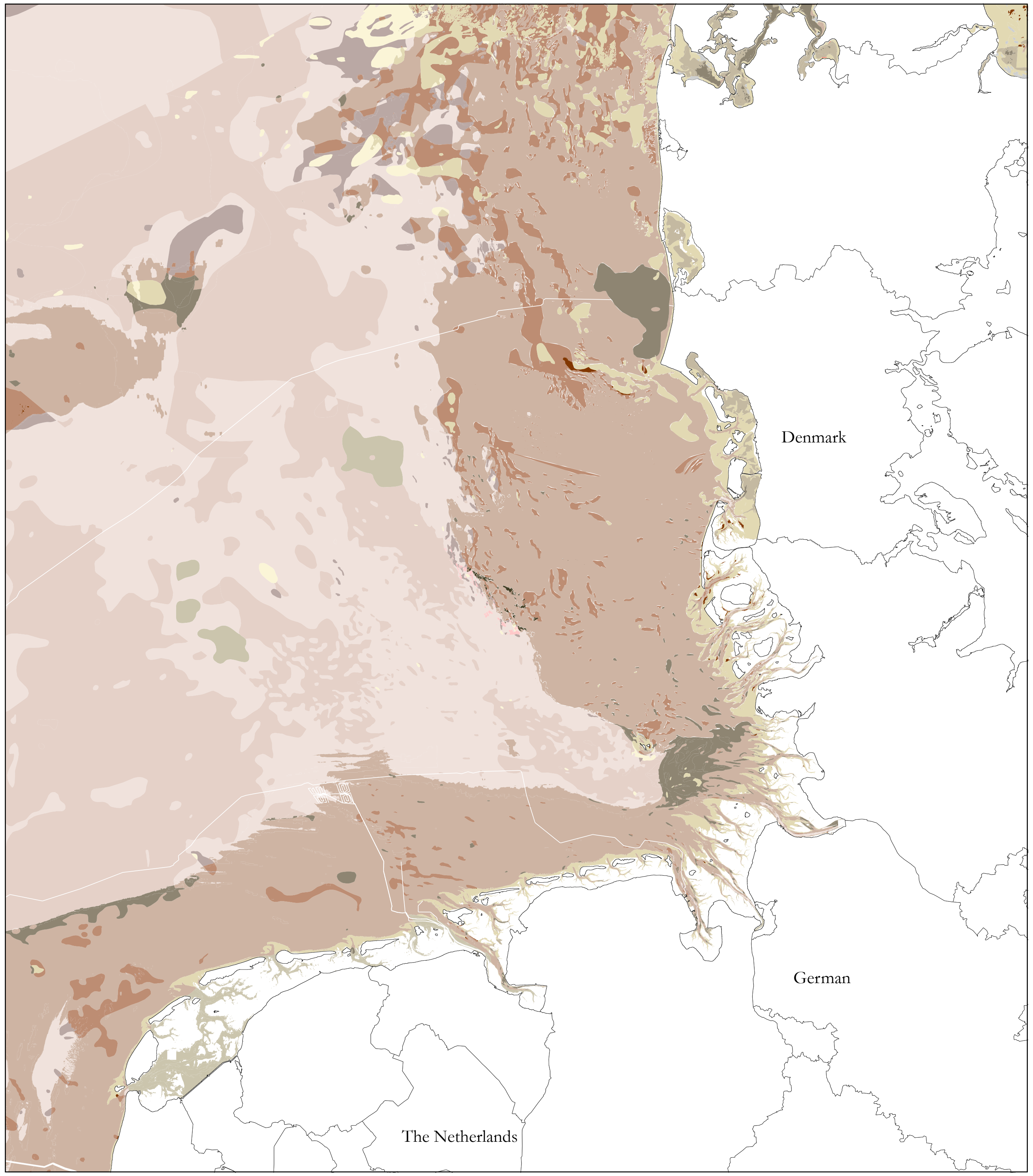
Structures and hiking route on the mudflats.
Data: www.wadgidsenweb.nl. Image: Zhaolei Li, 2023.

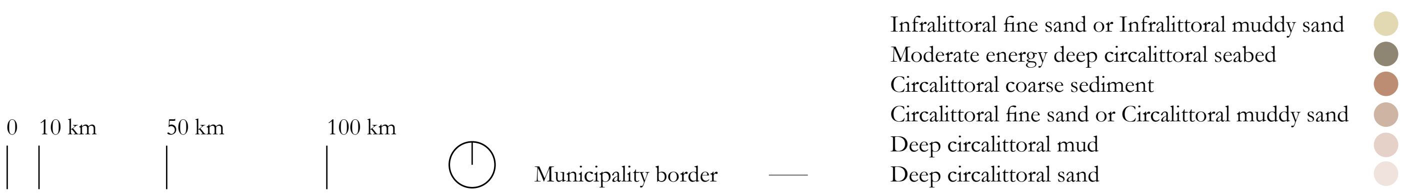


Seabed Habitat

Data: The European Marine Observation and Data Network, 2022.
Image: Xinjian Jiang, 2023.

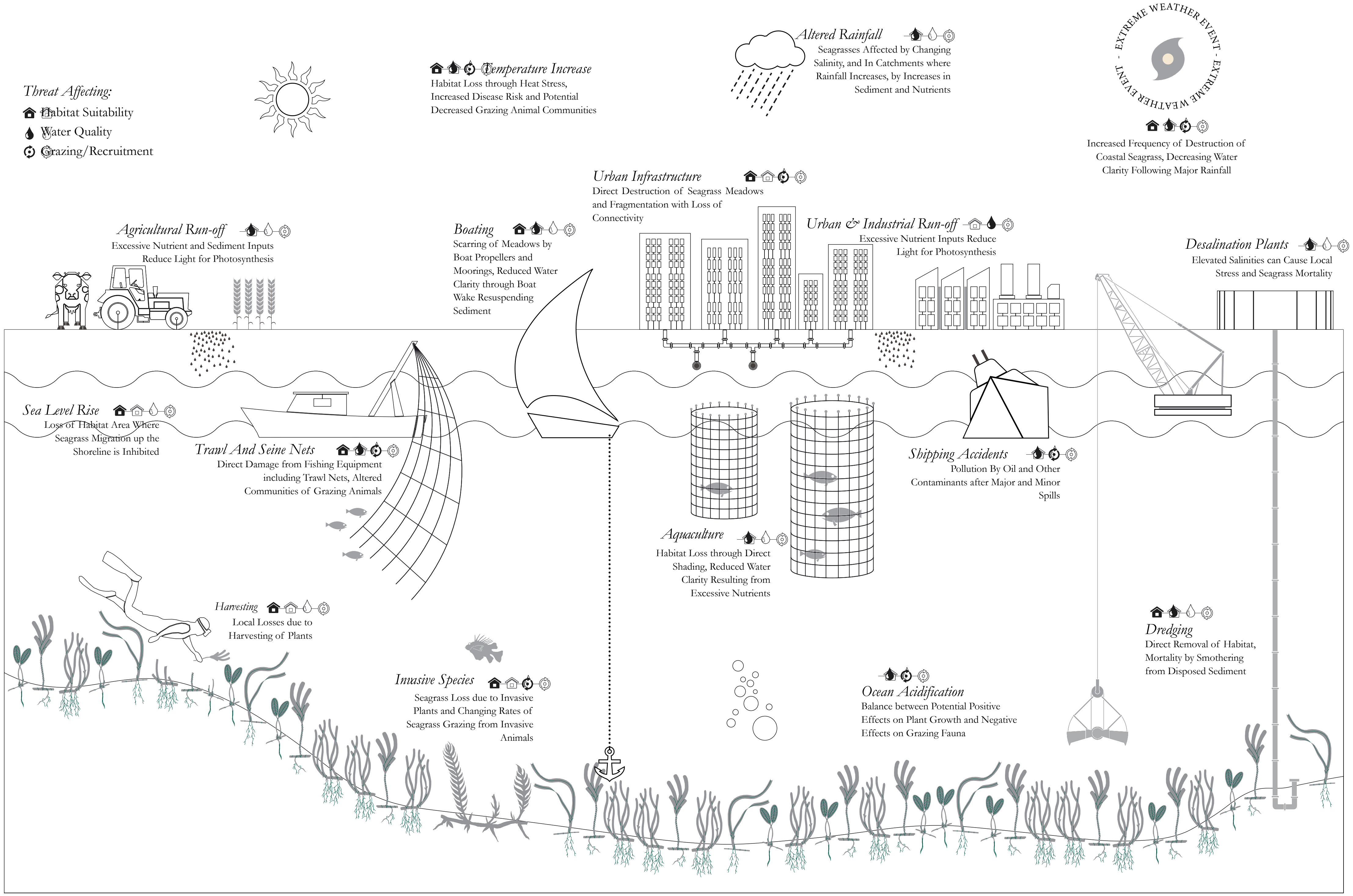
The Wadden Sea provides habitats for up to 10,000 species (de Jong, 2015) and is crucial for fishes and migratory waterbird species that use the East Atlantic Flyway for staging, molting, and wintering.
This image displays the seabed habitat, the seafloor, whose knowledge is crucial to protect the marine environment. In this case, data are related to energy infrastructure (in white).





Seagrass Ecosystem Survices

Data: United Nations Environment Programme, 2020.
Images: Xinjian Jiang, 2023.



In the Wadden Sea, seagrass grows mainly in sheltered areas near islands and high sands. Seagrass ecosystems are incredibly important coastal habitats that provide a wide range of functions and benefits to both marine life and human communities, such as:

- habitat and nursery grounds for a diverse array of marine species
- biodiversity support hosting a variety of plant and animal species
- carbon sequestration helping to mitigate climate change
- coastal protection by stabilizing sediment and reducing
- oxygen production, contributing to the oxygenation of coastal waters and supporting aerobic respiration in marine organisms
- economic value since seagrass ecosystems provide significant economic benefits to coastal communities through fisheries, tourism, and recreational activities.

Sea level rise or extreme events (e.g. dry summers) could threaten seagrass in the future.

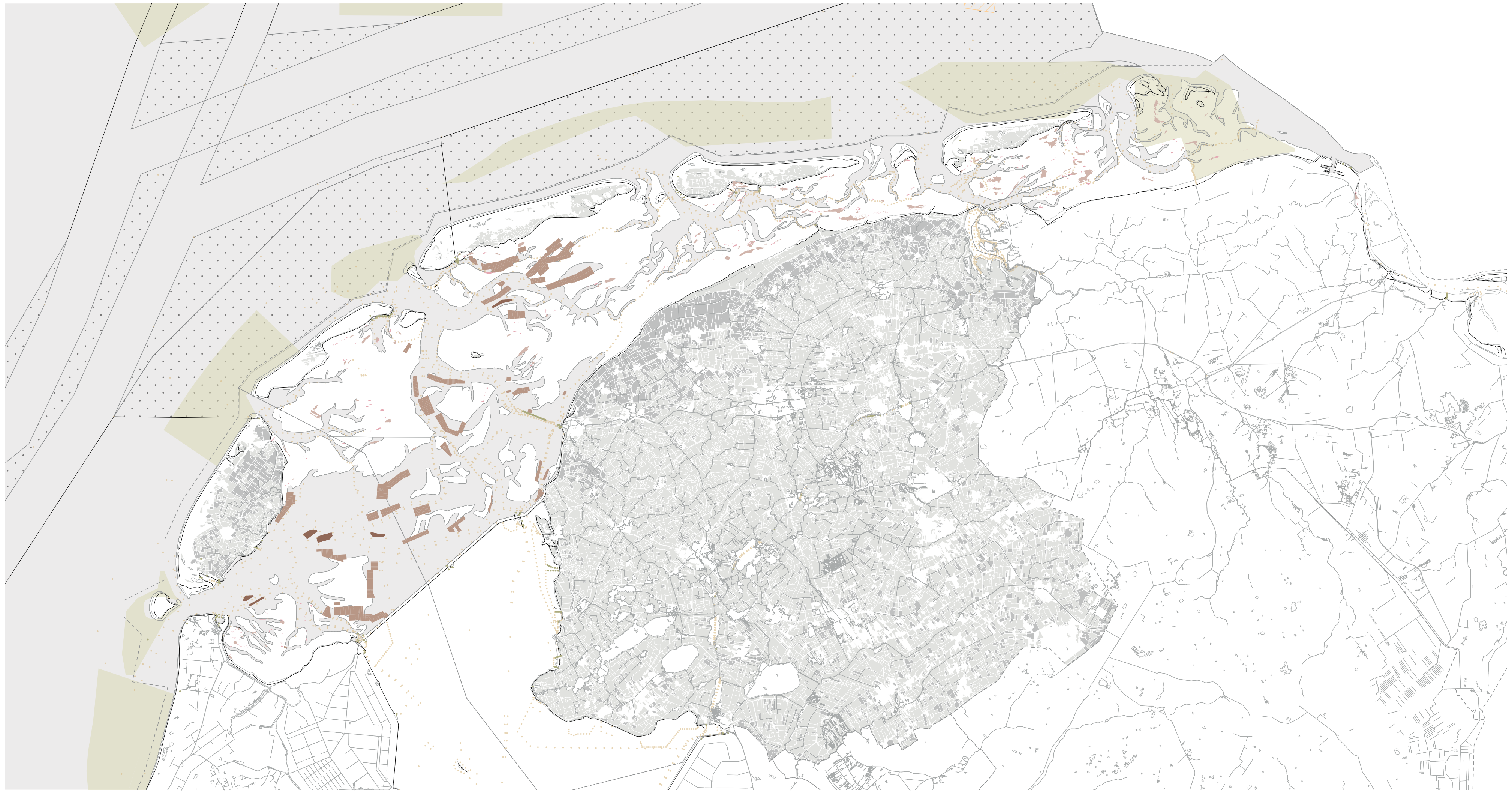
Agricultural Land Use

Data: BRP Gewaspercelen, pdok.nl, 2022.
Image: Hanneke Wander, 2022.

Subsidies implemented by the EU and Dutch governments significantly impacted the recent expansion of Frisian agricultural land (Plantinga and Molema, 2020). The abolishment of the 'milk quota' in 2008, which aimed to control the development of the dairy market, further contributed to the upscaling of agriculture (Plantinga and Molema, 2020). Abolishing all quotas resulted in the growth of average farm sizes and megafarms, significantly dropping the number of farms in Friesland. In 2021, 77% of the Frisian landscape was dedicated to agriculture. Nearly 1 million m2 of land is attributed to seed potato production, while dairy cattle use up to 500,000 m2 (Centraal Bureau voor de Statistiek, 2022).

The soil structure of the region influences the land use of the area. The clay soils are highly fertile when compared to the peat and sandy soils of the hinterland, turning the coast into a 'potato valley' as it is the main crop produced on the fertile shore. The inland area of Friesland is used mainly for dairy farming, with occasional corn and fodder grass production (Municipality of Groningen, 2023).

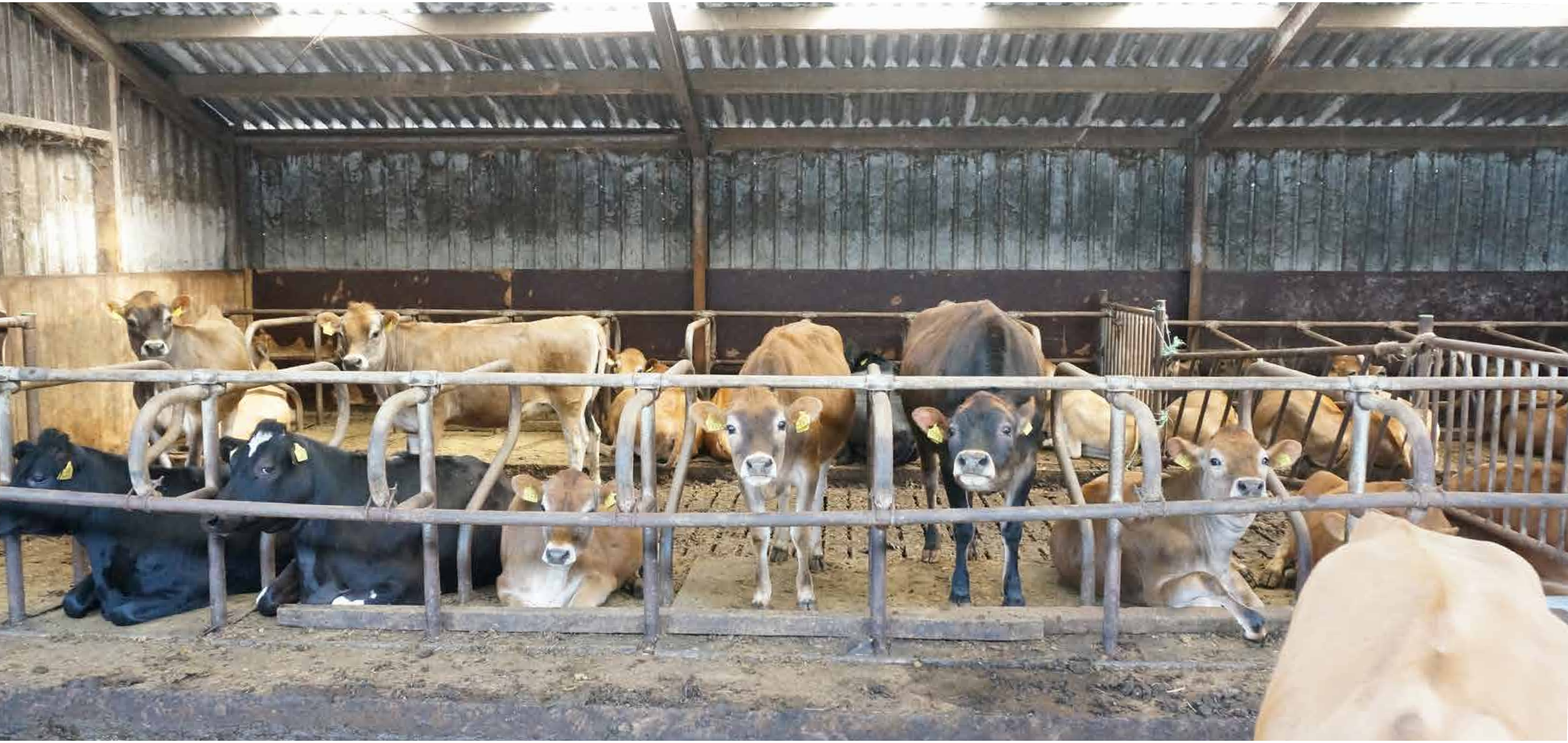
The abolishment of all the implemented restrictions created an economic environment in which the upscaling of agriculture became significantly more accessible. Currently, Friesland and Groningen are among the largest exporting provinces for markets outside of the EU. Overall, 23% of all seed potatoes in the world come from Groningen (Municipality of Groningen, 2023). In 2021, Friesland had the highest population of dairy cows in the country (Centraal Bureau voor de Statistiek, 2022). This upscaling led to larger farms, turning the small family-led businesses into mega agrarian corporations.



0 10 km 30 km

Fixed waterway marks
Floating waterway marks
Traffic separation scheme
Crop production
Grasslands

Anchor areas
Closed areas for fishing
Mussel and oyster habitats
Shellfish plots
Mussel seed capture installations



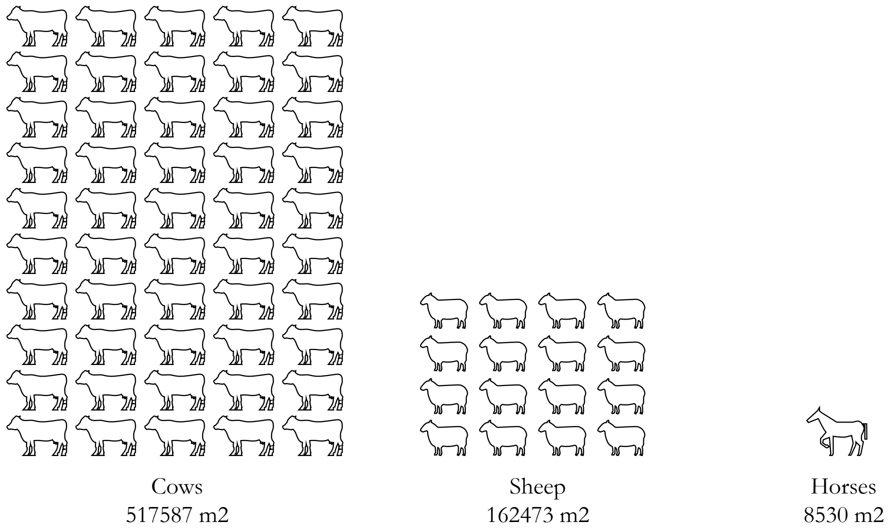
Cows in the barn at Hans Kroodsma's farm.
Photo: Hanneke Wander, 2022.

Agricultural Land-Use in Friesland

Crop production is highly concentrated on the higher clay formations along the coast of Friesland. Here, agricultural production consists of a large proportion of potatoes, grains, and sugar beets. The other part of Friesland consists mainly of grasslands—a highly typical characteristic of the province—primarily consisting of open landscapes with long sight lines.

Upon analyzing statistics for the whole of the Netherlands, it can be seen that the total area of the Netherlands is 4,152,800 hectares. In 2000, a total of around 48% was in use for agriculture. The total percentage of agriculture is slightly declining; for example, in 2016, approximately 43% was still used for agriculture (Nederlandse Akkerbouw, 2017).

In the province of Friesland, the agricultural sector makes up most of its land use. Overall, 77% of land in Friesland was being used for agriculture in 2017, which is well above the Dutch average of 43% in 2016. Also, the province has experienced a slight decline in agricultural land use. Over the last 15 years, this use has decreased by nearly 3%. In most cases, agricultural land was transformed into urbanized, recreational, and natural areas (Nederlandse Akkerbouw, 2017).



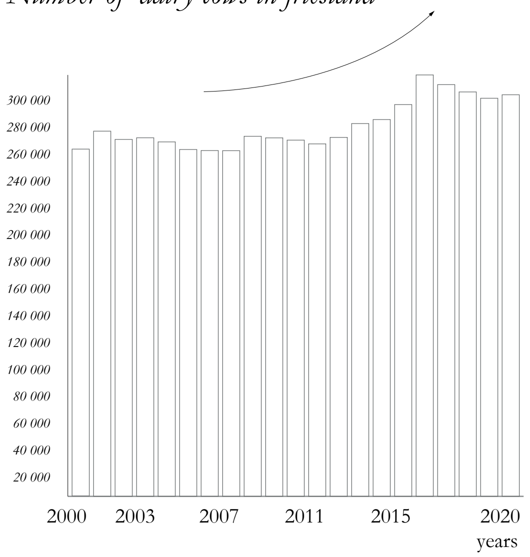
Number of farm animals in Friesland.
Data: CBS, 2022.

Farm along the Wadden Coast.
Photo: Heather Wong, 2022.

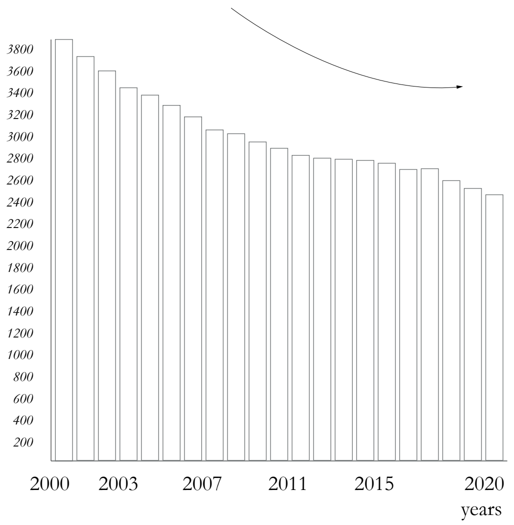
Upscaling and Higher Profits
Data: CBS, 2020.

The number of farmers in the Netherlands has decreased rapidly over the last 16 years. Simultaneously, the average farm size and its production are increasing. In 2000, there were 97,390 farmers in the Netherlands, while in 2016, 55,680 farmers were remaining (Nederlandse Akkerbouw, 2017). The same trend can be seen in Friesland. The number of dairy farms fell sharply in this province: from just under 4,000 farms in 2000 to 2,772 in 2017. During the same period, the average number of cows per dairy farm grew enormously, from an average of 65 to 114 cows per farm. In 2016, there was a trend break, and the number of cows per farm fell again. This is related to measures taken against the phosphate surplus (Plantinga and Molema, 2020).

Number of dairy cows in friesland



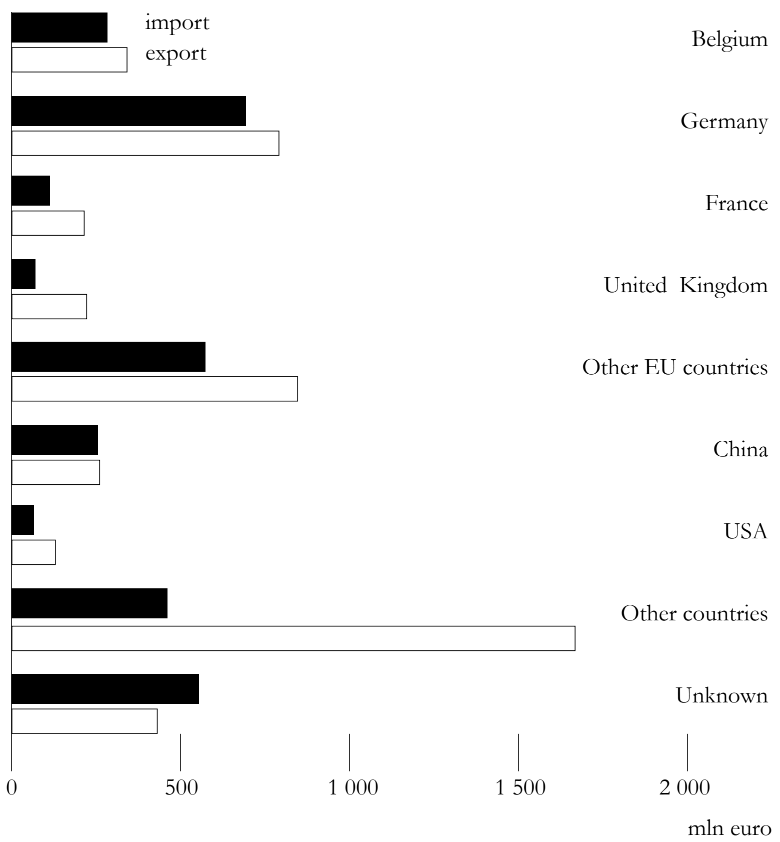
Number of dairy farms in friesland



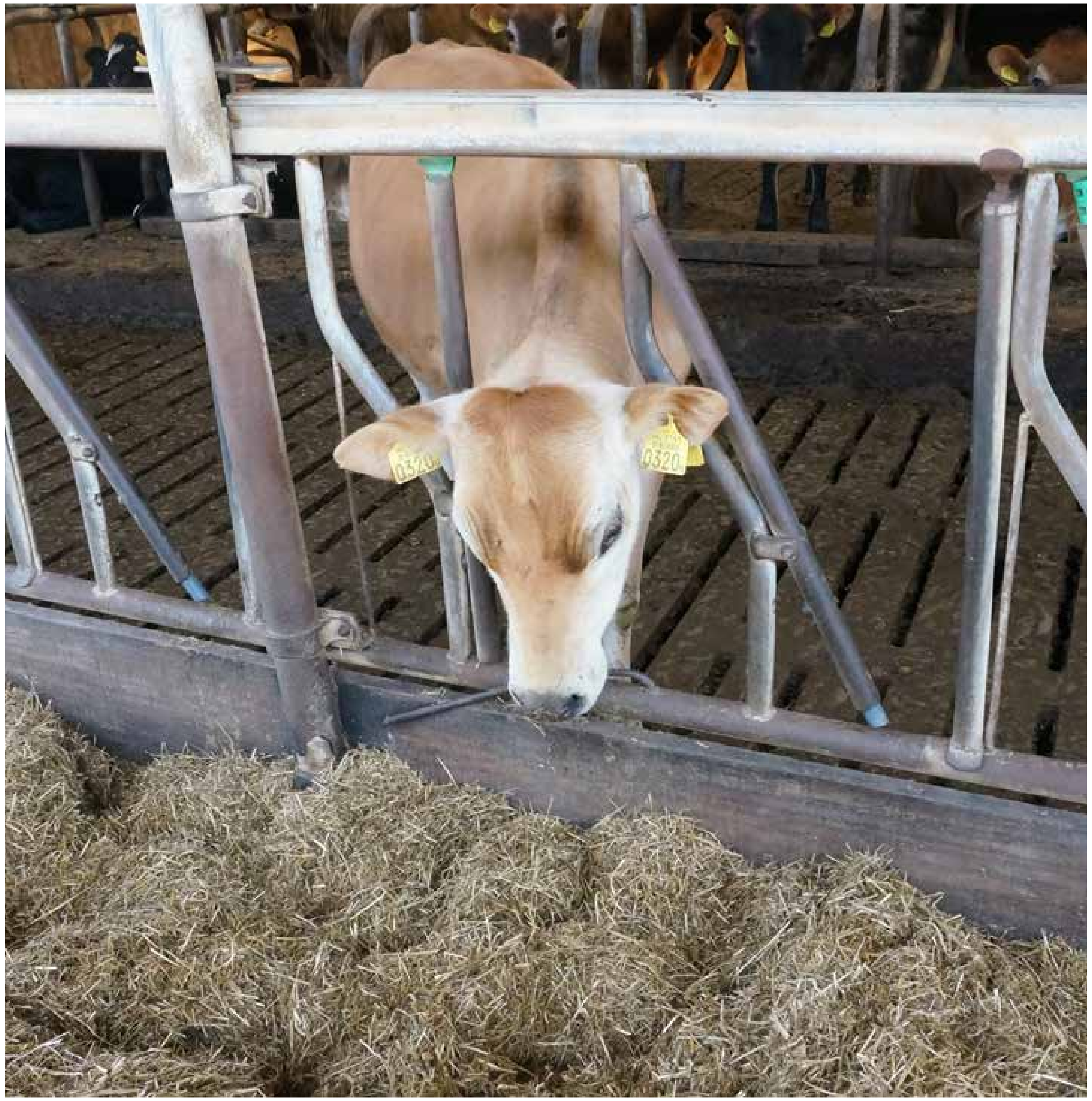
Friesland Farm.
Photo: Anna Gorokhova, 2023.

International Goods Trade from Friesland by Country

Of all the Dutch provinces, Fryslân exports the most to countries outside the EU. This encompasses nearly half of everything that is exported—mainly dairy products. Nationally, this involves nearly 28% of all exports (Centraal Bureau voor de Statistiek, 2016a). For Fryslân itself, the export of agricultural products is of great importance. In 2017, the total export value amounted to more than 2 billion euro, corresponding to 39% of the province's total export value (Centraal Bureau voor de Statistiek, 2016b).



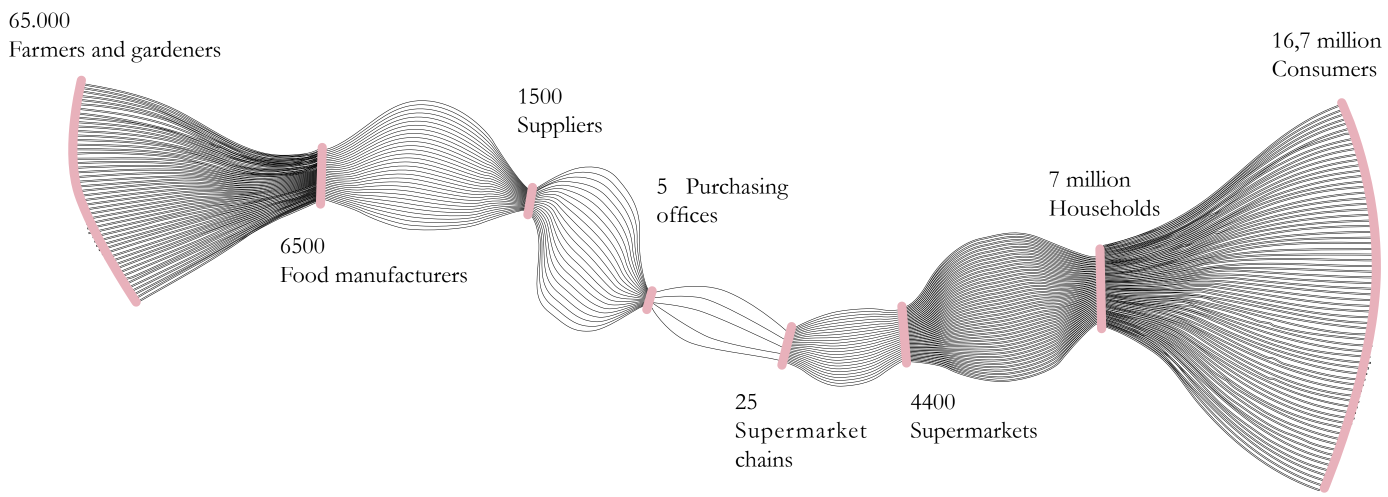
International goods trade from Friesland to country expressed in million euro
Data: Factsheet Friesland, CBS, April 2016.



Young milkcow at Hans Kroodsma's farm.
Image: Hanneke Wander, 2022.

Distance Between Consumers and Farmers

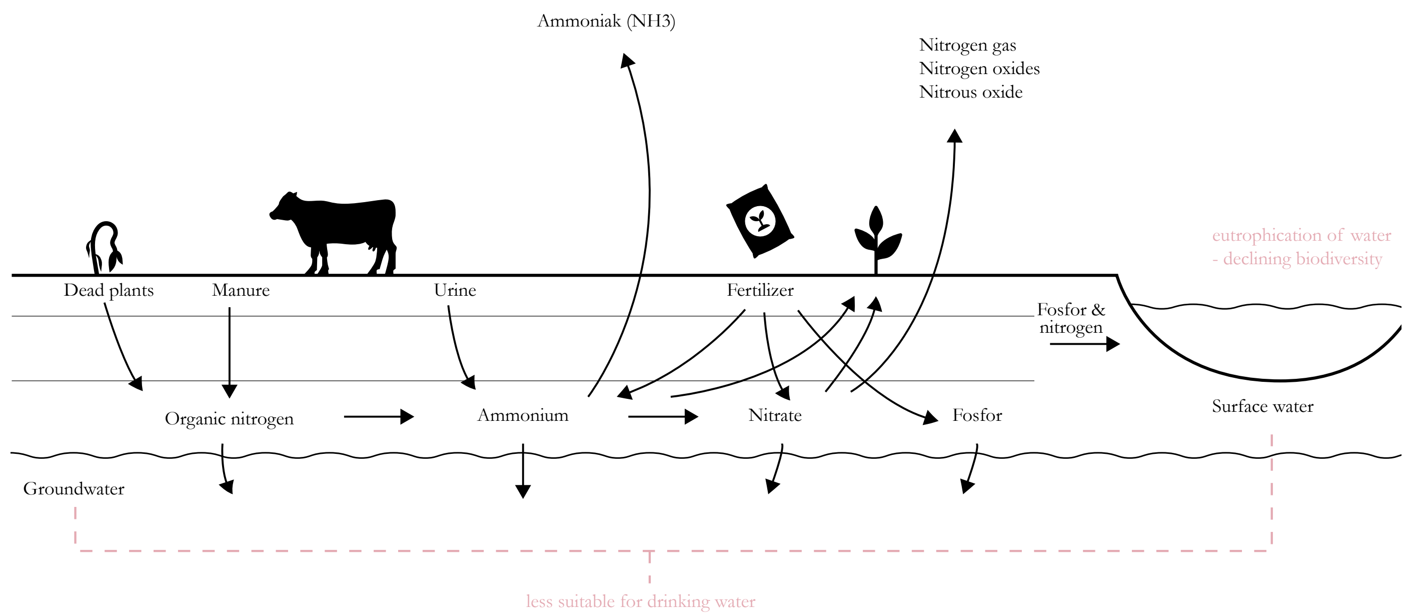
The human connection within the food system has been increasingly lost in recent decades. Due to the many middlemen and traders, consumers often have no idea who made their food or where it comes from. As a result, they also fail to see the social and ecological implications of the production process. Consumers may pick up the cheapest carton of milk from the supermarket shelf. Still, they do not realize that this creates a monotonous, low-diversity landscape to produce this milk as cheaply as possible. On the other hand, farmers often do not know where their products end up or what a consumer is willing to pay for a certain quality. Margins are tiny, and the only thing the farmer can often compete on is price (Fairfood, 2020).



The middle parties between farmers and consumers. Source: Planbureau Leefomgeving, 2012. Image: Hanneke Wander, 2022.

Nitrate and Phosphorus Surplus

Nitrate and phosphorus surplus refers to the excessive accumulation of these nutrients in the environment, particularly in water bodies, which can lead to various ecological and environmental problems.
The diagram shows how nitrate and phosphorus surplus, primarily originating from agricultural runoff, wastewater discharge, and industrial activities, can lead to eutrophication, a process in which an overabundance of nutrients stimulates the rapid growth of algae and other aquatic plants.



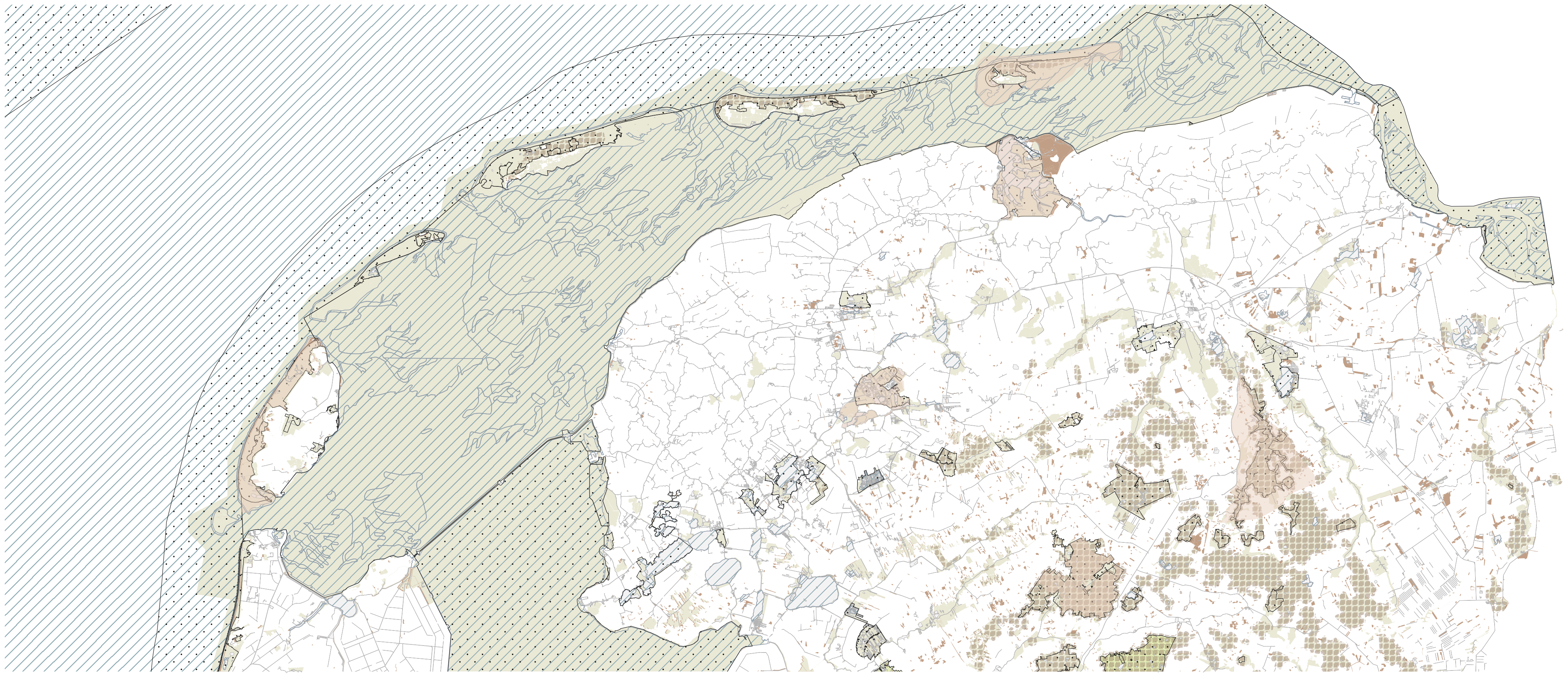
Processes in the ground resulting from manure and fertilizers. Source: RIVM, 2020. Image: Hanneke Wander, 2022.

Nature Network

Data: Nationaal Georegister, 2020.
Image: Hanneke Wander, 2022.

Despite nature networks being present in Friesland, these areas are scarce. A harsh line divides the protected nature area of the Wadden Sea, which became a UNESCO World Heritage in 2009, with Friesland behind the sea dike. Biodiversity loss, water pollution, and a lack of ecological corridors are consequences of the current monocultural agricultural practices.

Natura 2000 is a European network of protected nature areas to preserve biodiversity. Biodiversity in Europe has been under pressure for years. Therefore, the EU decided that the sustainable protection of flora and fauna is desperately needed. In this way, nature preservation is managed at the European level. All EU Member States designate protected areas for specific habitats of animal species. These form the Natura 2000 network (Ministry of Agriculture, Nature and Food Quality, 2020).
All Natura 2000 areas are part of the Nature Network of the Netherlands (NNN). The NNN includes further existing and planned nature areas and safeguards the quality of the natural values present. The protection of the Natura 2000 areas is stricter than that of the NNN since the latter does not have European targets set for preserving species and habitats (Provincie Zuid-Holland, 2020).



Nature areas outside NNN
National parks
Wav (Ammonia and Livestock Farming Act)
Main water bodies
Natura 2000
Dutch Nature Network (NNN)

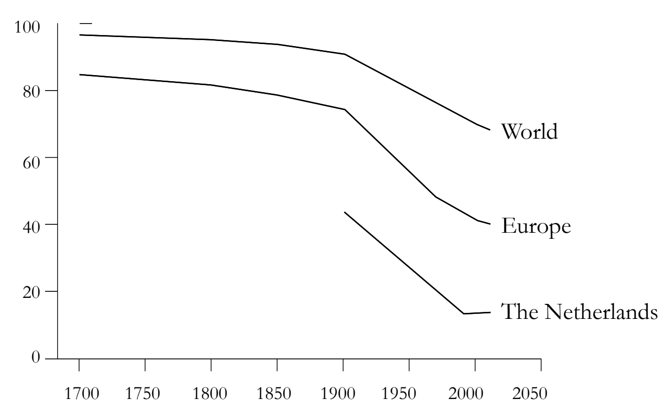
0 10 km 25 km 50 km

Biodiversity on a Rapid Decline

Data: Environmental Data Compendium 2020.

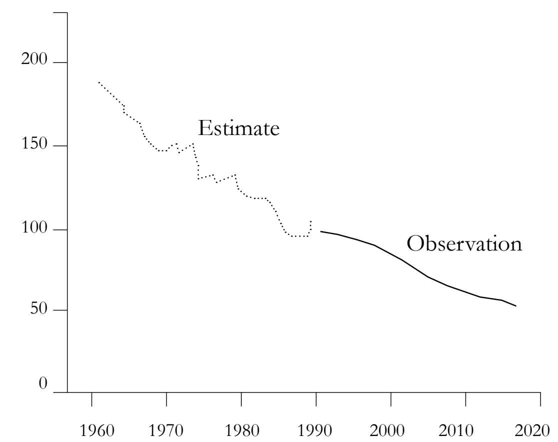
Biodiversity is the total variety of life on Earth and not only relates to individual species but also the diversity of ecosystems and their connections. Diversity increases the chance of survival when the environment changes. Biodiverse ecosystems are generally more resilient and thus able to cope with unpredictable conditions. Since biodiversity loss leads to increased vulnerability, the system can no longer perform its functions properly once disturbances occur. The World Food Organization has warned of the adverse effects on our food supply when sharp declines in biodiversity continuously occur (Erisman and Slobbe, 2019).
As seen in the graph below, biodiversity is at a record low in the Netherlands and well below the European average. Only 15% of the indigenous plant and animal species occurring in the Netherlands in 1900 have remained. Meanwhile, the European average is 40%. Few living habitats for species and intensive agriculture are the leading causes of this dramatic loss.
Moreover, this trend has translated to the populations of many native animal species, such as meadow birds, declining for years in the Netherlands. Numerous campaigns have been organized to raise awareness of this trend (Birger, 2020).

Biodiversity



Mean species abundance
% of reference

Meadow birds in the Netherlands



Meadow bird indicator

Loss in Landscape Diversity

Over the years, the agricultural landscape has been heavily transformed to be able to produce the highest possible agricultural yields. Diverse landscape elements have disappeared, including house animal species and essential habitats. Biodiversity loss and ongoing changes in agricultural practices have led to a more monotonous and monocultural landscape, replacing small-scale and diversified allotments. Consequently, these changes have also influenced the aesthetic qualities of the landscape.

Lapwing (Kievit) | Black-tailed godwit (Grutto) | Oystercatcher (Scholekster) | Redshank (Tureluur)

Friesland Peatscapes.
Photo: Anna Gorokhova, 2023.