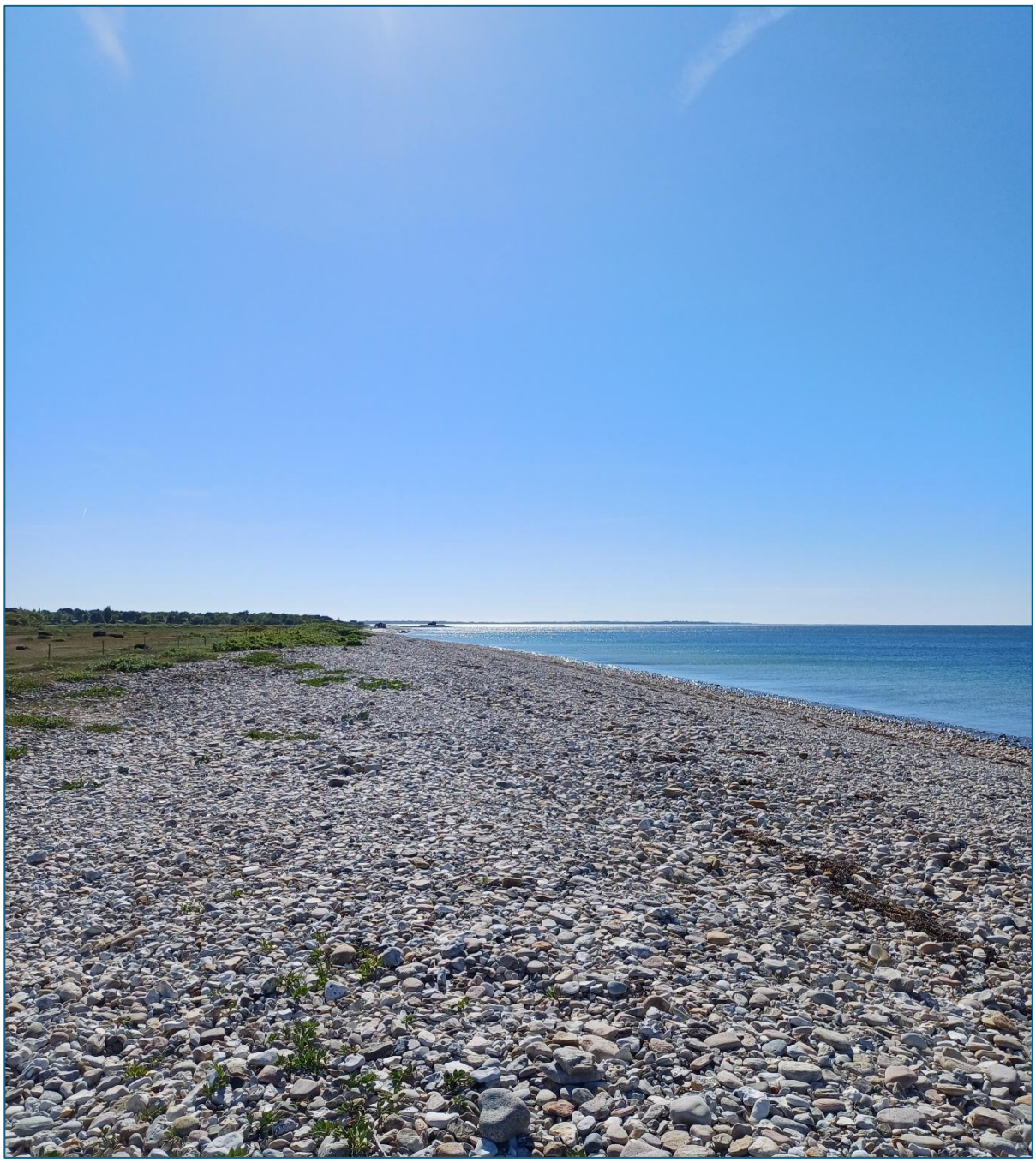

Odsherred Insights

Living Landscapes of Odsherred

5th Edition

10 May – 18 May 2025

GHENT UNIVERSITY

DEPARTMENT OF GEOGRAPHY

UNIVERSITY OF COPENHAGEN

Roskilde Universitet

Introduction

Every year, students in the Master of Science in Geography and Geomatics of Ghent University (Belgium) undertake a research trip abroad. Since 2021, the destination of this project work has been Odsherred, Denmark, in collaboration with Roskilde University and the University of Copenhagen. This fifth edition took place from the 10th to the 18th of May 2025 in Udsigten.

Apart from excursions in Odsherred and the surrounding areas, the research trip has included an intensive geographic fieldwork project where students actively investigate the local spatial dynamics in the more rural area of Odsherred. The overall aim of this project work is to enhance students' scientific and intellectual competencies in geography through critical literature reviews, research design, fieldwork (e.g., surveys and interviews with locals), data collection, scientific analysis, and oral and written presentations. The topics investigated are all self-defined research projects, applying skills from other courses in a context abroad. The project work emphasises an interdisciplinary approach, covering different aspects (physical geography, landscape research, social and economic geography, as well as geomatics).

The students were assisted by teachers and researchers from Ghent University, the University of Copenhagen, and Roskilde University, as well as people from Geopark Odsherred, the Municipality of Odsherred, and local organisations and inhabitants. Below you can find an overview of the different research projects that were undertaken.

1. Seascape character assessment

- Anna Deckmyn, Elise De Mulder, Jasper Depuydt, Xander Luyckx, and Maurien Stroobant -

Where land meets sea: Seascape character assessment of Odsherred, Denmark.

2. Potential natural vegetation

- Mortada Benayad, Pieter Denoo, and Armani Passtoors -

Before the plough: Mapping potential natural vegetation – Rewilding potential based on geotopes in Odsherred, Denmark.

3. Flood risk and perception

- Sander Clemmens, Tijs Depoorter, Joren Garré, and Laurien Vetsuypens -

Down the drain: Evaluating the flood risk and perception in Odsherred, Denmark.

4. Urban development

- Tomas Week, Lennart Freriks, Arno Pottie, and Lukas Van Lishout -

From ny to new: Reimagining Nykøbing's urban future – Exploring urban redevelopment opportunities for an aging population.

5. Friluftsliv

- Remi Demeulemeester, Thomas De Visscher, Manon Dhelft, and Joren Trybou -

All paths lead to nature: PGIS survey analysis of friluftsliv in Odsherred, Denmark.

The 5th Edition of the Odsherred Insights was made possible by the collaboration of many people from several organisations.

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Stakeholders that were involved:

The Municipality of Odsherred
Geopark Odsherred
All interviewed locals
Local organisations

Special thanks to:

Per & Katia from Udsigten

FACULTEIT WETENSCHAPPEN

MASTER OF SCIENCE IN GEOGRAPHY AND GEOMATICS

WHERE LAND MEETS SEA

SEASCAPE CHARACTER ASSESSMENT OF ODSHERRED, DENMARK

Word count: 10945

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1 INTRODUCTION

Coastal regions, such as the municipality of Odsherred in Denmark, are shaped by the dynamic interplay of land and sea, supporting diverse ecosystems, vibrant communities, and a rich cultural heritage (Krüger, 2021; Lemkow & Hansen, n.d.). Yet, despite their significance, the integration of marine environments into Landscape Character Assessments remains limited. Traditional approaches, including those previously applied in Odsherred (Lemmens *et al.*, 2024; Odsherred Kommune, 2012), largely focused on terrestrial features, often neglecting the sea as an active and characterizing element. This oversight is not unique to Denmark, but reflects a broader research gap in coastal and marine planning across Europe (Hill *et al.*, 2001; Natural England, 2012; LUC, 2014).

The omission of the sea from Landscape Character Assessments is particularly problematic in Denmark, whose identity and economy are closely tied to its coastline (Worm, 1997; Fitton *et al.*, 2020). The coast and sea are not merely a backdrop; they are a finite and contested space, increasingly subject to pressures from urbanisation, tourism, renewable energy and climate change (Cheret, 2021; Danish Maritime Authority, 2021). The development of Denmark's maritime spatial plan and the adoption of the Act on Maritime Spatial Planning in 2021, mark a shift towards integrated management and acknowledging the need for robust evidence on the character and value of both marine and coastal environments (MSP Country Fiche Denmark, 2024). However, effective planning and conservation of these environments are hindered by a lack of comprehensive and context-specific Seascape Character Assessment (SCA) (Northern Ireland Environment Agency, 2014; NatureScot, 2025a).

SCAs offer a methodology to map, describe, and understand the unique qualities of coastal and marine areas, integrating both physical features and human perceptions (LUC, 2015; Marine Management Organisation, 2018). In Odsherred, with its glacial landscapes, diverse habitats, and long-standing maritime traditions, such an approach is essential for sustainable management and planning (Krüger, 2016; Olesen *et al.*, 2021).

This report addresses the central research question: How can a seascape characterisation be developed for the sea and coast of Odsherred, while identifying the unique characteristics of each seascape? The aim is to produce a Seascape Character Assessment that integrates both physical and perceptual dimensions, drawing on established methodologies and adapting them to the local context (Natural England, 2012; Van Eetvelde *et al.*, 2024). By filling this gap, the study supports more informed spatial planning and policy-making, providing a practical tool for stakeholders and contributing to the long-term conservation of Odsherred's unique coastal and marine environments (Danish Maritime Authority, 2021; NatureScot, 2025a).

2 LITERATURE STUDY

2.1 Definitions

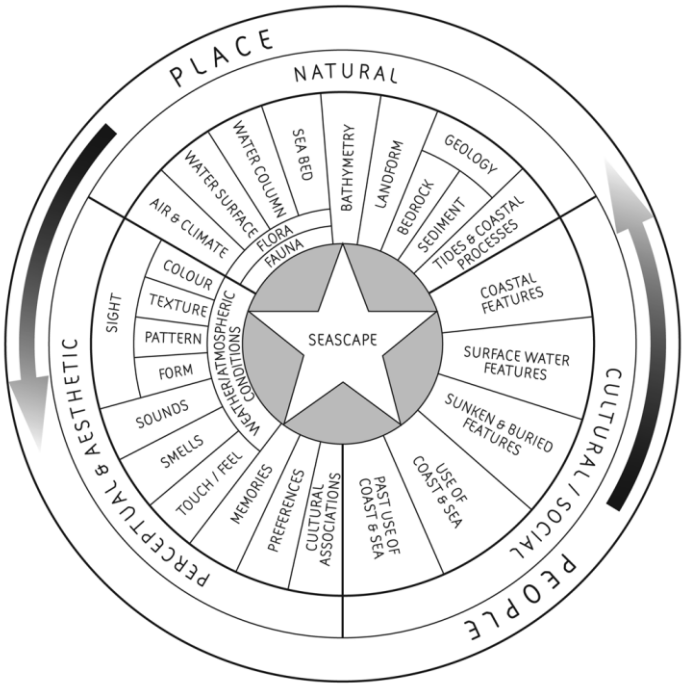
Before a Seascape Character Assessment is performed, it is essential to define what exactly is meant by 'Seascape Character'. The definition of 'landscape' is a great starting point for this. The European Landscape Convention (Council of Europe, 2000) defines a landscape as: "An area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors." Landscapes are defined not only by their objective parameters and characteristics, but also by the perception and experience of people regarding the landscape. A seascape is no different to this, which explains why Natural England (2012) defined seascapes as "An area of sea, coastline and land, as perceived by people, whose character results from the actions and interactions of land with sea, by natural and/or human factors". This definition is exactly the same as the landscape definition, only adding in the 'sea, coastline and land' part. Seascape is about the sea, but also about the land and the coastline, where land and sea meet and interact. This connection is very important to take into consideration because neither the sea nor the land can be understood as separate entities in coastal areas.

Natural England also created the Seascape wheel (Figure 1). It shows the parameters to define the character of a seascape in a holistic way. A similar wheel for Landscape Character Assessments (LCA) already existed. The place and its interaction with the people living, working, and travelling through are the base of all. Underneath these umbrella factors, a variety of psychological, environmental, geographical, cultural and social parameters all play a role in defining seascape characters.

Finally, a definition can be formed for a Seascape Character Assessment. It is a method to assess, characterize, map and describe different seascape character areas (Natural England, 2012). These areas have distinct identities and characters, which differentiate them from other areas. The SCA approach is very similar to the already existing LCA, only adding attention to some specific issues for coastal regions. An SCA solely has an informing and advisory role. Decisions about the quality, value and/or suitability of a region are not performed during an SCA, they can be informed by its outputs however.

Figure 1:

The seascape wheel.



Note. Taken from "An Approach to Seascape Character Assessment," by Natural England, (2012), *Natural England Commissioned Report. P.9 (https://assets.publishing.service.gov.uk/media/5a7e2cb1ed915d74e33f088b/seascape-character-assessment.pdf).*

It is important to note that, for each area, there is no objectively true seascape character. As the characters are highly dependent on the individual perceptions of people and the individual meanings that these people give to an area, the result is always subjective to some extent. However, by following a structured and transparent approach and by having plentiful inputs, the 'objectively true character' can be approximated.

An SCA can be performed in any coastal region on Earth, and there is not one true method to follow. Of course, the basics of each performed SCA method should be similar, but every region has its own issues, its own people, its own characteristics, etc. These properties all demand for a tailored and distinctive approach. That is why each SCA method needs to be adapted to the region where it is performed. While performing an SCA, people could have limited resources and skills, or there could be local restrictions that demand a different methodology. Therefore results of different SCAs can be harder to compare to each other, but that is not what they are meant for anyway. The results should only be used locally for spatial planning by local authorities. As long as the performed method is communicated transparently, there is no issue with adapting the method to the study area and its purpose.

While all SCAs can have different methods, there are five key principles that need to be considered in any assessment:

- Principle 1: Landscape/seascape is everywhere, and all landscape/seascape has character.
- Principle 2: Seascape occurs at all scales and the process of Seascape Character Assessment can be undertaken at any scale.
- Principle 3: Seascape Character Assessment should involve an understanding of how the seascape is perceived and experienced by people.
- Principle 4: Seascape Character Assessment provides an evidence base to inform a range of decisions and applications.
- Principle 5: Seascape Character Assessment can provide an integrating spatial framework.

Note. Taken from "An Approach to Seascape Character Assessment," by Natural England, (2012), *Natural England Commissioned Report. P.9 (https://assets.publishing.service.gov.uk/media/5a7e2cb1ed915d74e33f088b/seascape-character-assessment.pdf).*

2.2 Research gap and motivation

LCAs traditionally only focus on the land rather than including the sea, as is the case with the LCA of Odsherred done by a group last year (Lemmens *et al.*, 2024) and the Danish government (Odsherred Kommune, 2012). Including the coast and sea in the character assessment is typically seen as meaningless, as the sea is perceived as inaccessible yet omnipresent, while still off-limits for the majority of developments (Hill *et al.*, 2001). The sea has a considerable impact on the land near it however, shaping the history and culture of that land. That is the case, especially for maritime nations like Denmark whose maritime culture emerged from small towns and settlements that lived from trade and fisheries (Worm, 1997). Nearly half of the Danish population currently still lives in these areas (Fitton *et al.*, 2020). Exclusion of the coastal areas from LCAs can therefore wrongly imply that there can be no impacts from development in these areas on the rest of the environment. However, planning and management activities taking place on land or in the sea can have significant effects on both terrestrial and marine environments (Northern Ireland Environment Agency, 2014).

The coastal areas are highly valued environments for countries in addition to their social and economic assets (Northern Ireland Environment Agency, 2014). They are for instance a leading holiday and leisure location. Although substantial parts of the Danish coastline remain natural, these areas face nearly constant pressure for development, as the coast and its seascape are a finite resource. These developments comprise urban areas, agricultural activities, technical installations, and tourism in the form of holiday homes and recreational areas

(Fitton *et al.*, 2020). Additionally, there is an increasing demand for maritime space considering the crucial role of the ocean itself e.g. the green transition and recreational activities, and as an important source of food (Danish Maritime Authority, n.d.). The sea is becoming more crowded with an increasing number of wind farms, port extensions, large cargo and cruise ships, and fishermen (Cheret, 2021). Possibilities for future renewable energy generation among others strengthen the interest in coastal and offshore development. While at the same time, there are increasing requirements and demands for protection of the sea (Danish Maritime Authority, 2021). This emphasizes the need to consider the coast more fully in terms of planning and assessment (Scottish Natural Heritage, 2018).

Danish coastal management has evolved over centuries, with regulations dating back to the thirteenth century (Worm, 1997). Planning regulation of Danish coastal zones began in 1977, recognizing the coast as a unique cultural and natural resource to be protected and establishing protected zones to safeguard it. The Danish government emphasises that it is of national concern to ensure that the open coasts remain a significant natural and landscape resource. So, while the Danish territorial waters are managed by the government, they belong to the public (MSP Country Fich Denmark, 2024). Thus, all coastal areas, privately or publicly owned, are open for activities like bathing and walking.

The Act on Maritime Spatial Planning adopted in 2021, sets out the guiding principles and procedures for the strategic management of Denmark's marine areas (MSP Country Fich Denmark, 2024). The maritime spatial plan encompasses the entire Danish marine territory, extending from the coastline to the outer limits of the Exclusive Economic Zone. Marine plans provide the framework for all activities that happen in and on a nation's coasts and seas (NatureScot, 2025b). Denmark's encompasses a wide array of goals: to promote economic growth, the development of marine areas, and the use of marine resources on a sustainable basis. The plan divides the sea into zones according to activities, use, and future potential (Cheret, 2021). A significant number of ocean areas are designated for present and future offshore windfarms, which makes Denmark one of Europe's most ambitious in terms of offshore wind energy (Danish Maritime Authority, n.d.). Besides offshore energy, the plan also sets the overall planning framework for fisheries and aquaculture, maritime transport and transport infrastructure, extraction of natural resources at sea, land reclamation, and the conservation, protection, and improvement of the environment (Danish Maritime Authority, 2021).

Seascapes are an essential part of the sense of identity and culture of maritime nations like Denmark, which have a long tradition with exploiting the sea (Hill *et al.*, 2001). They capture the perceptual and experiential

qualities of the coast and relate them to their given locality (Natural England, 2012). While SCAs identify, map and describe the coastal and marine areas, they also underpin marine plans and development plans (NatureScot, 2025a). The SCA considers additional characteristics in the assessment that are associated specifically with the coast e.g. the character of the coastal edge and its immediate hinterland or marine influences (LUC, 2013). SCAs can however contribute towards maritime planning, aid in informing the appropriate authorities, and play an integrating role in discovering spatial patterns in coastal landscape and seascape issues (Northern Ireland Environment Agency, 2014). The effects of change from new developments can be judged against the baseline provided by the SCA. This can aid in informing decision making in a wide range of applications.

2.3 Realised seascape projects

Every study conducted before, first performed a desk study followed by a field survey. The SCAs performed in Wales, Northern Ireland and England also involved stakeholders (LUC, 2015; Natural England, 2012; Northern Ireland Environment Agency, 2014). The SCAs of Scotland, Anglesey and Pembrokeshire Coast National Park did not (Fiona Fyfe Associates, 2013; NatureScot, 2025a; Pembrokeshire Coast National Park Authority, 2013).

The assessment of England proposes a range of scales, from 1:250,000 to 1:150,000 for national and regional evaluations, 1:50,000 or 1:25,000 for regional assessments, and 1:10,000 to 1:5,000 for site-specific studies (Natural England, 2012). Van Eetvelde *et al.* (2024) also recommend a scale of 1:50,000.

The SCAs from Wales and Northern Ireland use a boundary of twelve nautical miles offshore (LUC, 2015; Northern Ireland Environment Agency, 2014). However, they say that the boundaries are not fixed and can vary locally. Scotland goes beyond the border of twelve nautical miles. Northern Ireland goes five km inland while Wales goes only to the high water line. England doesn't propose specific boundaries as it hasn't carried out an SCA but just says to determine these boundaries (Natural England, 2012). It is an approach to SCA and the basis for other countries and/or regions.

The datasets used in SCAs generally fall into three categories: base mapping, natural factors, and cultural/social factors. Natural factors include bathymetry, geology, and geomorphology, while cultural/social factors encompass heritage and economic activities. Scotland's study does not explicitly mention the data sources used (NatureScot, 2025a).

The first SCA was conducted by Natural England (2012), forming the foundation for later assessments in other countries. However, this initial study did not include a visual assessment. The visual aspect was first introduced in Anglesey (2013) and Pembrokeshire Coast National Park (2013), both in Wales (Fiona Fyfe Associates, 2013; Pembrokeshire Coast National Park Authority, 2013). Subsequent studies, such as the South Marine Plan Areas (2014), and the South East Inshore Marine Plan Area (2018), explicitly incorporated visual aspects, performing both a Marine Character Assessment (MCA) and a Visual Resource Mapping (VRM) (LUC, 2014; LUC, 2015; Marine Management Organisation, 2018). Scotland's 2018 study also included views and visibility within its visual assessment (NatureScot, 2025a).

2.4 Study area

In the northwest of the Danish island of Zealand lies the municipality of Odsherred. This region is bordered by Sejerø Bugt to the west, Hesselø Bugt to the north, and the Isefjord to the east. To the south, it borders the municipalities of Kalundborg and Holbæk. Odsherred has a population of 33,000, with more than half living in its seven largest towns. With over 23,000 summer houses, Odsherred is Denmark's largest vacation destination (Olesen *et al.,* 2021).

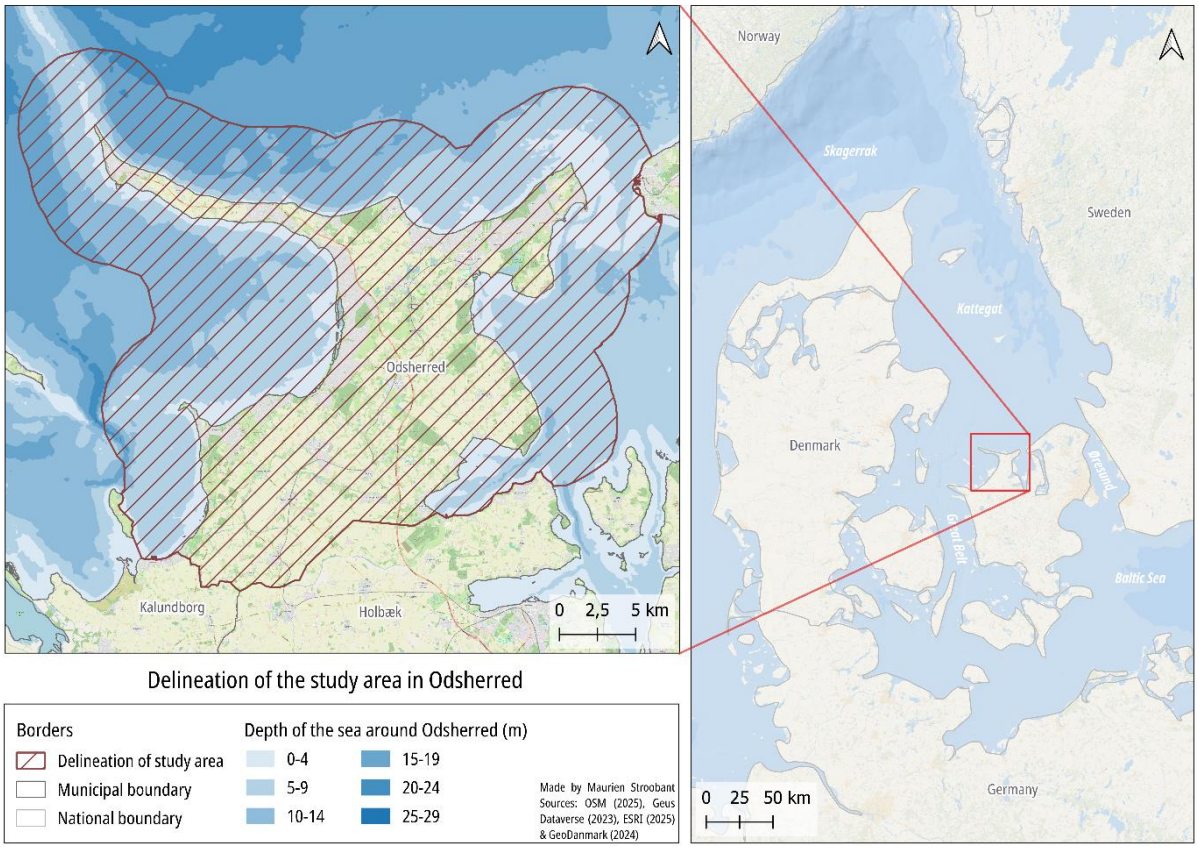
The Odsherred Arches define the region's landscape (Krüger, 2021). These hills were formed as moraines during the Weichsel glaciation period due to the back-and-forth movement of glaciers and the deposition of soil, making them responsible for Odsherred's distinctive shape (Lemkow & Hansen, n.d.). When ice caps advanced from the southeast during the Stone Age, large parts of the landscape were flooded, making Odsherred almost an island. As the ice receded, the land gradually rose, causing the seafloor to dry out. Coastal erosion led to the disappearance of cliffs, while sediment deposits reconnected the once-isolated islands and peninsulas (Olesen *et al.*, 2021).

The geological subsoil of Odsherred consists primarily of clay, gravel and sand, with certain areas containing marine deposits where former seabeds were lifted and dried up. These low-lying regions, often old fjords, have a high content of organic material and clay, making them highly fertile and valuable for agriculture (Krüger, 2016). In contrast, the higher hills in the landscape are less suitable for farming and are instead covered by forests or grasslands used for grazing (Olesen *et al.*, 2021).

The study area encompasses the whole coastline of the municipality of Odsherred with a seaward buffer of 5 km (Figure 2). This buffer details what part of land and sea will be taken into consideration for the SCA. Everything in the immediate vicinity seawards will be included this way, while neighbouring islands or municipalities on the other side of the Isefjord are excluded. The five km is locally adjusted to exclude any land not belonging to the municipality of Odsherred. Previous studies have used boundaries of several km or miles or have been limited to the highwater line (Natural England, 2012; Marine Management Organisation, 2018; LUC, 2013; Pembrokeshire Coast National Park Authority, 2013; LUC, 2014; LUC, 2015 ; Northern Ireland Environment Agency, 2014; Scottish Natural Heritage, 2018). Marine Spatial Planning Guidelines that are implemented by the Intergovernmental Oceanographic Commission (IOC) emphasise the importance of appropriate spatial scales for planning.

Figure 2:

Delineation of the study area in Odsherred

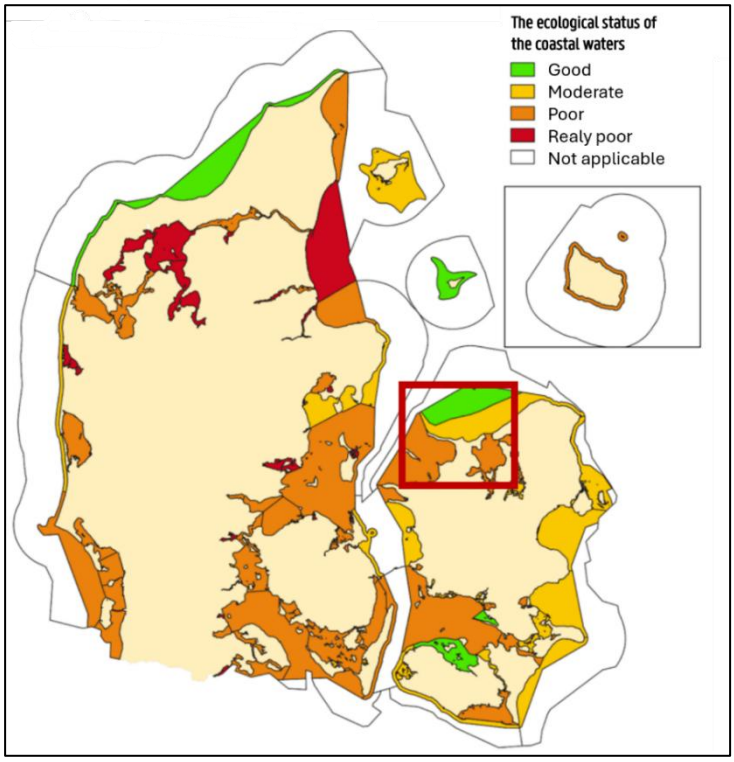


An important part of the study area is the sea around Odsherred, namely The Kattegat. This is a shallow sea that serves as a key transition zone between the brackish waters of the Baltic Sea and the saline waters of the North Sea (Nielsen, 2005; Rosenberg, 1996). The sea is located between the east coast of Denmark's Jutland Peninsula and the west coast of Sweden, stretching from the Skagerrak in the north to the Øresund and the Great Belt in the south. This region acts as an important marine strait, linking the Baltic Sea to the North Sea.

The Kattegat is characterized by a stable two-layer stratification, maintained by the inflow of high-salinity water from the Skagerrak and the outflow of low-salinity water from the Baltic (Andersson & Rydberg, 1988; Nielsen, 2005). These contrasting water sources create a delicate balance, with the low-salinity water from the Baltic mixing with the saline oceanic waters from the Skagerrak. From an ecological perspective, the Kattegat faces challenges related to eutrophication, particularly in its southern areas. The ecological status of the coastal waters around Odsherred ranges from moderate to poor (Cheret, 2021; Figure 3). Due to human activities, such as discharging waste into the water, there is a lot of pressure on the entire ecological system.

Figure 3:

Ecological status of the coastal waters of Denmark



Note. Adapted from "The Danish marine environment is under pressure," by H. Cheret, (2021), *Magasinet Grøn Omstilling (https://rgo.dk/en/det-danske-havmiljoe-er-under-pres/).*

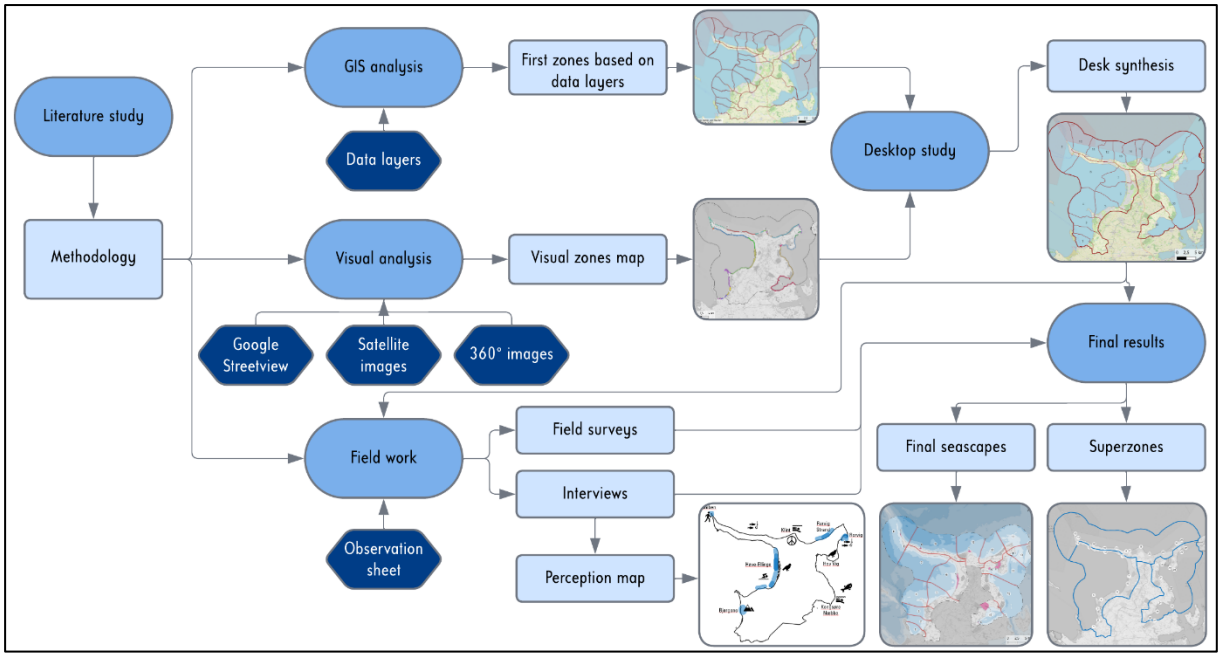
3 METHODOLOGY

This research is anchored in a central research question: *How can a seascape characterisation be developed for the sea and coast of Odsherred, while identifying the unique characteristics of each seascape?* To answer this, the methodology for this project consists of several steps, namely a desk study, a field study, and the final integration of both into a comprehensive Seascape Character Assessment map of Odsherred (Figure 4). The desk

study includes a first step that analyses existing data sources to develop a preliminary understanding of the area. This involves reviewing previous landscape and seascape characterisation documents, marine spatial plans, and GIS data. A second step reviews satellite images and online mapping tools such as Google Maps. Based on the combination of these analyses, an initial seascape classification is made. During the field study, several selected locations in Odsherred will be visited to verify whether the preliminary classifications correspond to the actual situation on site. If necessary, adjustments will be made based on visual observations. In addition, new visual inputs will be gathered, and interviews will be conducted to gain insight into the perception and use of the sea and coast by the local population. The final step consists of combining the findings from both the desk and field studies, resulting in a detailed and validated seascape map of the region and simultaneously identifying potential superzones with overarching characteristics.

Figure 4:

Schematic representation of the SCA methodology



3.1 GIS Analysis

The first step of the desktop study involves combining various data layers to gain a comprehensive spatial understanding of the region. The data is used to define unique areas in Odsherred, characterized by maximum internal similarity and maximum dissimilarity between areas. This approach ensures that each region has a distinct identity and character that sets it apart from the others, making the classification both practical and

meaningful for further analysis. Borders between regions are furthermore consistently influenced by the different classes and borders of the data layers used.

3.1.1 Natural factors

The datasets for the natural factors consist of the topography and bathymetry, the sedimentology of the sea, the geology and geomorphology of the land, the coast types and the rate of chronic erosion (Figure 5 – Figure 9). Sandy coasts and dunes are the most prominent coastal type of the area, with soft cliffs coming in second place. The sediments on the seabed are mostly sand or muddy sand. The mainland of Odsherred consists of clayey till which was deposited by glaciers and has a hummocky topography while the coast is mostly built up of saltwater sand and has a marine plain geomorphology which was deposited after the glacial period. Erosion takes place mostly on the northern-facing coasts, where the sea is less secluded by the Sejerø Bugt or fjord.

Figure 5:

Topography and bathymetry

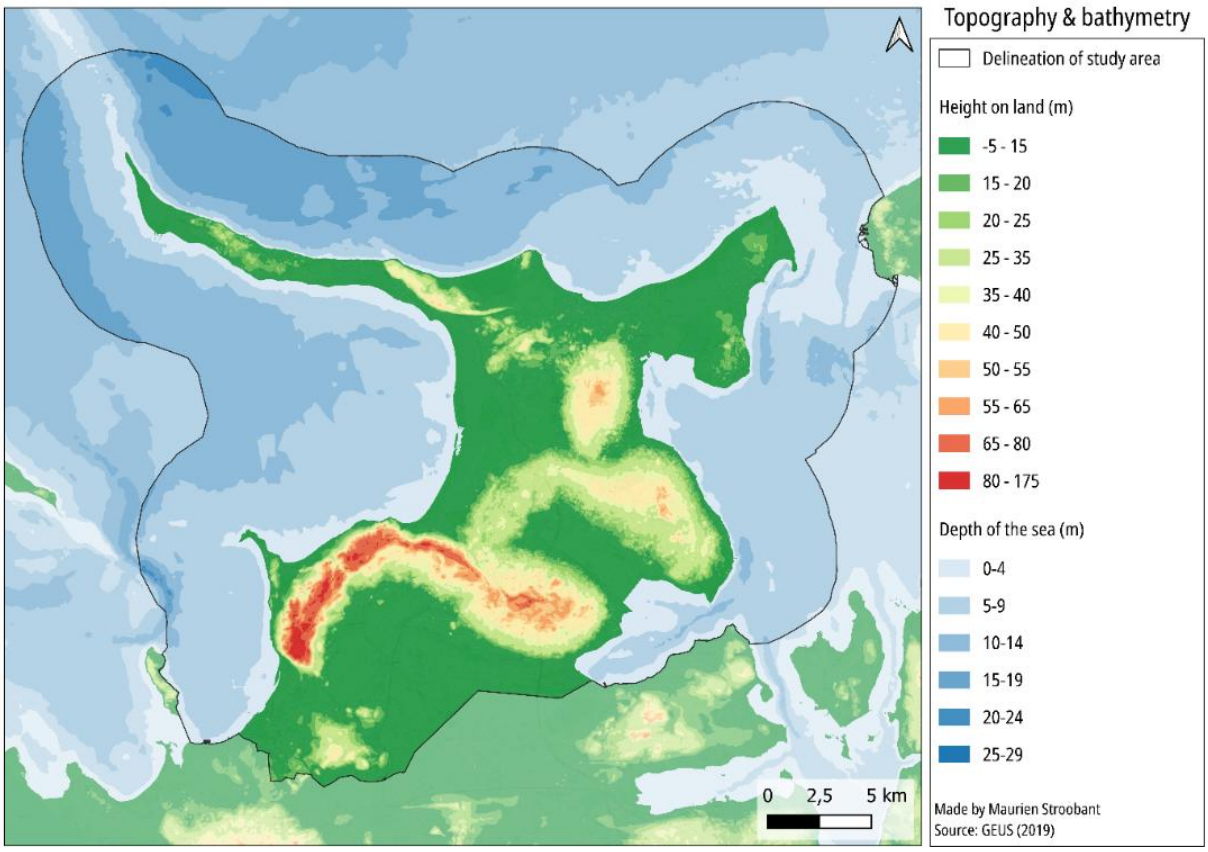


Figure 6:

Coast types and seabed sediment

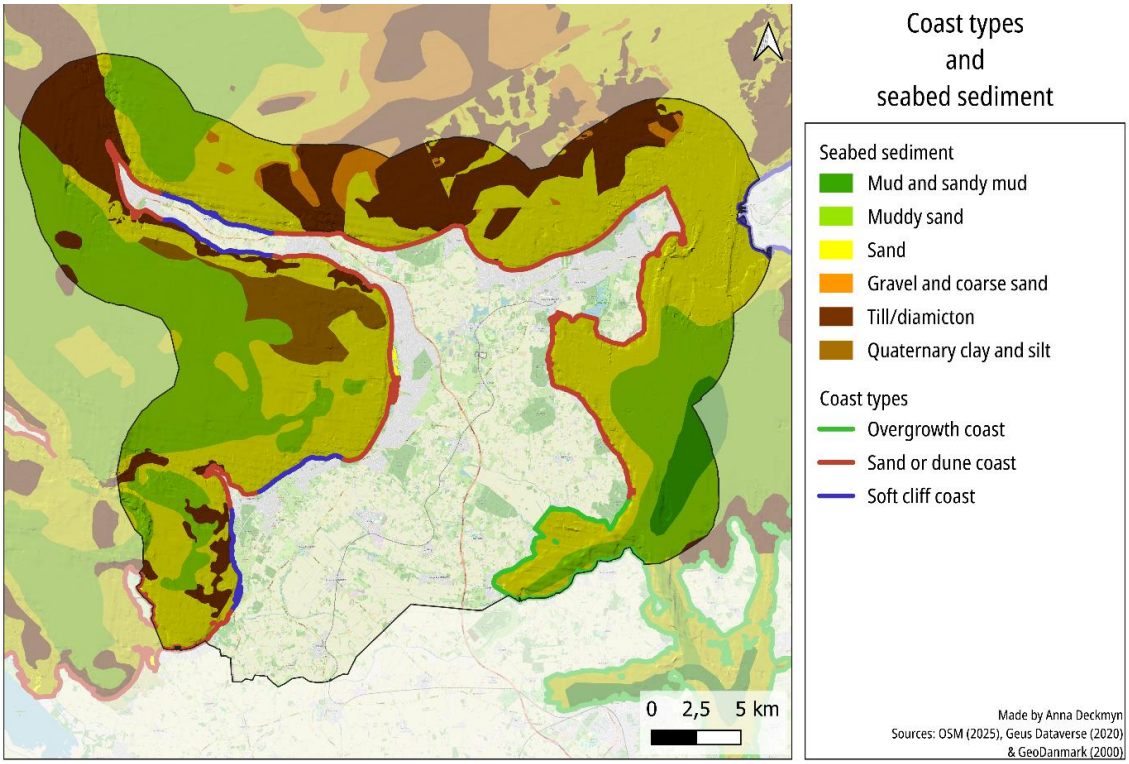
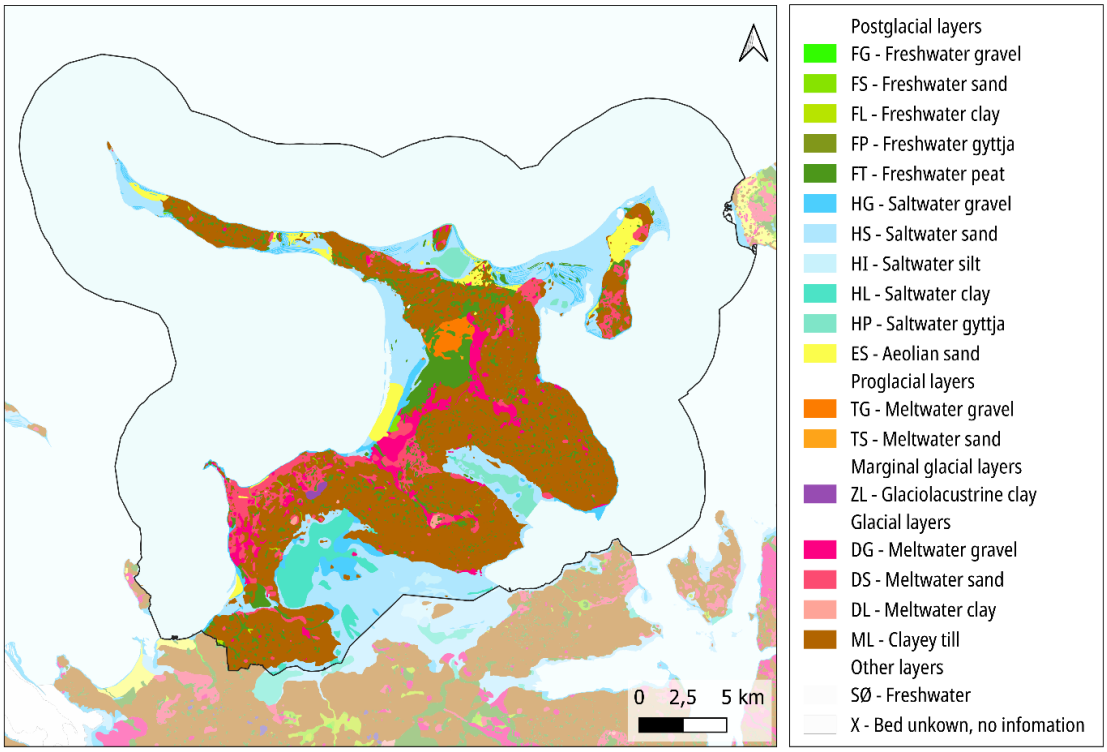


Figure 7:

Surface geology



Surface geology

Made by Anna Deckmyn
Source: Geus Dataverse (2024)

Figure 8:

Geomorphology

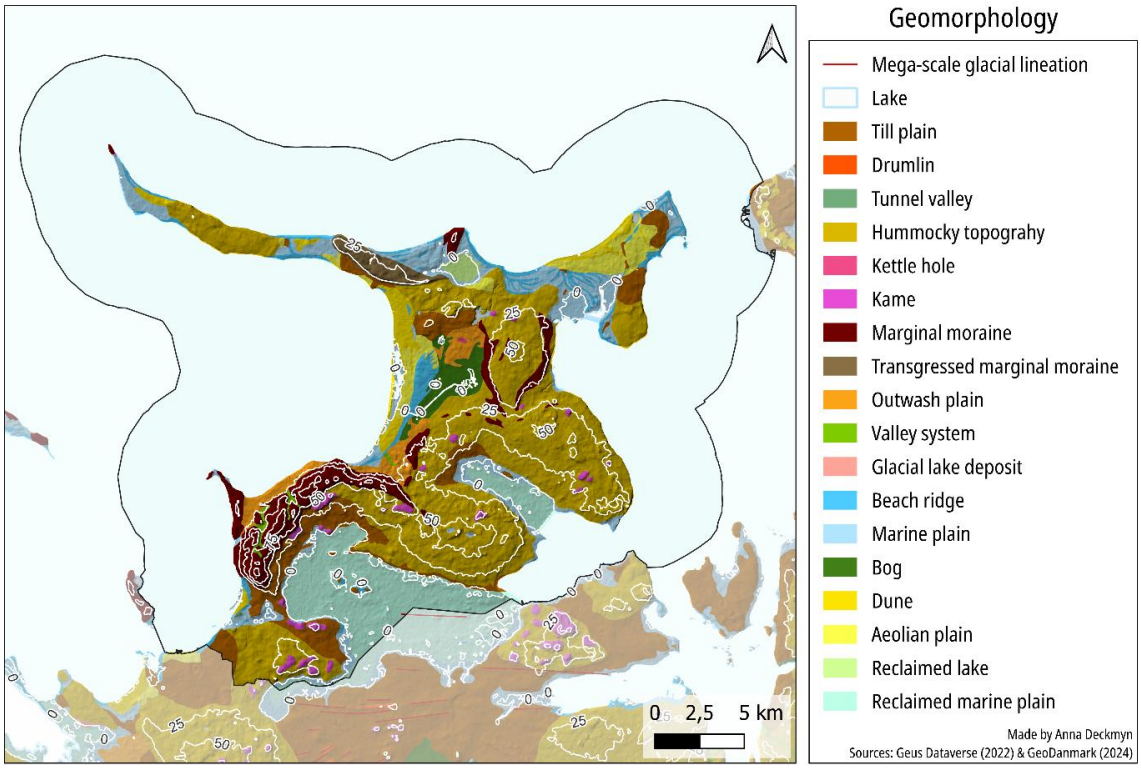
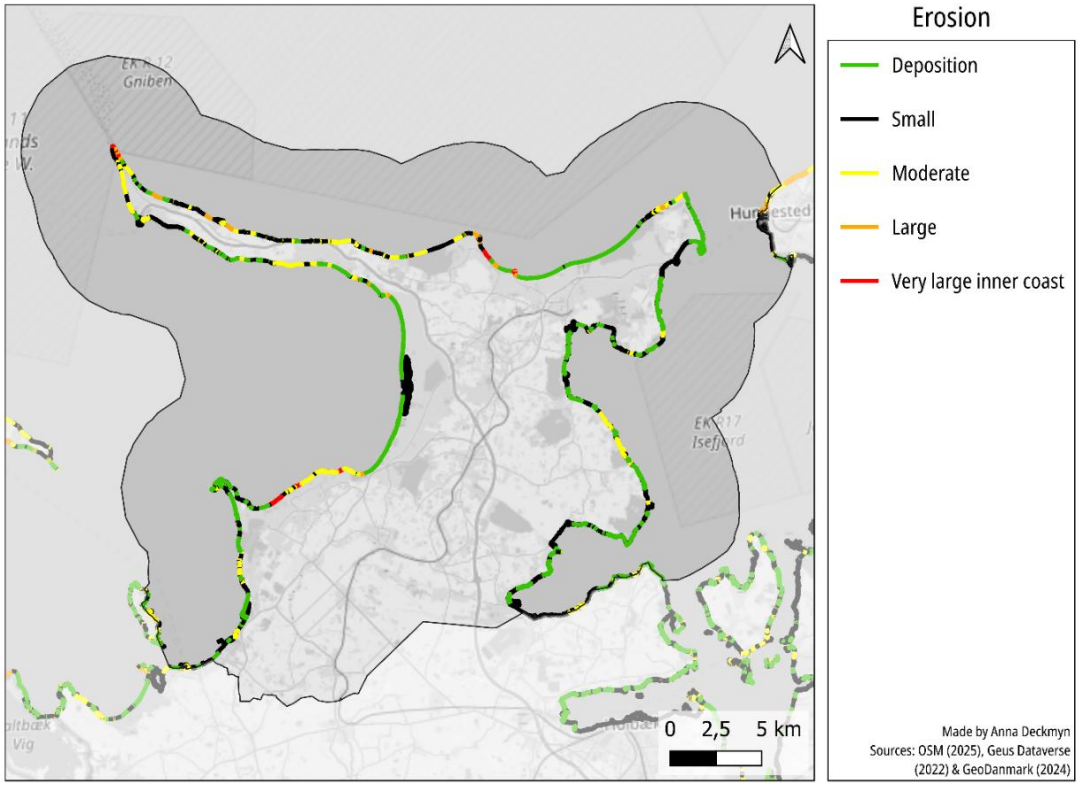


Figure 9:

Erosion

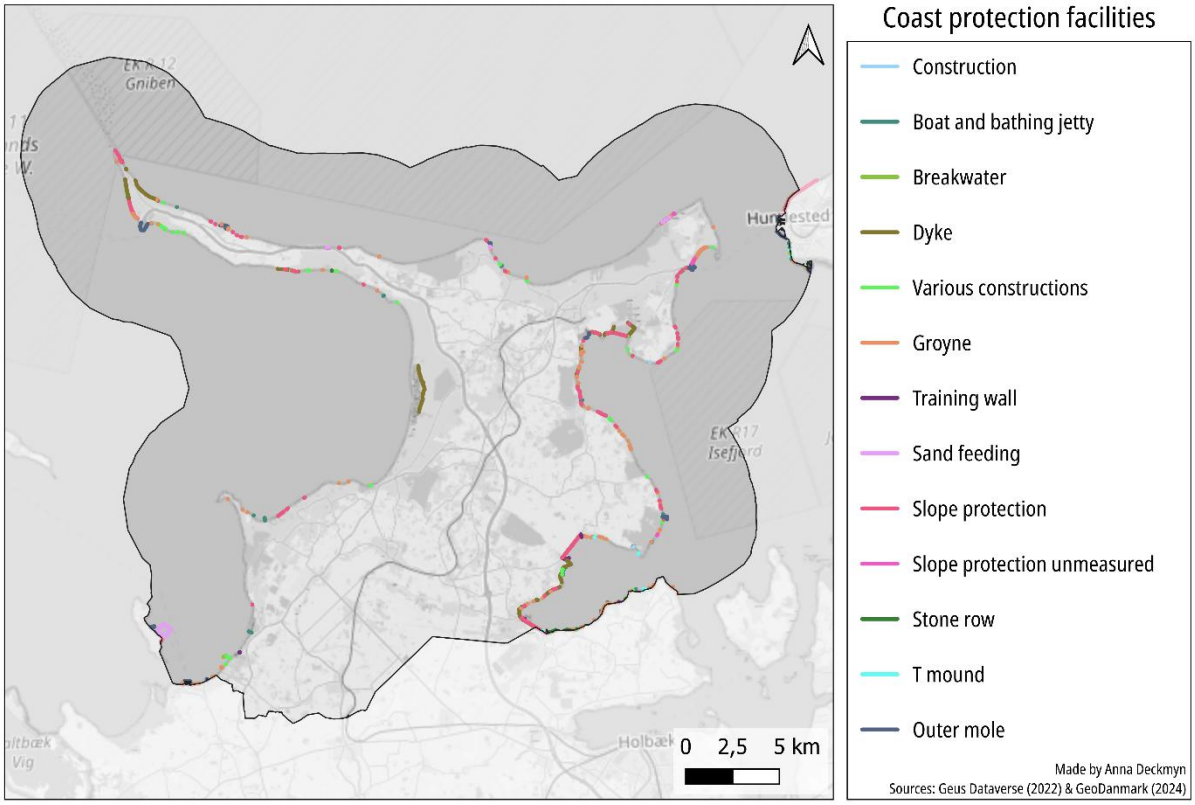


3.1.2 Cultural factors

The data for the cultural factors consists of (underwater) cultural heritage and coast protection facilities (Figure 10). The coast of Odsherred is protected by different kinds of protections, for example dykes and breakwaters. Initially, the (underwater) cultural heritage and the Natura 2000 areas were set to be incorporated in the research. However, later on it was decided that these were not of any importance to distinguish different character areas.

Figure 10:

Coast protection facilities



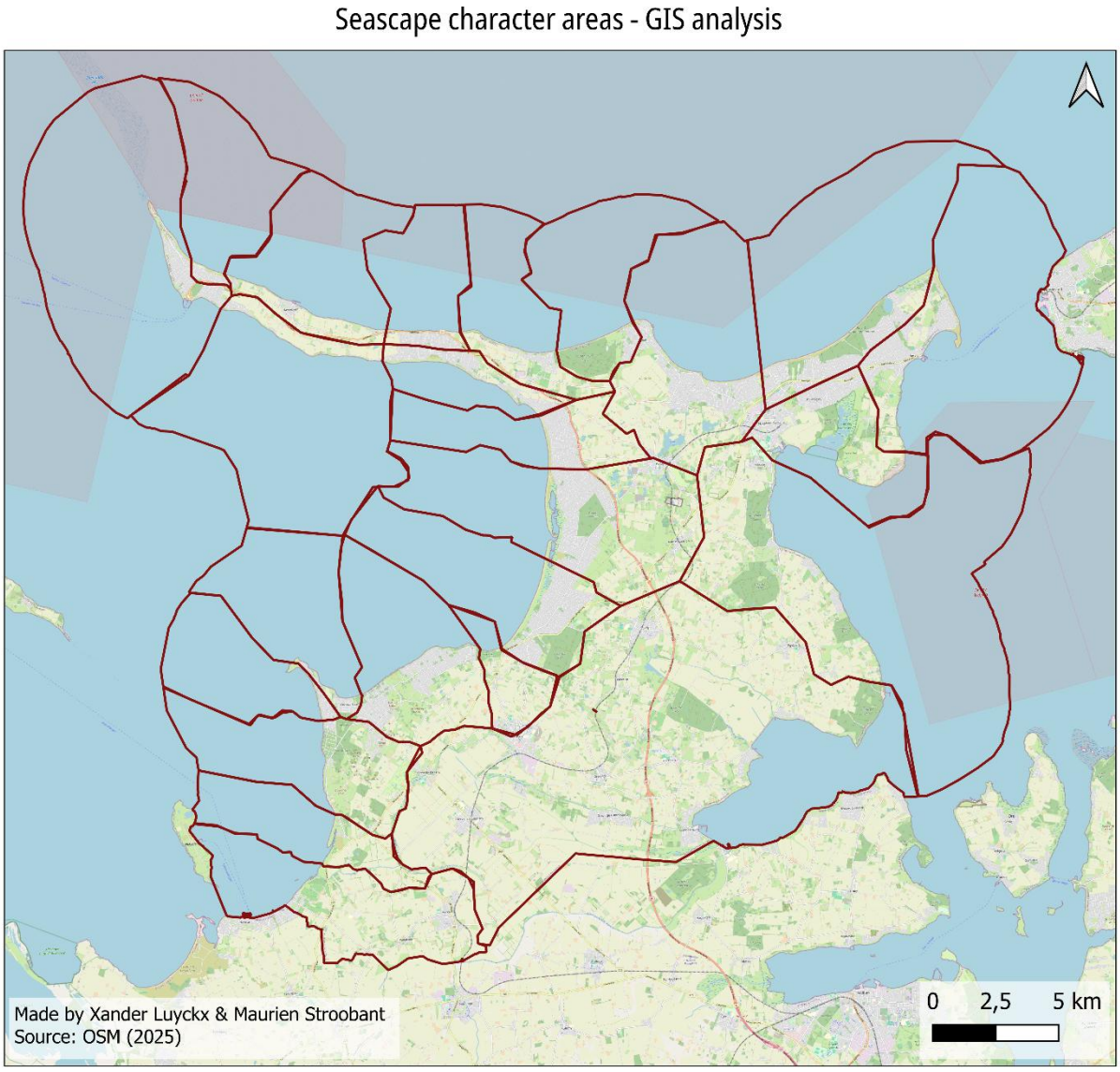
3.1.3 Seascape character areas – GIS analysis

Not all data layers were given equal importance in the area definition process. The pre-defined coast types carried significant weight due to their strong influence on landscape structure and coastal dynamics. In contrast, features such as ancient monuments and Natura 2000 areas had less influence, as they represent more localized or specific land uses rather than broad landscape-forming factors. Seabed sediment, seabed relief, surface geology, and geomorphology were all weighted equally and, alongside the defined coast types, formed the

backbone of the regional distinctions. These natural and geological factors were considered crucial for understanding the foundational characteristics of each area. Although initially expected to be more influential, coastal protection facilities turned out to be less significant due to the limited variation and scope in the available data. Their distribution was too homogeneous to contribute meaningfully to the differentiation of broader seascape zones. The result was a delineation of 24 distinct areas encompassing sea, coast, and land, each with its own defining features and spatial coherence. The map illustrates the spatial extent and configuration of the identified areas (Figure 11).

Figure 11:

Seascape character areas- GIS analysis



3.2 Visual analysis

The second step of the desktop study is a visual analysis of the study area. According to the SCA wheel (Figure 1), a seascape can be characterized based on its 'Place' factors, but the 'People' factors are of equal importance seeing as they experience it. While a seascape can only truly be experienced in person, this analysis was conducted prior to any field visits, meaning the researchers' initial impressions were shaped solely by maps, satellite images, and photographs, without any prior personal or emotional connection to Odsherred. This approach provided a practical overview of the area's appearance and helped establish a foundation for the fieldwork.

Perception of an area is something difficult to describe and is not easily classifiable, it depends heavily on a whole range of factors: Who is the person sharing their perception and what is their background? What prior experiences do they have with this region or similar regions? In what mood were they when they experienced the area? What were the conditions of the area at that specific moment in time? These are only a handful of reasons why perceptions are highly subjective. Objectifying them isn't just difficult, it is impossible to do, as the subjectivity is carved into the definition of perception. In this research, it is important to note that the perceptions are primarily those of the researchers, shaped by their own backgrounds and experiences. Others might have quite different ideas, making this visual analysis hard to reproduce exactly. To try and objectify this visual analysis to some extent, the pictures were observed with certain factors kept in mind. However, perception cannot be explained solely on the basis of these factors; there is always something intangible, rooted in senses and emotions rather than rational thinking. The factors considered include, for example:

- Calmness/crowdedness of the area
- Urban setting or rural setting
- Vegetation
- Type of beach
- Visual reach
- Function of the area (if visible on the picture or map)

A last caveat about this visual analysis is that the perception of the researchers, and people in general, is based on what can be seen on the maps and pictures. Pictures capture one single moment in time, reflecting the environmental condition of that specific moment, some of the factors that can change over time and significantly influence someone's perception.

The visual analysis was performed on desktop using maps, satellite images, airborne pictures, and (panoramic) terrestrial photos. Specifically, all terrestrial photos of Odsherred that were available at the time of this study (April 2025) on Google Maps were used for this analysis. Figure 12 shows an overview of their locations. As for the maps, many maps that were covered in this paper were used, along with maps and satellite images from Google Maps, and Open Street Map. The result of the visual analysis is a collection of 23 seascape character areas, as shown in Figure 13. For each area, a short description was written out with the most determining characteristics of that area (Appendix). Some regions might be quite unique, others might be very similar to each other. There is furthermore a variety of sizes among the areas, some being small like the 'Odden-Århus færgehavn', other regions, like the east coast of Odsherred along the Isefjord, being much bigger.

Figure 12:

Locations of the pictures of the visual analysis

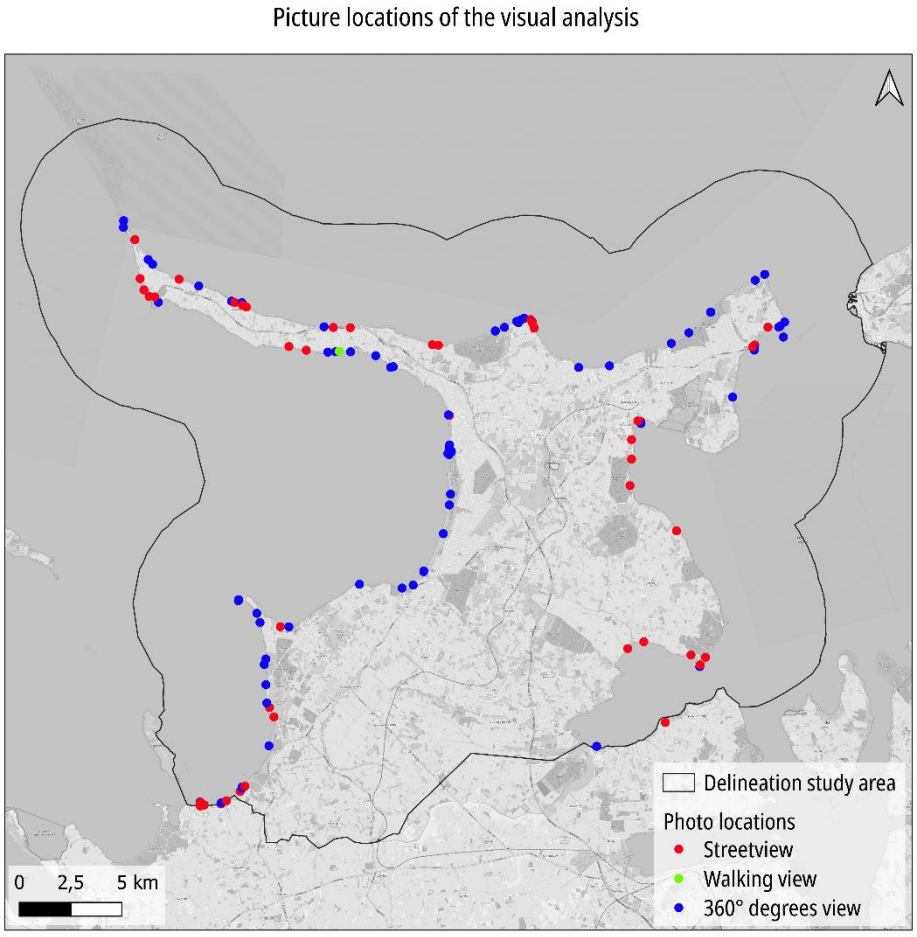
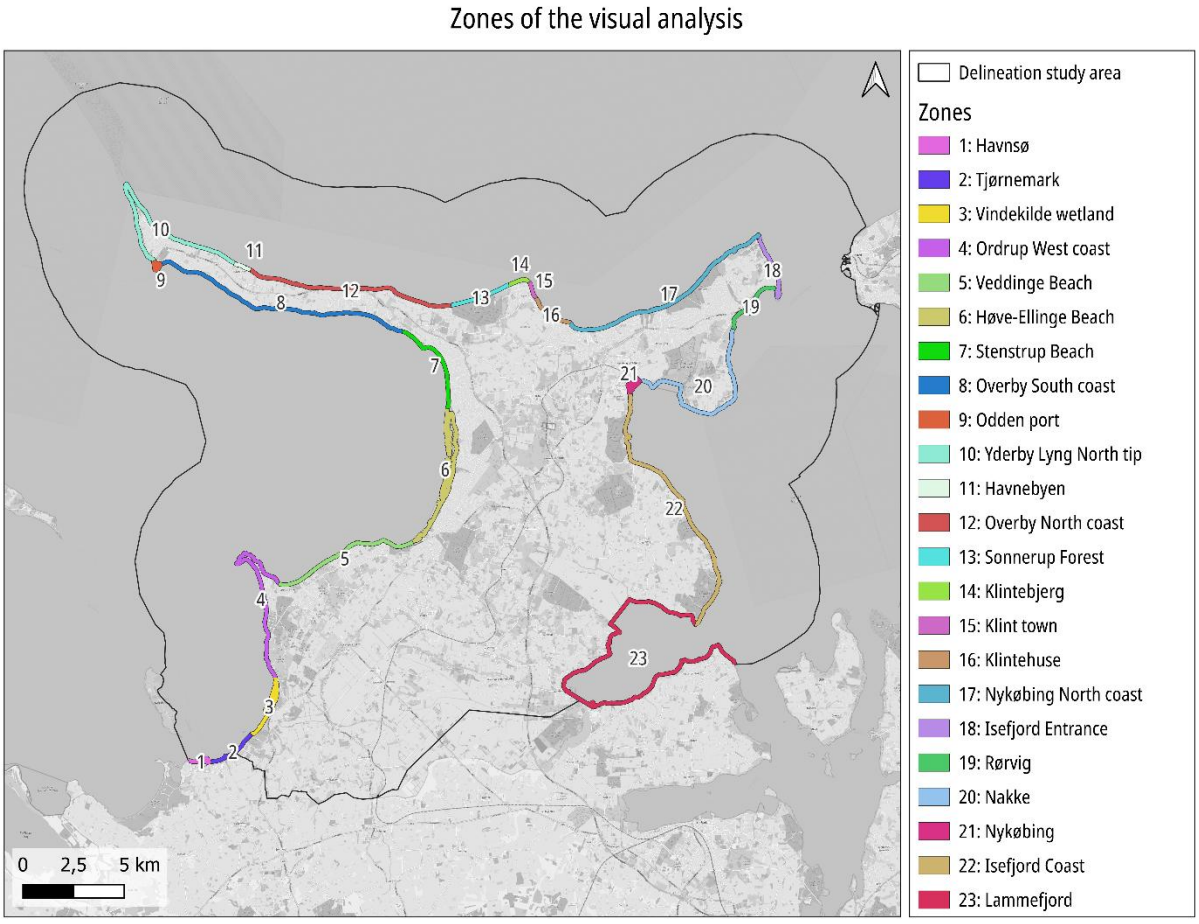


Figure 13:

Seascape Character Areas – Visual Analysis



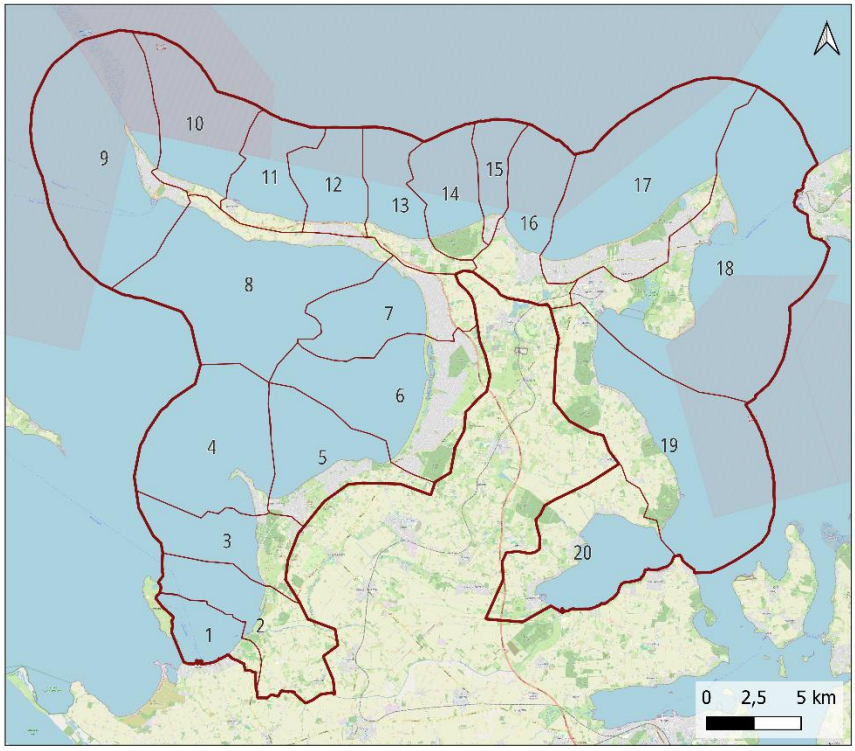
3.3 Desktop study synthesis

When the GIS analysis and the visual analysis were completed, they were combined to create the provisional SCA (Figure 14). The map generated from the GIS analysis served as the base layer, which was then refined using insights from the visual analysis. Where needed, borders were adjusted or zones were merged or split. These provisional SCA were then used as a backbone for the fieldwork. The defined zones were validated, changed and enhanced to transform into the final SCA. From this step onward, the study area was adjusted with a landward buffer of approximately 2 km, instead of encompassing the entire inland area of Odsherred in the SCA. This buffer was modified where geomorphology, often in combination with vegetation, prevented the inland visibility.

Figure 14:

Seascape Character Areas – Combined desktop study

Seascape character areas - Combines desk study



Number	Name seascape character area
1	Starreklinte
2	Vindekilde Wetland
3	Bjergene Coast
4	Ordrup Næs
5	Veddinge Beach
6	Høve-Ellinge Wetland
7	Stenstrup Beach
8	Overby South Coast
9	Gniben Tip
10	Yderby Lying North Coast
11	Havnebyen East Coast
12	Overby Northen Coast West
13	Overby Northen Coast East
14	Sonnerup Forest
15	Klintebjerg
16	Klinte Coast
17	Rørvig Strand
18	Nykøbing Nakke
19	Isefjord coast
20	Lammefjord

Made by Xander Luyckx and Maurien Stroobant
Source: OSM (2025)

3.4 Field work

A terrain sheet (Table 1) was created based on Van Eetvelde *et al.*'s (2024) landscape classification sheet and adapted to incorporate sea-related questions. During the fieldwork this terrain sheet was used to assess the various aspects contributing to the seascapes. These aspects included topics such as geology, topography, human influences, natural features, visual impressions, and, where relevant, additional remarks. The survey sheet was made available as a Google Form, allowing it to be completed digitally on site at each survey location. Additionally, each survey location was photographed from all possible angles and a 360° panoramic picture was taken. While such panoramas provide a comprehensive overview of each site, they often contain considerable distortion, especially around the edges. These pictures were solely made to illustrate how a zone looked at the time of the field research. Sometimes, the imperfections caused by the distortions in these pictures can be too much from a photographic point of view, but they were never meant to be 'photographically perfect'. A total of 37 locations were selected and visited for this study (Figure 15). These locations were chosen based on the provisional seascape character areas delineated beforehand, ensuring that each zone was represented by at least one site.

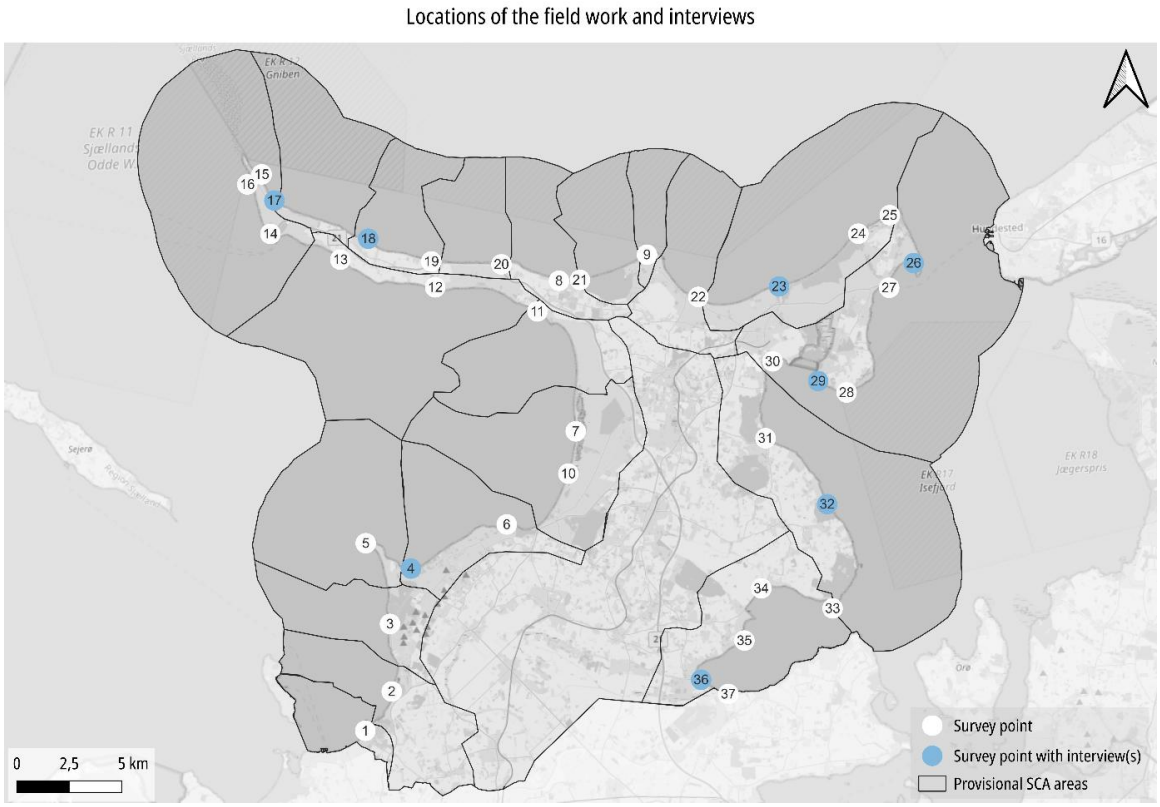
Table 1:

Terrain sheet for the Seascape Character Assessment

General
Stop number
Seascape Area from desktop study
Circumstances (date, time, weather conditions)
Geology and topography
Distinct topographic features of the land
Distinct topographic features of the beach
Distinct microtopography features
Colour gradient in the water
Coastal type
Flood risk areas
Antropogenic effects
Human influence
Land use and activities
Connectivity between land and sea
Pattern and positioning of buildings related to the sea
Nature and perception
Present plants and animals
Smells and sounds
Crowdedness
Calmness/roughness of the sea
Visual analysis
Visual beacons
Openness/closedness of the view
Visibility obstacles
Other
Other characterizing features

Figure 15:

Locations of the field work and interviews



In addition to the survey sheet, eleven interviews were conducted with local residents or visitors at several survey locations (marked in blue on Figure 15). Each interview focused on five main questions regarding respondents' perceptions and use of the coast and sea of Odsherred (Table 2). In three of these questions, the respondent had to indicate places or zones on a map of Odsherred. Lastly, the respondent was asked for their opinion on the provisional seascape character areas delineated beforehand and what they would do differently. The interviews were conducted to gain additional insight into the study area and to incorporate this information into the final Seascape Character Assessment.

Table 2:

Questions of the interview

Questions with marking on the map
Do you live at the coast? Can you mark it on the map?
Can you mark a distinct coastal region of Odsherred on the map. Why would you define this as a distinct region?
Can you mark your favourite coastal region of Odsherred on the map? Why is this your favourite region?

Questions without marking on the map
We made these zones (Show zones made beforehand). Are there any zones that are similar and should be merged to one zone or are there zones that should be split up?
What do you use the coast and sea for? Which activities? (Fishing, walking, swimming…)

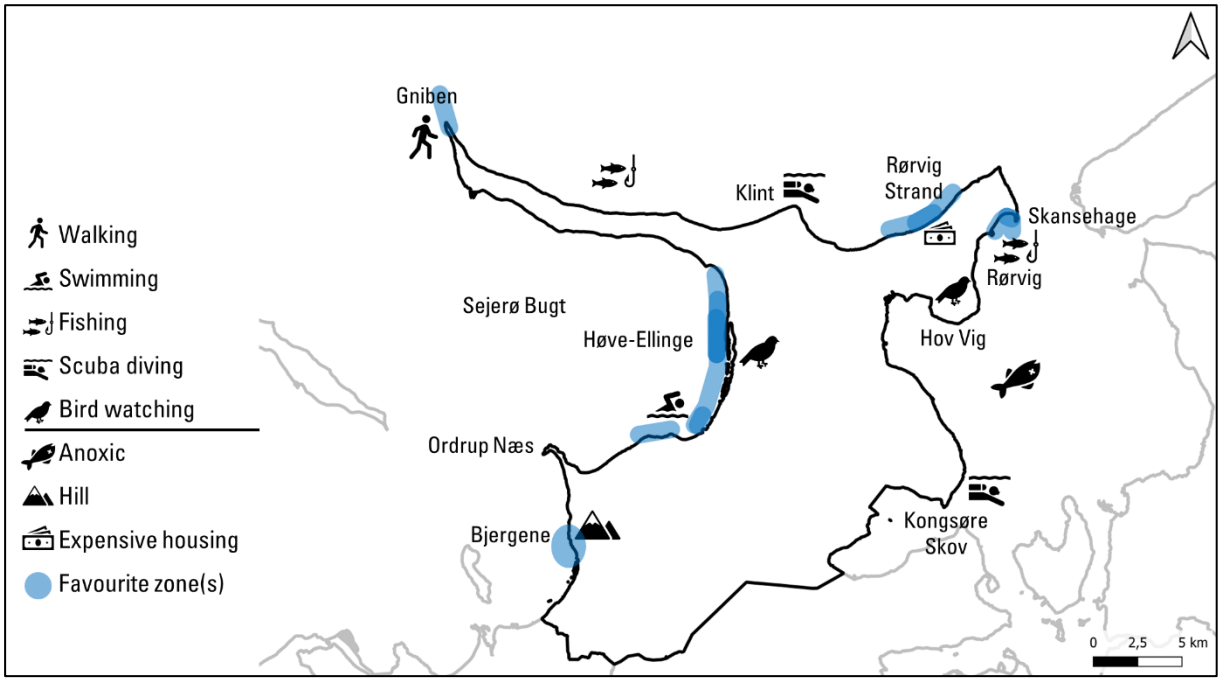
4 RESULTS

4.1 Perception of local residents and visitors

Interviews with residents and visitors in Odsherred reveal a wide range of perceptions and connections to the coastal landscape. Opinions vary between parts of the peninsula, but clear patterns emerge in terms of valued places, recreational use, and attitudes toward land use and tourism. The responses from the interviews were aggregated in Figure 16, showing respondents' perceptions, coastal activities, and favourite zones.

Figure 16:

Perception, activities and favourite zone(s) of the respondents



Firstly, the western Serejø Bugt and southwestern coast are widely appreciated for their peaceful atmosphere, scenic beaches, and quieter spots. The Høve-Ellinge area stood out as one of the most frequently mentioned favourite zones, praised for its beautiful combination of forest and beach. It is a popular destination for swimming, walking, birdwatching, and simply enjoying nature. The surrounding landscape between Ordrup Næs and Høve are also highlighted for its natural character and recreational appeal, particularly for biking and hiking.

Further north, the Gniben tip is remembered as a unique place for walking and fishing. While it is now a restricted military area, many people still recall how fantastic and special it used to be. The north coast is seen as rougher and more natural, with Klint noted for diving and Rørvig Strand as a particularly popular destination during the summer months. The area is characterized by higher-priced summer houses and is also associated with a more socially exclusive or elitist atmosphere. The light and atmosphere around Rørvig were praised for their beauty, and the coast between Skansehage and Rørvig Harbour was seen as a particularly pleasant stretch.

The eastern fjord coast received more critical responses. Several respondents mentioned the poor water quality and low oxygen levels, which negatively affect biodiversity and make fishing less viable. This issue was noted by several respondents who had experience with both the fjord and the open sea. Still, some find meaning in the area due to long-term residence or recreational activities such as biking, paddling, and diving. The waters near Kongsøre Skov, along the southeastern coast of the fjord, were mentioned as favourite diving and boating areas.

Views on summer houses are divided. Some accept them, while others raise concerns about spatial pressure and seasonal crowding, especially in Nykøbing and Rørvig. This tension between tourism and ecological balance was a recurring theme. Despite this, public access to the coast is ensured by Danish law, which guarantees a 10-metre-wide public buffer.

Everyday coastal activities such as walking, swimming, fishing, paddling, and birdwatching are central to life for many residents. Some walk the coast daily, while others seek out quiet areas away from the crowds. The coastline is not only valued for recreation but also for its atmosphere and long-standing personal connections.

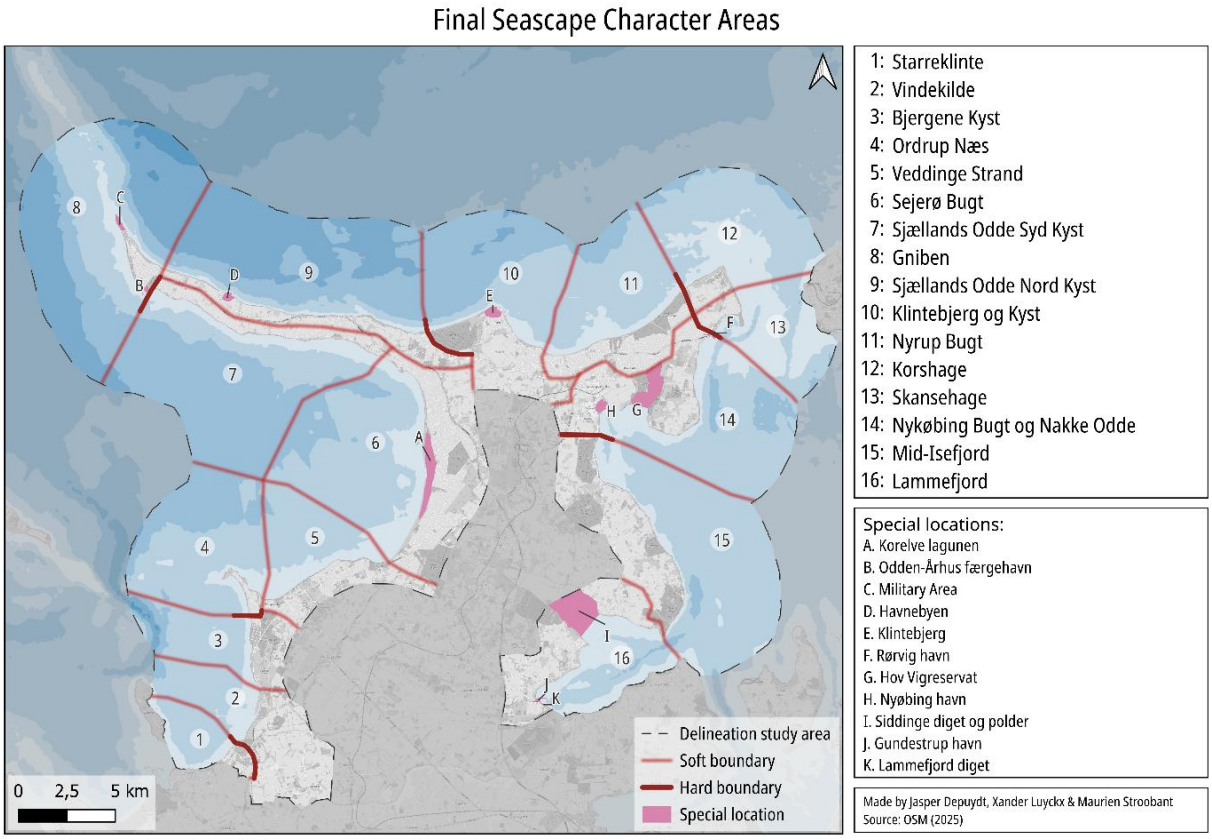
Finally, several interviewees proposed adjusting coastal zones to better reflect local experience, suggesting that zones 5–7 and 10–12 be merged, and that zones 14–16 could be combined.

4.2 Final Seascape Character Assessment

The final outcome of the Seascape Character Assessment identifies sixteen distinct zones (Figure 17). Each of these zones has its own unique characteristics. Before presenting the detailed descriptions of these individual zones (4.2.1–4.2.16), this section first discusses the nature of the boundaries between the zones, as well as several special locations that were identified.

Figure 17:

Final Seascape Character Areas

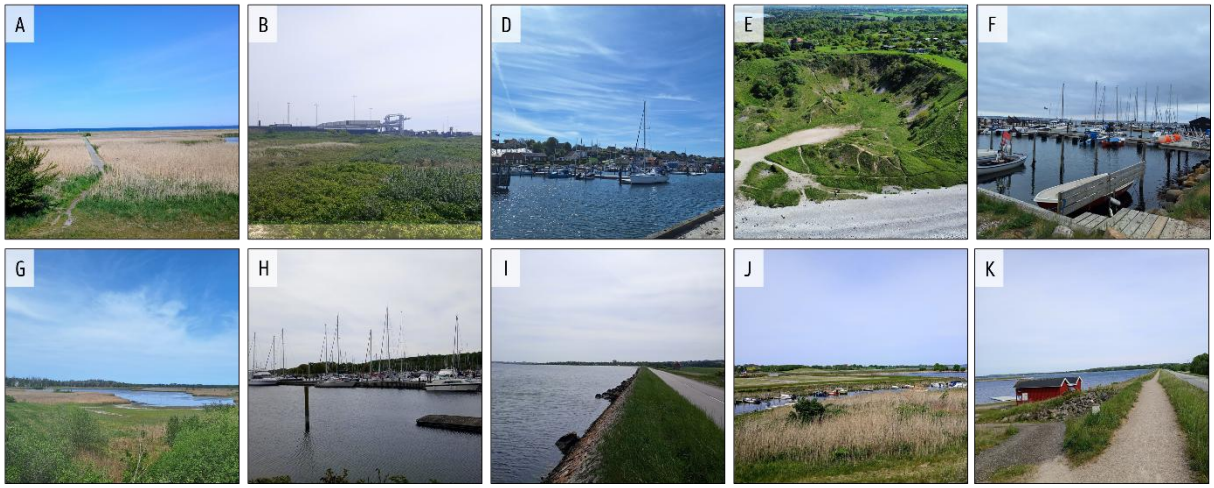


To account for the often subtle transitions in the landscape, a distinction was made between hard and soft boundaries. In many cases, it is not immediately clear where one zone ends and another begins. Soft boundaries indicate gradual transitions that are less easily observed in the field, while hard boundaries represent a clear, abrupt shift in the landscape character. In the study area, only seven hard boundaries are present, the rest of the boundaries are considered soft boundaries. These hard boundaries are mostly an abrupt transition between a rocky coast and a sandy coast. An example of another hard boundary is the Odden-Århus færgehavn, which also marks the border between different erosion zones.

In addition to the sixteen zones, the map (Figure 17) also highlights eleven special locations. These locations fall within specific zones but offer a different visual or functional experience. They may include a harbour or port, a dyke, natural areas, etc. These locations are not classified as separate zones. One reason for this is the scale at which the regionalisation was performed. On a different, more detailed scale, some of these locations, such as Klintebjerg, might be considered separate zones. These locations are thus specific sites with unique features but do not define the overall character of the entire zone. Figure 18 shows a photo of each special location, excluding the military zone as it is not accessible. The letter on each photo corresponds to the letter of the special location in Figure 17.

Figure 18:

Photos of the special locations, corresponding with the letters on Figure 17 (excluding the military zone)



Note. The photos were taken between 11 and 14 May 2025. Photo E was taken by Pieter Denoo.

4.2.1 Starreklinte

The first zone, namely Starreklinte, has a predominantly stony beach, with a sandy base. The flat landscape hosts typical Danish holiday homes nestled within small forest patches, creating a semi-open experience; open towards the sea, and filtered by vegetation on the landward side. This is visible in Figure 19. Seaward, the coastline is protected by a large breakwater, clearly visible from the beach, offering both coastal protection and serving as a landmark for orientation. Around this structure, slope protection is implemented, further reinforcing the anthropogenic character of this otherwise natural zone. The geomorphology of the inland terrain reveals a homogeneous beach ridge and till plain, which contributes to the flatness and regularity of the landscape. The underwater sea floor is relatively flat and homogeneously sandy, with a noticeable change in water colour, likely due to sediment distribution or depth differences. This setting, combined with the clear and calm conditions of the bay, makes it a popular site for scuba diving. Despite its simplicity, the area's calm atmosphere is accentuated by soft waves, low levels of disturbance, and distant views toward islands, ferry traffic, and coastal protection structures. Visual markers include the Bjergene hills, islands, the ferry, and a stone mound offshore, while screens are formed by both trees on land and the breakwater at sea. This zone transitions sharply into the next, marked by a sudden change from stony to sandy coastline. On top of this, the topography rises abruptly with some high hills, in contrast of the low-lying area of Starreklinte. This boundary is comparable to the LCA boundary from Odsherred Kommune (2013).

Figure 18:

Location and photos of Starreklinte

4.2.2 Vindekilde

The Vindekilde zone is shaped by the dynamics of tide and deposition, forming a wide mudflat and beach area that regularly floods and dries. This shoreline is popular for walking with several footpaths and wooden bridges present near the wet areas as seen in Figure 20. Some built structures are present, like a small number of houses and a camping site. The surrounding landscape mainly consists of open grass fields and pastures, giving the zone a mostly rural and undeveloped character. The coast itself is defined by a sandy dune system that's generally accessible and open. Inland, the terrain becomes gently hilly with hummocky features, including kames and remnants of glacial activity such as a till plain in the north and a marine plain with an old tunnel valley. These elevation changes add texture and variety to the flat surrounding farmland. The seafloor here is flat and sandy, creating calm and shallow water conditions. The sea shows a distinct colour gradient, from light blue near the shore to deeper blue further out. The open view over the bay is a key part of the experience, though partly interrupted by trees and a low moraine inland. Landmarks aiding orientation include visible islands, the complete curve of the bay, and the glacial moraines of Bjergene. The transition into the next zone roughly corresponds to a border of the LCA of Odsherred (Lemmens *et al.*, 2024).

Figure 20:

Location and photos of Vindekilde

4.2.3 Bjergene Kyst

The following coastal zone features a narrow, stony beach composed mainly of pebbles and rocks with stone ridges as seen in Figure 21. The coastline curves gently with relatively small height differences. Directly inland, the land rises sharply, forming a soft cliff. This steep slope is covered with shrubs and low vegetation, giving the area a closed feel when looking inland unlike the view in the sea. The beach itself appears to be used mainly for walking, with very little built-up infrastructure nearby. There are almost no summerhouses here and the few farmhouses present are further inland behind the hill, remaining out of sight from the beach. As the coastline nears Ordrup Næs, the slope becomes less steep, easing the transition between land and sea. The waves are calm, and the seabed remains similar to previous zones; flat and sandy near the shore, although further out there's a noticeable depression beneath the water surface. The inland terrain consists of a hilly landscape shaped by glacial features. A marginal moraine dominates the area, with some outwash plains in the north and valley systems running though the inland parts of the moraine. The soil material includes meltwater sand and gravel, contributing to the well-drained slopes and vegetation. Contrasts strongly shape this zone; an open view to the sea with landmarks like islands and the curve of the bay, but a closed view toward land, blocked by the steep relief and vegetation. The area feels quiet and somewhat remote with minimal human presence. The border to the next zone corresponds roughly to the LCA of Lemmens *et al.* (2024) again with a hard border due to the sudden change in topography. The steep cliffs are replaced by gentler slopes in a very abrupt way. The beach type changes as well, going from pebbles and rocks to a sandier beach.

Figure 21:

Location and photos of Bjergene Kyst

4.2.4 Ordrup Næs

The coastal zone at Ordrup Næs is shaped by a long, narrow peninsula. The coastline is a combination of rocky and sandy elements with a thin curving pebble beach that gently slopes toward the water. Just inland the land rises into soft hills where summerhouses are tucked between patches of forest. This section of the coast is mostly used for walking and quiet recreation with limited infrastructure and a calm natural setting. Further along the peninsula the landscape transitions into open grasslands with grazing sheep, wild herbs and low shrubs as seen in Figure 22. This preserved area is part of a nature reserve and has no buildings. This gives the area an uninterrupted view and a strong sense of space. The beach becomes more rugged as it nears the steep cliffs of Brændeklint. Inland the terrain consists of rolling hills and several shallow lakes formed within a marginal moraine built up of meltwater sand and saltwater gravel. The seafloor is mostly flat and composed of muddy sand with occasional patches of till and diamicton near the southern tip of the peninsula. The water shows a clear colour shift from a lighter blue near the shore to deep blue further out. The waves remain calm reinforcing the tranquil mood of the area. Compared to the LCA (Lemmens *et al.*, 2024), the borders of the SCA are narrower around the peninsula.

Figure 19:

Location and photos of Ordrup Næs

4.2.5 Veddinge Strand

The following coastal zone features a gently sloping sandy beach that serves as a popular spot for recreation. The coastline here is less steep than the western parts of Ordrup making the area more accessible for activities like swimming, walking and boating. Scattered pebbles mix with the sand but the beach remains mostly fine-grained. Directly behind the beach, the terrain rises into softly sloping hills where many summer houses are located, partially enclosed by forest. The seafloor is uneven and composed of sand and muddy sand. The water near the beach is very clear with a light blue colour that deepens with distance giving the seascape a vibrant and clean appearance. The underlying geomorphology reveals an outwash plain near the coast with a marginal moraine further inland that marks the inner boundary of the region. Human influence is visible but modest with features like a small pier and a stone dam interrupting the shoreline, which can be seen in Figure 23. Recreational use is present, but the landscape retains a natural character. Visual orientation is aided by elements such as piers and the Ordrup Næs peninsula. Views are semi-open both to land and sea, slightly enclosed by the curving bay, low hills and scattered tree patches. The border to the next zone corresponds to both the LCA borders.

Figure 20:

Location and photos of Veddinge Strand

4.2.6 Sejerø Bugt

This coastal zone presents a dynamic and well-used recreational landscape shaped by natural deposition and human intervention. A wide, sandy beach stretches along the coast, bordered by calm waters and a prominent mudflat zone (Figure 24). Behind the beach, low dunes and dense vegetation provide a natural buffer with wooden boardwalks, guiding visitors across the lagoon. Unlike the steeper inland areas to the north the zone is predominantly flat with no distinct hills rising behind the beach. Instead, a beach ridge separates the shore from a landscape of summerhouses, forest and wetland zones. These houses are generally more modest and affordable than in other coastal areas and set within a mixed-use zone that also includes grazing areas and small forest shelters. The beach has remained public since the 1950s, deliberately preserved as a recreational space for all. The seabed is bumpy and consists of sand, muddy sand and clay. The coastal geomorphology is defined by sandy dunes and marine and aeolian plains with ongoing uplift from glacial rebound contributing to the shifting coastline. Inland the beach ridge gives way to bogs and outwash plains in the north while the southern part of the zone transitions into marginal moraine formations. This creates a patchwork of flat coastal terrain and low inland relief. Visually the area is semi-open towards both sea and land. Trees and low hills in the distance as well as a peninsula create soft boundaries while the open beach and bay offer wide views towards the sea. Landmarks such as the islands and distinct vegetation zones help with orientation. The northern boundary of this zone roughly corresponds to both the LCA borders.

Figure 21:

Location and photos of Sejerø Bugt

4.2.7 Sjællands Odde Syd Kyst

This coastal zone along the south coast of the Overby Peninsula features a narrow rocky beach as seen in Figure 25. The coastline here is shaped by a mix of till, clay and sand resulting in a pebbly beach with a sandy base. The land climbs just behind the shoreline, more sharply in the central part of the zone where the hills are highest. The terrain becomes less steep near Overby Lyng in the east, allowing for a stretch of flat grassy land that is used for walking and quiet recreation. Despite local differences in relief, the coastline behaves consistently throughout the zone with calm waves, a half-open sea view shaped by a bay-like curve and a landscape defined by soft transitions between land and water. Inland the topography is gently hilly and hummocky, formed by clay till and glacial deposits with beach ridges and small patches of aeolian and marine plains appearing eastward. The seafloor contrasts the land remaining mostly flat but becoming more uneven further offshore. Few summerhouses are present in the central parts of this zone, due to higher flood risk and steeper slopes. Instead this area is mainly used for agriculture with fields and pastures. They are mainly open spaces with low vegetation like grasses and shrubs. Some human impact is visible in the form of local dykes, piers and remnants of concrete, especially near Odden-Århus færgehavn. Still the coastline retains a largely natural feel. Colours shifts in the sea, from brown to green to deep blue, reflect changes in depth and sediment. Visible markers are islands and a ferry harbour. The views are semi-open both toward the sea and inland, occasionally blocked by vegetation and relief. The border to the next zone is roughly consistent with the LCA (Lemmens *et al.*, 2024) border and is a hard boundary due to the ferry port.

Figure 22:

Location and photos of Sjællands Odde Syd Kyst

4.2.8 Gniben

The coastal zone at the tip of the peninsula presents a combination of rugged nature, coastal infrastructure and restricted access because of a military base. The shoreline is defined by a narrow rocky strip with a sandy base. Along the north coast a consistent pattern emerges: pebble beach followed by a grassy strip and then a zone of summerhouses in a pine tree forest. Moving northwards, the coastal slope flattens giving the landscape a more open feeling. One of the most defining features is the reef, which stretches far into the sea. The waves are more noticeable here than in the more sheltered bay areas, and the colour of the sea transitions from green to deep blue. Human influence in this zone is strong. The ferry port dominates the area with extensive roads, parking lots, piers and industrial structures. This infrastructure has a sharp contrast with the otherwise calm and scenic coastline. Other human influences in the zone are the prominent military domain, complete with masts, buildings and fencing. Since recent global conflicts, these areas have limited public entry. Visible landmarks are the offshore islands, Klintebjerg, the ferry port and a notable shipwreck. The land is mostly flat, situated on a marine plain, but the presence of dunes, grassland and tree patches between the summerhouses add variation in the landscape. The sea is mostly open while the inland view is partially closed which can be seen in Figure 26. Once popular for walking and fishing, many locals now regret the loss of public access to parts of the coastal zone. The border to the next zone roughly follows the Lemmens *et al.* (2024) LCA boundaries once more.

Figure 26:

Location and photos of Gniben

4.2.9 Sjællands Odde Nord Kyst

The North coast of the peninsula presents a rugged and shifting landscape, shaped by erosion. The shoreline consists of a rocky beach with a sandy base, often strewn with dead seaweed and bordered inland by a grassy strip that separates the beach from green fields (Figure 27). The landscape is gently rolling with hummocky relief and transgressed marginal moraines, creating local height differences with scattered summer houses. Erosion is visible in this zone, some hills turn to low cliffs. The area feels quiet while walkers and fishers are present in the area. Closer to Havnebyen the atmosphere becomes more urban and functional. The old port town is a fishing hub with boats moored in the harbour and infrastructure like piers, breakwaters and coastal defences. The seafloor is mostly flat with sand and gravel. The sea shows a deep blue to dark blue colour gradient. In some places, roads have collapsed due to erosion as the result of frequent winter storms. Various coastal protection strategies are employed as a countermeasure. Sand nourishment, steel nets filled with stone and embankments are used. The inland use includes summerhouses nestled in forested patches, grassy fields and agricultural land. Despite the presence of infrastructure, the visual character of the area remains semi-open. Wide sea views are occasionally interrupted by harbour elements while landwards views are often blocked by vegetation and relief. Visible landmarks are the harbour, Klintebjerg and the masts of the military base. The boundary between this zone and its eastern neighbour Klintebjerg og Kyst is considered a hard boundary because of various reasons. It follows the outlines of the Sonnerup Skov. This forest has straight edges, creating a clear contrast to the fields and summer houses. There is also an abrupt geomorphological change from a marginal moraine to a marine plain with beach ridges. Lemmens *et al.* (2024) defined this same boundary in their LCA.

Figure 27:

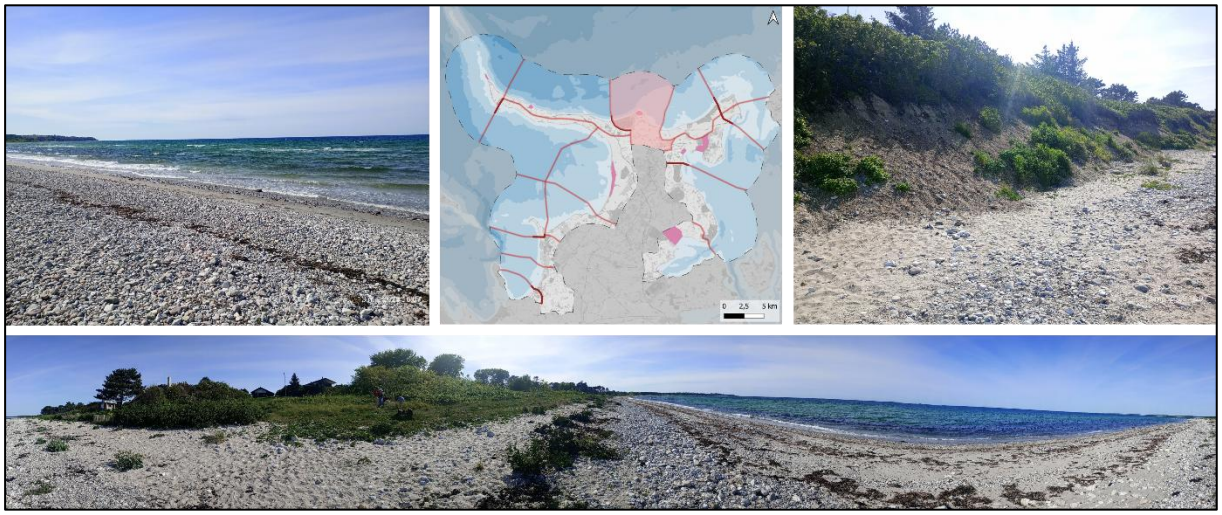
Location and photos of Sjællands Odde Nord Kyst

4.2.10 Klintebjerg og Kyst

The coastal zone around Klintebjerg offers a highly distinctive landscape shaped by geological forces and human history. The coastline has a rocky character with a narrow pebble beach and a sandy base. Just inland a gentle incline leads to a large forested area, marking a clear transition between coast and woodland, as seen in Figure 28. The area is flat near the shore but further inland soft rolling hills define the topography, with the high and visually dominant Klintebjerg rising as a central landmark. Klintebjerg itself is the remnant of an old quarry. Its hollowed-out shape gives it the appearance of a natural amphitheatre faced to the open sea. Due to its elevated position at the northern tip of a cape, the hill provides very open views over the water. Large boulders along the beach are famously used by visitors to build small stone towers. The beach zone is rocky with a sandy underlayer and few coastal protection structures which has left the cliffs vulnerable to erosion. The sea floor is flat but bumpy and is made of a mix of till, diamicton and sand. The colour of the sea shifts from brown nearshore to green and then deep blue. The sea conditions and water clarity make this area popular for scuba diving and the surrounding walking paths make it a favourite among hikers and nature enthusiasts. Klint is a small harbour town with an active port filled with recreational boats. Summerhouses are present behind grassy fields. The place has developed a reputation as a gathering spot for hikers. Visible landmarks beside the Klintebjerg are the masts of the military base and the outer points of the bay. No boundaries are made here by both LCAs.

Figure 28:

Location and photos of Klintebjerg og Kyst

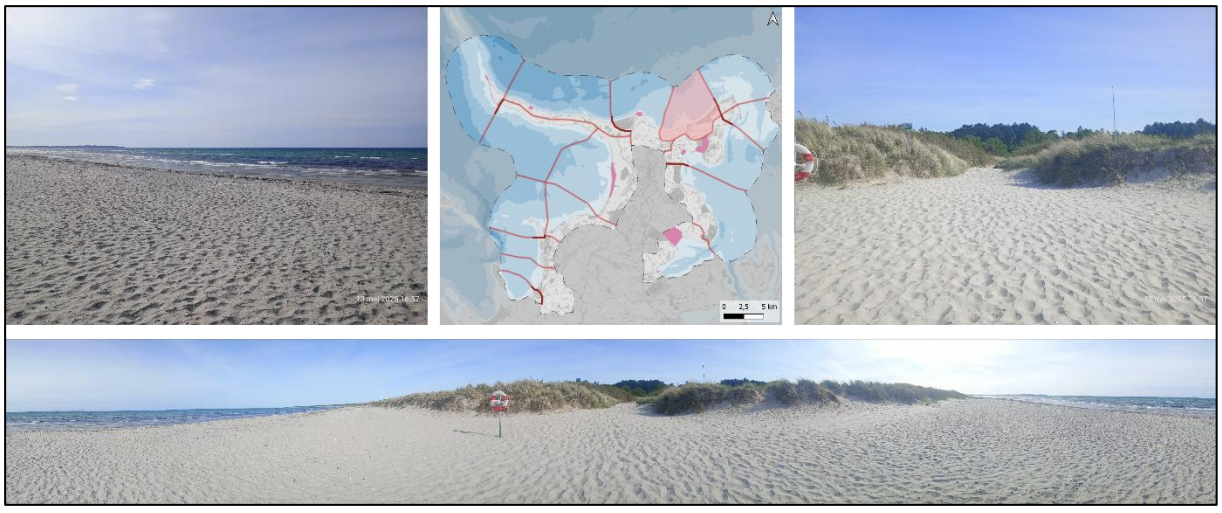


4.2.11 Nyrup Bugt

This coastal zone features a wide and gently sloping sandy beach with dunes that gradually merge with the land. The beach is composed of fine saltwater sand and is backed by a dune belt with typical coastal vegetation such as grasses and low shrubs, which can be seen in Figure 29. These dunes mark the only real elevation in an otherwise flat landscape. Behind the dunes lies a stretch of forest where summerhouses are scattered. These houses are often more expensive and owned by people from Copenhagen. The coastal geomorphology is shaped by aeolian and marine plains with dune formations and beach ridges between the land and sea. The sea floor is bumpy and made up of sand, gravel and patches of till or diamicton. The water shows a clear colour change from green to deep blue as it gets deeper. The area is one of the more actively used recreational beaches in the region. Human influence is visible through the presence of beach infrastructure such as lifeguard posts, benches, marked swimming zones and others. Despite the developed character, the summerhouses remain set back behind the dunes allowing the beach itself to stay open. The spatial experience is open towards the sea, while inland views are semi-closed by vegetation on the dunes and the forest behind. A visual landmark is the distant Klintebjerg. The boundary between Nyrup Bugt and the next zone, namely Korshage, gives an abrupt transition between a sandy coast and a rocky coast. Therefore, the boundary is considered to be hard. The main reasons for this lies in the geomorphology, with aeolian plains in the west and till plains in the east. SCA boundary follows the LCA (Lemmens *et al.*, 2024) boundary. The inland border on the south of this region does not follow a straight line. This is because the town of Nykobing is part of another zone., while the summerhouse area of Øster Lyng is incorporated in Nyrup Bugt.

Figure 29:

Location and photos of Nyrup Bugt



4.2.12 Korshage

The Korshage coastal zone is characterized by a broad, open landscape where flat marine and till plains meet the sea with a gradual slope. The coastline features medium-sized stones on a sandy base that mark the boundary between land and sea. The terrain is mostly flat. The sea floor is composed of a mix of sand, gravel, and till/diamicton with a bumpy structure. The zone is known for stronger wave activity compared to nearby areas. The area is calm and has an structured feeling partly due to the influence of nearby summerhouses and managed landscapes. Land use includes recreation, grazing grasslands and a mix of open meadows and forest patches. The first 200 meters inland are relatively open, providing clear views, until the line of trees closes off the perspective, as seen in Figure 30. The summerhouses are more expensive than in other areas. The sea view is fully open while the landward view is open up to the forest edge. The boundary to the next zone roughly follows the Lemmens *et al.* (2024) LCA borders.

Figure 23:

Location and photos of Korshage

4.2.13 Skansehage

The next coastal zone features a flat and gently sloping landscape, shaped by a combination of marine plains, beach ridges and till plains. The shoreline consists of a sandy coast with patches of dense coastal vegetation, giving the area a natural, slightly overgrown appearance, this is visible in Figure 31. The sea floor is flat and composed of muddy sand. The transition from land to sea is smooth with a minimal elevation change. The land is characterized by open grasslands and meadows eventually changing into a dense forest. This contrast creates a semi-open land experience while the sea is semi-open as well because of the curving shape of the bay. Along the Skansehage coast runs the entrance to the Isefjord, connecting it to the Kattegat. There is visible human presence and infrastructure; parking lots near the coast, toilets, walking paths and a number of summerhouses located behind the vegetated dune zone. These features confirm the beach's recreational use. There are also a lot of fishers in this zone compared to the rest of the fjord. Visible landmarks include Skansenhage, the local harbour, the ferry route and the coast on the other side of the Isefjord. Between this zone and the next, there is a sharp transition, marked by a change from a sandy to a rocky coast, separated by the Rørvig harbour. This hard boundary to the next zone also corresponds roughly to the Lemmens *et al.* (2024) LCA borders.

Figure 24:

Location and photos of Skansehage

4.2.14 Nykøbing Bugt og Nakke Odde

This coastal zone lies in the Isefjord, offering a very different character from the open sea coasts found elsewhere in Odsherred. The landscape is flat, a result of land reclamation, with marine and till plains, beach ridges and clay-rich soils dominating the area. The sea floor is flat, composed of muddy sand, and the coastline lacks the wide sandy beaches that are common to other parts of the region. The shoreline here features thin, rocky beaches covered with sea algae making it less suited for classic beach recreation. Seaweed and coastal vegetation such as grasses and low shrubs are abundant as seen in Figure 32. The view across the fjord is defined by landmarks like Hundested on the opposite shore. The semi-enclosed bay shape creates a half-open sea view, while the inland side is half-open to closed, defined by small relief, shrubs and hedgerows. Human presence is strong, especially near Nykøbing, the largest city in Odsherred. Although the town lies slightly inland, its port extends into the fjord, giving the area an urban feel. The harbours, paths, piers and summerhouses all shape the coast's perception. The zone becomes busy in summer with both Nykøbing and Rørvig attracting many visitors. This makes these places crowded and less favoured by locals during peak months. Despite the developed character, the coast also holds significant ecological and historical value. The nearby Hov bird reserve supports biodiversity. The boundary between this zone and the next zone, namely Mid-Isefjord, gives an abrupt transition between a rocky coast and a sandy coast. This hard boundary to the next SCA zone corresponds mainly to a Lemmens *et al.* (2024) LCA border even though this zone consists of several LCA zones in both LCAs.

Figure 25:

Location and photos of Nykøbing Bugt og Nakke Odde

4.2.15 Mid-Isefjord

The next coastal zone is characterized by a quiet atmosphere. There is less human activity compared to the busier north. The landscape is mostly flat, the result of former reclamation from the fjord, though hilly patches remain where the land was left in its natural state. These elevations, formed by kames and marginal moraines, are often covered with dense forest offering a contrast to the open meadows and grasslands in the area. The coastline transitions gradually into the sea, forming a muddy-sandy shore with visible silt deposits as seen in Figure 33. This leads to colour shifts from brown near the beach, turning green, and then blue further out the sea. The sea floor is flat and the water remains calm. The beach shows traces of moderate erosion and is marked by a mixture of grasses, shrubs and visible seaweed. Land use here is low-intensity and dispersed: stone houses, farmland, grassland and forest management facilities are scattered throughout the region. Recreational use is present but subtle. Activities such as walking and fishing are present and locals use the area to enjoy an outdoor lifestyle. Visible landmarks include distantant views of boats, wind turbines, a pier and other coastal features. The zone is semi-open towards the sea, shaped by the curve of the bay, while inland views shift from very open meadows to more enclosed forested areas. This last border to the next zone does not correspond to any LCA boundary.

Figure *26:*

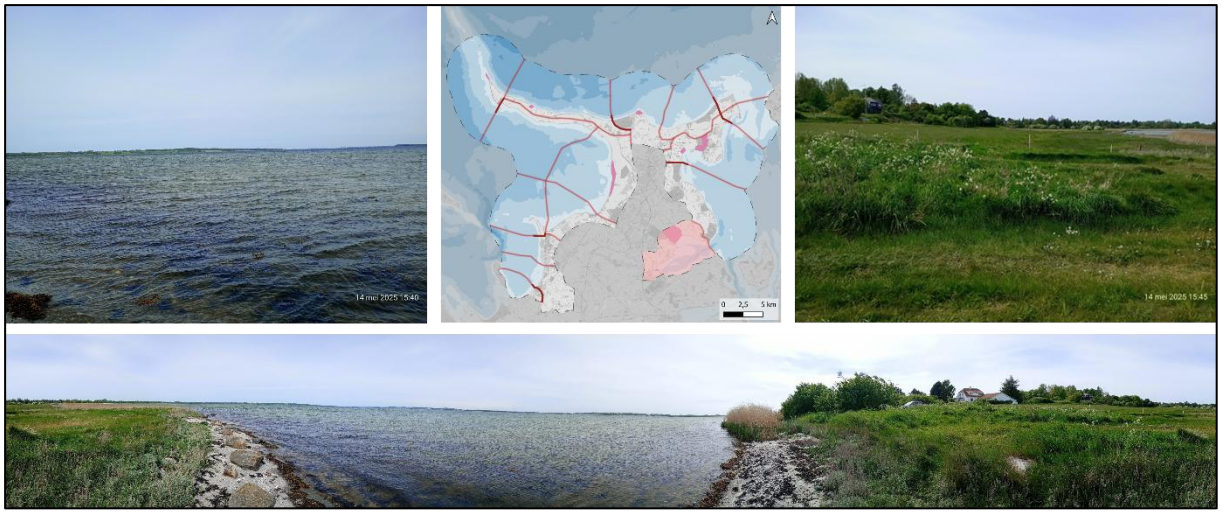
Location and photos of Mid-Isefjord

4.2.16 Lammefjord

The Lammefjord coastal zone, situated along the eastern edge of Odsherred, presents a serene and secluded landscape. Acting as a bay within the fjord, the opposite shoreline is always in view, which creates an enclosed and intimate atmosphere that distinguishes it from the more open-sea coasts elsewhere in the region. This stretch of coastline is notably overgrown, with the vegetation often reaching the waterline, which can be seen in Figure 34. The transition from land to sea is generally gradual but the dykes introduce a more abrupt edge in some places. The terrain consists of lightly rolling hummocky topography, shaped by clay till and flat reclaimed marine plains used intensively for agriculture. Most of the landscape is composed of fields and pastures, with only scattered rural homes and farm buildings along the coast. There are few forests or summerhouses. The sea floor is flat and composed of muddy sand, and the shoreline contains occasional sandy strips with scattered pebbles, alongside modest coastal protection structures like small dykes, mooring posts and steps. Visual landmarks are the edge of the bay, distant wind turbines and a small harbour across the fjord. The sea is visually closed off by the bay's curve, while the land varies from open agricultural plains to semi-closed areas shaped by vegetation and low forested patches.

Figure 27:

Location and photos of Lammefjord

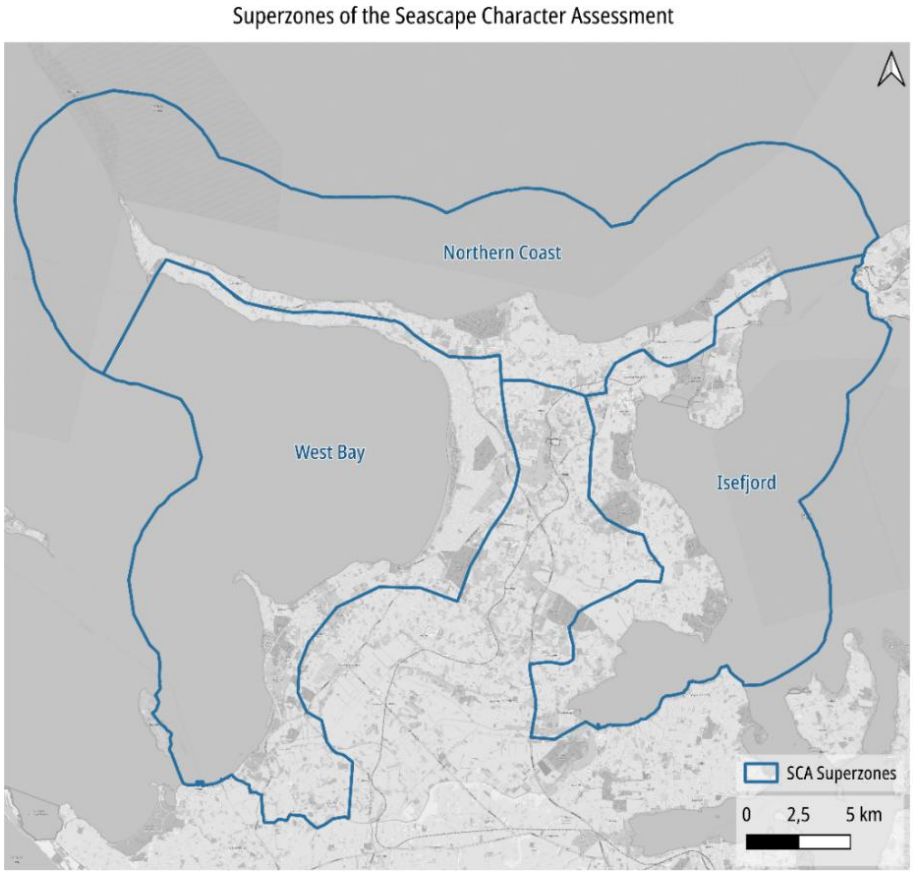


4.3 Superzones

On a larger scale, the sixteen zones are then categorized into three overarching 'superzones', based on shared characteristics (Figure 35). The three superzones are named the West Bay, the Northern Coast and the Isefjord. Each superzone has distinct traits that define its overall identity, which are reflected in the individual zones it encompasses. The first superzone, namely the West Bay, is characterised by a sandy coastline. Due to post-glacial uplift, the land here is gradually rising from the sea, causing the coastline to grow. However, the area is also vulnerable to flooding due to strong currents coming in from the west. This zone is used for a lot of recreational activities, such as swimming, walking and even bird watching. The Northern Coast is characterized by a rocky coast. It is exposed to heavy wave action and erosion, countered by coastal protection facilities. This zone is mostly used for fishing, but also for walking and swimming. Lastly, the Isefjord shapes the eastern coast. This sheltered fjord is enclosed by land, making the water calm. However the water is not good for fishing due to the anoxic conditions that are present in this fjord. The area is less dynamic and more tranquil than the open coasts. The sheltered environment, however, supports other forms of recreation, such as swimming, walking, etc.

Figure 35:

Superzones



5 DISCUSSION

This is a regionalisation exercise. Apart from the regions, the boundaries between these regions are of high importance. By default, soft boundaries were drawn, since clear borders are generally not visible in the field. The transitions between the Seascape Character Areas are gradual, stretching over lengths of tens to hundreds of meters. This means that, when standing on the coastline and watching left and right, the two views are not significantly different from each other. These gradual changes along the coastline make defining boundaries challenging, but it remains a necessary part of the SCA. The boundary locations that resemble the seascape character at best were chosen through combining inputs from the fieldwork, visual analysis, GIS data and the LCAs (Odsherred Kommune, 2012; Lemmens *et al.*, 2024). In some cases, hard boundaries were used when there was a very sudden and severe difference between two bordering areas. An example of this is the ferry port (Odden-Århus færgehavn), splitting the regions of Gniben and Sjællands Odde Syd Kyst. Over the water, the boundaries are always soft.

The Seascape Character Areas were defined on two scales. There are the three superzones and the sixteen Seascape Character Areas, which have areas of 11 to 84 km². The scale of this approach was never an explicit decision, and the number and size of the regions were shaped during the research, not predefined. However, the scale of an SCA is important, as it has a significant impact on the results and can be chosen beforehand. A bigger scale, results in bigger areas, but also ignores differences in characteristics. This means that one region can still be made up of heterogeneous, smaller regions. The decision of scale for an SCA should be made in the context of the final purpose of the SCA. For instance, if the government of Denmark wants to have a general idea of its coastal regions, solely based on its primary functions and outlooks, the regions can be quite big and internally heterogeneous. However, if a coastal municipality wants to incorporate the perceptions and opinions of its local population, the scale should be smaller, and the regions should be kept as homogeneous as possible.

An SCA incorporates perceptual factors and people's stories, experiences and opinions, which introduces a degree of subjectivity. As a result, outcomes may be slightly different if another group of researchers tried to reproduce it, even using the same methodology. The subjectivity is due to several factors. The researchers play a key role in how the results shape out. Their ideas of a place are affected by their backgrounds and relationship with the study area or other similar coastal areas, their mood and emotions during the fieldwork. The same can be said about the respondents to the interviews, as their responses depended on who happened to be present during

fieldwork. Some important perceptions might have been missed, because none of the people who could share them were present at the time of the interview.

Furthermore, the perception of a place is dependent on the circumstances of the moment of recording. The pictures used for the visual analysis, as well as the short visits at each stop, were mere snapshots in time. To get a better, and more objective understanding of a place, long-term monitoring might be a better idea, although time-consuming. This might exclude the influence of weather and light conditions and might incorporate the seasonal changes of an area. Because there was only a limited time of a few days for the fieldwork, this was not possible to accomplish for this research. Another consequence of the scarce field time is the limited amount of stops around the coast. 37 stops is an acceptable number, but a maximum of stops is preferable. Most ideally, the continual coastline would be visited. This could be combined with visits to the inland and a boat tour to incorporate the views from sea to land. This way, the influence of the choice of stop locations would be avoided and a complete view of the study area would be assembled.

To address the subjectivity, caused by the previously discussed factors, in the best way possible, it's very important to use a systematic approach. The methodology used for this assessment, consisting of an objective GIS data analysis, a visual analysis, a combining provisional regionalisation, and verification on the field using a terrain sheet, is a systematic methodology highly recommended for any future SCA initiatives. This way, the objective 'true' character of each area can be approximated.

Linked to this, it is also highly recommended to use a LCA of the study area as a starting point for a SCA. There are two reasons for this. Firstly, it can help in understanding the characteristics of each landscape and region on land. In some cases, the boundaries of these landscape character zones might be very good indicators for seascape character zones. During this research, an LCA of Odsherred performed by a research group in 2024 was used as input for the SCA, as well as the one performed by the municipality in 2013 (Odsherred Kommune, 2012; Lemmens *et al.*, 2024). Secondly, the approach and the questions that were answered during an LCA can be used for an SCA as well, though slightly adapted. In many cases, the questions are specific to the study area, as each country or region has its own characteristics and/or issues that need to be addressed during the assessment.

The map with the Seascape Character Areas that were defined during this research was made for different purposes. First of all, one of the motivations for this research was to create a methodology for an SCA, especially for Odsherred. This methodology can then be used as a basis for other SCAs in Denmark or similar regions of the

world. If other research groups want to use this approach for their own assessment, they should still be critical about every step and every question in this approach. It is important to wonder whether each step/question is relevant to their research, whether it needs some changes or if there is a need for other questions.

Secondly, the results of this SCA could be used to advise governments, stakeholders and policymakers when planning the future of Odsherred. The character of the areas and the relationship that each zone has to the local population should be kept in mind when planning future functional areas like tourism infrastructure, (marine) wind turbine parks, neighbourhoods, new summer houses, nature reserves etc. For some specific purposes, for example planning out new or refurbished fishing grounds, more research would still be necessary on top of this SCA, as there might be factors that are very important to the fishing industry that were not incorporated in this research. So, as this Seascape Character Assessment can be very useful for advising policymakers and planners, the used methodology and the results should still be approached critically.

An SCA only has an informative and advisory role for such purposes. It does not make any decisions about the quality, value, strength and/or sustainability of the character of an area. Although these decisions could be valuable for planning activities, they are not within the scope of an SCA. However, they could be made using the information provided by an SCA.

6 CONCLUSION

The sea and coast of Odsherred could be characterized into sixteen distinct seascape character areas, grouped into three overarching superzones: the West Bay, the Northern Coast, and the Isefjord. This study was realised through a systematic methodology that integrated spatial GIS data, visual landscape analysis, field observations and local perceptions gathered via interviews. This approach allowed both natural and cultural dimensions to be included, reflecting the core principles of Seascape Character Assessment.

The central research question; How to develop a seascape characterisation for the sea and coast of Odsherred while identifying the unique characteristics of each seascape?, was addressed by creating a validated map of sixteen coherent seascape areas, each defined by distinct geomorphological, ecological, visual, and perceptual features. Special attention was given to the transitions between zones, where both soft and hard boundaries were mapped based on physical changes and perceptual shifts in landscape character.

The integration of local perceptions provided crucial insight into how residents and visitors use, experience, and value different parts of the coast. This confirmed that seascapes are not just shaped by natural processes, but also by personal and cultural meaning. The resulting Seascape Character Assessment contribute to more nuanced and place-specific coastal planning, offering a practical tool for sustainable management and policy-making in Odsherred and potentially beyond.

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8 APPENDIX – DESCRIPTIONS VISUAL ANALYSIS

1. Havnsø

Small, calm port town. Coastline is urbanized. Nekselo Island plays a prominent role in the view over the sea.

2. Tjørnemark

Sand beach along (summerhouse) suburb of Havnsø. The beach is used for recreational purposes. Along the beach, there is some grass before hitting the sea parallel road.

3. Vindekilde Wetland

Wetland/beach area that gets flooded/dried because of the tides. Used for walking, there are some walking paths and bridges. Except for some buildings and a camping, the lowland mainly contains grass fields and pastures.

4. West coast Ordrup

There is a thin, rocky beach that does not follow a straight line. Directly next to that, it goes uphill, where there are summer houses. It looks like this beach is only used for walks. Closer to the Ordrup Næs, the slope of the hill gets less steep.

5. Veddinge Beach

From Ordrup to Veddinge, there is a strip of sand beach that is used recreationally. The slope of the hills behind the beach varies from place to place but is generally less steep than on the West Coast of Ordrup. Directly on this hill, along the coast are summer houses.

6. Hove-Ellinge wetland

There is a big wetland on the west coast of Odsherred. The sandy beach is permanent and seems to be used frequently for recreational activities. A lot of small boats are anchored along the beach. The beach is also protected by a lot of vegetation and small dunes. There is no real 'hill' behind the coastline anymore as the land gets flatter. There are a lot of summer houses along this strip, which may explain the recreational activities.

7. Stenstrup beach

North of the wetland, a clear pattern appears with a sand beach, dune vegetation and then coniferous trees with summerhouses. Again, the beach seems to be used for fun activities.

8. Overby South coast

The south coast of the Overby peninsula gets rocky again, and a hill appears right after the coastline. The rocky beach is a thin stretch of low-lying land. In Overby Lyng, the hill is less steep and further from the coast. This allows for a stretch of grass along the beach. Here, walkers seem to enjoy the coast. In the centre of this zone, there are no summer houses, just fields. This is where the hills are higher. Still, it is considered one zone. The coastline and its beach behave in a very similar way and have the same characteristics.

9. Odden Port

This big seaport is the ferry port to Aarhus and Jutland. It is quite big, has a lot of roads and parking places. It feels industrial, which is remarkable in the calm region. It is a discrepancy between two similar coastal zones.

10. Yderby Lyng North tip

The coastline continues with a thin, rocky strip, very similar to the Overby South coast. The more to the north you go, the flatter the hill gets. There is a strip of grass along the coast, before you hit the summer house area. This pattern of rock beach – grass is especially present on the north coast of the peninsula's tip.

11. Havnebyen

The coast of Havnebyen feels urban again. It looks like an older port town. There are fishing boats in the port, suggesting that it is still used for fishing.

12. Overby northern coast

Again, there is a rocky coast with a strip of grass further inland, separating the beach from the fields. The beach looks very calm, not really used for any activities. For a long stretch, in Overby Lyng, a road separates a summerhouse neighbourhood from the coast.

13. Sonnerup Forest

The rocky coast runs along the coast, but this time there is a big forest. There is an incline again where the trees start. The photos suggest that this area is used for walking.

14. Klintebjerg

The Klintebjerg is a very distinct area with its own unique character. It looks like a hill that has been quarried out. The hill and 'crater' look out over the sea. As it is on the northern tip of a cape, you can only see sea from here and no neighbouring coastline. It is a popular tourist destination. The big rocks on the beach are used to make hundreds of rock piles on the beach.

15. Klint town

Klint is a small town that has a small port. The many small boats suggest that this harbour is very popular for recreational purposes. The small beach strip is very rocky. There is a certain 'small town' atmosphere.

16. Klintehuse

The rocky beach from the north Klint continues. The terrain is flat. Behind the beach, there is mostly a large field of grass before hitting the houses.

17. Nykobing North coast

The beach gradually transforms into a broad sandy beach. Behind are some dunes with vegetation. It is only behind the dunes that there are trees with or without summer houses. The houses may explain the popularity of this beach as recreational area.

18. Isefjord entrance

The beach is much thinner here and less suitable for typical beach recreation. It is covered in a layer of sea slurry. The other side of the Isefjord entrance, with the town of Hundested, is a point of focus in the view from here.

19. Rørvig

The coast around Rørvig feels less rural than most other coastal areas. It feels quite busy and urban, mainly because of the port that acts as a station for the ferry to and from Hundested.

20. Nakke

The coast around Nakke, between Rørvig and Nykøbing, does not really have a 'beach' like most previous coastal areas have. It spans along the Isefjord, so not the sea, which might explain this. It is remarkable that there are much less pictures available of the fjord coast. It suggests that there are fewer tourists or people who use the coast for recreational purposes. These people are much more likely to take and post such pictures online than the local population. The land here was reclaimed from the fjord, hence it is very flat.

21. Nykøbing

Nykøbing is the biggest city of Odsherred. It lies a bit inland, but its port forms a tentacle towards the fjord. In this area, it feels urban.

22. Isefjord Coast

The Isefjord coast feels very calm, almost deserted. It looks like not many people visit or pass through this area. There are some summer houses, but not as much as on the west and north coasts. The land is very flat, except for some hilly areas that were not reclaimed from the fjord. These are covered by trees.

23. Lammefjord

The coast around the Lammefjord has the same calm vibe as the 'regular' Isefjord coast. However, the Lammefjord acts as a bay that secludes itself from the rest of the fjord. You can easily see the other side of the fjord from the coast. This gives a very 'closed' feeling, which gives this stretch of coast its very own character.

FACULTEIT WETENSCHAPPEN

MASTER OF SCIENCE IN GEOGRAPHY AND GEOMATICS

BEFORE THE PLOUGH: MAPPING POTENTIAL NATURAL VEGETATION

REWILDING POTENTIAL BASED ON GEOTOPES IN ODSHERRED

Word count: 10 080

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Course: Integrated International Projectwork

Academic year: 2024 - 2025

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1. INTRODUCTION

Ecological conservation and restoration have gained significant momentum within international, European, and Danish policy frameworks. Global agreements such as the 2022 UN Convention on Biological Diversity (COP15) have established ambitious restoration targets, including the commitment to protect 30% of land and oceans by 2030 (Convention On Biological Diversity, 2023). At the European level, the Nature Restoration Law reinforces this momentum by requiring the restoration of at least 20% of the EU's land and sea areas (European Commission, 2023). Denmark has taken additional steps by implementing the Green Tripartite Agreement, which sets out to restore 10% of the national territory (Bjerre, 2024; Hedley, 2024). This includes the creation of approximately 250 000 ha of new forest and 140 000 ha of peatlands and meadows.

Rewilding has become an increasingly prominent tool in this policy landscape. It focuses on reintroducing ecological processes, often by encouraging the return of large herbivores or predators, rather than managing ecosystems toward specific conservation endpoints (Mutillod et al., 2024). In highly fragmented and agriculturally altered landscapes such as those in Denmark, rewilding offers a unique opportunity to rehabilitate abandoned farmland and marginal areas that have low human utility but high ecological potential (Pereira & Navarro, 2015; Skov et al., 2009).

To effectively guide such initiatives, it is essential to identify areas that are ecologically suitable for restoration. This study explores the concept of potential natural vegetation (PNV), defined as the vegetation that would occur in the absence of human disturbance (De Keersmaeker et al., 2013). The PNV maps are then used as a scientific basis for evaluating rewilding potential. By integrating high-resolution geotope data, which describe the smallest homogenous land units based on soil, hydrology and topography, detailed PNV maps were generated for the Odsherred municipality in Denmark. This approach enables a spatially explicit assessment of rewilding potential based on the physical characteristics of the landscape.

The objective of this report is to combine theoretical frameworks, GIS-based modelling, and field validation to identify and evaluate areas most suitable for natural restoration. The results are intended to support Denmark's restoration goals by offering an ecologically grounded and spatially detailed prioritization tool for rewilding efforts.

2. THEORETICAL FRAMEWORK

2.1 Rewilding & restoration

Rewilding and restoration are two similar terms that are often used interchangeably in literature, as they share a common core: the recovery of ecosystems that have suffered anthropogenic degradation (Mutillod et al., 2024). Nonetheless, there are some notable differences between them, mainly regarding the goals and approaches. While restoration often applies a bottom-up method, where the focus is on the recovery of plants and abiotic factors like soil, rewilding follows a top-down approach. Here, attention is given to all trophic levels and megafauna like large herbivores and predators are introduced or stimulated to drive ecological functions. The management of rewilding is often more "laissez-faire", compared to restoration which requires specific management plans and predetermined end goals. However, both methods do entail taking historical ecosystems as a reference and both aim to recover natural ecosystems and processes (Mutillod et al., 2024). This justifies the use of potential natural vegetation, which aims to determine the hypothetical vegetation without human intervention (De Keersmaeker et al., 2013).

Historically, the landscapes of Denmark and much of Europe have undergone extensive anthropogenic transformation (Marquer et al., 2017). The start of this process generally coincided with the introduction of farming during the Neolithic period. This led to a first wave of large-scale changes in land use, as forests were cleared for settlements, fields, and fuel. Two more waves followed during the latter half of the classical era and after the Industrial Revolution. The introduction of monocultures and the removal of natural or semi-natural structures such as hedgerows, thickets, and solitary trees during land consolidation contributed to ecosystem homogenization (Bronstert et al., 1995; Jepsen et al., 2015). Cumulative pressures severely diminished the capacity of ecosystems to self-regulate and recover, creating a fragmented and ecologically impoverished landscape (Vera, 2000). Rewilding has emerged in response to this legacy, aiming not only to restore physical habitats but also to reintroduce ecological processes that were historically lost due to centuries of intensive human land use (Pereira & Navarro, 2015).

The growing attention to rewilding and restoration in Denmark is not occurring in a vacuum but is embedded within larger international and national policy frameworks. Following the 2022 UN Convention on Biological Diversity (COP15), global targets were set to protect 30% of land and oceans by 2030 (Convention On Biological Diversity, 2023). The European Union responded with the Nature Restoration Law, which mandates that at least

20% of land and sea areas be restored by the same deadline (European Commission, 2023). In line with this, Denmark launched its own Green Tripartite Agreement, committing to the restoration of 10% of its territory through measures such as rewilding, afforestation, and peatland recovery (Bjerre, 2024; Hedley, 2024). These policy efforts not only legitimize rewilding as a strategy but also create funding and institutional support for large-scale ecological interventions on marginal or abandoned lands. This context is essential in understanding why rewilding is becoming increasingly prominent in Denmark's conservation landscape.

These broader policy frameworks are reflected in multiple restoration and/or rewilding projects. One of the largest is Lille Vildmose, located approximately 25 km south-east of Aalborg. This initiative aims to sustain and restore raised bogs by reintroducing megafauna like moose and European bison (Henriksen, 2021; 'Reintroducing Moose to Lille Vildmose', 2017). Lille Vildmose serves as a great example of efforts to return the landscape to its potential natural vegetation. A smaller-scale program was set up near Jyderup, in the municipality of Holbæk, called the Kattrup Vildnis. The original goal here was similar: introducing megafauna species to create a self-regulating ecosystem (*Kattrup Vildnis*, n.d.). However, more recently, the project was revised to only include fallow deer, red deer and wild boar (Hansen, 2024).

These case studies highlight not only the growing momentum behind rewilding in Denmark but also the practical challenges of defining ecological baselines. To guide such efforts, especially in landscapes that have undergone centuries of transformation, tools like potential natural vegetation offer a scientifically grounded reference point for what ecosystems might have looked like under minimal human influence.

2.2 Potential natural vegetation

The potential natural vegetation (PNV) is defined as the hypothetical vegetation of a location without human or ecological disturbances (De Keersmaeker et al., 2013). The concept is fixed in time and thus doesn't take into account natural succession. The determination of PNV strongly differs between studies. Some only consider climatological conditions (Bertrix et al., 2025), some look at both climatological and soil characteristics (Hinze et al., 2023) and others focus solely on pedological and topographical conditions (De Keersmaeker et al., 2013). The choice is often scale-dependent. For large scale studies, climatological factors will have a much bigger impact on the PNV types than soil characteristics, while the opposite applies for small scale studies.

The concept of PNV has found a wide array of practical applications across ecological and land management disciplines. At the European level, PNV has been used for ecological classification and to assess the degree of anthropogenic impact on natural systems (Neuhäuslová, 2005; Schlüter, 2005). It provides a useful baseline for comparing current vegetation with natural reference conditions, making it a valuable tool for assessing ecological integrity and restoration potential.

One of the most important applications of PNV is in restoration and rewilding planning. By identifying the types of vegetation that would occur under minimal human influence, PNV maps help set ecological targets for both passive and active restoration initiatives (Cross, 2005; Rodwell, 2005). This is particularly relevant in regions where land use has drastically altered ecosystems, such as Denmark. PNV is also applied in the designation and evaluation of protected areas, including the EU's Natura 2000 network (Evans, 2005; Hettwer, 2005). These assessments ensure that conservation efforts are representative of natural vegetation types and not biased toward altered or degraded landscapes.

On a more strategic scale, PNV data have informed landscape-scale planning and carbon sequestration assessments, by offering insight into natural net primary productivity and potential forest composition (Hofmann & Jenssen, 2005; Schmidt, 2005). Furthermore, the PNV concept has gained interest as a benchmark for climate change resilience. By comparing actual vegetation shifts with predicted PNV types under changing climates, researchers and policymakers can anticipate future biodiversity changes and develop adaptive strategies (Hinze et al., 2023; Walther, 2005).

2.3 Geotopes

Geotopes are described as the smallest homogenous units in terms of physical factors (V. Van Eetvelde, personal communication, December 10, 2024). This study builds upon an unpublished study by Christensen et al. (2025), which defined and mapped geotopes in a large part of Zealand, Denmark. Christensen et al. determined sixteen different geotope types, as shown in Figure 1. They are determined by a combination of different factors. These can be grouped into three categories for clarity: topographic ("toposphere"), lithological ("lithosphere"), and hydrological ("hydrosphere") variables.

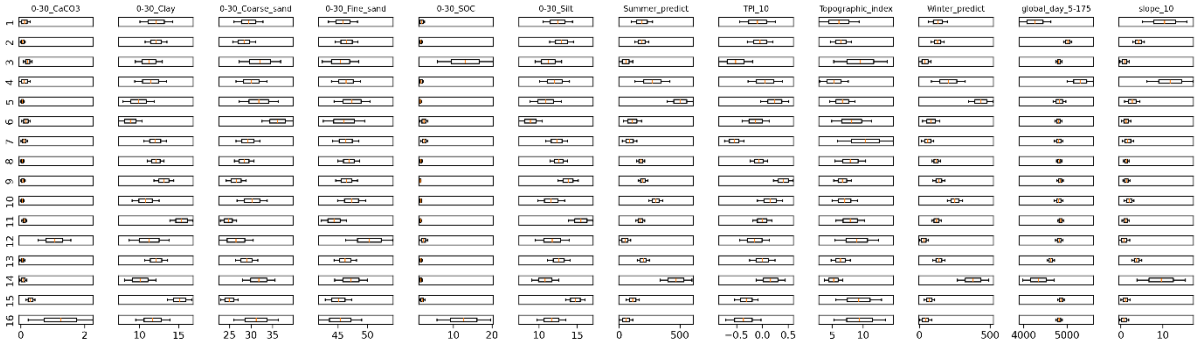
The lithological factors include the percentage of clay (0-30_Clay), silt (0-30_Silt), fine sand (0-30_Fine_sand), coarse sand (0-30_Coarse_sand), organic carbon (0-30_SOC) and chalk (0-30_CaCO3) in the topsoil, defined here

as the upper 30 cm of the soil. The topographic factors are: topographic position index (TPI_10), which describes the relative elevation of a location compared to its immediate surroundings (De Reu et al., 2013); topographic drainage (Topographic_index), also known as the topographic wetness index or compound topographic index, which reflects the variation in soil moisture as influenced by local relief (Kopecký et al., 2021); solar radiation (global_day_5-175), which represents the potential daily incoming solar energy at a site (i.e. without taking into account cloud cover), expressed in Wh/m^2/day; and slope inclination (slope_10), expressed as a percentage, indicating the steepness of the terrain. The hydrological factors are limited to the groundwater depth in summer (Summer_predict) and winter (Winter_predict).

Based on these variables, a geotope classification map with a 10 m resolution was created for a large portion of Zealand. However, data availability limited the scope of this study to the Odsherred municipality, and the analysis presented here focuses solely on that area.

Figure 1

Overview of the sixteen geotope types and their determining factors



Note. Taken from *Økotop kort v1.0*, (n.d.), ArcGIS experience (https://experience.arcgis.com/experience/b8f3547fec04454bbe345773fb501588).

Although the concept of geotopes is still under development, initial applications have suggested value in spatial planning and land management (A. A. Christensen, personal communication, May 16, 2025). Seeing as new applications are interesting to further evaluate and refine the concept, we explored their potential for generating high-resolution (10 m) potential natural vegetation (PNV) maps. Traditional PNV maps that cover Denmark are often derived from coarse-scale climate data and are typically of limited spatial resolution (e.g., Bertrix et al., 2025; Bohn et al., 2000; Hinze et al., 2023). In contrast, geotopes offer a physically grounded, fine-grained classification system that allows for more nuanced ecological interpretations.

By linking geotope types to specific physical conditions associated with natural vegetation types, we aimed to create PNV maps that reflect local soil, topographic, and hydrological characteristics, rather than relying solely on broader climatic zones. Ultimately, our goal is to use this refined ecological baseline to identify areas with potential for rewilding or restoration.

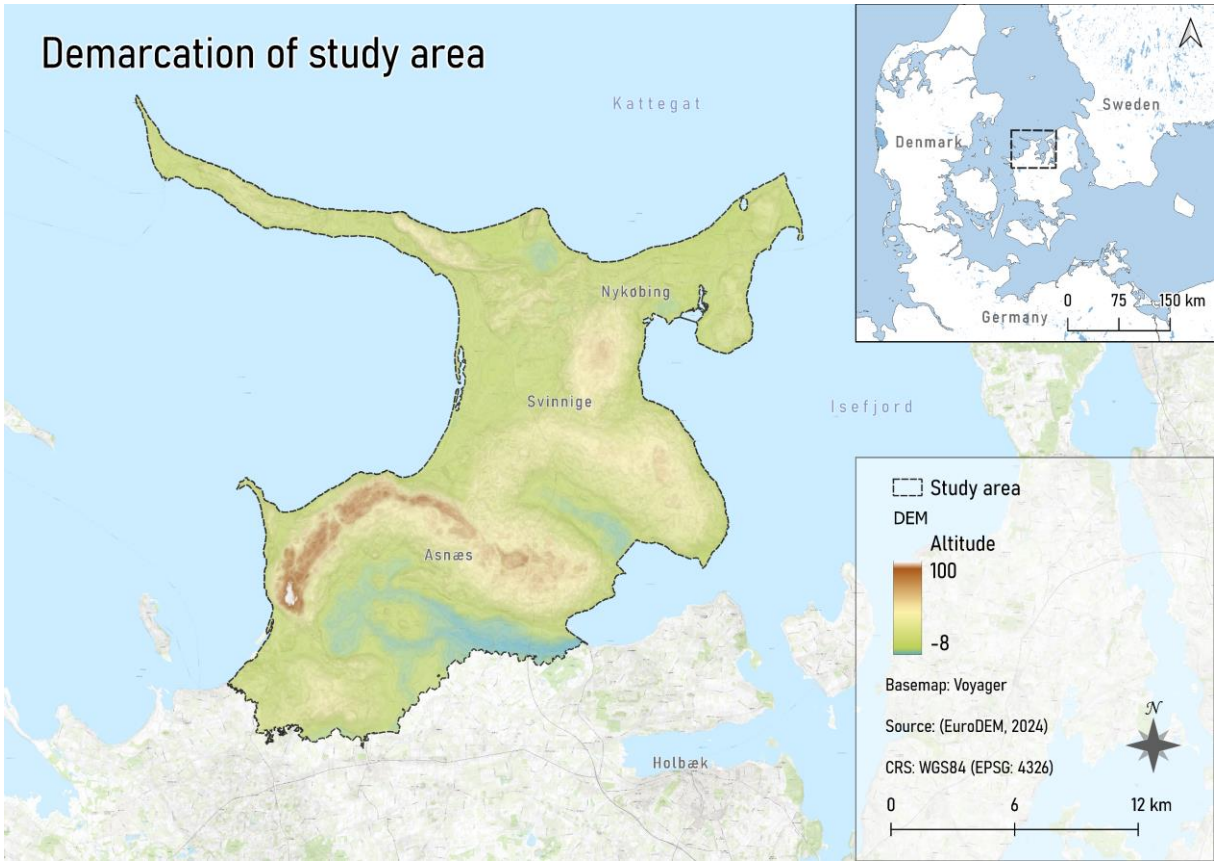
3. MATERIALS & METHODOLOGY

3.1 Study area

The study area for this research corresponds to the Danish municipality of Odsherred and is shown on Figure 2. This municipality overlaps with the peninsula of Odsherred on the island of Zealand, which borders the Isefjord on the east and Kattegat to the north and west. The region has some topographical variation with a maximum altitude of 114 m and is characterised by three distinct moraine arches. These terminal moraines are remnants of the Weichsel Ice Age (Council of Europe, n.d.). The 100 m mark (indicated with white on the map) is only surpassed on the most southern moraine arch, west of Asnæs. Other areas are more uniform and flatter, with some lying beneath sea level (indicated with blue on the map), like the reclaimed land in the Lammefjord, south of Asnæs.

Figure 2

Map of the study area



3.2 Prerequisites

The potential natural vegetation (PNV) in Denmark consists mostly of deciduous forest and, to a lesser extent, wetlands, bogs, or peatlands (Skov et al., 2009). As such, the focus will be on rewilding of deciduous forest types, rather than coniferous. Four types of potential natural vegetation are distinguished: eutrophic beech (*Fagus*) forests; oligotrophic oak and beech (*Quercus & Fagus*) forests; alluvial and wet lowland forests; and peatland. These types are based on the European potential natural vegetation by Bohn et al. (2003), comprising around 82% of the terrestrial area in Denmark, and each of these types require different soil and topographic conditions to grow properly (Skov et al., 2009). To determine these requirements, the concept of potential natural vegetation (PNV) is used. The decision to depend on the PNV instead of contemporary vegetation relies on the fact that landscapes are highly manipulated by people, often ignoring whether the biophysical conditions are optimal or not. Table 1 provides an overview of the biophysical prerequisites identified for each vegetation type.

3.2.1 Eutrophic beech forest

Eutrophic beech forests typically thrive on fertile, base-rich soils such as chromic and distric Luvisols or Cambisols, often formed on loamy substrates with a high silt content and low proportions of sand and clay (Blanco et al., 2003; Brumme & Khanna, 2009; Runhaar et al., 2009). These soils exhibit high base saturation and moderately high pH values averaging around 6, indicating favourable chemical conditions for nutrient availability and uptake (Blanco et al., 2003; Fichtner et al., 2012). The organic matter content in the topsoil remains relatively low (4–6%), suggesting rapid turnover and decomposition processes supported by a biologically active mull humus layer (Brumme & Khanna, 2009). Additionally, these forests often occur on moderately moist to dry soils with good drainage capacity, as indicated by low to moderate soil moisture levels (De Keersmaeker et al., 2001; Reif et al., 2017).

Topographically, eutrophic beech forests are found across a range of slopes from flat lowlands to steep inclines, frequently with north to northeast-facing aspects that provide shaded conditions and reduce evaporative stress (De Keersmaeker et al., 2001; Reif et al., 2017). Annual precipitation in these habitats typically ranges between 600 and 1 300 mm. The soils are generally poor in calcium carbonate (Runhaar et al., 2009). Despite this, the combination of loamy texture, high silt content and efficient nutrient cycling creates ideal growing conditions for *Fagus sylvatica* and associated mesotrophic herbaceous species.

3.2.2 Oligotrophic oak & beech forests

Oligotrophic beech forests often co-occur with acid-tolerant oak species such as *Quercus robur* and *Q. petraea* (Bohn et al., 2003; Brumme & Khanna, 2009). They thrive under strongly acidic and nutrient-poor conditions. These forests are commonly found on distric Cambisols with a distinct textural profile: a high silt fraction, low clay content and a sand fraction ranging from low to intermediate (Brumme & Khanna, 2009; Runhaar et al., 2009). The soils are derived from siliceous parent materials such as sandstone or glacial deposits and are characterized by extremely low base saturation and $CaCO_3$ content (Runhaar et al., 2009). Soil pH values are markedly acidic, typically between 3.4 and 4.0, creating unfavourable conditions for nutrient cycling and biological activity (Brumme & Khanna, 2009).

The organic layer in these forests is typically a moder humus type with a depth of 10-20 cm and contains intermediate levels of soil organic carbon in the topsoil (Brumme & Khanna, 2009). Due to the low pH and

reduced faunal activity, decomposition is slow. This leads to a build-up of organic matter and fine root density in the surface soil, which further inhibits herbaceous diversity. These forests occur across a range of topographies, from flat outwash plains to steep slopes, and are typically south-facing, receiving relatively high levels of sunlight (Brumme & Khanna, 2009). Annual precipitation is often around 1 200 mm, with seasonal fluctuations in the depth to the water table (Brumme & Khanna, 2009; Nijp & Jalink, 2022). Ranging from 85-100 cm in winter to 120-160 cm in summer, these values indicate intermittently moist but generally well-drained conditions. While their soil texture is broadly similar to that of eutrophic beech forests, oligotrophic forests are generally sandier, further limiting their capacity to retain moisture and nutrients (Brumme & Khanna, 2009).

3.2.3 Alluvial and wet lowland forests

Skov et al. (2009) does not explicitly give 'alluvial and wet lowland forests' as a vegetation type in Denmark. However, they do classify multiple vegetation types that fall into this category (e.g., alder carrs, pedunculate oak-ash forests), each of these only comprises a small percentage of the total land area (<2.5%). Despite their limited spatial extent, wetland forests are ecologically significant due to their role in biodiversity conservation, water purification, and flood mitigation (Nijp & Jalink, 2022; Roy et al., 2007; Runhaar et al., 2009). As to not overly expand the scope of this study, it was decided to combine these vegetation types into one category: alluvial and wet lowland forests.

Alluvial and wet lowland forests occur on moist to wet sites where tree roots have consistent access to the groundwater table, often in areas subject to periodic inundation (Claessens et al., 2010; De Keersmaeker et al., 2001). These forests typically develop on a wide variety of soil textures, particularly those with moderate to high clay content, as long as moisture remains available. Soil pH ranges widely from moderately acidic to near-neutral (approximately 4.2–7.5), reflecting the influence of both natural site conditions and hydrological dynamics (Claessens et al., 2010; De Keersmaeker et al., 2001; Vares et al., 2004). High base saturation and, in many cases, elevated levels of $CaCO_3$ further contribute to nutrient availability (De Keersmaeker et al., 2001; Runhaar et al., 2009). When sites lack direct groundwater access, annual precipitation of at least 1 500 mm is typically required to maintain the hydrological conditions necessary for these forest types (Claessens et al., 2010).

These ecosystems are highly tolerant to disturbed or degraded soils, often establishing themselves where other vegetation types may struggle (Kuznetsova et al., 2010; Roy et al., 2007). Nitrogen-fixing species like alder play

a foundational role, enabling colonization of nutrient-poor or contaminated substrates and facilitating successional recovery after human disturbance (Claessens et al., 2010; Kuznetsova et al., 2010; Roy et al., 2007). Their success across a variety of soil types is thus strongly tied to their hydrological niche and physiological adaptations rather than narrow edaphic preferences. Despite their general resilience, many species typical of these forests exhibit low shade tolerance, favouring canopy gaps or dynamic floodplain processes that allow light penetration (Roy et al., 2007). Consequently, alluvial and wet lowland forests often represent ecologically dynamic systems that respond to fluctuations in moisture availability, disturbance, and successional feedbacks.

3.2.4 Peatland

Peatlands are defined by a suite of distinct biophysical conditions that reflect their formation through the slow accumulation of organic matter under waterlogged, anoxic conditions (Bohn et al., 2003). Histosols are found frequently in these systems, a soil classification indicative of high organic content and poor decomposition due to persistently saturated conditions (De Keersmaeker et al., 2013). These soils are rich in organic carbon, as they accumulate decomposed plant matter over millennia (Bohn et al., 2003; Leuschner & Ellenberg, 2017). Consequently, peatlands are among the most carbon-dense ecosystems globally.

Soil moisture in peatlands remains very high year-round, which is a prerequisite for both peat formation and the persistence of peatland vegetation (Bohn et al., 2003; Runhaar et al., 2009). Peatlands consistently exhibit shallow groundwater tables. It is often less than 0.5 m from the surface, even during summer months (Runhaar et al., 2009). Altogether, the combination of Histosols, high soil organic carbon, high moisture, and minimal fluctuation in water levels makes peatlands ecologically unique and vital carbon sinks (Bohn et al., 2003; De Keersmaeker et al., 2013).

Table 1

Prerequisites of the PNV types

Variables	Corresponding geotope variables	Eutrophic beech	Sources	Oligotrophic beech & oak	Sources	Alluvial & wet lowland forests	Sources	Peatland	Sources
Soil type	\	Distric/chromic Luvisols, distric/chromic Cambisols	Blanco et al., 2003; De Keersmaeker et al., 2001	Distric cambisol	Brumme and Khanna, 2009	Everything if wet/moist; sites where roots have access to groundwater table	De Keersmaeker et al., 2001; Claessens et al., 2010	Histosols	De Keersmaeker et al., 2013
Sand fraction	Course sand + fine sand	Low to very low	Brumme & Khanna, 2009; Runhaar et al., 2009	Low to intermediate	Brumme and Khanna, 2009; Runhaar et al., 2009				
Silt fraction	Silt fraction	High to very high	Brumme & Khanna, 2009; Runhaar et al., 2009	High	Brumme and Khanna, 2009; Runhaar et al., 2009				
Clay fraction	Clay fraction	Low	Brumme & Khanna, 2009; Runhaar et al., 2009	Low	Brumme and Khanna, 2009; Runhaar et al., 2009	Intermediate to high	De Keersmaeker et al., 2001		
Base saturation	\	High	Fichtner et al., 2012			High	De Keersmaeker et al., 2001		
Organic content	Soil organic carbon	Low in topsoil (4-6%)	Blanco et al., 2003; Brumme & Khanna, 2009	Intermediate in topsoil	Brumme and Khanna, 2009			High	Leuschner & Ellenberg, 2017
pH	\	5-8 (avg. 6)	Blanco et al., 2003	3.4-4	Brumme and Khanna, 2009	4.2-7.5; 4-8; 4-7.5	Claessens et al., 2010; De Keersmaeker et al., 2001; Vares et al., 2004		
Soil moisture	\	Low to moderate	De Keersmaeker et al., 2001; Reif et al., 2017			High to very high	De Keersmaeker et al., 2001; Leuschner & Ellenberg, 2017	Very high	Runhaar et al., 2009
C/N	\	~10.7	Blanco et al., 2003						
Slope	Slope	Flat to steep	De Keersmaeker et al., 2001	Flat to steep	Brumme and Khanna, 2009				
Aspect	Global day (hours sunshine)	Shady (NW - NE)	Reif et al., 2017	South	Brumme and Khanna, 2009				
Humus type and depth	\	Mull thin	Brumme and Khanna, 2009	Moder 10-20 cm	Brumme and Khanna, 2009				
Precipitation	\	600 – 1 300 mm	Blanco et al., 2003	1 193 mm	Brumme and Khanna, 2009	Min 1 500 mm, if no access to groundwater	Claessens et al., 2010		
Depth to water index (lowest)	Winter predict			85-100 cm	Nijp & Jalink, 2022				
Depth to water index (highest)	Summer predict			120-160 cm	Nijp & Jalink, 2022			< 0.5 m	Runhaar et al., 2009
Shade	\					Low tolerance	Roy et al., 2007		
CaCO3	CaCO3-content	Low	Runhaar et al., 2009	Very low	Runhaar et al., 2009	High	Runhaar et al., 2009		
Extra info		Occur on loamy, fertile soils		Similar soil texture fractions as eutrophic beech, but more sandy	Brumme and Khanna, 2009	Well adapted to poor, degraded & disturbed soils. Alder fixes nitrogen, so can grow pretty much everywhere moist/wet, unless outcompeted; Alders are key organisms in restoring ecosystems disturbed by human activity (incl. contaminated sites).	Claessens et al., 2010; Kuznetsova et al., 2010; Roy et al., 2007		

3.3 Desktop analysis

The GIS pipeline consists of two large parts. First, a GIS analysis is performed for every PNV type, producing maps that show the suitability of different areas within the study area based on geotopes. To do this, a data-driven scoring-based approach is employed. The defining factors of the geotopes are compared to the prerequisites of each PNV type identified in the literature, with each corresponding criterion awarding points to the geotope. For each prerequisite, a threshold is set: if the mean value for a geotope exceeds this threshold, one point is added to its suitability score. This way, geotopes with higher scores are considered theoretically more suitable for a given PNV type. The increment for every variable is deliberately binary instead of weighted, in order to avoid a potential bias towards certain variables. The relative importance of the variables is undoubtably not the same for each of the variables, but this could not be derived from literature with a high confidence.

Since many of the prerequisites found in literature are case sensitive, they cannot always be directly applied as a threshold. For example, eutrophic beech forests thrive on loamy soils (De Keersmaeker et al., 2013), but the texture fractions that correspond to the soil in the soil classification of this study are different than loamy soils in the Danish classification. Thus, easily comparable values ranging from very low to very high are used where possible (see Table 1). Thresholds were then established using quintiles of the values in the study area. The qualitative prerequisites very low, low, intermediate, high and very high correspond to the first, second, third, fourth and fifth quintile respectively. The suitability score range varies depending on the PNV type, since not necessarily all the variables that are used for a certain PNV type are useful for another type. The suitability analysis for eutrophic beech forests, for example, was performed using seven variables, while peatland has significantly fewer defining criteria in literature, resulting in only two variables that could be used.

3.4 Fieldwork

3.4.1 Fieldwork methodology

After obtaining maps of the PNV suitability based on the geotopes, the output could be verified and evaluated with fieldwork. This fieldwork consisted of soil sampling using a soil auger and the measurement of external variables which are not included in the geotopes, like soil wetness and pH, to see if the geotopes would benefit from the inclusion of additional soil variables. For every soil sample, which extended as deep as the groundwater depth in most cases, a thorough description of soil texture, colour, horizons and inclusions was made. Based on

these characteristics, an estimation of the ideal potential natural vegetation type was determined that could be compared to the output of the geotope analysis.

For the sampling strategy, a 1x1 km grid was overlaid on top of the suitability maps, to choose heterogenous high suitability sites for every PNV type. Within each grid cell, several sample locations were selected to capture both areas of high suitability and transitional zones between high and low suitability. This approach ensured a comprehensive representation of the model's output. In many cases, visible changes in the landscape, such as a noticeable decline in vegetation density or shifts in vegetation type, were used as indicators of differing soil conditions. These sites were prioritized for sampling, and in some instances, ad hoc samples were added during fieldwork when such features suggested a potentially interesting deviation from model predictions. This allowed for the detection of possible mismatches between the predicted potential natural vegetation (PNV) and actual field conditions.

3.4.2 Statistical metrics

After empirically determining the potential natural vegetation type for every sampling point, the performance and accuracy of the model can be evaluated using statistical methods. Some metrics that will be used are the probability of detection (POD) and the false alarm rate (FAR), which can be calculated using the following equations (see Table 2 for variables) (Boneh et al., 2015):

$$POD = \frac{a}{a+c} \quad ; \quad FAR = \frac{b}{a+b} \tag{1}$$

Based on these metrics, a more general F_1-score can be calculated:

$$F_1 = 2 \cdot \frac{POD \cdot (1 - FAR)}{POD + (1 - FAR)} \tag{2}$$

This metric is especially useful as it compensates for imbalance in the dataset. This means that it is reliable even when category sample sizes differ significantly (*F1 Score in Machine Learning*, 2025).

Table 2

Example of a contingency table

		Observed	
		True	False
Predicted	True	a	b
	False	c	d

Finally, an overall model score, the Heidke Skill Score (HSS), will be determined. This score assesses whether the model has a higher proportion of correct responses than would be expected by random chance (Nurmi, 2007).

$$HSS = \frac{observed\ accuracy - random\ accuracy}{1 - random\ accuracy} \tag{3}$$

$$random\ accuracy = \frac{1}{N^2}\sum_i (T_i \cdot P_i) \tag{4}$$

With T_i = sum of row i and P_i = sum of column i. HSS ranges from -∞ to 1. If the HSS is lower than 0, the model performs worse than chance, while a score of 1 indicates a perfect model.

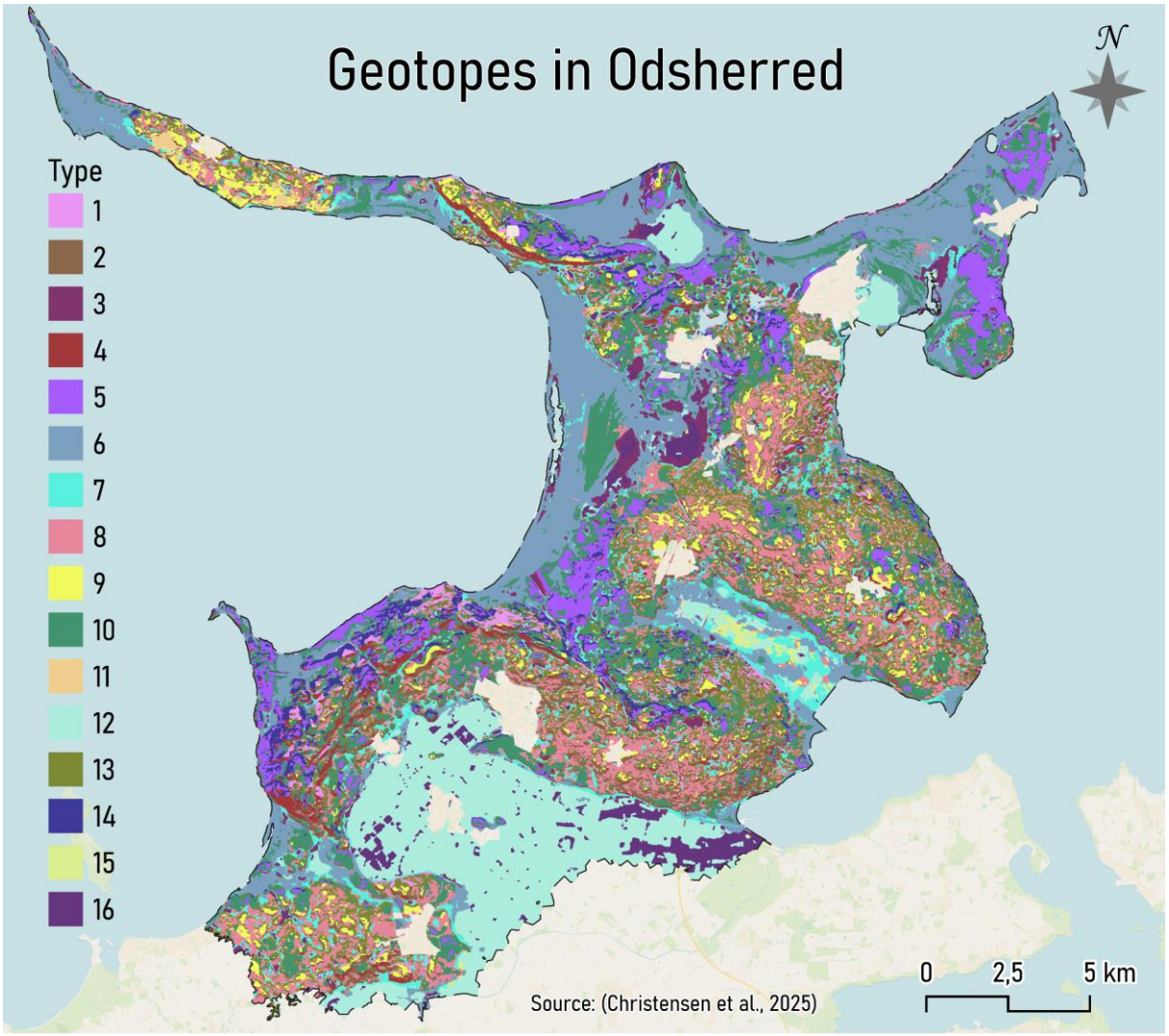
4. RESULTS

4.1 Suitability scores

Figure 3 shows the distribution of the geotope types in Odsherred. Comparing this map to Figure 2 gives some context for this distribution, as the three terminal moraines are clearly visible as highly heterogenous zones in terms of geotope variation. Geotope types 8, 9 and 13 take up a large part, as well as type 5 in the west. The reclaimed land of the Lammefjord and the historical lakes in the north are more homogenous, consisting mostly of types 12 and 16. The sandy coasts in the west and north are also very homogenous, almost completely overlapping with type 6.

Figure 3

Map of the spatial distribution of geotopes in the municipality of Odsherred



For the calculation of the suitability score for the eutrophic beech forest, a total of seven variables were used. Most of the thresholds related to the variables could be linked to quintiles of the datasets in a useful manner, like the texture fractions and the groundwater depth in the winter. Soil organic carbon (SOC), however, ranges from 0 to 27%, with the difference between the limit of the first and the lowest value of the fifth quintile being barely half a percent. In this case, a hard constraint in such small differences would result in some geotopes being ignored, while others with a negligible difference would have a suitable value. A threshold of 5% is derived from literature (Blanco et al., 2003; Brumme & Khanna, 2009). Eutrophic beech forests grow naturally on both flat to steep areas but prefer shady slopes over sunny slopes. Therefore, a threshold of 5000 W/m²/day is used, as the average lies a little below this value and higher values correspond to slopes facing south. In Table 2, the total suitability scores for the geotopes are shown. Types 8, 9, 11 and 13 have the highest scores (6), while type 3 has the lowest score (1). No geotope has a score of 0 or 7.

Table 3

Suitability score for eutrophic beech forest

EUTROPHIC BEECH FOREST									
Geotopes	**Sand fraction**	**Silt fraction**	**Clay fraction**	**CaCO3**	**SOC**	**Summer predict**	**Winter predict**	**Global day**	**Score**
1	X	X			X	\	X	X	**5**
2	X	X		X	X	\	X		**5**
3						\		X	**1**
4	X	X			X	\			**3**
5			X	X	X	\		X	**4**
6			X		X	\		X	**3**
7	X	X			X	\		X	**4**
8	X	X		X	X	\	X	X	**6**
9	X	X		X	X	\	X	X	**6**
10				X	X	\		X	**3**
11	X	X		X	X	\	X	X	**6**
12	X				X	\		X	**3**
13	X	X		X	X	\	X	X	**6**
14				X	X	\		X	**3**
15	X	X			X	\		X	**4**
16	X					\		X	**2**
Rule	Low to very low: < 77%	High to very high: > 12%	Low: < 10%	Low: < 0.11%	< 5%		Low to intermediate: 103-164 cm	Shady conditions: < 5000	

The criteria for the oligotrophic oak and beech forest are similar to the eutrophic beech forest. The calculation of the score uses a total of six variables instead of seven like eutrophic beech, the only difference being that there was no information of solar radiation preference for the oligotrophic oak and beech forest. This PNV type can tolerate drier and more sandy soils than the more species-rich counterpart. It can also have more organic carbon in the topsoil (upper 30 cm). The more forgiving thresholds result in a minimum score of 2 for the types 3, 6 and 16, and a maximum score of 4 for types 1, 4, 5, 9 and 13, as shown in Table 3.

Table 4

Suitability score for oligotrophic oak & beech forest

OLIGOTROPHIC BEECH & OAK FOREST									
Geotopes	**Sand fraction**	**Silt fraction**	**Clay fraction**	**CaCO3**	**SOC**	**Summer predict**	**Winter predict**	**Global day**	**Score**
1	X	X			X	\	X	\	**4**
2	X	X			X	\		\	**3**
3	X	X				\		\	**2**
4	X	X			X	\	X	\	**4**
5	X	X	X		X	\		\	**4**
6			X		X	\		\	**2**
7	X	X			X	\		\	**3**
8	X	X			X	\		\	**3**
9	X	X			X	\	X	\	**4**
10	X	X			X	\		\	**3**
11	X	X			X	\		\	**3**
12	X	X			X	\		\	**3**
13	X	X			X	\	X	\	**4**
14	X	X			X	\		\	**3**
15	X	X			X	\		\	**3**
16	X	X				\		\	**2**
Rule	Low to intermediate: < 80%	High: > 10%	Low: < 10%	Very low: < 0.04	Slightly higher than eutrophic beech: < 7%		Prefers drier soils than eutrophic beech: 135-225 cm		

Table 4 shows the suitability scores for the third type of forest, being alluvial and wet lowland forest. Four criteria are used, with the first two thresholds (clay and chalk fraction in topsoil) determined by the quintiles. In this case, both summer and winter groundwater depth are used, as the seasonal nature of the water logging is important. The soil can never be too dry but cannot be too wet year-round either (De Keersmaeker et al., 2001). A score of 0 is achieved by six types of geotopes, while the maximum achieved value of 3 is only reached by geotope 3.

Table 5

Suitability score for alluvial and wet lowland forest

ALLUVIAL AND WET LOWLAND FOREST									
Geotopes	**Sand fraction**	**Silt fraction**	**Clay fraction**	**CaCO3**	**SOC**	**Summer predict**	**Winter predict**	**Global day**	**Score**
1	\	\		X	\			\	**1**
2	\	\			\			\	**0**
3	\	\	X		\	X	X	\	**3**
4	\	\	X	X	\			\	**2**
5	\	\			\			\	**0**
6	\	\			\	X		\	**1**
7	\	\		X	\	X		\	**2**
8	\	\			\			\	**0**
9	\	\			\			\	**0**
10	\	\	X		\			\	**1**
11	\	\		X	\			\	**1**
12	\	\	X		\		X	\	**2**
13	\	\			\			\	**0**
14	\	\			\			\	**0**
15	\	\			\	X		\	**1**
16	\	\			\	X	X	\	**2**
			Intermediate to high: 10.16-11.39%	High: 0.10-0.12%		50-175 cm	< 50 cm		

Lastly, the suitability scores for peatland are shown in Table 5. Only two criteria have been found in literature, being soil organic carbon and groundwater depth in summer (i.e. the maximum depth). Soil organic carbon has to be sufficiently high for potential peatland, which is only the case for two geotopes. The soil must also be wet enough year-round (lowest groundwater level less than 50 cm deep) to allow peatland to persist. With these requirements, only geotopes 3 and 16 have a maximum score of 2, while the majority has a score of zero.

Table 6

Suitability score for peatland

PEATLAND									
Geotopes	**Sand fraction**	**Silt fraction**	**Clay fraction**	**CaCO3**	**SOC**	**Summer predict**	**Winter predict**	**Global day**	**Score**
1	\	\	\	\			\	\	**0**
2	\	\	\	\			\	\	**0**
3	\	\	\	\	X	X	\	\	**2**
4	\	\	\	\			\	\	**0**
5	\	\	\	\			\	\	**0**
6	\	\	\	\			\	\	**0**
7	\	\	\	\			\	\	**0**
8	\	\	\	\			\	\	**0**
9	\	\	\	\			\	\	**0**
10	\	\	\	\			\	\	**0**
11	\	\	\	\			\	\	**0**
12	\	\	\	\		X	\	\	**1**
13	\	\	\	\			\	\	**0**
14	\	\	\	\			\	\	**0**
15	\	\	\	\		X	\	\	**1**
16	\	\	\	\	X	X	\	\	**2**
					> 10%	< 50 cm			

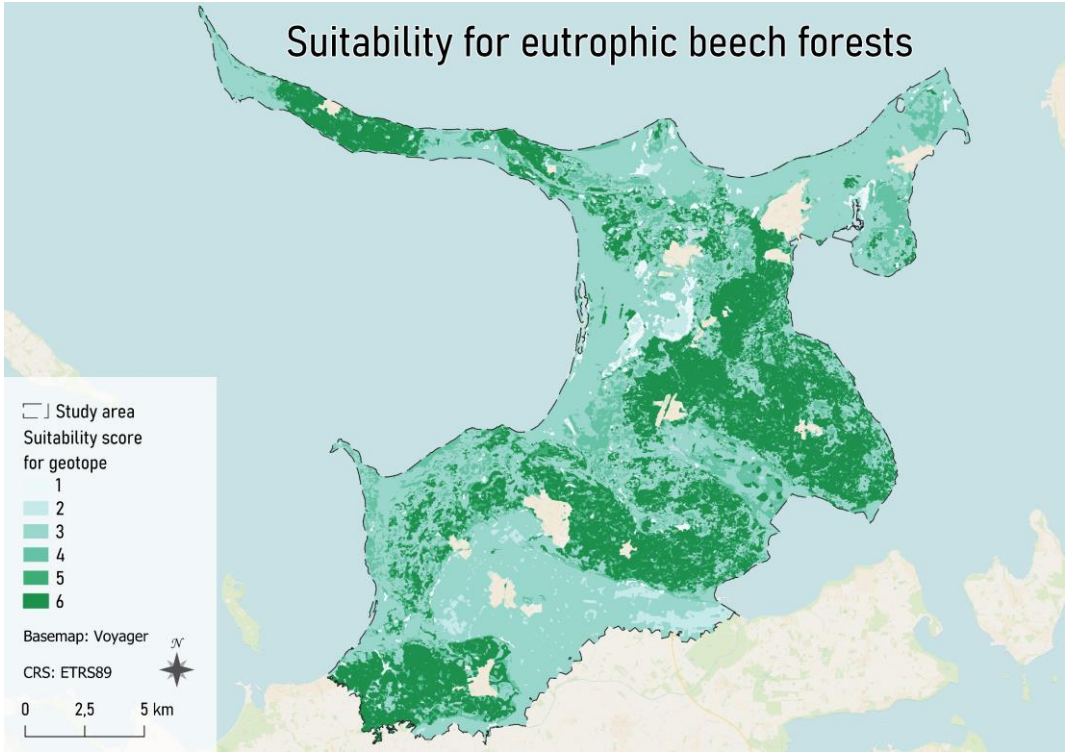
4.2 Potential natural vegetation mapping

Using the results from Tables 2, 3, 4 and 5, a series of suitability maps for the different PNV types is generated. However, the maps are not directly comparable, as each PNV type has a different range of suitability scores. While the darkest green consistently indicates the highest score within each map, the actual values these colours represent vary between PNV types. The same holds true for the lowest values. As a result, the colour scales may be misleading when comparing maps across PNV types, but they remain useful for interpreting relative suitability within each individual map.

Figure 4 illustrates the suitability for eutrophic beech forests in Odsherred based on the geotope suitability scores. A relation between high suitability and elevation seems visible on the map, with the moraine ridges sticking out, as well as hilly areas in the south. A notable exception is the terminal moraine in the southwest of Odsherred, which generally has a lower score than the other moraine deposits. The middle of the thin peninsula in the northwest is also highly suitable, but isn't clearly linked to topographic characteristics. The lowest scores are found in very wet and carbon-rich soils.

Figure 4

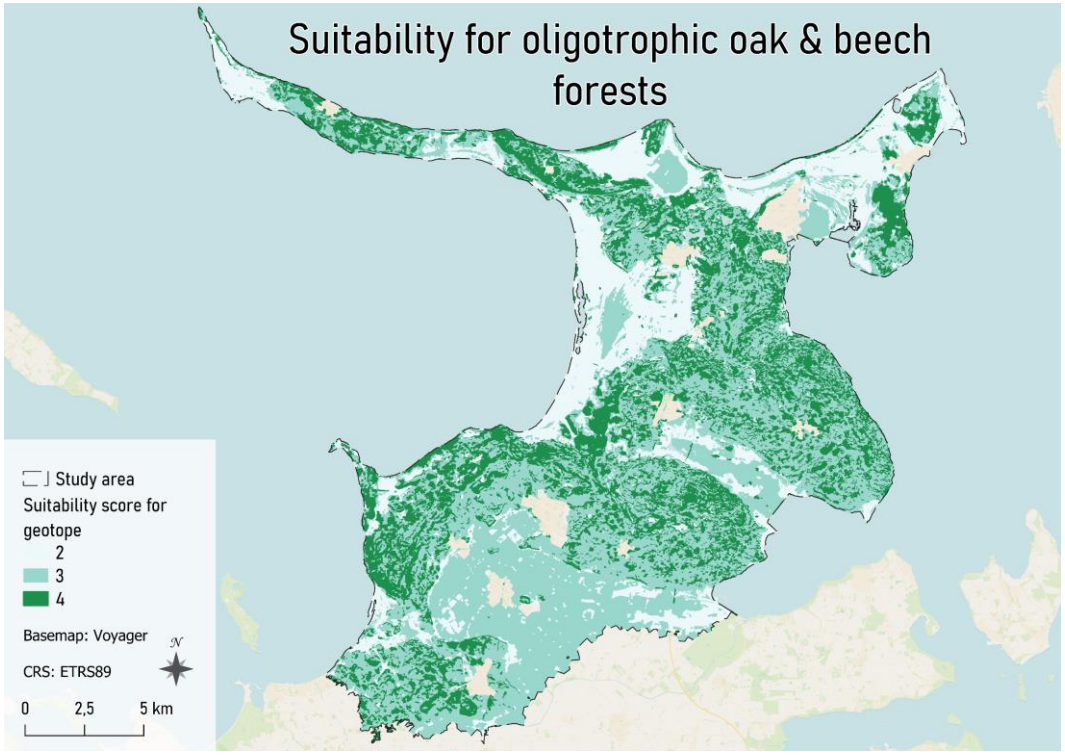
Map of the suitability scores for eutrophic beech forests



The spatial distribution of suitability scores for oligotrophic oak and beech forests resembles the eutrophic beech forest, but there are differences. On average, high suitability patches are more scattered and smaller in size. It also seems to follow the topography, even though no topographical variables are included in the score. High suitability zones are visible along the southwestern ridge and on the northeastern peninsula, while this isn't the case for eutrophic beech forests.

Figure 5

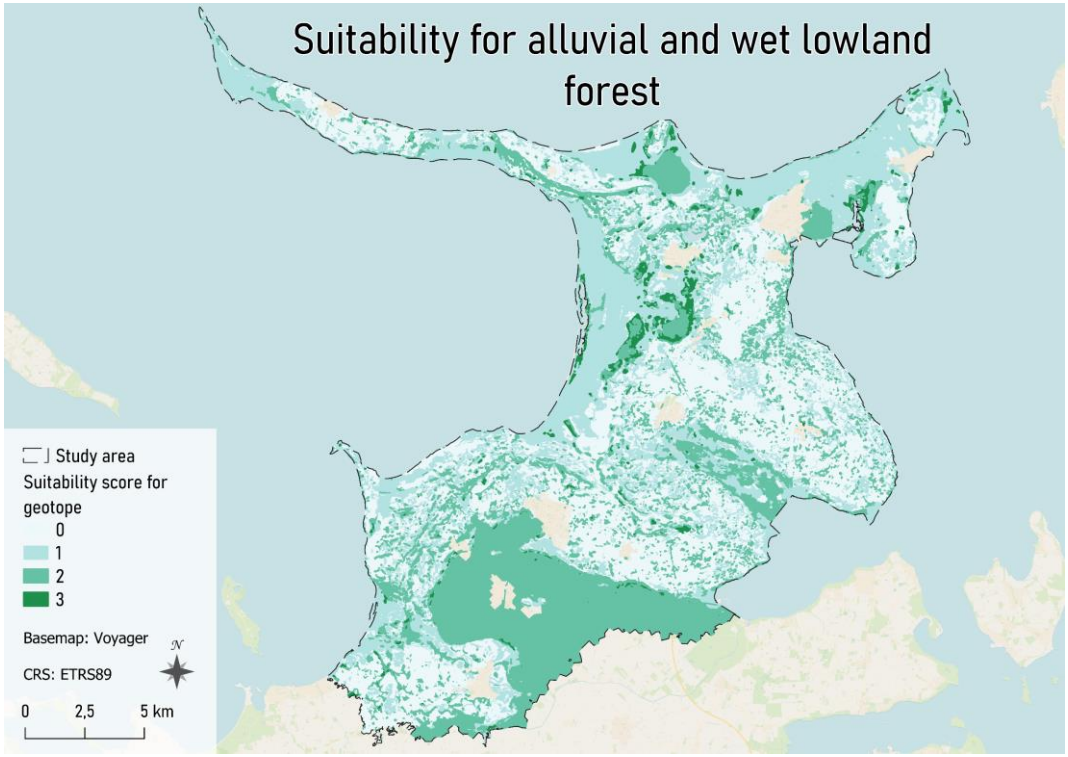
Map of the suitability scores for oligotrophic oak & beech forests



High suitability sites for alluvial and wet lowland forests occur mostly on the edge of current peat- or wetlands, like Trundholm Mose in the centre of Odsherred, or polders like the Lammefjord and the historical lakes in the north (Figure 6). The more elevated areas are too dry for alluvial forests to occur and have a low suitability, which is to be expected. Surprisingly, some zones with high elevations do have a relatively high suitability for this PNV type, like on the ridge in the southwest. This is due to ideal texture fractions, which gives it a score of two, even though the soils are generally too dry.

Figure 6

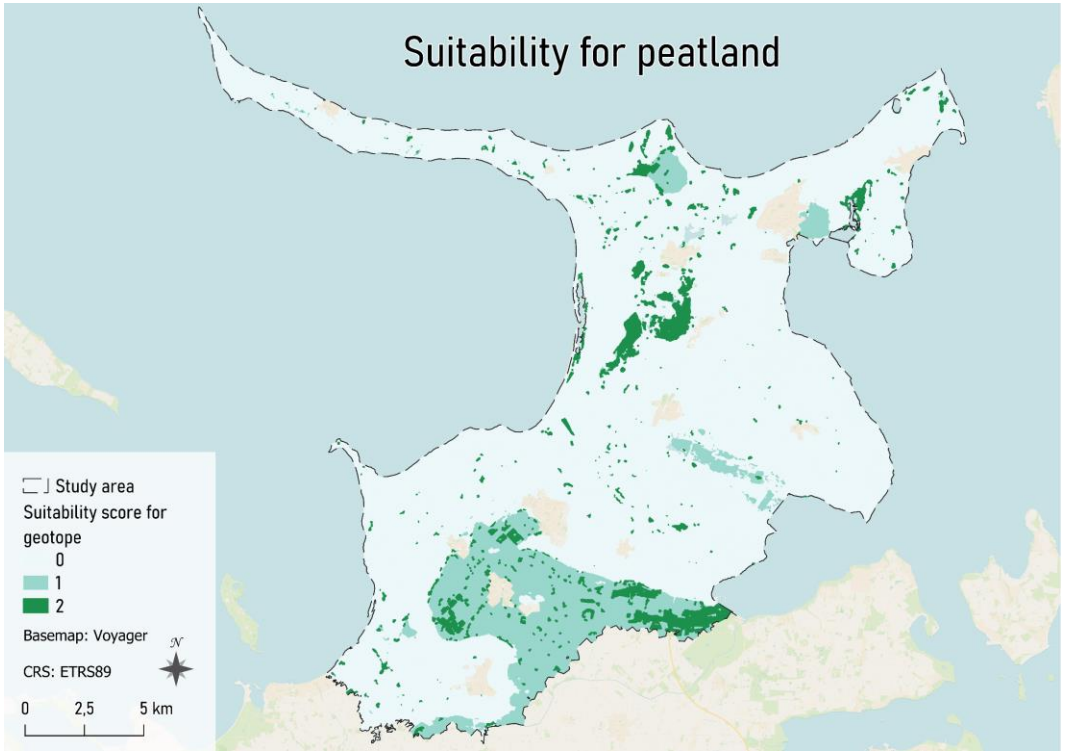
Map of the suitability scores for alluvial and wet lowland forests



Peatland occurs naturally in similar areas as alluvial forests according to Figure 7, though less widespread. The patches of high suitability are very dispersed, with clear exceptions like the Lammefjord and Trundholm Mose.

Figure 7

Map of the suitability scores for peatland



4.3 Soil sampling

4.3.1 Sampling locations

Based on Figures 4-7, three sites of high suitability are chosen after overlaying a 1x1 km grid. Selection was guided by a holistic spatial overview of suitability patterns across the landscape, rather than strictly quantified averages. One grid cell is located in Nakke, in the northeast, where the suitability for oligotrophic oak and beech forests is high. This site is primarily composed of agricultural land with some forest patches, and lies close to the Hovvig nature reserve, a large wetland bird sanctuary (*Hovvig Naturreservat*, n.d.).

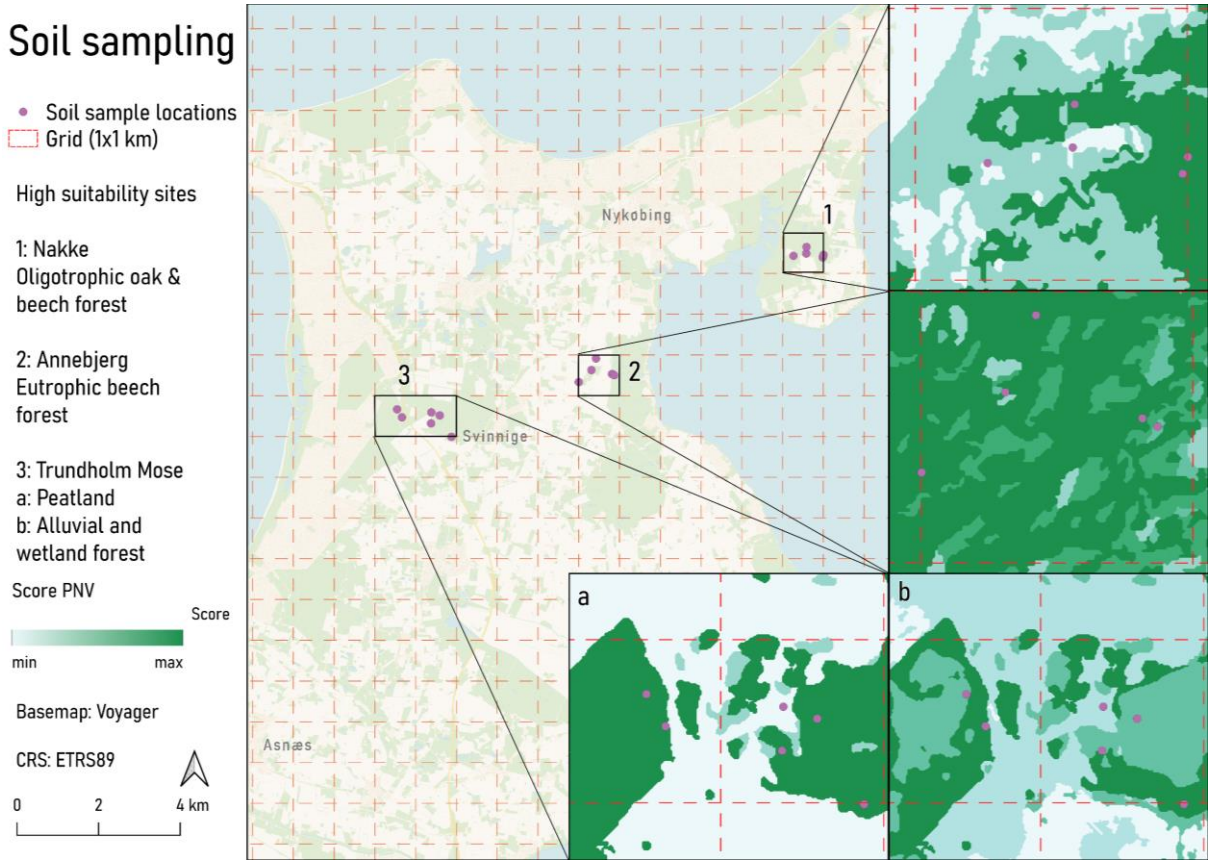
Another grid cell lies adjacent to Annebjerg Skov, a historically rich and ecologically diverse forest near the former Ulkerup village (*Historie - Ulkerup og Annebjerg Skov*, n.d.). The area is part of the UNESCO-designated GeoPark Odsherred, where active efforts are focused on natural forest regeneration and cultural heritage. Suitability here is high for eutrophic beech forests.

The final sampling area consists of two adjacent grid cells in Trundholm Mose, a low-lying former bog formed from a post-glacial lagoon (*Trundholm Mose*, n.d.). Though now largely drained and used for agriculture, the area is significant for its natural history and archaeological importance (e.g. the discovery site of the Bronze Age Sun Chariot). This site was chosen to represent both other PNV types: peatland and alluvial and wet lowland forests, which occurred side-by-side in the suitability maps.

A total of sixteen sample locations were selected: six in Trundholm Mose and five in each of the other two sites (Figure 8).

Figure 8

Map of the sample locations and corresponding high suitability PNV scores



4.3.2 Soil profiles

Out of the sixteen soil profiles collected, we chose to describe only a selection in detail: those that revealed particularly interesting mismatches, confirmations, or insights relevant to the PNV suitability map. While this

still includes nearly half of the total samples, the goal was to focus on a representative subset that best illustrates the strengths and limitations of the geotope-based predictions.

4.3.2.1 Trundholm mose: Mismatch between predicted and reality

This soil was classified as highly suitable for peatland. However, the actual soil profile and site description significantly deviate from expectations. One of the primary concerns is the groundwater table. For peat to establish and thrive, the water table generally needs to remain within 50 cm of the surface. At the first sampling site, there was a notable discrepancy between the predicted and actual groundwater levels, leading to an inaccurate assessment of peatland suitability. This difference may be due to intensive artificial drainage practices that have lowered the water table more than anticipated. When applying the results of our geotope suitability map, it is essential to investigate the specifics of the site's drainage infrastructure. Equally important is evaluating the feasibility of rewetting the area to restore appropriate conditions for rewilding.

4.3.2.2 Shooting range 2

This soil sample was taken in a reed area in conditions with an elevated groundwater level. The saturated soil was very dark and contained rests of organic material (particularly a lot of roots in the top 15-30 cm). The soil could be described as a clay soil with a dark colour, typically associated with soils that are permanently waterlogged. Impressively the soil pH was relatively neutral despite the wet conditions. This is largely due to the interaction with calcareous material in the form of gyttjä. The calcium carbonate in the soil would react with the acidic water and stabilize the soil pH as a consequence of the reaction. The clay present did not show signs of vivianite or other mineral decompositions typically associated with non-organic clays leading to the conclusion that the top layer of soil is likely composed of a large part organic material, the dark colour of the soil further confirmed this idea.

4.3.2.3 Nakke forest north

This soil sample was taken inside the forests of Nakke. This part of the forest contained a lot of beech trees but lacked in other types of vegetation typically associated with oligotrophic conditions, like oak trees. The soil observed was very deep where the depth exceeded 225 cm and lacked clear soil profiles despite its supposed undisturbed nature and present leaf litter. The soil did however have a gradation in terms of colour (darker colour at the top typically associated with organic material enrichment and lighter colour at the bottom

reflective of the original material deposed on the hill). The soil was very dry and well drained both conditions typically associated with this type of vegetation. The neutral soil pH observed can be partly attributed to the characteristics of sandy soils. Due to their coarse texture, these soils generally have a low cation exchange capacity, which limits their ability to retain and buffer nutrients. In addition, the high permeability of sandy soils leads to increased leaching of minerals by rainwater. This process removes essential buffering compounds, contributing to a lower-than-expected soil pH (Huang & Hartemink, 2020). Importantly this would also cause this soil to be sensitive to external pH input causing acidification or alkalinisation. The lack of a distinct humus layer can be explained by the current land use as this forest is used for logging and has been planted for economic purposes.

4.3.2.4 Nakke forest mismatch

This soil was present in the middle of an area marked as having a high suitability for oligotrophic beech and oak forest. However, the soil present was far too wet to house beech forests as beech trees do not tolerate prolonged waterlogging. The soil consisted of a clay layer at the top which was impermeable causing stagnating water to form a small lake and below it a loamy sand reminiscent of the surrounding area. These small lakes are a direct result of the dead ice landscape typical of the region. As meltwater from retreating glaciers flows over areas with buried ice, it causes the formation of small depressions in the landscape. These localized depressions often accumulate mineral clays transported by the surrounding glacial meltwater. Mapping the presence of these features however can be challenging especially when working with lower resolution soil/water data. The pond had a diameter of 50 meters indicating a considerable size yet however this was not marked on our suitability map.

4.3.2.5 Annebjerg Skov

This soil sample was taken from the Annebjerg Skov. The forest soils had a loamy texture, which contributes to their high suitability for eutrophic beech forest development due to the relatively high loam content. Within the forest, several lower-lying areas were identified in the suitability maps as having slightly reduced suitability for eutrophic forest. This reduction is attributed to increased soil wetness, which poses challenges for beech growth. These lower areas exhibit a horizontal gradient in soil moisture, resulting in diverse and transitional vegetation patterns. In the lowest parts, where water is present at the surface year-round, peat development is possible. Moving slightly upslope, the moisture conditions create a transitional zone that supports both alluvial forests and shallow-rooted beech trees. This is supported by the observed presence of a mixed stand of beech and oak

trees near the bog's edge. Interestingly, this part of the forest is less densely vegetated compared to the surrounding areas, allowing more light to reach the forest floor, an uncommon feature in the otherwise closed canopy of the forest. The presence of wetland indicator species such as soft rush (*Juncus effusus*) and tussock sedge (*Carex paniculata*) further supports the ecological significance of soil wetness for local biodiversity. The soil in these lower-lying areas was notably darker and finer in texture, resembling peat soils. Undecomposed organic matter was still visible, suggesting ongoing peat formation. However, the soil pH did not match the typically low pH associated with peat, indicating a different chemical environment despite the peat-like physical characteristics.

Figure 9

Area surrounding the sample taken in the Annebjerg Skov shows less canopy density than the background and varying grass types. (Taken by Pieter Denoo on 21/05/2025)

4.3.2.6 Annebjerg field

This soil sample was taken from a field near the forest in Annebjerg. Although the surrounding area consists mostly of loamy soils and is used as ploughed agricultural land, this particular field served as a grazing area, suggesting it was less suitable for cultivation. At the lowest point of the field, a small pond indicated the presence of an impermeable layer beneath the surface. The soil profile confirmed this, revealing an impermeable clay layer at the bottom. Notably, the clay found here was a greyish-blue mineral clay with gleyic characteristics, suggesting a different origin than typical organic-rich depressions. Rather than resulting from organic material

accumulation, the layer likely formed through glacial processes, specifically the formation of kettle lakes. These small depressions are created when isolated blocks of glacial ice (dead ice) melt, leaving behind basins that fill with mineral deposits from glacial meltwater. This process explains the mineral clay observed at the site. Although distinct lamination was not clearly observed in our sample (likely due to sampling limitations), it is plausible, especially closer to the pond, where fine sediments may have settled in layers over time. Many of these small kettle lakes remain unmapped, primarily because their small size makes them difficult to detect using standard interpolation techniques.

4.3.2.7 Annebjerg Skov

This sample represents the ideal condition for the growth of a eutrophic forest. Importantly this soil was well drained and consisted mainly of loam, this paired with the high pH (7.5) indicating a possible higher cation exchange capacity (CEC) alludes to the possibility for a species rich eutrophic beech forest (Uttam, 2014). Furthermore, the soil in the forest had a lot of unweathered minerals (tiny granite fragments, micas, other magmatic rocks) indicating a young soil and further proving that the soil will be enriched with minerals which once again explains the high CEC.

4.4 Model performance

Table 7 shows the results of the expected potential natural vegetation based on the PNV map vs the observed PNV based on the results of the soil sampling. Decisions on the potential vegetation were made by analysing conditions that would make a specific vegetation type unlikely to develop naturally in the region. An example of this a low water table making the development of peat unlikely as shown in sample 1. The table highlights notable discrepancies between the predicted potential natural vegetation (PNV) and actual field conditions. These differences can be attributed partly to the nature of the geotope map and the sampling method, which focused on areas with abrupt visible landscape changes. In low water table areas, deviations were often caused by man-made structures such as drainage canals. In two cases where conditions were unexpectedly wet, the discrepancy stemmed from the geotope map failing to account for kettle lakes in dead ice landscapes. Lastly, mismatches related to pH were influenced by both soil pH and texture, which together affected the estimated cation exchange capacity (CEC). For instance, in soil sample 7, the unexpectedly low pH combined with a finer texture suggested that an oligotrophic forest was unlikely. Conversely, samples 15 and 16 indicated that high mineral content from the parent material and a loamy texture favoured the natural development of a eutrophic forest.

Table 8 shows the classification output in a confusion matrix. The sum of the samples in the matrix equals twenty instead of sixteen as Table 7 would suggest. This is due to the model occasionally classifying two PNV's with the same probability for one soil sample. In that case the soil sample is counted twice in the confusion matrix, once for each PNV type. The green diagonal line in the table shows the number of samples for each category that were identically classified by the model and the soil analysis. The samples are unevenly distributed across categories: eutrophic beech (EB) and alluvial forests (AF) were identified as the most suitable vegetation types at eight and five locations respectively, whereas only three locations each were classified as most suitable for oligotrophic oak and beech forests (OOB) and peatlands (P).

Table 7

Fieldwork output compared to model predictions

VEGETATION MAP VALIDATION					
Region	**Soil samples**	**Expected PNV**	**Observed**	**Reason**	**Correct**
Trundholm Mose	1	P	AF	Water table too low	
	2	P	AF	Water table too low	
	3	P	P		X
	4	EB	EB		X
	5	AF & P	AF	Water table too low	±
	6	P	P		X
Nakke	7	EB	OOB	pH too low	
	8	OOB	OOB		X
	9	OOB	OOB		X
	10	OOB	P	Too wet	
	11	EB	EB		X
Annebjerg	12	EB	EB		X
	13	EB & AF	AF	Too wet	±
	14	EB	EB		X
	15	EB & OOB	EB	Loam soil with high pH	±
	16	EB & OOB	EB	Loam soil with high pH	±

EB = eutrophic beech forest
OOB = oligotrophic oak & beech forest
AF = alluvial and wet lowland forest
P = peatland

The metrics that are derived from the confusion matrix (Table 8 bottom) are useful for the model evaluation. The probability of detection (POD) is fairly good for most categories, with around 70% of observed EB, OOB and P being classified as such by the model. However, alluvial forests have a much lower score of 33% due to the model often confusing it with peatland. The false alarm rate (FAR), on the other hand, is zero for alluvial forests, meaning that even though the model underestimates how often it occurs, it never wrongly classified the PNV. The FAR is also low for EB, with only 25%. OOB and P seems to be harder to correctly classify for the model, as both PNV's have a FAR of 60%. Of the five samples that were classified as peatland in the model, three of them were observed to be more suitable for AF. In general, the false alarm rate is perhaps more important than POD in this study, as an incorrect classification (number of false positives increase with FAR) of the most suitable vegetation for a certain location is more costly than the missing of a suitable location. This is especially the case if the aim is to use the model as a tool for rewilding policy. Overall, EB has the best score (as seen by the F_1-score), while the other three PNV's have an intermediate score.

Table 8

Confusion matrix and derived metrics of the fieldwork and model output

	Observed			
Expected	EB	OOB	AF	P
EB	6	1	1	0
OOB	2	2	0	1
AF	0	0	2	0
P	0	0	3	2

Probability of detection	0,75	0,67	0,33	0,67
False alarm rate	0,25	0,60	0,00	0,60
F1-score	0,75	0,50	0,50	0,50

To get a view of the overall performance of the model, the Heidke Skill Score (HSS) is calculated using Equation 4:

$$random\ accuracy = \frac{1}{20^2}(8 \cdot 8 + 5 \cdot 3 + 2 \cdot 6 + 5 \cdot 3) = 0{,}265 \quad (5)$$

$$observed\ accuracy = \frac{12}{20} = 0{,}6 \quad (6)$$

$$HSS = \frac{0{,}6 - 0{,}265}{1 - 0{,}265} = 0{,}456 \quad (7)$$

A score of 0,456 indicates that the model performs significantly better than chance, but there is still room for improvement.

4.5 Rewilding potential

Our suitability maps, developed on the basis of potential natural vegetation (PNV) and geotope data, offer a valuable ecological baseline for identifying areas that may support rewilding. These maps can highlight locations where current abiotic conditions align well with specific types of PNV, such as eutrophic beech forests or peatlands, and thus provide a preliminary shortlist of sites with strong ecological potential for rewilding initiatives.

For instance, in the case of Annebjerg Skov, high suitability for eutrophic beech forest suggests that natural expansion westward is biophysically plausible. Similar suitability signals can be observed in other areas bordering existing nature, such as Nakke. These findings are particularly useful for early-stage planning and spatial prioritization, especially under national restoration goals like those set by the Green Tripartite Agreement.

However, identifying a site with ecological suitability is only one part of determining rewilding potential. True implementation depends on a broader set of factors, including: land ownership and land use conflicts, such as agricultural dependency or sensitive parcels where land transfer would be socially or politically complex; economic considerations, including, but not limited to, costs related to land acquisition, fencing, species

reintroduction, and long-term monitoring; social acceptance and stakeholder involvement, especially where rewilding may impact local livelihoods or land traditions; biodiversity and connectivity goals, which require integration with species distributions, habitat corridors, and existing protected areas; and field-based validation, since many ecological variables (e.g. microhabitats, disturbance regimes, legacy land use) are not entirely captured in GIS-based modelling alone.

Ultimately, our suitability maps should be seen as an ecological pre-screening tool: a way to identify areas where rewilding could work from a biophysical perspective. They are not a substitute for comprehensive feasibility studies, but rather a scientifically grounded input into more integrative and participatory decision-making processes.

5. DISCUSSION

5.1 PNV considerations

In order to keep the study manageable in scope, multiple wetland and alluvial forest types were grouped into a single PNV category. This approach allowed us to broadly capture relevant site conditions while maintaining analytical feasibility. However, it is important to acknowledge that this aggregation potentially masks ecologically important distinctions among individual subtypes, which may respond differently to biophysical variables like hydrology, soil texture and pH. Consequently, the use of a combined category may have constrained our suitability assessments, underestimating the specific rewilding potential of sites that would support only a subset of these forest types. Future research could refine this methodology by distinguishing more narrowly defined PNV types and adapting the scoring thresholds accordingly.

Another consideration is that while PNV classifications are defined under current climatic conditions, they may become less applicable in specific regions under future climate change scenarios. Shifting temperature and precipitation patterns could lead to novel site conditions where currently mapped PNV types are no longer the best ecological reference (Skov et al., 2009). This does not invalidate the PNV framework itself, but it highlights the importance of context: its relevance depends on the stability of environmental baselines. As such, integrating climate projections or dynamic vegetation models into PNV-based suitability assessments would be a logical next step to improve the resilience and future-proofing of rewilding strategies.

5.2 Discussion of the used variables

This study utilized the geotope map developed by Roskilde University. It incorporates a collection of variables describing certain geophysical characteristics. Some limitations of our findings are directly linked to the limitations of the datasets used to create the geotope map. A primary concern is the resolution of the data. Certain variables were collected by using remote sensing data while others relied on using interpolation. However, issues arise when using this data to describe smaller features in the landscape. An example of this is the presence of kettles and perched water tables creating small lakes or areas too wet to sustain a certain predicted vegetation type. These features, though small, have visible consequences on the landscape and significantly influence potential natural vegetation. In Annebjerg Skov, one such kettle reduced forest density and allowed for the presence of alternative species, such as grasses and non-dominant trees. While these features are difficult to map (especially if techniques like interpolation are used), they have a considerable ecological importance representing important habitats for key plants species but equally being of great importance as a breeding ground for various species of amphibians, insects and fish (Lozada-Gobilard et al., 2019).

One variable that was not included in the current model but merits consideration is soil pH. Although it is not yet clear whether pH is a strong predictor of potential natural vegetation (PNV), it remains a potentially important factor. Soil pH maps for Denmark are still under development, and its spatial distribution is influenced by a combination of underlying geology, land use intensity, and soil texture. This suggests that pH patterns may partially overlap with variables already captured in the geotope map. While pH can vary with depth, our field measurements across all sampling locations showed no extreme values, with even wetland samples consistently falling between pH 6 and 7. This indicates a relatively stable pH in the upper 30 cm of soil and raises the possibility that pH could serve as a complementary parameter in future studies. However, an important limitation is its temporal variability. Certain soil types, such as the sandy Arenosols found in the Nakke forest, are especially susceptible to pH fluctuations caused by acid rain and agricultural practices. As a result, incorporating soil pH into spatial models would require frequent monitoring and remapping to maintain accuracy over time.

A final variable that wasn't used but should be considered for further approaches is the redox height map. A redox height map currently exists but its use is limited due to its low spatial resolution. This map would, however, be useful in the prediction of area's where wetland restoration is possible. An important prerequisite for the

development of peatland is the presence of anaerobic conditions throughout the year, which result from prolonged waterlogging. These conditions slow the decomposition of organic material and lead to the acidification of peat soils. According to the USDA Wetland Restoration Manual (USDA NRCS, 2023), soils with high hydricity (defined as soils that experience extended periods of water saturation) are key indicators for suitable wetland restoration areas, including peatland development. The redox height helps give an indication of the locations where these anaerobic conditions are met on shallow soil depths.

5.3 Causality vs Correlation vs Necessity

An important challenge that emerged during this research was the questions surrounding causality, correlation, and necessity when defining the conditions for potential natural vegetation. As we sought to describe the vegetation types, it became apparent that some environmental conditions often listed as defining features might actually be consequences rather than prerequisites of the vegetation itself. One example concerns the presence and characteristics of a humus layer. While one might expect a well-developed humus layer to be indicative of mature or stable forest ecosystems, this assumption does not hold for eutrophic beech forests. Due to the high fertility of the soils in these systems, biological activity (e.g. earthworms, fungi, and bacteria) is intense, leading to rapid decomposition of organic material (Brumme & Khanna, 2009). As a result, the humus layer in eutrophic beech forests tends to be very thin or even barely visible. This challenges the notion that a thick humus layer is a prerequisite for the development of certain forest types. Instead, it highlights how some soil characteristics are shaped by vegetation and its associated processes, rather than being pre-existing conditions that define potential vegetation types.

A similar complexity arises with soil pH; a variable often treated as a fixed environmental constraint but which in many cases is influenced by the vegetation itself. In peatlands, for instance, anaerobic conditions slow the decomposition of organic matter, leading to the accumulation of organic acids and resulting in acidified soils (Bohn et al., 2003). This raises the question of whether low pH is a necessary precursor for peat formation or merely a byproduct of it. However, this relationship is not consistent across all ecosystems. In beech forests, for example, the distinction between eutrophic and oligotrophic types is strongly tied to the availability of minerals in the soil, with soil pH serving as a useful proxy (Fichtner et al., 2012). In this context, a low pH may indeed limit the development of eutrophic forest types, while higher pH levels are more conducive to their establishment. These examples illustrate the importance of carefully considering the directionality and ecological meaning of observed correlations when modelling potential vegetation.

5.4 Future challenges and possibilities

This study demonstrates a new possible application of geotopes by using its variables to construct a map of potential natural vegetation. A key challenge encountered in this process was the unequal influence of the different variables in determining the most suitable conditions for vegetation. For example, soil moisture frequently emerged as a defining factor, often exerting a much stronger limiting effect on certain vegetation types than soil organic carbon. Treating all variables equally may not accurately reflect their ecological significance. To address this, the use of weighted variables could offer an important refinement to the methodology. Weights could be assigned through expert knowledge, drawing on literature from the fields of descriptive ecology or biology. Alternatively, field observations of existing ideal natural vegetation could inform the weighting process by linking observed conditions to the suitability of different variables. These conditions include tree density, species diversity (which helps distinguish between eutrophic and oligotrophic forests), and ground cover density, which is particularly relevant in moisture-influenced shrub- or grass-dominated areas. Incorporating such weighting methods would allow the potential vegetation model to better reflect real-world ecological patterns and constraints.

6. CONCLUSION

This study presents an integrated approach to mapping potential natural vegetation (PNV) as a foundation for assessing rewilding potential in Odsherred, Denmark. By combining geotope classification with suitability scoring and field validation, it is demonstrated that high-resolution physical landscape data can be used effectively to identify areas that are ecologically appropriate for rewilding interventions. Our maps highlight key zones, such as Annebjerg Skov and Nakke, where respectively eutrophic and oligotrophic forest types are most viable. They also point to low-lying sites like Trundholm Mose, where restoring peatland and alluvial and wet lowland forest appears promising.

The modelling results, supported by field sampling and statistical validation, show that the geotope-based approach performs significantly better than random chance. Eutrophic beech forests had the most reliable predictions, while peatlands and alluvial and wet lowland forests were more difficult to model accurately. This was due in part to the complexity of hydrological regimes and the limited resolution of available data. Despite these challenges, the model's false alarm rates remained acceptable, making it a useful tool for early-stage restoration planning.

However, the study also highlights some limitations. Interpolated datasets were less effective at capturing small but ecologically important features such as kettles and perched water tables. These features often influence vegetation patterns but are easily missed without high-resolution input. Additionally, variables such as soil pH and redox potential were not included in the model due to data constraints, but they could be valuable additions in future work.

Overall, this approach offers a practical tool to support rewilding initiatives in Denmark. It provides an initial screening method to identify areas with high ecological potential and can inform more detailed feasibility studies. By aligning with national and international restoration goals, geotope-informed PNV mapping can play a meaningful role in designing effective and resilient restoration strategies.

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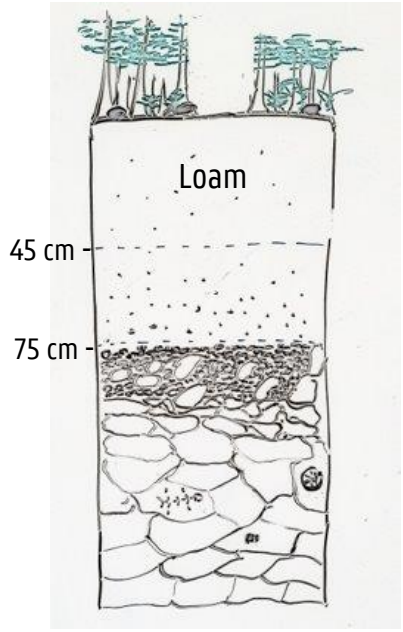
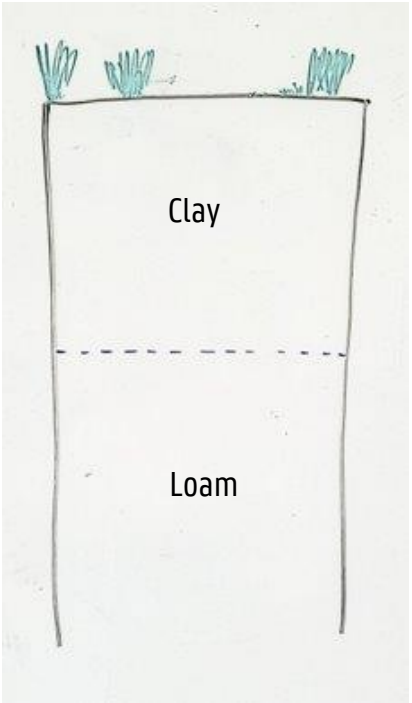
8. APPENDIX: SOIL SAMPLES

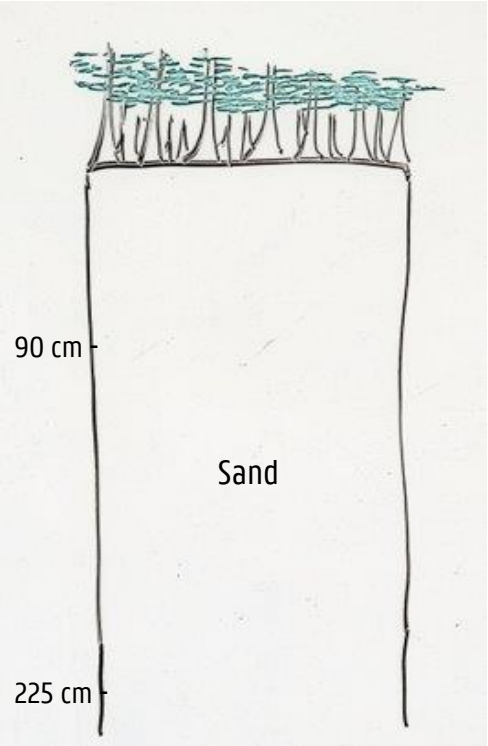
Match eutrophic beech forest:



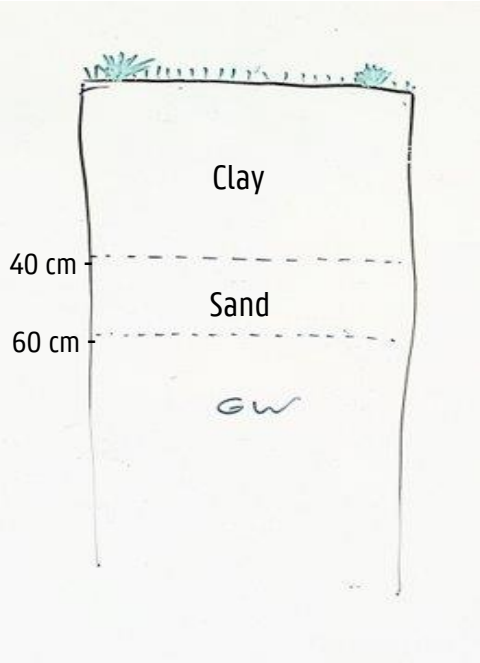
Mismatch eutrophic beech forest:



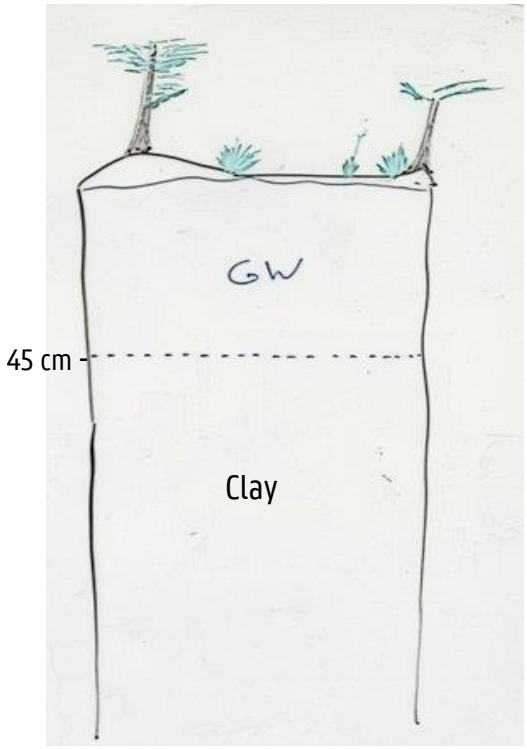
Match oligotrophic oak and beech forest:



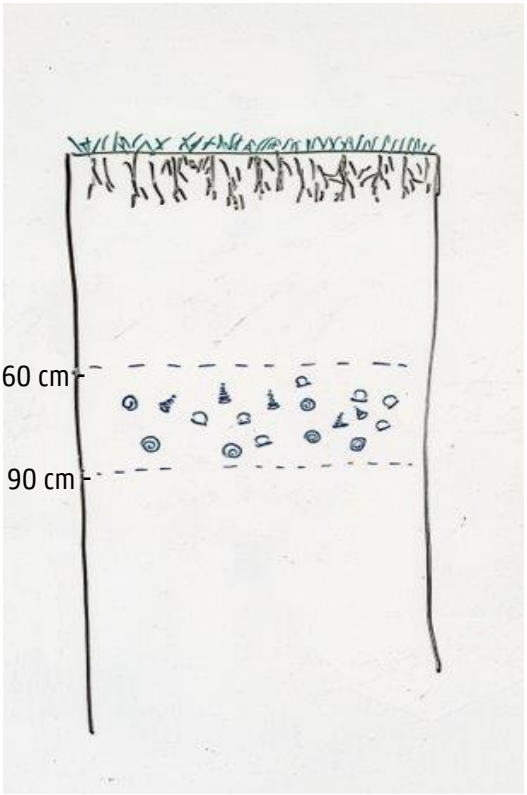
Mismatch oligotrophic oak and beech forest:



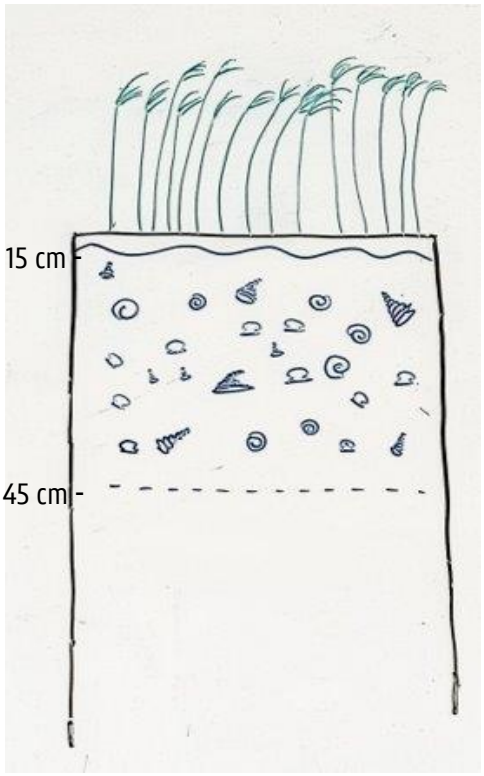
Match alluvial and wet lowland forest:



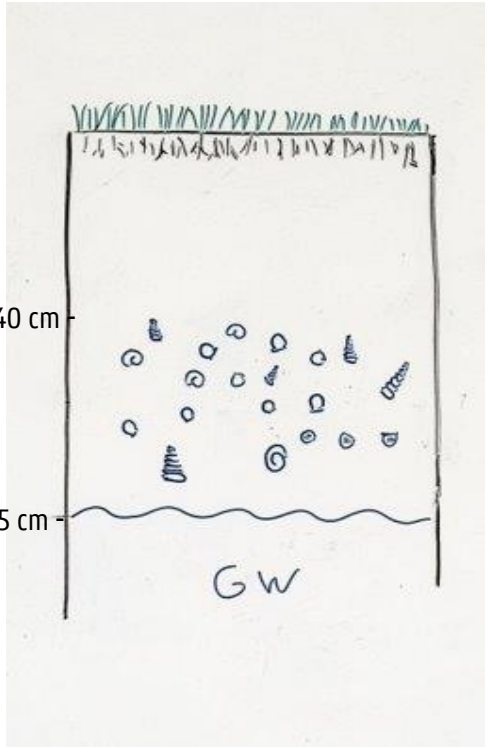
Mismatch alluvial and wet lowland forest:



Match peatland:



Mismatch peatland:



FACULTEIT WETENSCHAPPEN

MASTER OF SCIENCE IN GEOGRAPHY AND GEOMATICS

DOWN THE DRAIN

EVALUATING THE FLOOD RISK AND PERCEPTION IN ODSHERRED

Word count: 10508

Sander Clemmens, Tijs Depoorter, Joren Garré & Laurien Vetsuypens

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Academic year: 2024 - 2025

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Table of content

1. INTRODUCTION

Climate change increasingly exposes coastal regions worldwide to heightened flood risks, primarily driven by more frequent and intense storm surges and heavy rainfall events. Projections indicate that under medium and very high emission scenarios, events like 5-year, 20-year and 50-year storm surges and heavy rainfall will significantly increase in intensity and frequency by 2070, with some 5-year events potentially reaching the intensity of current 100-year events. These alarming forecasts underscore the urgent need for robust flood risk management strategies.

In this context, the municipality of Odsherred, located in Denmark, is identified as a vulnerable area facing significant flood risks due to a combination of heavy rainfall and storms. While the Danish government has identified specific risk areas, the effectiveness of current flood prevention measures and, crucially, the public's perception of these risks and protective strategies remain underexplored.

This paper aims to shed light on these critical aspects. The central research question guiding this study is: "How is the perception among Odsherred's people about the flood risks?". To comprehensively address this, the research further investigates the extent to which residents are aware of these risks, evaluates the perceived effectiveness of current drainage techniques (such as maintained sewage systems in urban areas and ditches for summerhouses, as well as engineered structures like earthen walls, rock barriers and dams) and explores additional measures suggested by the local population to enhance flood protection. Furthermore, the study examines potential differences in perception between residents living in flood-prone areas and those in non-flood-prone areas. Data for this research was primarily gathered through 75 surveys conducted in Nykøbing Sjælland and Rørvig, engaging inhabitants to understand their experiences and views. By analysing these perceptions, this paper seeks to provide valuable insights for developing more effective and community-aligned flood resilience plans in Odsherred and similar coastal communities.

2. THEORETICAL FRAMEWORK

2.1 Precipitation in Denmark

2.1.1 Annual precipitation

According to recent calculations, the total annual precipitation in Denmark has increased over the past few decades. A comparison between the precipitation maps from 1961-1990 and 1991-2009 (Figure 1) reveals a rise in rainfall across the entire country (DMI, 2010). Overall, the average annual precipitation in Denmark has grown from 636 mm during the period 1874-1900 to 759 mm in the period 1991-2020 (Figure 2) (Christiansen, 2024). During the most recent climate period (1991 to 2020), precipitation levels were nearly 20% higher compared to the period before 1900. In 2023, precipitation levels hit 976,7 mm, setting a record for the wettest year (DMI, 2025).

Figure 1:

Precipitation maps of Denmark (source: Danish Meteorological Institute, n.d.)

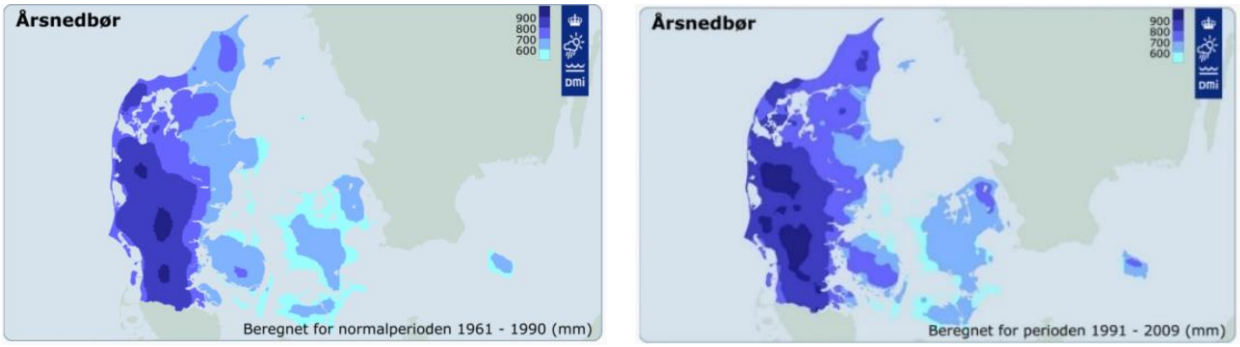
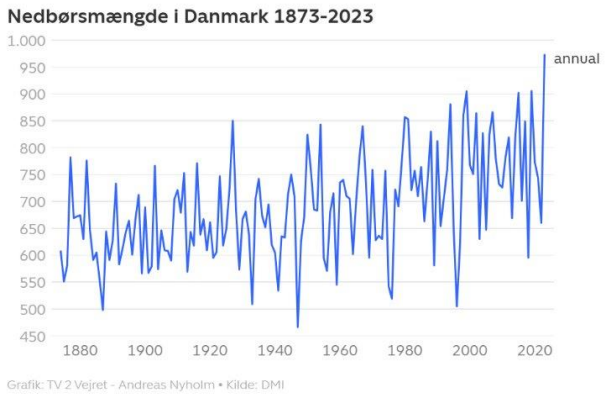


Figure 2:

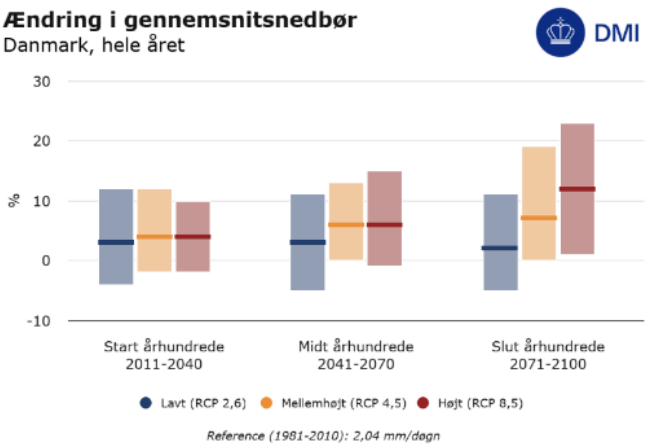
Precipitation chart from 1873 to 2023 (source: Christiansen, 2024)



To assess whether the observed trend of increasing annual precipitation is likely to continue, the Danish Meteorological Institute (DMI) developed a graph (Figure 3) projecting future changes in average annual precipitation under various emission scenarios. The projections cover three distinct time periods: early century (2011–2040), mid-century (2041–2070) and late century (2071–2100). Each period is further divided into three Representative Concentration Pathways (RCP's), representing low (RCP2.6), medium (RCP4.5) and high (RCP8.5) emission scenarios. Under the low-emission scenario, the projected median increase in annual precipitation remains below 5% throughout all three periods. However, the uncertainty margins indicate a small possibility of a decrease in average annual precipitation toward the end of the century. In the medium-emission scenario, a more pronounced increase is observed: the median change rises from approximately 5% in the early century to about 8% by the end of the century. In this case, the uncertainty intervals generally remain above 0%, suggesting that a decline in annual precipitation is unlikely. The high-emission scenario presents the most significant increase, with the median rise in annual precipitation ranging from 5% at the beginning of the century to 12% by its end. Again, the uncertainty margins lie above 0%, reinforcing the expectation of a continued increase in precipitation. These projections suggest that, regardless of the emission scenario, Denmark is likely to experience an overall increase in annual precipitation, with the extent of change closely tied to future greenhouse gas emissions.

Figure 3:

Future projections of annual precipitation in Denmark according to emission scenarios (2011–2100) (source: Danish Meteorological Institute, n.d.)



2.1.2 Extreme precipitation

On July 2, 2011, Copenhagen experienced a significant cloudburst. In Denmark, a cloudburst is officially defined as an event where more than fifteen mm of precipitation falls within a half-hour period (University of Copenhagen, 2022). The intensity of the rainfall was remarkable: Copenhagen's Botanical Garden recorded 135,4 mm in a single day, while the suburb of Ishøj saw 31 mm fall within just ten minutes. This event led to widespread flooding across many of the capital's streets, as well as in basements and ground-floor apartments in low-lying area.

Cloudbursts have also been recorded in various other regions of Denmark. For instance, on June 23, 2023, the city of Odense, located on the island of Funen, experienced an intense downpour in which 34,2 millimetres of rain fell within just 30 minutes (Flensborg Avis, 2023). On the same day, cloudburst events were also reported in several other municipalities. These occurrences underscore the widespread nature of extreme precipitation events across the country and highlight the increasing vulnerability of both urban and rural areas to short-duration, high-intensity rainfall.

While recent cloudbursts underscore Denmark's vulnerability, historical data further confirms a sustained increase in extreme precipitation. A study by Gregersen et al. (2015) meticulously examined long-term variations in extreme rainfall events across Denmark and southern Sweden. Based on six daily rainfall time series spanning 137 years (from 1874 to 2010), supplemented by 61 shorter series (45 to 100 years), their findings unequivocally indicate a general increase in the frequency of extreme rainfall events from 1874 to the present. This frequency also displays a distinct oscillatory pattern with cycles of 25 to 40 years, while the magnitude of these events fluctuates with shorter cycles of 15 to 30 years and smaller amplitudes. Given this established historical increase, the critical next step is to understand how these patterns are projected to evolve in the coming decades.

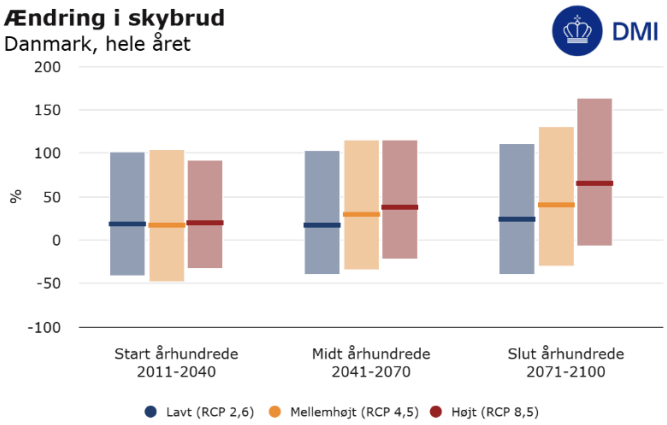
The Danisch Meteorological Institute (DMI, n.d.) has conducted climate projections for Denmark extending to the year 2100. Figure 4 illustrates the projected changes in the frequency of cloudbursts across the country. This figure has the same three time periods and RCP's as Figure 3. The vertical axis indicates the percentage change in cloudburst frequency relative to the historical baseline.

Under the low emission scenario, the projected increase in cloudburst frequency is the smallest. The median change remains relatively stable at around 20–25% throughout the century. The medium emission scenario, shows a more pronounced increase, with the median rising from approximately 20% in the early century to around 40% by the end. The high emission scenario presents the most concerning projection, with an increase ranging from 20% early in the century to as much as 65% by 2100.

It is important to note that the height of the bars in the figure also reflects the uncertainty inherent in climate model projections. In some cases, the lower bounds of the projections fall below zero, indicating a small probability of a decrease in cloudburst frequency. However, the most likely outcome (represented by the horizontal line across each bar) still indicates an overall increase.

Figure 4:

Impact of emission scenarios on projected cloudburst frequency in Denmark (2011 – 2100) (source: Danish Meteorological Institute, n.d.)



2.2 Flood risks in Denmark

Historically, Denmark has experienced a significant number of storm events. According to the Danish Meteorological Institute (DMI, n.d.), a total of 197 storms have been recorded since 1891.

Due to Denmark's geographical location between two major bodies of water (the North Sea and the Baltic Sea) and a coastline stretching over 7314 km (VisitDenmark, n.d.), it is not surprising that the country is particularly vulnerable to coastal flooding. The Danish coasts are exposed to storm surges from all directions. However, more than 90% of storms primarily originate from the west (DMI, n.d.). This is because westerly storms travel across a long fetch of open sea, allowing strong winds to push large volumes of water toward the Danish coast. Typically, two to three westerly storms per year cause high water levels along Denmark's western coastline. Storm surges in Denmark's internal water occur less frequently, on average about once per year. Westerly storms usually last for half a day, while storms from the east or north can persist for up to one and a half to two days. These longer-lasting storms tend to cause the most severe damage.

Denmark is separated by a series of narrow straits, such as the Great Belt and the Øresund, that links the North Sea with the Baltic Sea. These narrow passages allow for a particular type of storm surge event, often referred to as a 'silent storm surge' (DMI, n.d.). This phenomenon occurs when westerly winds push water from the North Sea, while northerly winds simultaneously force water through the Kattegat and northeasterly winds transport water across the Baltic Sea. The simultaneous convergence of these forces funnels large volumes of water toward Danish coastal areas from multiple directions. Because this process does not necessarily involve intense local wind or wave activity, the water level may rise gradually, potentially leading to significant flooding. These silent storm surges are particularly dangerous because they can affect both open coasts and inner Danish waters.

2.2.1 Flood risk act

As the result of significant flooding events in several European countries, the EU established the Floods Directive in 2007 (Klimatilpasning, n.d.). The purpose of this directive is to reduce the adverse impacts of extreme floods on human health, the environment, cultural heritage and economic activities. Denmark has implemented the directive through the Flood Risk Act. The Danish Coastal Authority is responsible for identifying flood risk areas. The risk areas in Denmark are shown in Figure 5 (Kystdirektoratet, n.d.), comprising a total of 25 risk areas as of 2024. However, municipalities falling under the scope of the Floods Directive are responsible for preparing or updating flood risk management plans based on the mapping data provided by the Danish Coastal Authority.

However, in response to severe cloudbursts in 2011, the Danish government and the Local Government Denmark (Kommunernes Landsforening) introduced a national agreement in 2013 requiring all municipalities to develop climate adaptation plans (Klimatilpasning, n.d.). The plans were required to include an assessment of flood risk as well as a prioritization and description of the proposed measures. The plans were incorporated directly into, or as an addition to, the 2013 municipal plans. Since then, the municipal climate adaptation plans have formed the core of the municipalities' climate adaptation efforts. Subsequently, in 2018, amendments to the Danish Planning Act came into force, legally enabling municipalities to require preventive measures in areas designated as being at risk of flooding or erosion (Klimatilpasning, n.d.). This marked a shift from policy-based to legally embedded adaptation planning. The new rules apply to both urban and rural areas, enabling municipalities to set requirements in cases revolving new urban developments, densification of existing cities, technical facilities at risk of flooding or erosion. National data and tools, such as the KAMP screening platform, support municipalities in this work.

Figure 5:

Identified flood risk areas in Denmark by the Danish Coastal Authority (source: Kystdirektoratet, n.d.)

2.3 Study area

This research focuses on the northeastern part of the municipality Odsherred, located in the northwest of Seeland, Denmark. A key urban center in this area is Nykøbing Sjælland, a town with approximately 6000 inhabitants. The town functions as the natural hub of a vast summerhouse region that stretches from Rørvig in the east to Klint in the west, making it a significant seasonal destination.

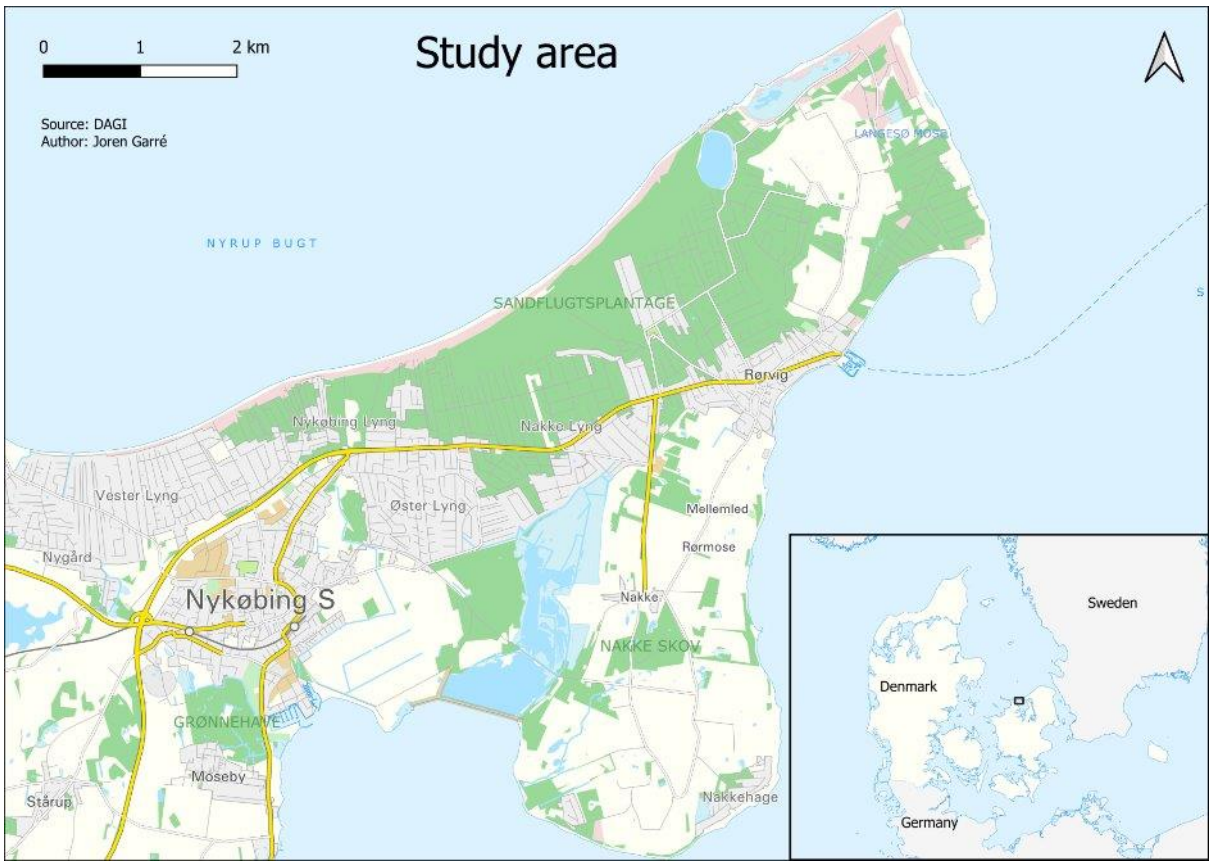
The landscape of northeastern Odsherred is characterized by low elevation, ranging between 0 and 20 meters above sea level. This relatively flat topography, combined with the area's proximity to the sea, contributes to a heightened sensitivity to coastal and meteorological hazards. While the Danish Coastal Authority does not officially classify the northeast of Odsherred as a conventional flood risk area, the peninsula's extensive coastline and direct exposure to the sea make it particularly vulnerable to storm-related hazards (Topographic map, n.d.).

In addition to storm-related threats, the area is also susceptible to extreme precipitation events. As climate projections indicate a likely increase in both the frequency and intensity of cloudbursts in Denmark, low-lying areas like northeastern Odsherred may face greater challenges related to surface water flooding. This is particularly relevant for urbanized zones such as Nykøbing Sjælland, where existing drainage infrastructure may struggle to cope with high-intensity rainfall events (Nykøbing Sjælland, n.d.).

It is in this context that the outlined study area (Figure 6) was defined.

Figure 6:

Map of the study area



2.4 Climate adaptation

According to Odsherred Kommune's 2022 climate plan (Klimaplan Sammen om Klimaet – Odsherred for Fremtiden), drainage management is identified as a key priority within the municipality's broader climate adaptation strategy, particularly in light of increasing extremes in precipitation and storm surges. The 2022 climate plan acknowledges that both urban and rural areas face growing pressure on existing drainage systems, which are increasingly incapable of handling intense rainfall events. This leads to heightened flood risks, especially in areas with vulnerable soil and groundwater conditions.

The plan indicates that the effectiveness of current drainage techniques is particularly limited in regions characterized by high groundwater levels and restricted discharge capacity. Problem areas include Sejerø Bay and low-lying agricultural lands such as the reclaimed polders Lammefjorden and Sidinge Fjord. These regions already experience saturated soils and elevated shallow groundwater levels, with projections indicating a further rise of approximately 0,25 meters. This trend poses a direct threat to both agricultural productivity and water management in the area.

Furthermore, the plan identifies the capacity of various drainage systems, such as municipal road drainage and private drainage infrastructure, as inadequate in these vulnerable zones. The increasing frequency of extreme rainfall events, combined with already elevated groundwater levels, undermines the effectiveness of existing infrastructure and necessary adaptation.

Within this policy framework, the municipality places significant responsibility on its residents. Citizens are expected to take individual action to climate-proof their properties. This includes maintaining private drainage ditches and canals, as well as submitting requests for modifications or expansions to existing drainage systems. The same cost principle applies to coastal protection projects, where landowners who benefit are also expected to finance the initiatives.

The municipality adopts a facilitating and advisory role, using information campaigns, demonstration projects and public events to raise awareness and encourage citizen action. This approach reflects a co-productive model in which the effectiveness of municipal measures largely depends on the willingness of residents to actively engage. The climate plan emphasizes that residents should not see their living or health conditions deteriorate compared to 2021 due to climate change. To ensure this, the municipality aims to provide all citizens with access to knowledge and advice on climate-resilient living.

Although the climate plan does not contain empirical data on current citizen engagement, the emphasis on individual responsibility and public participation suggests that this is viewed as a critical success factor for the adaptation strategy. Through learning processes and local engagement, the municipality aims to foster an active role for its residents. This marks a shift from a top-down approach to a more shared responsibility model, in which government and citizens jointly shape the implementation of climate measures.

The case of Odsherred illustrates not only the technical challenges of climate adaptation in low-lying coastal regions, but also the social dimensions of adaptation policy. Effective flood risk management requires not only physical infrastructure adjustments but also active involvement, ownership and behavioural change among citizens. The extent to which this behavioural component is successfully integrated into policy practice will ultimately determine the region's long-term resilience.

2.5 Risk perception and willingness to pay

Risk perception refers to how individuals subjectively assess the chance that a negative event, such as flooding, will occur and how serious its consequences would be. Researchers note that risk perception has two main dimensions: a cognitive component (how much people know about the risk) and an emotional component (how they feel about it) (Zeng et al., 2022). These subjective perceptions often diverge from objective risk estimates (such as statistical flood probability) because they incorporate personal experience, intuition and available information. For instance, a person who has lived through a flood or heard vivid stories about flooding is likely to perceive a higher flood risk than someone with no experience.

In flood-risk management, experts recognize that measuring subjective risk perception is critical. Subjective risk measures such as perceived flood risk are now seen as key indicators in flood-prone communities (Veeravalli, 2020). Public awareness and concern about flooding influence how people prepare and respond to warnings. Two neighbours living equally close to the sea might judge their danger differently based on factors like prior experience, trust in authorities or media coverage. Therefore, understanding residents' risk perception helps planners identify which hazards "occupy people's minds" and tailor communication and preparedness efforts accordingly.

Willingness to pay (WTP) is an economic concept used to express the value individuals place on avoiding a risk or obtaining a protective measure. Formally, WTP is defined as "the maximum amount of money an individual is willing to spend in order to receive one unit of the good in question" (Entorf & Jensen, 2020). In the context of flood adaptation, this could mean the amount a resident is willing to pay for improved dikes, better drainage, flood insurance, or other mitigation measures. Estimating WTP translates people's preferences into a monetary value, essentially capturing how much they value a reduction in flood risk.

Figure 7:

Example of the existing dike structure

WTP estimates are widely used in cost–benefit analyses of adaptation projects. For example, the IPCC explains that cost–benefit analysis involves valuing all costs and benefits of a project "on the basis of willingness to pay (or willingness to accept compensation) on the part of project beneficiaries" (Thornes, J. E. & IPCC). In practice, this means that if residents are willing to pay a certain amount for flood protection, that amount is treated as the benefit of the project when comparing it to construction costs. In this way, willingness to pay provides a monetary measure of the perceived value of an adaptation or safety measure from the individual's perspective.

Empirical studies show that people's risk perception and their WTP for protection tend to go hand in hand. In flood contexts, residents who perceive higher flood risk generally exhibit higher willingness to pay for mitigation. For instance, Netusil et al. (2020) found that willingness to pay for flood insurance increased with both objective flood risk and with individuals' perceived flood risk. In other words, when people feel more threatened by flooding, they place a higher monetary value on protective measures. Understanding this link helps policymakers gauge public support: higher perceived risk usually means residents will invest more in safety, which is crucial information when planning and financing flood adaptation strategies.

2.6 Nature based solutions

Given Odsherred's mixed urban-rural character and its vulnerability to both pluvial and coastal flooding, nature-based solutions (NBS) and green infrastructure (GI) are particularly relevant tools for climate adaptation in the region. Recent research highlights a wide range of interventions that could be effectively tailored to Odsherred's local conditions, provided that physical and social context are carefully considered.

In dense urban areas such as Nykøbing Sjælland and smaller village centers, small-scale NBS like rain gardens, green roofs, permeable pavements and multifunctional city parks have shown significant potential to reduce surface runoff while enhancing urban liveability. Skrydstrup et al. (2022) emphasize the dual benefit of these measures, which combine flood mitigation with recreational and aesthetic functions, even in areas of less than one hectare. Similarly, Liu and Jensen (2018) demonstrate how multifunctional GI (including bioretention systems, wetlands and urban vegetation) can attenuate peak flows and improve ecological connectivity.

Tree-based greening strategies also present clear opportunities for Odsherred. Vesuvianno et al. (2025) evaluated the 3–30–300 rule, which promotes increased tree canopy and accessible green spaces. Their findings indicate that strategic tree planting, especially in areas with currently limited greenery, can substantially reduce surface runoff. This could be particularly valuable in village centers and suburban neighbourhoods with impermeable surfaces.

In Odsherred's rural zones and low-lying coastal areas larger-scale landscape interventions may be more appropriate, in areas such as Lammefjorden and Sejerø Bugt. Cuenca-Cambronero et al. (2023) highlight the value of ponds and pondscapes, which can buffer stormwater, delay peak flows and enhance biodiversity. These could be implemented as networks across agricultural landscapes, enhancing the area's climate resilience. Wetland restoration, riparian buffers and reforestation (Oral et al., 2021) are further measures that offer co-benefits for water regulation and biodiversity and align well with the municipality's mix of natural and cultivated land.

In addition to technical effectiveness, stakeholder engagement is critical to the long-term success of climate adaptation in Odsherred. The municipality's climate plan (Odsherred Kommune, 2022) already emphasizes co-responsibility and participatory governance. Research by Koutsovili et al. (2023) supports this approach, illustrating how participatory planning in a Greek river basin enabled local actors to co-design flood solutions, including small dams and reforestation. A similar co-creation model could be instrumental in Odsherred to ensure that interventions align with local needs, values and landscape dynamics.

Agricultural areas in Odsherred could also benefit from controlled flood management. Zandersen et al. (2021) proposed a Payment for Ecosystem Services (PES) scheme that compensates farmers for allowing controlled flooding on their land to mitigate downstream flood risk. This model could be adapted for use in flood-prone farmland near Lammefjorden, where integrating flood storage with agricultural production may enhance both ecological and economic outcomes.

Coastal flood risk, especially along vulnerable stretches near Sejerø Bugt and Nykøbing Sjælland, also calls for integrated adaptation strategies. Jørgensen et al. (2022) present landscape-based coastal defence systems used in Køge Bay as scalable solutions for other Danish municipalities. These combine hybrid infrastructure with natural buffers and stakeholder engagement and may serve as a model for Odsherred's coastal adaptation efforts.

3. METHODOLOGY

3.1 GIS analysis

To identify the flood-prone areas in our study area, a total of three maps were created. These maps visualise which areas would be flooded during storm surges and heavy rainfall events with a 5-year, 20-year and 50-year recurrence period.

To perform this analysis, two datasets were taken from the Danish Climate Data Agency. The first dataset, Havvand på land (Sea on land), is a raster layer in which each pixel indicates the sea level height above mean sea level that would result in flooding at that location. It shows how much the sea-level must rise in order to flood a certain area. The second dataset is the Bluespot Hydrologiske Højdemodel (Hydrological Elevation Model). This is a raster layer that indicates the susceptibility of areas to pluvial flooding. Each pixel value represents the amount of rainfall (in meters) required to trigger surface flooding at that specific location. It is important to note that these datasets, do not account for the effects of sewage systems or infiltration into the ground.

To model the 5-, 20- and 50-year flood events, we used data from the Danish Meteorological Institute (DMI). These values are based on the reference period 1980–2010 and represent the estimated sea level rise caused by storm surges with different recurrence intervals. According to the DMI, a storm surge with a 5-year return period causes a temporary sea level rise of 155 cm, while the 20-year and 50-year events result in rises of 181 cm and 193 cm, respectively.

For extreme rainfall events, we focused specifically on the region of Odsherred, using data from the DMI's Climate Atlas. The atlas indicates that a 5-year return period rainfall event corresponds to an average of 20,22 mm of precipitation per hour and 52,27 mm per day. For 20-year and 50-year events, these values increase to 29,40 mm/hour and 71,80 mm/day and 37,24 mm/hour and 86,36 mm/day, respectively.

Based on this data, the flood map for a 5-year return period event was created by combining thresholds from both datasets. Specifically, all pixels in the Sea on Land raster layer with values less than or equal to 155 (representing the sea level rise during a 5-year storm surge) and pixels in the Bluespot Hydrological Elevation Model with values less than or equal to 52,27 mm (corresponding to daily rainfall during a 5-year heavy rainfall event) were assigned the same shade of blue. These two raster layers were then overlaid to visualize the combined extent of flooding during a 5-year event. The same methodology was applied to generate flood maps for the 20- and 50-year return periods, using the respective threshold values for each scenario.

To assess the long-term impact of climate change on flood risk, we recreated the flood maps using future projections from the DMI for the period 2071–2100. These projections were derived from the same datasets and analysed using the same methodology, but with updated threshold values based on two emission scenarios: the medium emission scenario (RCP4.5) and the very high emission scenario (RCP8.5).

For the 5-year event, the sea level and rainfall thresholds increase from 155 cm and 52,27 mm (historical) to 197 cm and 56,24 mm under RCP4.5 and to 214 cm and 60,55 mm under RCP8.5. For the 20-year event, thresholds rise from 181 cm and 71,80 mm to 223 cm and 77,09 mm under RCP4.5 and to 240 cm and 84,09 mm under RCP8.5. For the 50-year event, the thresholds increase from 193 cm and 86,36 mm to 235 cm and 92,52 mm under RCP4.5 and to 252 cm and 92,52 mm under RCP8.5. These changes show that both coastal and pluvial flood risks increase under future climate scenarios. However, the relative increase in sea level rise is much greater than that of rainfall, especially under high-emission scenarios.

Our initial aim was to incorporate both the sewage system and soil infiltration into the flood maps by distinguishing between built-up and non-built-up areas. For non-built-up areas, we planned to adjust flood thresholds based on average infiltration rates per soil type, while for built-up (impervious) areas, we intended to account for average sewage system capacity. This approach was feasible for heavy rainfall events. However, since no data was available on the depth of flooding caused by storm surges, only the extent of flooded areas, this aspect of the analysis had to be abandoned.

3.2 Public risk perception and willingness to pay

3.2.1 Questionnaire

To better understand how residents of Odsherred perceive and respond to flood risks, a survey was developed focusing on the social dimension of flood risk. The objective was to assess local awareness, personal experiences and attitudes toward both individual and collective mitigation strategies. This information complements technical flood protection measures and policy frameworks, offering a more comprehensive view of climate adaptation challenges at the community level.

The survey begins with background questions to gather contextual information, including the structural characteristics of the respondent's home and the geographic location of their residence. To enable spatial analysis, respondents were asked to indicate the location of their home on an interactive map using UMap.com. This made it possible to determine whether their residence was located within an flood-prone area.

Next, participants were shown three flood risk maps of the Odsherred region, which were produced through the GIS analysis conducted in this study. These maps served as a visual reference to prompt reflection on local flood exposure.

Further the survey examined whether participants had ever personally experienced flooding and, if so, what they believed to be the main cause of those events. It then explored their awareness of drainage infrastructure in their immediate environment, as well as the protective measures either already taken or considered, both by themselves and by local authorities, to reduce flood risks.

In the final section, respondents evaluated eight statements related to concern, preparedness, willingness to pay and responsibility for managing future flood events. Each statement was rated on a 7-point Likert scale, ranging from strongly disagree (1) to strongly agree (7).

The complete survey is attached in the appendix.

3.2.2 Reliability of perception scale

To ensure that the eight survey items used to assess respondents' perceptions and attitudes were methodologically sound, we first evaluated the reliability of the scale. The following section outlines the steps taken to examine the internal consistency and dimensional structure of these items.

The internal consistency of the eight-item scale on perceived flood risk and willingness to act was tested using Cronbach's alpha. The resulting score of 0,664 reflects an acceptable degree of reliability. This suggests that the items share a meaningful relationship, allowing them to be considered together for analysis. However, the correlation between them was not so strong as to indicate redundancy, so the individual items were retained in their original form.

Although a factor analysis was conducted to explore potential underlying dimensions in the eight survey items measuring risk perception and willingness to act, the decision was made not to combine items into a single composite scale. One of the main reasons for this is the relatively low Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, which was 0,622. This value falls just above the commonly accepted minimum threshold of 0,6, suggesting that the dataset is only marginally suitable for factor analysis.

A low KMO value indicates that the correlations between variables are not strong enough to justify summarizing them into fewer factors. In other words, the items do not consistently measure a single latent construct. As a result, combining them into one overall scale could lead to a loss of nuance and reduce the interpretability of the results.

Therefore, instead of aggregating all items into one or more scales, we opted to analyse the individual items separately. This approach allows for a more accurate understanding of how specific aspects of risk perception and behavioural intention vary across the sample.

3.2.3 Statistical approach

To test whether concern about flooding and willingness to adopt or support adaptation measures varied by location and personal experience, statistical comparisons were made. Independent-samples t-tests were used to compare responses from those who perceived their home to be in a flood-prone area with those who did not. In addition, cross-tabulation analysis with chi-square tests was used to examine the association between flood risk and the presence of physical drainage features (e.g., gutters, sewer systems, or ditches). All analyses were conducted using SPSS Statistics v.29.

The following hypotheses were examined:

- H1: People who live in or near high-risk flood zones express greater concern about flood hazards.
- H2: Individuals with stronger perceptions of risk are more inclined to favour collective or large-scale solutions over individual actions.
- H3: Previous personal or local flood experience increases willingness to take action.
- H4: Drainage features are more frequently observed in areas with higher flood risk.

To complement the quantitative findings, open-ended survey responses were analysed using word frequency analysis. Commonly used words were identified and counted to reveal key terms frequently mentioned by respondents. This approach highlighted recurring patterns in individual actions and Odsherred's residents expectations of how local authorities should address flooding.

3.3 Interview

To better understand the policy context and to validate the findings form our survey, a semi-structured, exploratory interview with researcher Mette Juhl Jessen, a PhD in Landscape Architecture and Planning at the University of Copenhagen, was performed. Her expertise includes regional climate adaptation, coastal vulnerability and landscape-based planning, with the Horizon Europe Regions4Climate project serving as a key point of departure.

The purpose of the interview was to contextualize local governance challenges related to climate adaptation in Odsherred, with a focus on four key themes: (1) the discrepancy between official and experienced flood risk, (2) responsibility, insurance and governance structures, (3) nature-based solutions and current adaptation measures and (4) broader understandings of risk and planning approaches. In total 9 main questions were prepared to guide the interview. The prepared questions are added to the appendix.

4. RESULTS

4.1 GIS analysis

4.1.1 Modelled flood zones

The modelled flood zones for a 5-year recurrence event, as shown in Figure 8, show that the major flooding zones primarily impact agricultural lands (indicated in light yellow) and natural areas (indicated in green), rather than densely populated residential zones (indicated in grey). The most significant effects on permanent residents are limited to a few streets adjacent to the nature reserve, the agricultural area southwest of Nykøbing and homes built close to the shoreline. In contrast, the bog area represents a (seasonal) residential flood risk due to the high concentration of summer houses.

When comparing this to the 20-year event map (Figure 9), the differences are relatively limited. The main flood zones expand slightly, encroaching further into urban areas by a few streets. Notably, the agricultural area southwest of Nykøbing now extends to flood the railway station (indicated with a white circle) and the major road (indicated in yellow) in that area. Other larger flood zones also increase in size. In addition, several new small, localized flood zones appear across the map, especially near lower-lying areas and the edges of built-up zones.

In the 50-year event map (see Figure 10) shows modest changes but more pronounced than in the 20-year scenario. The most noticeable expansion occurs in the Langesø Mose bog area, which significantly increases in extent. Additionally, several small, previously isolated flood zones now overlap with major (yellow) roads and smaller but important (white) roads at various locations, indicating a growing risk to transportation infrastructure.

Figure 8:

Modelled flood zones for a 5-year recurrence event

Source: Danish Meteorological Institute, Dataryselsen, Author: Joren Garré

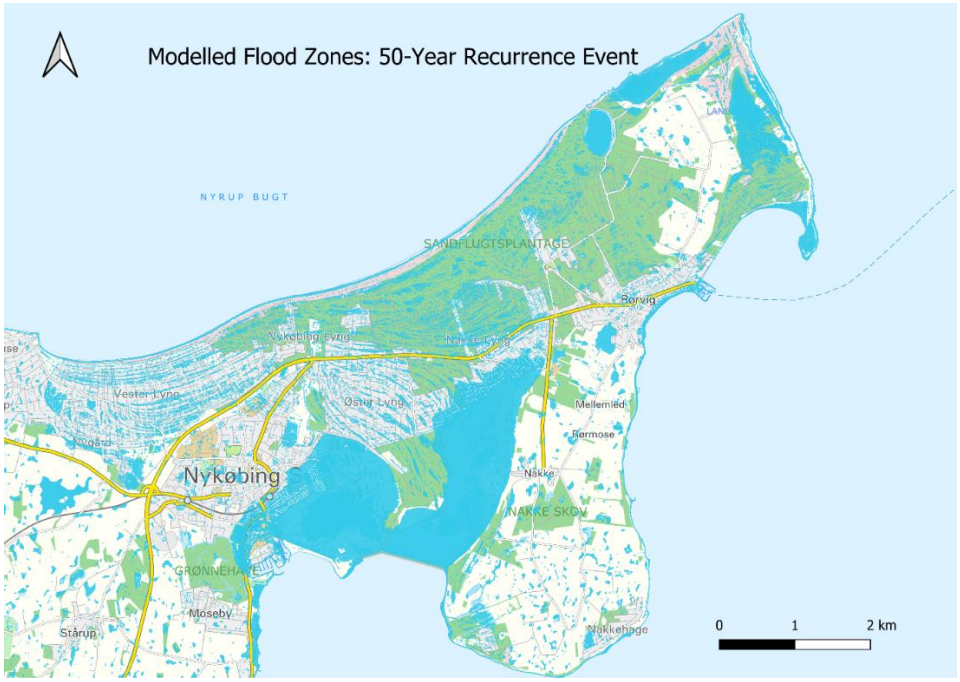
Figure 9:

Modelled Flood zones for a 20-year recurrence event

Source: Danish Meteorological Institute, Dataryselsen, Author: Joren Garré

Figure 10:

Modelled Flood zones for a 50-year recurrence event



Source: Danish Meteorological Institute, Dataryselsen, Author: Joren Garré

4.1.2 Modelled flood zones under medium emission scenario

When comparing the 5-year recurrence flood maps for the present day (Figure 8) and the medium emission scenario (Figure 11) projected for 2071–2100, only modest differences are observed. In the future scenario, the main flood zone within the Hov Vig Nature Reserve expands slightly. A similar pattern is observed in the flood zone southwest of Nykøbing, where flooding of the railway station is now certain and the main coastal road leading south from the town is also affected.

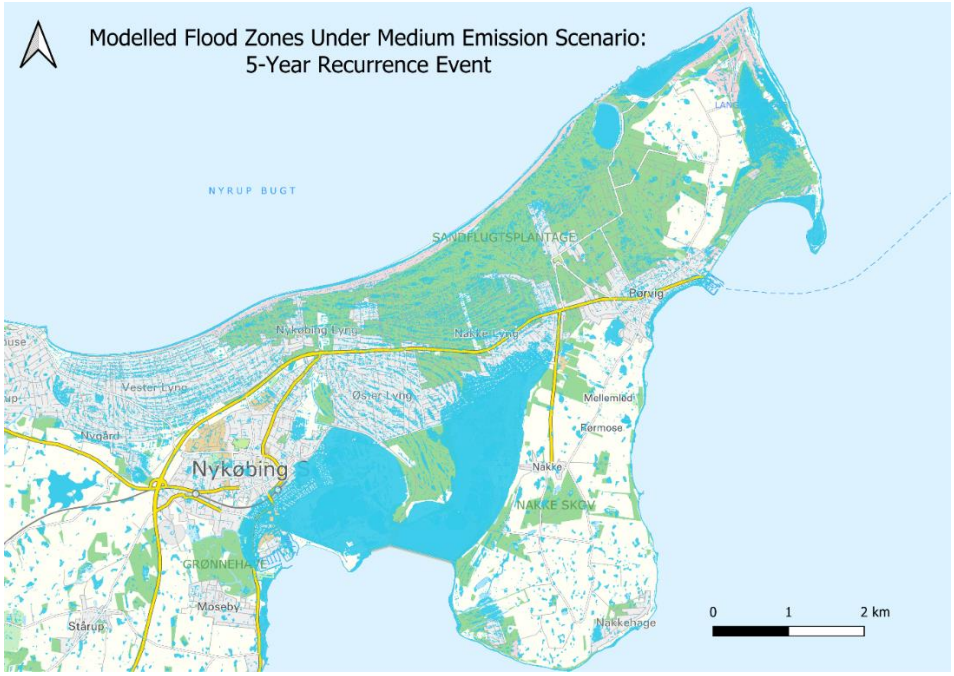
Across the entire coastline, there is a slight inland shift of the narrow coastal flood zones. This shift is most pronounced in the area around Rørvig. A more significant expansion is observed in the flood zone located in the bog northwest of the peninsula, which grows substantially in extent and floods multiple summer houses located in the area.

For the 20-year flooding event under a medium emission scenario (Figure 12), the overall picture remains largely the same, with slight expansions observed across all major flood zones. The most notable change is the connection of the flood zone west of the bog area to the narrow coastal flood zone. For the 50-year flooding event under a medium emission scenario (Figure 13), the differences compared to the 20-year event are minimal. Only very slight expansions of the modelled flood zones are visible.

Overall, while the changes are relatively minor, they show a gradual increase in flood risk, particularly for transportation infrastructure and seasonally inhabited zones.

Figure 11:

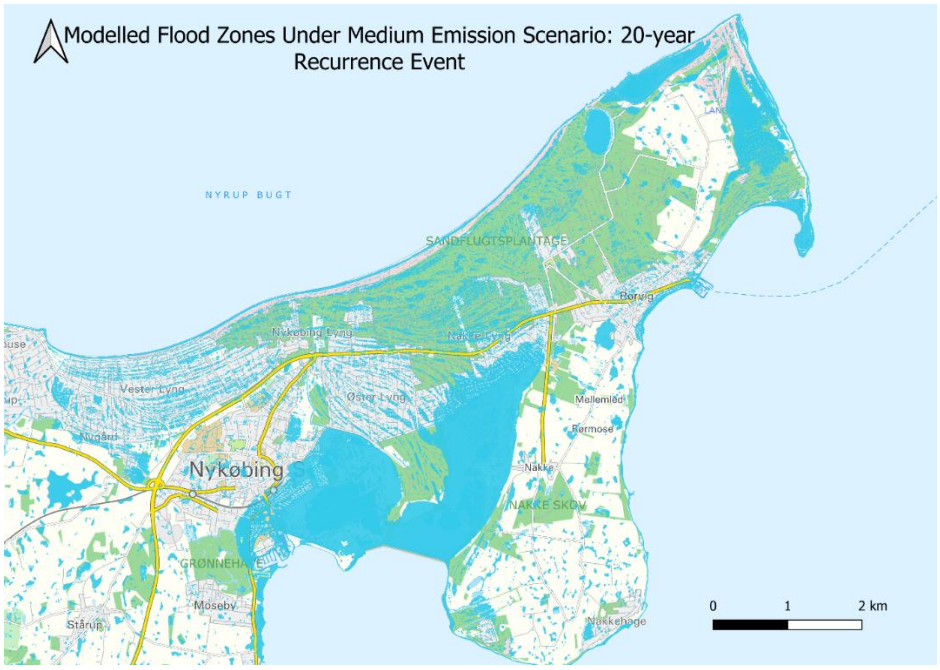
Modelled Flood zones for a 5-year recurrence event under a medium emission scenario



Source: Danish Meteorological Institute, Dataryselsen, Author: Joren Garré

Figure 12:

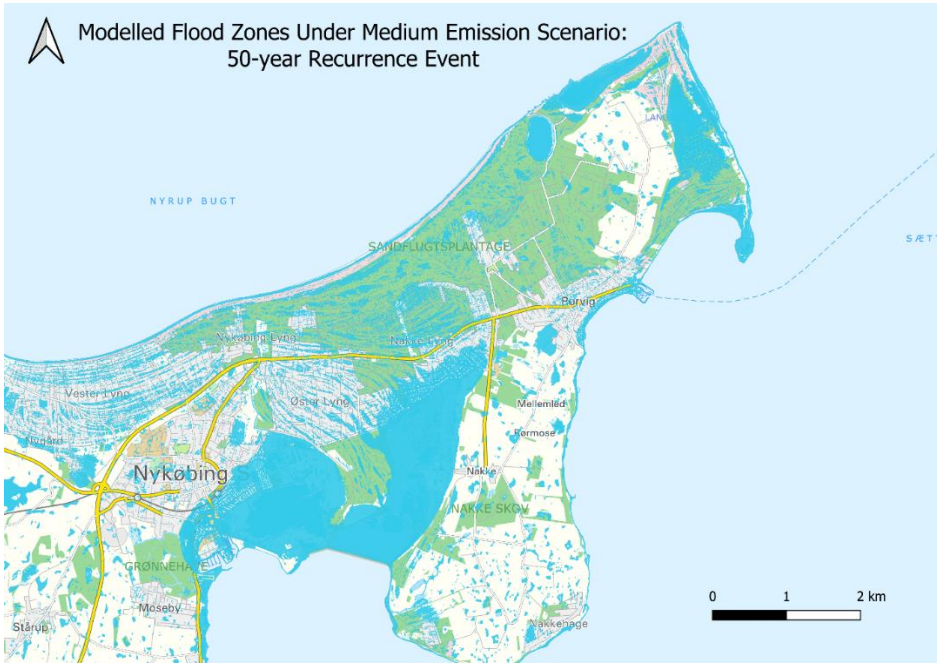
Modelled Flood zones for a 20-year recurrence event under a medium emission scenario



Source: Danish Meteorological Institute, Dataryselsen, Author: Joren Garré

Figure 13:

Modelled Flood zones for a 50-year recurrence event under a medium emission scenario



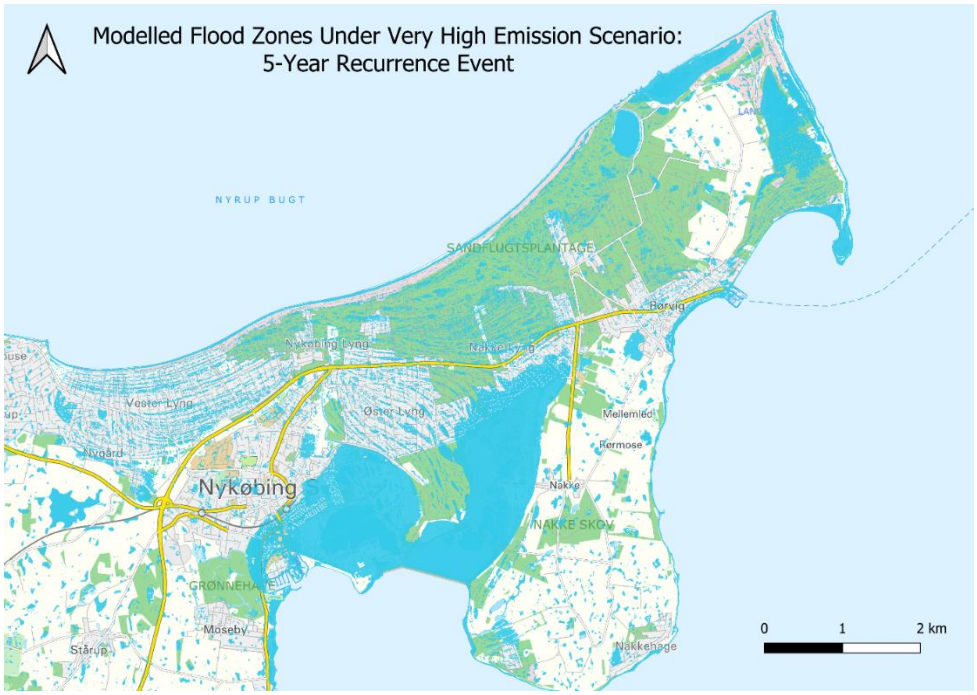
Source: Danish Meteorological Institute, Dataryselsen, Author: Joren Garré

4.1.3 Modelled flood zones under very high emission scenario

Comparing the medium (Figure 11, 12, 13) and very high emission scenarios (Figure 14, 15, 16) yields limited insights, as the spatial patterns and differences across recurrence intervals closely mirror each other. The only noticeable distinction is that the very high emission scenario features slightly more small, localized flood zones, which are also marginally larger than those in the medium scenario.

Figure 14:

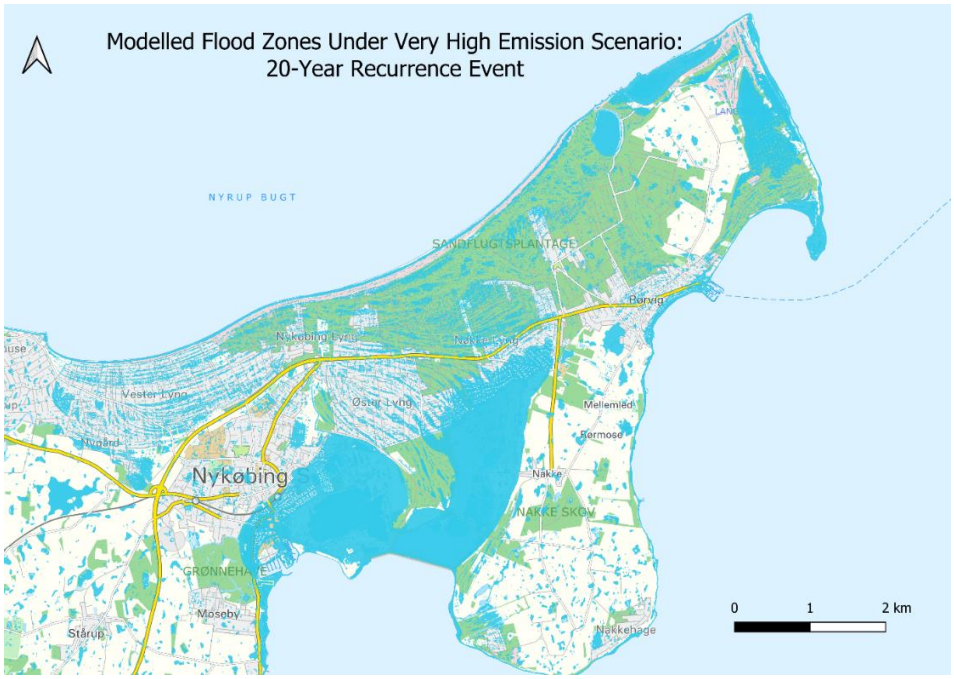
Modelled flood zones for a 5-year recurrence event under a very high emission scenario



Source: Danish Meteorological Institute, Dataryselsen, Author: Joren Garré

Figure 15:

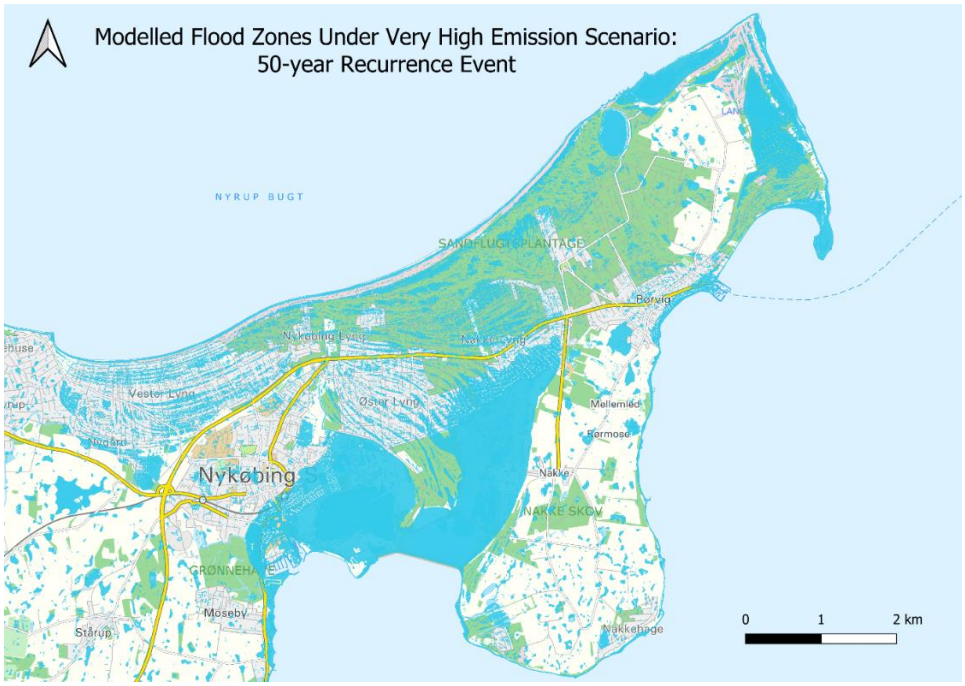
Modelled flood zones for a 20-year recurrence event under a very high emission scenario



Source: Danish Meteorological Institute, Dataryselsen, Author: Joren Garré

Figure 16:

Modelled flood zones for a 50-year recurrence event under a very high emission scenario



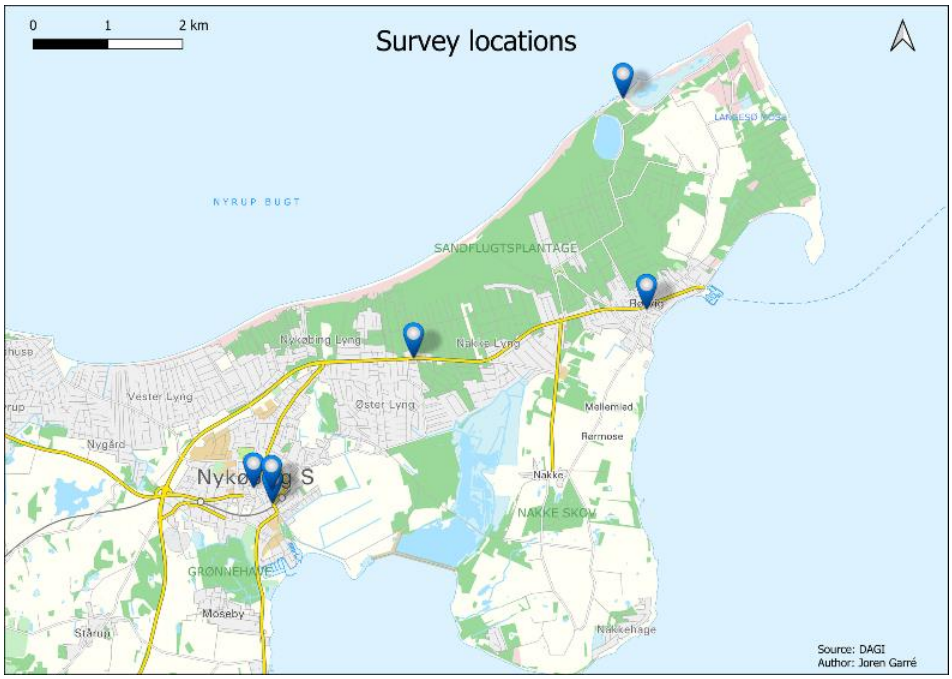
Source: Danish Meteorological Institute, Dataryselsen, Author: Joren Garré

4.2 General overview of the survey

Figure 17 illustrates the exact locations where the surveys were administered, spread across five well-distributed sites within the study area. This approach enabled direct interaction with a diverse range of local residents. In total, 75 responses were collected. As mentioned earlier, each respondent was asked to indicate their place of residence within the research area. As shown in Figure 18, the respondents are well distributed across the area.

Figure 17:

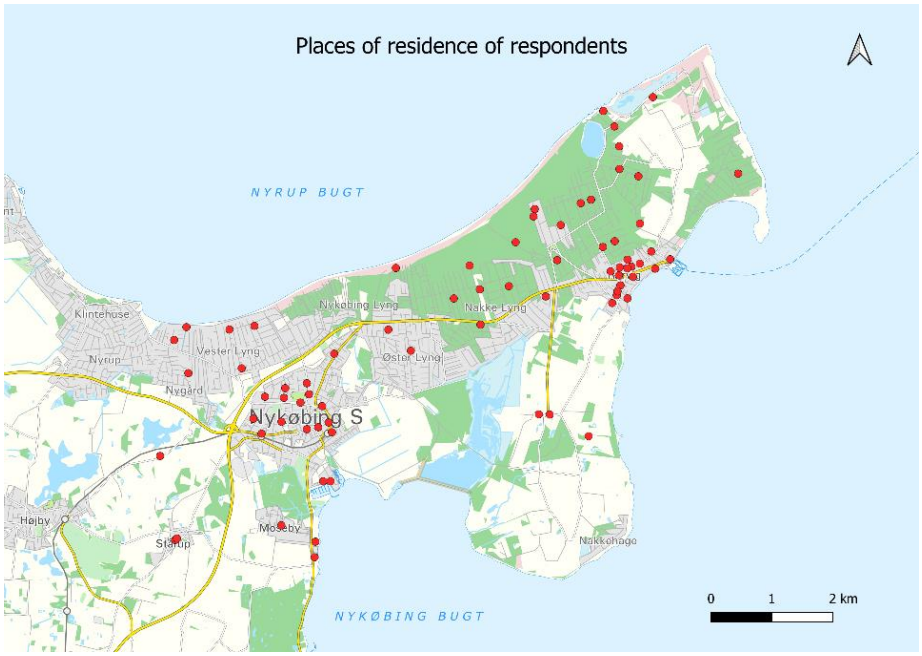
Survey locations



Source: Dataryselsen, Author: Joren Garré

Figure 18:

Places of residence of respondents



Source: Dataryselsen, Author: Joren Garré

4.3 Public risk perception and willingness to pay

4.3.1 Respondent profile

Table 1 provides a summary of key survey data on housing characteristics, perceived flood risk, previous flood experiences and the presence of drainage infrastructure in Odsherred. The majority of participants have lived in the area for up to 40 years. Most homes are raised above ground level (65.33%) and do not have a basement (82.67%), both of which are relevant to flood vulnerability. Only a small proportion of residents (16%) believe their homes are located in flood-prone areas, although more than two-thirds (68%) are aware of potential flood risks. Notably, over 70% believe that flood risk has increased since 2015, suggesting a rising public awareness of climate-related hazards. About a third of the respondents reported that their immediate surroundings have already been affected by flooding. In terms of infrastructure, conventional systems like gutters and sewer networks are more commonly present, while innovative techniques like permeable pavement are rarely found in the area. These insights form a valuable foundation for understanding local risk perception and evaluating the adequacy of current flood mitigation strategies.

Table 1:

Sample characteristics

Variable	Category	Number	Percentage
Years living in Odsherred	0–20 years	31	41.33%
	20–40 years	27	36.00%
	40–60 years	11	14.67%
	> 60 years	6	8.00%
Is your home raised more than 10 cm above ground level?	Yes	49	65.33%
	No	26	34.67%
Does your home have a basement?	Yes	13	17.33%
	No	62	82.67%
Is your home a single-level house?	Yes	47	62.67%
	No	28	37.33%
Is your home located in a flood-prone area?	Yes	12	16.00%
	No	63	84.00%
Were you aware that your home might be at flood risk?	Yes	51	68.00%
	No	24	32.00%
Do you think flood risk has increased since 2015?	Yes	53	70.67%
	No	22	29.33%
Has your living environment (<1 km) been affected by flooding before?	Yes	26	34.67%
	No	49	65.33%
Drainage system present – *Gutters*	Yes	28	37.33%
	No	47	62.67%
Drainage system present – *Permeable pavement*	Yes	4	5.33%
	No	71	94.67%
Drainage system present – *Sewer systems*	Yes	38	50.67%
	No	37	49.33%
Drainage system present – *Ditch*	Yes	19	25.33%
	No	56	74.67%

4.3.2 Descriptive insights on flood risk perception

Table 2 presents the descriptive statistics for the eight survey items (Q1 to Q8), which assess respondents' attitudes toward flooding and potential adaptation strategies. These items cover a range of perspectives, including concern about potential storm or cloudburst events (Q1), willingness to pay for measures to prevent flooding (Q2) and the importance of considering the ecosystem in the development of new flood protection strategies (Q3). Respondents were also asked about their support for natural solutions, such as wetlands or green spaces, over engineered structures (Q4) and whether they prefer making adjustments to their own homes rather than relying on large-scale adaptations like dunes or dikes (Q5). Additional items explored worry about the financial consequences of flooding for one's household (Q6), openness to participating in local flood prevention initiatives (Q7) and acceptance of government strategies such as giving land back to the sea to reduce flood risk (Q8).

The means range from 2,96 (Q5) to 4,99 (Q3), indicating overall neutral to moderately positive attitudes across the sample. The median values generally align with the means, suggesting the distributions are roughly symmetric. Standard deviations range from 1,789 to 2,118, reflecting a substantial degree of variance in responses. This variability suggests that attitudes toward flood-related concerns and solutions are not homogeneous within the sample and may depend on factors such as geography, personal experience with flooding or socio-economic status.

These descriptive findings serve as an essential first step in understanding the underlying data structure and the extent of attitudinal spread, which will inform further inferential analyses such as t-tests.

Tabel 2:

Descriptive statics of the eight survey items

Statistics									
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
N	Valid	75	75	75	75	75	75	75	75
	Missing	0	0	0	0	0	0	0	0
Mean		4,07	3,47	4,99	4,27	2,96	4,04	5,11	4,31
Median		4,00	4,00	5,00	4,00	3,00	4,00	5,00	5,00
Std. Deviation		2,056	1,898	2,010	2,056	1,789	2,108	1,813	2,118

4.3.3 T-test

Table 3 compares the means and standard deviations of each item between respondents living in flood-prone areas (Flood = 1) and those living outside such areas (Flood = 0). On average, residents of flood-prone areas reported slightly higher concern and agreement across most items. For instance, Q6 had a mean of 4,64 among flood-zone residents versus 3,68 for non-residents. However, in some cases (e.g., Q5), the differences were minimal, suggesting that geographical risk may not universally translate to greater concern or different attitudes.

Tabel 3:

Group statistics

Group Statistics					
	Flood	N	Mean	Std. Deviation	Std. Error Mean
Q1	,00	47	4,15	2,000	,292
	1,00	28	3,93	2,176	,411
Q2	,00	47	3,28	2,050	,299
	1,00	28	3,79	1,595	,301
Q3	,00	47	4,89	2,179	,318
	1,00	28	5,14	1,715	,324
Q4	,00	47	4,26	2,141	,312
	1,00	28	4,29	1,941	,367
Q5	,00	47	2,96	1,967	,287
	1,00	28	2,96	1,478	,279
Q6	,00	47	3,68	2,198	,321
	1,00	28	4,64	1,830	,346
Q7	,00	47	5,09	1,863	,272
	1,00	28	5,14	1,758	,332
Q8	,00	47	4,38	2,091	,305
	1,00	28	4,18	2,195	,415

To test whether the observed group differences were statistically significant, independent samples t-tests were conducted for each item. The assumptions of homogeneity of variance were tested using Levene's test. In three cases (Q2, Q5 and Q6), Levene's test was significant ($p < 0,05$), suggesting unequal variances. For those, results from the row "Equal variances not assumed" were interpreted.

No statistically significant differences in attitudes were identified between residents living within flood-prone zones and those residing in areas with lower modelled risk exposure, based on an alpha level of 0,05. Nevertheless, one item Q6 approached statistical significance with a p-value of 0,056, indicating a marginal trend that may hold interpretative value despite not meeting conventional thresholds for significance.

The mean score for Q6 was notably higher among respondents living in identified flood-risk areas, suggesting that financial vulnerability and economic risk perception may be more salient among individuals with direct exposure to flood-prone environments. While this result does not provide definitive statistical support for Hypothesis 1 (H1), which predicted greater concern among at-risk populations, it nonetheless aligns directionally with the hypothesis and may indicate an underlying pattern worthy of further investigation.

Beyond statistical significance, several non-significant findings are noteworthy due to their theoretical relevance or unexpected direction. For instance, item Q5 yielded a p-value of 0,986, suggesting an almost identical distribution of responses between the two groups. This contradicts Hypothesis 2 (H2), which posited that individuals in high-risk areas, presumably more aware of systemic vulnerabilities, would favour collective or large-scale infrastructural solutions over individual measures. Instead, the data suggest that preferences for individual versus large-scale adaptations are consistent across zones, regardless of exposure.

Similarly, item Q7 was also non-significant ($p = 0,895$), undermining Hypothesis 3 (H3), which suggested that prior exposure to flood events would correlate with increased willingness to engage in community-level mitigation. The relatively uniform responses indicate that community engagement potential is high across the board, but not evidently influenced by direct experience or risk proximity.

Tabel 4:

Independent samples test

Independent Samples Test											
		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Q1	Equal variances assumed	1,547	,218	,447	73	,328	,656	,220	,493	-,763	1,204
	Equal variances not assumed			,437	53,111	,332	,664	,220	,504	-,791	1,232
Q2	Equal variances assumed	5,215	,025	-1,125	73	,132	,264	-,509	,452	-1,411	,392
	Equal variances not assumed			-1,199	67,770	,117	,235	-,509	,425	-1,357	,338
Q3	Equal variances assumed	2,407	,125	-,517	73	,303	,607	-,249	,482	-1,210	,712
	Equal variances not assumed			-,549	67,346	,292	,585	-,249	,454	-1,155	,657
Q4	Equal variances assumed	1,188	,279	-,062	73	,476	,951	-,030	,494	-1,015	,954
	Equal variances not assumed			-,063	61,404	,475	,950	-,030	,482	-,994	,933
Q5	Equal variances assumed	4,515	,037	-,016	73	,494	,987	-,007	,430	-,864	,850
	Equal variances not assumed			-,017	68,968	,493	,986	-,007	,400	-,806	,792
Q6	Equal variances assumed	3,644	,060	-1,947	73	,028	,055	-,962	,494	-1,947	,023
	Equal variances not assumed			-2,040	65,116	,023	,045	-,962	,472	-1,904	-,020
Q7	Equal variances assumed	,004	,949	-,133	73	,447	,895	-,058	,436	-,926	,810
	Equal variances not assumed			-,135	59,569	,447	,893	-,058	,429	-,916	,801
Q8	Equal variances assumed	,216	,643	,402	73	,344	,689	,204	,509	-,809	1,218
	Equal variances not assumed			,397	54,696	,346	,693	,204	,515	-,828	1,236

Although most group differences were not statistically significant, effect sizes were calculated to determine the magnitude of observed differences. Cohen's d values for the items range from -0,145 (Q3) to 0,462 (Q6), indicating mostly small to moderate effects. The largest effect size was found for Q6, which reinforces earlier findings that financial concern is more pronounced among those in flood-prone zones.

Given the small sample size, statistical power may have been insufficient to detect differences of this magnitude as significant. Therefore, the effect size analysis adds value by highlighting practical significance, particularly for items with moderate effects like Q6 and Q1.

Tabel 5:

Independent samples effect sizes

Independent Samples Effect Sizes					
				95% Confidence Interval	
		Standardizer	Point Estimate	Lower	Upper
Q1	Cohen's d	2,067	0,107	-0,362	0,574
	Hedges' correction	2,088	0,106	-0,368	0,569
	Glass's delta	2,176	0,114	-0,358	0,586
Q2	Cohen's d	1,895	-0,269	-0,738	0,202
	Hedges' correction	1,915	-0,266	-0,733	0,198
	Glass's delta	1,595	-0,319	-0,792	0,159
Q3	Cohen's d	2,020	-0,123	-0,591	0,345
	Hedges' correction	2,041	-0,121	-0,585	0,342
	Glass's delta	1,715	-0,145	-0,613	0,325
Q4	Cohen's d	2,070	0,015	-0,483	0,453
	Hedges' correction	2,091	0,015	-0,478	0,449
	Glass's delta	1,941	0,016	-0,483	0,452
Q5	Cohen's d	1,801	0,108	-0,472	0,464
	Hedges' correction	1,820	0,107	-0,469	0,458
	Glass's delta	1,478	0,111	-0,472	0,461
Q6	Cohen's d	2,069	-0,465	-0,937	0,007
	Hedges' correction	2,091	-0,461	-0,929	0,010
	Glass's delta	1,830	-0,491	-0,928	0,053
Q7	Cohen's d	1,825	-0,032	-0,499	0,436
	Hedges' correction	1,844	-0,031	-0,494	0,432
	Glass's delta	1,758	-0,033	-0,501	0,435

Independent Samples Effect Sizes					
				95% Confidence Interval	
		Standardizer	Point Estimate	Lower	Upper
Q8	Cohen's d	2,130	0,213	-0,373	0,564
	Hedges' correction	2,152	0,212	-0,369	0,558
	Glass's delta	2,195	0,093	-0,376	0,561

4.3.4 Crosstabs

To examine whether there is a relationship between living in a flood-prone area and the presence of drainage systems (such as gutters, sewer systems, or ditches), a crosstab analysis was conducted, followed by a chi-square test. The variable 'Flood' indicates whether a respondent lives in a flood-prone area (1 = yes, 0 = no), while 'Drainage' reflects the presence of one of the mentioned drainage systems (1 = yes, 0 = no).

The crosstab (Tabel 6) shows that 75% of respondents in flood-prone areas have access to a drainage system, compared to 66% in non-flood-prone areas. While this suggests a slight difference in favour of flood-prone areas, the chi-square test (Tabel 7) indicates that the difference is not statistically significant ($\chi^2(1) = 0,675$, $p = 0,411$). Additional tests, such as Fisher's Exact Test, confirm this result ($p = 0,450$).

These findings imply that, based on this dataset, there is no conclusive evidence of a relationship between an area's flood risk and the presence of local drainage systems. It is possible that other factors, such as urban planning or local regulations, play a more significant role in the implementation of such measures.

Tabel 6:

Flood-drainage crosstabulation

Flood * Drainage Crosstabulation					
			Drainage present		
			,00	1,00	Total
Flood	,00	Count	16	31	47
		% within Flood	34,0%	66,0%	100%
		% within Drainage	69,6%	59,6%	62,7%
	1,00	Count	7	21	28
		% within Flood	25,0%	75,0%	100,0%
		% within Drainage	30,4%	40,4%	37,3%
Total		Count	23	52	75
		% within Flood	30,7%	69,3%	100,0%
		% within Drainage	100,0%	100,0%	100,0%

Tabel 7:

Chi-square tests

Chi-Square Tests					
	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	,675[a]	1	,411		
Continuity Correlation[b]	,317	1	,574		
Likelihood Ratio	,687	1	,407		
Fisher's Exact Test				,450	,289
Linear-by-Linear Association	,666	1	,415		
N of Valid Cases	75				
a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 8,59. b. Computed only for a 2x2 table					

4.4 Implemented and suggested flood strategies

Figure 19 summarizes the current drainage and flood prevention techniques implemented by the respondents. Ditches were mentioned most frequently, with a total of three references. As the number of additional responses is very low, the results are not used.

Figure 19:

Current drainage and flood prevention techniques in use

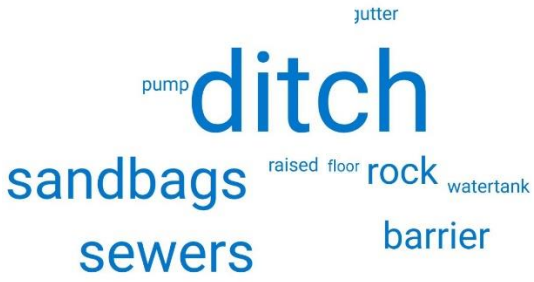
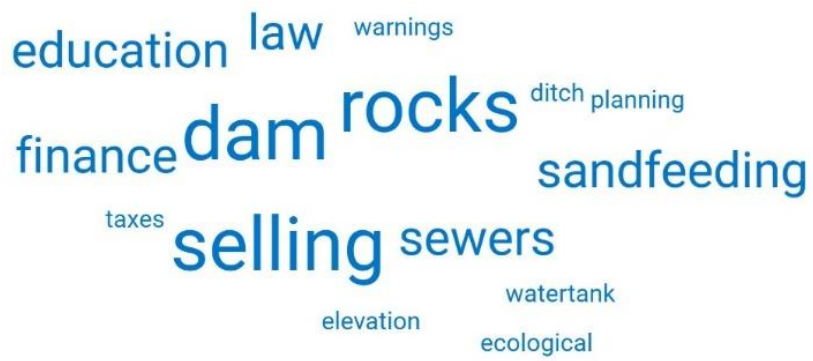


Figure 20 is an overview of the suggested measures that local municipalities should undertake according to the respondents. Suggestions such as “education” and “warnings” highlight the importance of raising awareness. Responses like “finance,” “taxes,” and “selling” are linked to the financial aspect of the ongoing debate on how preventive measures should be funded. The remaining suggestions can be categorized under the themes of policy and infrastructure, including both traditional and nature-based solutions.

Figure 20:

Suggested measures for the municipality and local government



4.5 Interview

To better understand the policy context and to validate our findings, we conducted an interview with researcher Mette Juhl Jessen. The interview was conducted on May 15th and took place online.

4.5.1 Official vs. experienced risk

Jessen acknowledged that as Odsherred is not officially classified as a flood risk area by national authorities, flooding still occurs regularly. This shows the importance of local-scale analysis and perception research, particularly in areas that fall below national risk thresholds. Her view aligns with our survey results, in which 35% of respondents reported past flooding in their immediate environment despite the area's "low risk" status.

4.5.2 Responsibility, insurance and governance

In Denmark, the homeowners carry the legal responsibility for storm or flood damage, even when living in high-exposure areas. Insurance coverage is typically limited to events with a 20-year return period. When damage occurs, houses are often rebuilt in the same vulnerable location, maintaining exposure to future risk. According to Jessen, this system does little to improve long-term resilience and reflects a broader policy model that shifts responsibility to the individual.

This raises ongoing political questions: Should public funds be used to protect privately owned coastal summerhouses? Or should those directly benefiting bear the full cost? These debates, she noted, remain unresolved and are particularly relevant in regions like Odsherred with extensive seasonal housing near the coast.

4.5.3 Adaptation measures and nature-based solutions

Jessen highlighted a potential climate adaptation project near Lumsås, where the restoration of a former wetland is being considered to mitigate flood risks. However, this project remains in the planning and discussion phase, mainly due to political hesitation and uncertainty over funding responsibilities. While more advanced NBS initiatives are taking place on Denmark's west coast, similar efforts in Odsherred are still limited. She specified that "Who pays?" is the key barrier to implementation.

Techniques such as wetland restoration or dynamic coastal protection are available, but few concrete steps have been taken. Public willingness to invest in collective measures remains a point of contention, particularly when the affected areas involve holiday homes. Jessen also pointed to the role of utility companies in managing drainage systems and noted that while Odsherred's 2014 climate adaptation plan existed, its primary focus was mitigation. Only in the 2022 revision did drainage, nature-based adaptation and citizen engagement become more central.

4.5.4 Rethinking risk and planning

Jessen emphasized a broader understanding of flood risk in terms of hazard (e.g., sea-level rise or rainfall), exposure (what is located in the floodplain), vulnerability (e.g., elderly populations or critical infrastructure) and response capacity. Even if an area is statistically "low risk," floods can still have severe consequences if hospitals, roads or supermarkets are affected. She referenced the national "Living with Water" campaign as an example of Denmark's attempt to raise awareness and promote adaptive behaviour. Still, she noted that political and financial fragmentation remains a major obstacle to large-scale climate action.

5. DISCUSSION

This study has provided valuable insights into the perception of flood risks and adaptation strategies among the residents of Odsherred. While the findings reveal certain nuances and indicative trends, they also underscore the complexity of risk perception and the necessity for further, in-depth research.

5.1 Insights from GIS analysis

The flood maps, derived from a GIS-based spatial analysis, reveal consistent patterns across all scenarios. Major flood zones are located in the Hov Vig Nature Reserve and the agricultural areas southwest of Nykøbing. While these primarily affect natural and rural areas, floodwaters from both zones extend into neighbouring housing, including permanent residences in Nykøbing and homes near the nature reserve. This expansion into residential zones increases the risk of property damage, loss of housing stability and potential devaluation of homes.

Critical infrastructure such as the railway station and main roads becomes increasingly exposed in the 20- and 50-year scenarios, particularly under future climate conditions. This could lead to frequent disruptions in public transport and road access, directly affecting residents' ability to commute, attend school, reach workplaces or access healthcare and emergency services. Such disruptions may disproportionately affect those without alternative transport options or with urgent medical needs. The bog area southeast of Nykøbing, where many summer houses are located, also becomes more vulnerable, potentially leading to loss of recreational value and financial burdens for property owners.

Under the medium emission scenario, flood zones shift slightly inland, most noticeably along the Rørvig coastline and in the bog northwest of the peninsula, which expands significantly. The very high emission scenario adds only marginal differences, mostly slightly more scattered or larger flood patches. The subtle differences between scenarios could lead to misinterpretation of risk severity. Residents and policymakers may underestimate the urgency or scope of needed adaptation, delaying protective measures.

5.2 Key findings and implications of the survey

One notable outcome of the statistical analysis was the near-significant result about the concern of financial consequences of flooding for households (Q6). Although the p-value of 0,056 falls just short of the conventional threshold for statistical significance, the mean response was considerably higher among participants residing in identified flood-prone areas. This suggests a marginal yet meaningful pattern in which financial vulnerability and economic risk perception are more pronounced among those with direct exposure to flood hazards. These findings support Hypothesis 1 (H1) that individuals in high-risk areas exhibit greater concern about flood hazards. Financial concerns appear to be at least related to the attitudes and behaviours related to adaptation, highlighting an important leverage point for policy interventions.

This near-significant outcome also points to a potential psychosocial dimension of risk perception, in which economic anxieties—rather than general environmental concern—may serve as a primary motivator for adaptation-related attitudes and behaviours. Given the complex interplay between risk awareness, perceived responsibility, and willingness to act, such financial concerns could represent a critical entry point for policy interventions, particularly in efforts aimed at increasing public engagement in climate adaptation strategies.

In contrast, the remaining hypotheses did not yield statistically significant differences between respondents in high- and low-risk zones. For example, preferences for home-based versus large-scale adaptation strategies (Q5) showed no significant variation, challenging Hypothesis 2 (H2). Similarly, willingness to participate in local flood prevention initiatives (Q7) was not significant ($p = 0,895$), countering Hypothesis 3 (H3). These findings suggest that preferences for adaptation strategies and potential for community engagement are relatively consistent, regardless of direct exposure to risk.

In general, public awareness of flood risk in Odsherred is relatively high, as 68% of respondents acknowledged potential flood risks and over 70% believed these risks have increased since 2015. However, only 16% considered their own home at risk, indicating a gap between general awareness and personal vulnerability assessments.

5.3 Assessment of drainage and infrastructure (indirect indicators)

Approximately one-third of respondents (34,67%) reported that their immediate area had experienced flooding in the past. Regarding the presence of drainage systems, 50,67% of respondents indicated their household had access to a sewer system, while only 25,33% reported nearby drainage ditches. Conversely, 49,33% lacked a sewer system and 74,67% reported no nearby ditches. These findings suggest that the existing drainage infrastructure may be insufficient. However, it is important to emphasise that these are indirect indicators: thus, no definitive conclusions can be drawn about drainage effectiveness. Cross-tabulation also showed no statistically significant relationship between residing in a flood-prone area and the presence of local drainage systems, implying that other factors, such as urban planning or local policy, may play a more decisive role.

Odsherred's Climate Adaptation Plan (2022) acknowledges that the current drainage infrastructure is increasingly inadequate in coping with intense rainfall, particularly in areas with vulnerable soil and groundwater conditions. Drainage effectiveness is especially limited in regions with high groundwater levels and restricted discharge capacity.

5.4 Wider context and expert reflections

This study defines risk perception as the subjective evaluation of flood likelihood and severity, shaped by knowledge, emotions and personal experience. It was assessed through eight survey questions (Q1–Q8) measuring concern, willingness to act and preferred solutions.

As noted by Jenssen, flood risk extends beyond individual properties. Even in low-risk zones, damage to vital infrastructure can impact residents, highlighting the communal nature of flood vulnerability and the need for collective preparedness.

Odsherred's co-productive governance model expects residents, including those with seasonal homes, to invest in individual climate-proofing. However, questions around funding for private coastal protection remain unresolved and are emerging in the responses in the survey of what is expected from the local government and municipalities. Nature-based solutions and green infrastructure are increasingly prioritized, especially following the 2022 revision of the municipal Climate Plan, which emphasizes citizen engagement and adaptive drainage strategies.

Recent extreme weather events underline the urgency of improved flood resilience. Despite official classifications, flooding still occurs regularly in so-called low-risk areas, stressing the limits of current infrastructure and the growing need for systemic adaptation.

5.5 Recommendations for future research

In light of the limitations of this study, due to a relatively limited amount of respondents, it is recommended that future research further investigates the observed trends, with particular attention to financial concerns in order to reach statistical significance on this topic and deepen the understanding of underlying mechanisms. First, incorporating demographic variables such as gender and income could reveal important variations in risk perception and willingness to adopt adaptation measures. Second, the use of detailed spatial data, such as maps illustrating soil infiltration rates and sewer system capacity, may provide a more accurate assessment of the effectiveness and coverage of local infrastructure. Third, it is advisable to distinguish between permanent and seasonal residences, as this may affect perceptions of flood risk and financial responsibility, especially in coastal areas with many summerhouses. Additionally, further research is needed to explore the reasons why general awareness of flood risk does not consistently translate into perceptions of personal vulnerability. Finally, studies should examine how residents evaluate the performance of existing drainage systems, as public perception of infrastructure reliability may significantly affect attitudes toward adaptation and investment in preventive measures.

6. CONCLUSION

The municipality of Odsherred in Denmark, like many coastal regions worldwide, is facing increasing flood risks, primarily due to heavy rainfall and storms. This study aimed to gain insight into residents' perceptions of these risks, assess the perceived effectiveness of current measures and explore whether perception differences exist between high-risk and low-risk zones.

Denmark has experienced a significant increase in annual precipitation and extreme rainfall events, such as cloudbursts. Projections indicate that both trends are likely to intensify in the future. Due to its extensive coastline, Denmark is also particularly vulnerable to coastal flooding, including so-called "silent storm surges." In response, Denmark has implemented the EU Floods Directive and requires municipalities to develop climate adaptation plans.

Odsherred's climate plan (2022) acknowledges that existing drainage systems are increasingly inadequate. This is confirmed by the flood maps of our study area in Odsherred. While flooding predominantly impacts agricultural and natural areas, several streets in Nykøbing and nearby residential neighbourhoods are also affected. Additionally, many houses along the coastline and summerhouses in the former bog area of Langesø Mose face significant risk. Under 20- and 50-year recurrence events, or even 5-year events under a medium emission scenario, critical infrastructure such as major roads and the train station in Nykøbing are flooded. Notably, the municipality places considerable responsibility on residents to climate-proof their own properties, adopting a facilitating and advisory role. This reflects a co-productive governance model in which citizen participation is essential.

Analysis of the survey data from 75 residents of Odsherred reveals that public perception of flood risk is complex. While a large majority (68%) is aware of potential flood risks and over 70% believe that these risks have increased since 2015, only a small proportion (16%) considers their own home to be at risk of flooding. This points to a gap between general risk awareness and personal assessments of vulnerability.

Statistical analysis showed no significant differences in attitudes between residents in high-risk flood zones and those in lower-risk areas for most of the topics investigated. However, concern about the financial consequences of flooding (Q6) approached statistical significance ($p = 0,056$), with respondents living in identified flood-prone areas reporting a notably higher average level of concern. This suggests that economic anxiety may be a primary driver of adaptation-related attitudes, particularly among those with more direct exposure to risk.

While this study provides valuable insights, knowledge gaps remain that warrant further investigation. Given the limited sample size, future research with larger samples is recommended to further explore the observed trends (especially those related to financial concerns) and to achieve statistical significance. In addition, further research could explore why general risk awareness does not always translate into personal vulnerability assessments, as well as residents' perceptions of the effectiveness of existing drainage infrastructure.

The success of climate adaptation in Odsherred depends not only on technical solutions, but also on the active engagement and ownership of the community, with effective communication about the financial dimensions of flood risk emerging as a potentially critical factor.

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9. APPENDIX

9.1 The survey

Evaluating the flood risk and perception in Odsherred

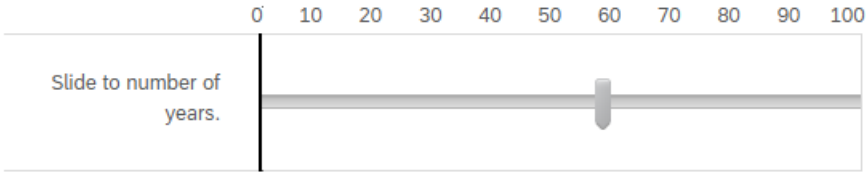
Climate change increasingly exposes coastal regions worldwide to heightened flood risks, primarily driven by more frequent and intense storm surges and heavy rainfall events. Projections indicate that under medium and very high emission scenarios, events like 5-year, 20-year and 50-year storm surges and heavy rainfall will significantly increase in intensity and frequency by 2070, with some 5-year events potentially reaching the intensity of current 100-year events. In order to evaluate the flood risk and perception in Odsherred, this Questionnaire was made. All information is gathered anonymously. The investigation is part of the assignment for the course "Integrated International Projecwork" and will only be used internally by these partners.

Q1 Positioning

Q1.1 The digital map is presented on which a point marker can be placed to indicate the residence.

Q2 Background information

Q2.1 For how many years are you a resident in Odsherred?



Q2.2 Does your house have the following features?

	Yes	No
Is your home raised more than 10 cm above ground level?	○	○
Do you have a basement?	○	○
Is your home a single level house?	○	○

Q3 Floods scenarios

Q3.1 Could your home be affected by flooding in the following scenarios?

Note: The scenarios were printed in A3 format and shown with this question.

	Yes	No
Scenario 1: 5-Year Recurrence Event	○	○
Scenario 2: 20-Year Recurrence Event	○	○
Scenario 3: 50-Year Recurrence Event	○	○

Q3.2 Were you aware/informed that your home might be at risk of flooding?

Yes	No
○	○

Q3.3 Do you think the risk of flooding increased since 2015?

Yes	No
○	○

Q4 Floods in own living environment

Q4.1 Has your living environment (within 1 km around your home) already been affected by flooding?

Yes	No	I don't know
○	○	○

If Q4.1 "Yes" is selected:

Q4.1.1 What was the main cause of the flood?

Heavy rainfall for an extended period of time	○
Cloudburst (Heavy rainfall in a short period of time)	○
Storm	○
Insufficient infrastructure	○
Other	○

If “Other” was selected:

Q4.1.2 What was the main cause of the flood?

_____

_____

_____

If Q4.1 “No” or “I don’t know” is selected:

Q4.2.1 What do you think are the main causes of floods in Odsherred?

Heavy rainfall for an extended period of time	○
Cloudburst (Heavy rainfall in a short period of time)	○
Storm	○
Insufficient infrastructure	○
Other	○

If “Other” was selected:

Q4.2.2 What do you think are the main causes of floods in Odsherred?

_____

_____

_____

Q5 Protective measures

Q5.1 What drainage techniques are present in your living environment to prevent flooding?

	Yes	No
Gutters	○	○
Permeable pavement	○	○
Sewer systems	○	○
Ditch	○	○
Other	○	○

Q5.2 What measures are you currently taking to prevent flooding?

_____

_____

_____

Q5.3 What actions do you believe the local government/region should take to reduce flood risk?

_____

_____

_____

Q6 A reflection of your perspective on the topic of flooding.

Q6.1 Given are a number of statements. Move the slider between:

1: Strongly disagree

2: Disagree

3: Somewhat disagree

4: Neutral

5: Somewhat agree

6: Agree

7: Strongly agree

I am concerned that a potential storm/cloudburst might happen.	
I am willing to pay for measures to prevent flooding.	
I find it important that the new measures take the ecosystem into account.	
I support the use of natural solutions (such as wetlands or green spaces) over engineered structures.	
I prefer adjustments to my home over large scale adaptations (such as dunes and dikes)	
I am worried about the financial consequences of flooding for my household.	
I am open to participating in local initiatives aimed at flood prevention.	
I am ok with the government giving land back to the sea to decrease the floodrisk.	

9.2 The interview

To guide the interview with researcher Mette Juhl Jessen, these 9 main questions were prepared:

1. How often do the x-year storms in reality occur in Odsherred? (x is the period, 10-year, …)
2. When one occurred, how severe was the damage?
3. What measures are already in place to prevent flooding?
4. What future measures are planned or considered?
5. How are these measures prepared for heavy rainfall or storms?
6. Which areas in Odsherred do you consider most vulnerable to cloudbursts or storm surges, and why?
7. To what extent are residents informed or involved in understanding the risks and their role in prevention?
8. What do you see as the main obstacles to making Odsherred more climate resilient against flooding?
9. Given the context and our research methodology, are there important considerations to have a holistic understanding and interpretation of the topic?

FACULTY OF SCIENCES

MASTER OF SCIENCE IN GEOGRAPHY AND GEOMATICS

FROM NY TO NEW: REIMAGINING NYKØBING'S URBAN FUTURE

EXPLORING URBAN REDEVELOPMENT OPPORTUNITIES FOR AN AGING POPULATION

Word count: 8.616

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Course: Integrated International Projectwork - C004173

Academic year: 2024 – 2025

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Contents

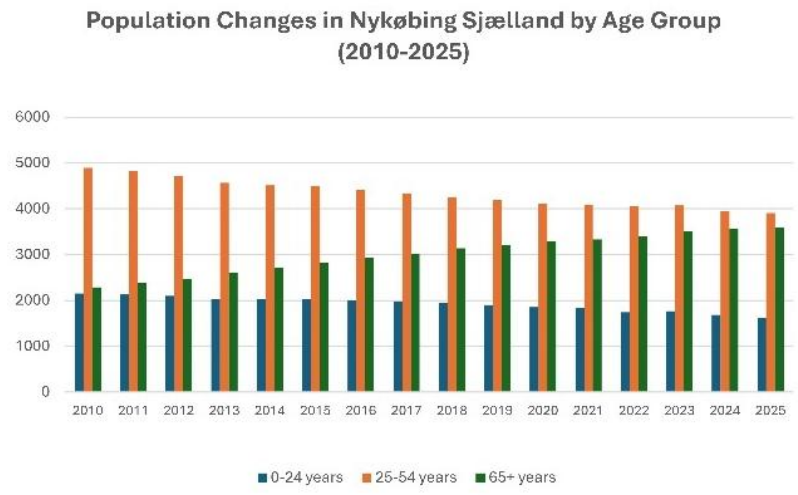
1 INTRODUCTION

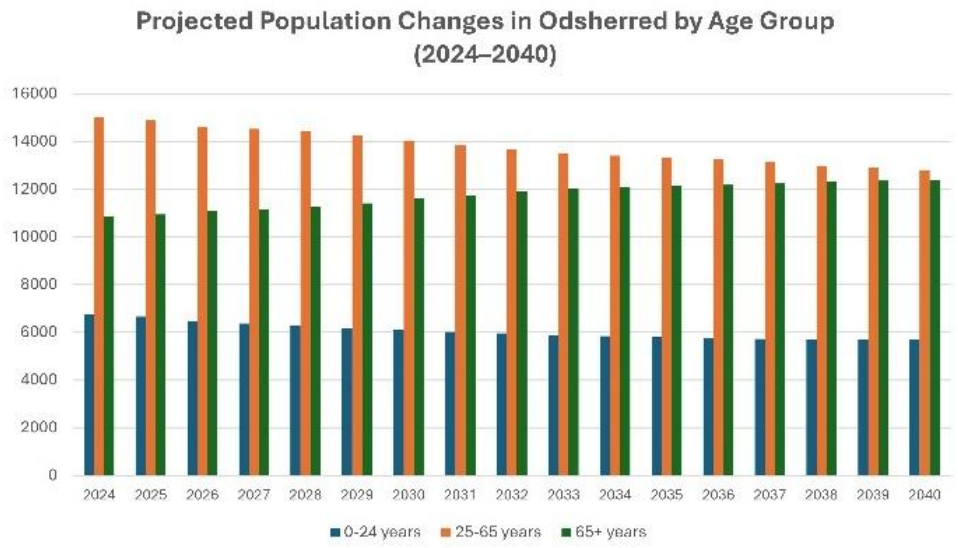
1.1 Context

The declining and ageing population in rural areas presents significant challenges for Denmark, as well as in the other Nordic countries (Heleniak & Gassen, 2020). These developments are largely caused by the limited availability of services, job opportunities, and infrastructure in rural areas. As a result, many people choose to move to cities in search of better living conditions. This movement further weakens rural communities, making it even harder for them to recover and retain residents (Søder, 2024). It is worth exploring which measures could help to slow down or reverse these demographic trends. These demographic trends serve as the motivation for our integrated international project, in which we will further explore urban redevelopment opportunities, with a specific focus on walkability within Nykøbing Sj. After analysing population data for the municipality of Odsherred and the small town of Nykøbing Sjælland, we observed similar patterns. We divided the population into three age groups: 0–24 years (youth), 25–64 years (working-age population), and 65+ years (pensioners), as shown in Figure 1. For Odsherred, we examined population projections from 2024 to 2040, while for Nykøbing Sjælland we analysed changes from 2010 to 2025. In both cases, the data reveal the same trend: a decline in the number of young people and working-age adults, and an increase in the number of elderly residents. This confirms the broader national trend of an ageing population in Denmark. Furthermore, both Odsherred and Nykøbing are experiencing an overall population decline (Statistics Denmark, n.d.).

Figure 1

Tables of recent demographic changes in Nykøbing and Odsherred. Source: Statbank



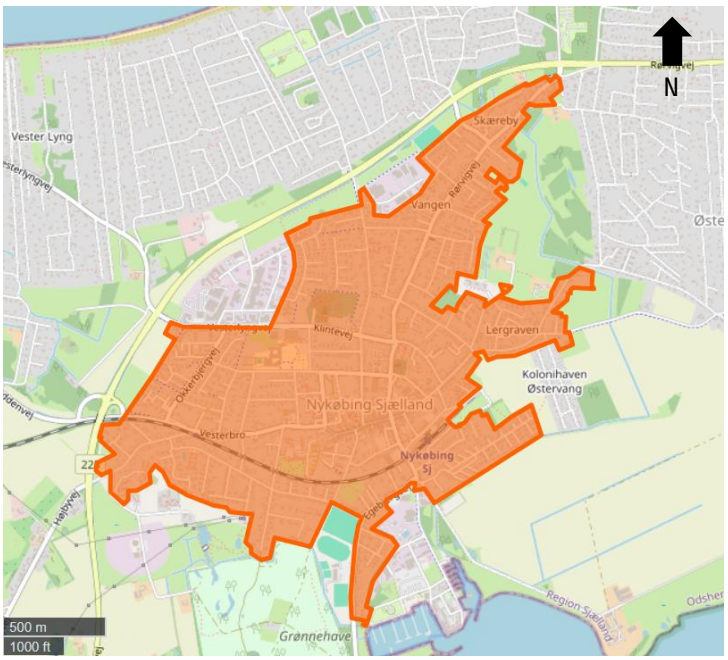


1.2 Problem Setting, Research Gaps, Questions, and Objectives

The study area used for this group project is the town centre of Nykøbing Sjælland. More precisely, the borders surround the built-up area in the town centre as identified by the Residential Area polygon # 119719068 drawn from OpenStreetMap. This study area impacted which residents were allowed to do the survey. If they lived between these borders, their input was recorded for the PPGIS part of the survey, otherwise it was ignored.

Figure 2

Study area and surroundings. Source: OpenStreetMap



As previously mentioned, Nykøbing Sjælland is a town characterized by a declining elderly population. Following a rapid rise in holiday home tourism after the Second World War—particularly in the 1960s and 1970s—the expansion of the city centre came to a halt (Wagner, 2013). This tourism boom led to the development of large summerhouse areas located outside the urban core.

The town now accommodates two distinct groups: permanent elderly residents and seasonally fluctuating tourist populations. These groups have different needs and varying levels of access to community services. The rise in car ownership further facilitated travel to rural holiday homes, embedding these areas more deeply into Danish leisure culture. This divergence in needs has contributed to the disappearance or seasonal operation of certain specialized shops, such as bakeries and butchers. Meanwhile, more general retail outlets like supermarkets remain widely available. A similar decline is evident in essential services such as healthcare and education, which have gradually diminished over the past few decades. Urban redevelopment that prioritizes walkability could improve access to services for the elderly, who often rely on proximity. However, as much of this population may not be present in twenty years, the study also considers the needs of all age groups. This broader focus is essential to ensuring the long-term sustainability and vitality of the town.

The aim of this research is to evaluate the current urban structure and service landscape in Nykøbing Sjælland and to offer policy recommendations for the local government. These recommendations will address population needs, identify potential zones for redevelopment, and consider how an ageing population influences demand for urban services. This will be done through the lens of walkability, drawing inspiration from the concept of the 15-minute city. To reach these goals, we have formulated the following research question and sub-questions:

What are the opportunities for urban redevelopment in Nykøbing based on the walking preferences of the ageing population?

The following three sub-questions have been developed to support the main research question. Each sub-question addresses a specific research objective, while also contributing to the overall understanding of the topic in this study.

1. What is the current spatial structure of the town?
2. What are the specific needs of people using the town's functions?
3. How does the ageing population influence demand for specific urban services?
4. Which areas are most suitable or desired for redevelopment?

This research is particularly relevant, as no previous studies or surveys have been conducted in Nykøbing Sjælland to assess the needs of residents or their perspectives on recent changes in the town. It is the first initiative aimed at giving local inhabitants a voice in shaping Nykøbing's future. In an interview, Ella Cadee, a spatial planning employee at the Municipality of Odsherred, noted that the local government seldom takes residents' opinions into account when developing future plans.

2 THEORETICAL BACKGROUND

2.1 Urban redevelopment

Urban redevelopment, refers to the process of improving urban areas by repairing old or damaged structures or by constructing new ones. This process may include the renovation or development of buildings, parks, roads, industrial zones, and residential areas (Urban Renewal | EBSCO, n.d.). Urban redevelopment was initially a concern mainly for large cities. However, as more people have moved from rural areas and villages to major cities, it has become increasingly important for smaller towns and villages as well, as they seek to retain their population.

Redevelopment in the Danish small town of Nykøbing Sjælland must be more than physical change or the re-use of empty buildings. Two recent Scandinavian studies emphasize the crucial importance of including and maintaining basic public services such as education, healthcare, retail and transportation in redevelopment strategies. Stenbäcka and Cassel (2024), writing in the context of Sweden, recognize the social risks of rural housing policies that do not consider the quality and provision of local services. For these authors, "the social sustainability of rural development depends upon proximity to schools, healthcare, and public transport" (Stenbäcka & Cassel, 2024, p. 6). In other words, housing without access to services can create inequality and harm social cohesion in the long term. For a town like Nykøbing Sjælland, this means that redevelopment needs to be explicitly linked to the maintenance or improvement of local services and infrastructure. Similarly, Åberg and Tondelli (2021) discuss post-COVID migration to a rural Swedish island and find that long-term population increase is only possible in areas with strong, established service infrastructure. They argue that without ongoing investment in services, rural renaissance is short term and mainly limited to tourist seasons. Basic services such as retail, schools, health care, and transport form the foundation of sustainable renewal.

Applied to Nykøbing Sjælland, redevelopment efforts, including the adaptive reuse of vacant buildings, need to be envisioned in tandem with mechanisms to maintain and enhance public services. It is only through this integrated approach that the town can be made sustainable and viable for current and future generations of residents.

2.2 Current infrastructure and future plans

To understand which redevelopment needs are still unmet, we first examined the existing infrastructure at two levels. At the macro scale, we used the multiple estate model to assess the town as a whole. At the meso scale, we analysed specific zones within Nykøbing. Additionally, we reviewed the municipality's development plans to identify already proposed or ongoing projects.

2.2.1 Macro-scale – Multiple Estate Model

Michael Aston's Multiple Estate Model (MEM) outlines a historical estate structure in which a central estate served as an administrative and commercial centre, surrounded by smaller towns with specific activities such as agriculture, animal husbandry, or artisan production. This model stresses the interconnectivity and hierarchical organization of an area (Antrop & Van Eetvelde, 2017). Although Odsherred Kommune in Denmark is a modern administrative unit, there are parallels between the Multiple Estate Model concepts and the municipality's current functional hierarchy of villages.

The municipality's administrative centre is in Højby, which is not the largest settlement. This is the location of the town hall, which handles civil affairs and municipal decision-making. Despite its small population of approximately 1,460, Højby serves as the local government's seat. Højby serves as the administrative hub for the municipality's outlying towns. This means that official matters, such as permits, registration and municipal policy choices, pass via this centre (Christiansen, 2025). Nykøbing Sjaelland dominates trade and facilities. With almost 5000 residents (CityPopulation.de, n.d.), it is Odsherred's largest town. The principal shops, hospital, cultural institutions, railway station, and secondary school are all located here. It serves as a regional hub for nearby villages, attracting daily visitors who require services that smaller towns cannot provide.

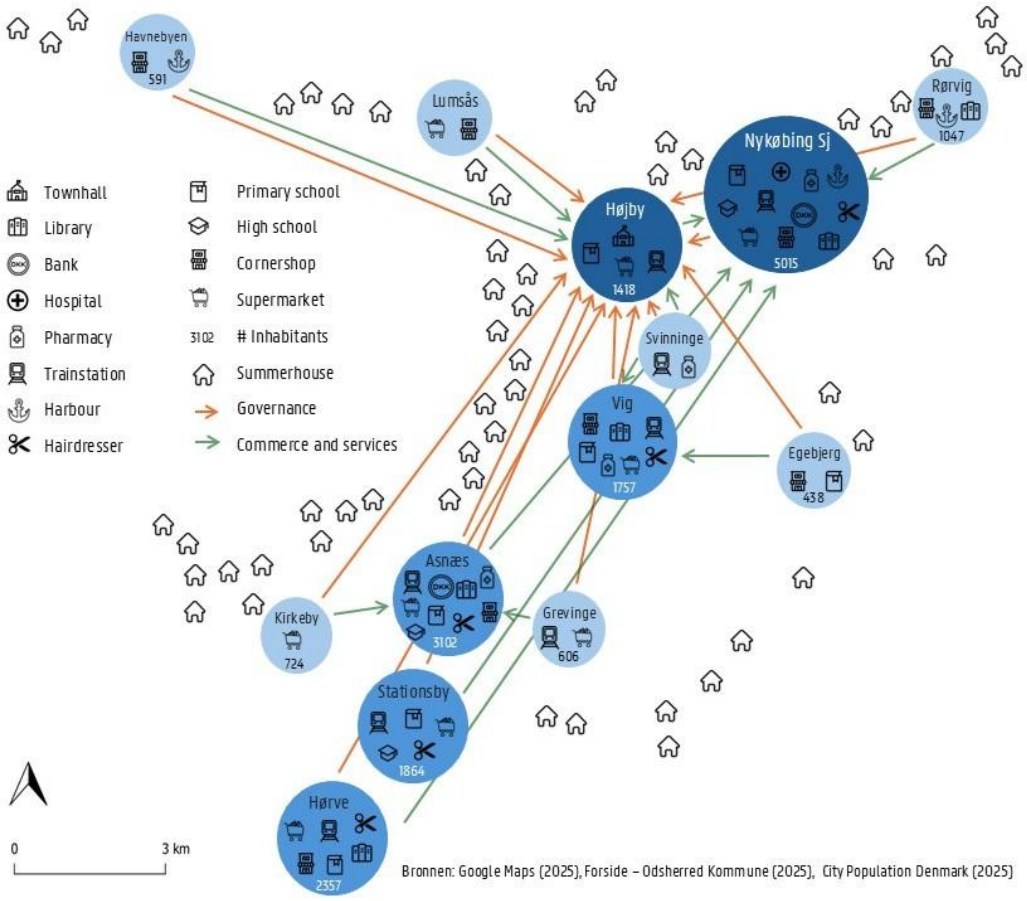
Asnaes, Vig, Hørve, and Stationsby have their own facilities, including supermarkets, general practitioners, primary schools, and in the case of Asnæs and Stationsby, a secondary school, as well as a regional shopping centre (Asnæs Centret). However, they continue to rely on Nykøbing for specific needs, such as specialized care or cultural venues. These places serve as an intermediate layer in the hierarchy, providing basic services to

nearby smaller communities while relying on a larger centre. Smaller villages like Rørvig, Grevinge, Fårevejle Kirkeby, and Havnebyen play a local role with minimal amenities including a shop, supermarket, and primary school. Rørvig is an exception due to its tourism importance, with a ferry connection to Hundested and recreational facilities (VisitDenmark, 2025). However, people still rely on larger centres for medical care and public services.Furthermore, the rural area comprises numerous hamlets and scattered farms. These so-called 'bebyggelser', small settlements with a minimum of clustered buildings but often no more than 200 persons (Danmarks Statistik, n.d.) and 'landsbyer', traditional agricultural villages often consisting of a few farms and residences lack central infrastructure (Porsmose & Møller, 2024). As a result, they completely rely on adjacent larger communities for basic services such as education, health care, retail, and public transportation.

Finally, summerhouses are identified on the MEM. These areas rely on nearby villages for almost everything. They do have different demands; the emphasis here is on pleasure and shopping rather than schooling or administrative functions. This is because the people who reside here are on vacation.

Figure 3

Multiple estate model of Odsherred



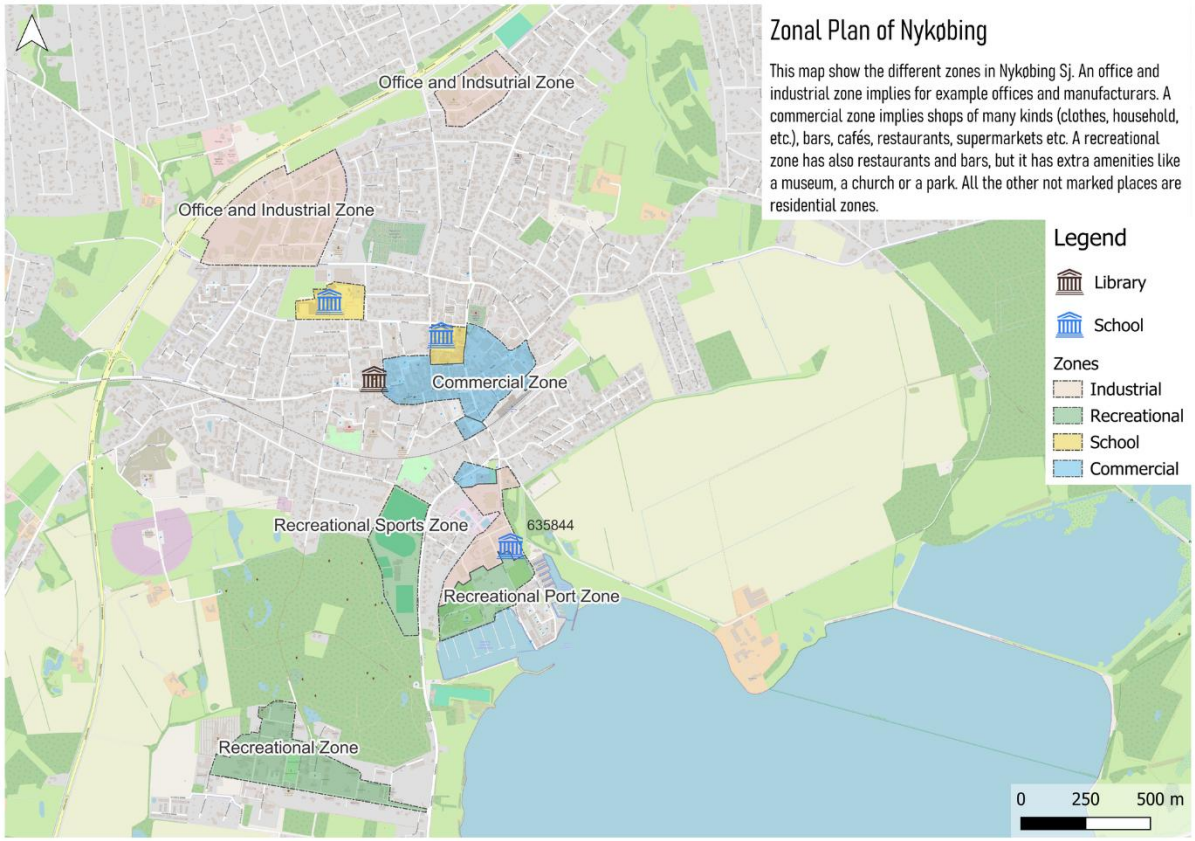
2.2.2 Meso-scale: Current situation - specific zones

To understand the current land-use patterns in Nykøbing, we have divided the town into five primary zones (see Figure 4). First, there is an office and industrial zone. This area accommodates a mix of corporate offices, manufacturing facilities, and other industrial enterprises. Unlike other zones, it is dispersed throughout Nykøbing. Secondly, there is a commercial zone. Concentrated in the town center, this zone contains the bulk of Nykøbing's retail shops, supermarkets, cafés, and restaurants. Its centralized layout raises the question of whether clustering all commercial activities in one area best serves residents' daily needs. Third, a recreational zone located primarily in the southern districts; this zone includes parks, sports fields, playgrounds, and the port area. The topography and available open space here make it ideal for leisure activities. Furthermore, there is a cultural and leisure site. Just outside the town limits lies a quieter complex with a park, several cafés, and a cultural centre. While this offers a tranquil retreat, its distance may limit accessibility, especially for older residents living in northern Nykøbing. Lastly, the educational zone encompassing the town's libraries, middle schools, and high schools overlaps partly with both recreational and commercial areas. (For example, libraries serve as learning and leisure facilities alike.) Our aim with this plan is to examine how Nykøbing's facilities are currently distributed and gauge resident satisfaction. A survey could reveal whether people feel amenities should be closer to their homes or if they're happy with the status quo.

We can also question the efficacy of strict zonal divisions. While separating functions has its benefits, blending complementary uses, such as placing shops and cafés near offices, might improve convenience. Today, many offices and industrial sites lie outside the town centre, making it harder for employees to run errands or grab a coffee after work. Recreational areas already mix activities, but their location relative to other zones can still pose accessibility challenges.

Figure 4

Zonal plan of Nykøbing



2.2.3 Macro Scale: Future

Besides the current zones and areas, future planned urban spaces are also important to consider. Local Plan 2023-15 nicknamed "Lindely," targets a long strip of undeveloped land on Nykøbing's east side (Figure 5) and lays out an ambitious vision for year-round living and community life. The proposal zones the area primarily for close-low residential buildings and apartment blocks, alongside mixed residential–commercial uses like care and rehabilitation centres. Clusters of buildings will be arranged around green, active courtyards designed to foster social interaction across generations. These courtyards varied outdoor spaces, and experiential walking paths will not only encourage community but also promote biodiversity by integrating native plantings throughout the site (Odsherred Kommune, n.d.-a).

In addition to its social and ecological goals, the plan prioritizes climate resilience and connectivity. It includes measures for rainwater and surface-water management, raising groundwater levels, and installing blue-green infrastructure to guard against flooding, erosion, and sea-level rise. Vegetation belts and new green corridors

will link the neighbourhood seamlessly to the existing urban fabric. Finally, recognizing Nykøbing's reliance on cars, the plan ensures smooth traffic flow and adequate parking facilities to balance accessibility with the area's pedestrian-friendly design (Odsherred Kommune, n.d.-a).

Figure 5

Global map of future plans in Nykøbing. Source: Odsherred Kommune

Figure 6 displays the Lindely master plan's primary layout, highlighting its residential clusters and surrounding green spaces. Figure 7 focuses on the project's water-management areas, underscoring their key role in the overall design.

Figure 6

Main map of Lindely. Source: Odsherred Kommune

Figure 7

Map of Lindely showing the blue and green areas. Source: Odsherred Kommune

The Havnevej plan, approved in 2007, aimed to create a small residential district by the harbour that would be fully public and strengthen the link between the city centre and the port (Odsherred Kommune, n.d.-b). According to the report, work began in 2008, and in 2014 an Aldi supermarket (now REMA 1000) was built on the site originally intended for housing (Krak, 2014). As demand for new homes declined, the residential element was never carried out, leaving the plot as another supermarket rather than the intended mixed-use gateway between town and harbour.

This outcome stands in contrast to the Lindely plan, launched in 2023 and still underway, which places strong emphasis on linking new housing to green and communal spaces (Odsherred Kommune, n.d.-a). One could argue that, instead of enhancing the city-harbour connection, Nykøbing simply added a fifth supermarket at Havnevej. On Figure 8, you can see a map illustrating what the harbour-front neighbourhood might have looked like if the original plan had succeeded (Odsherred Kommune, n.d.-b).

Figure 8

Havnevej visionary plan map

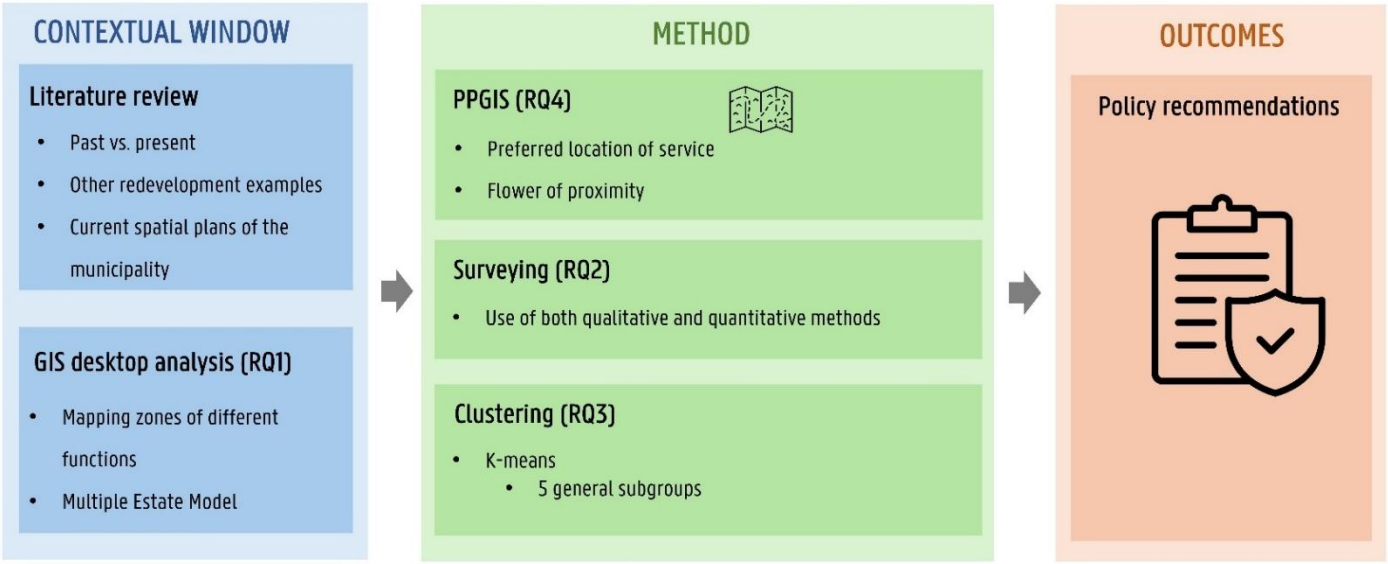
3 METHODOLOGY

In our research, we used three main approaches. First, we mapped the current spatial layout of town centre functions by locating facilities on Google Maps and the Danish Yellow Pages. We conducted an extensive desktop analysis to gain insight into the site's history. Understanding its historical significance for neighbouring towns and its development over the years was essential for interpreting the current spatial structure. From this, we developed a detailed microscale zonal plan of Nykøbing and, at the macroscale, applied the Multiple Estate Model to include nearby centres. Next, we reviewed academic frameworks to understand how people perceive town functions, discovering the "flower of proximity", an intuitive way to gauge residents' willingness to travel. Although we initially considered Transit-Oriented Development (TOD) and the 15-minute-city concepts, we ultimately downplayed them because our study area is relatively small. Instead, we focused on everyday walking patterns among different demographic groups in Nykøbing. Finally, we spoke with Ella Cadee, an urban planner at Odsherred Municipality, who updated us on current local projects.

After outlining the general context, we conducted on-site fieldwork consisting entirely of surveys with residents. The survey had two main components. The first gathered quantitative and qualitative data to identify residents' needs and concerns; using k-means cluster analysis, we distilled these responses into five distinct user profiles. The second component added a spatial dimension: respondents used the Flower of Proximity tool and marked locations to indicate where they would like various functions to be located, as well as their general location of residence. After completing fieldwork, we transformed the survey and spatial data into functional maps to guide local urban planners in crafting targeted policy recommendations. The sections that follow describe the specific methods and techniques we used in greater detail.

Figure 9

Schematic representation of the workflow



3.1 Survey

We recruited all Nykøbing residents, while prioritizing insights from those aged 50+ to capture the needs of an ageing population. This way our findings remain applicable as demographics shift over time. The survey combined closed- and open-ended questions to (1) identify residents' service needs and complaints and (2) use the Flower of Proximity alongside home location mapping and preference mapping to pinpoint where people would want services to be introduced or improved.

To reach a representative sample, we used a mixed-mode approach: door-to-door visits offering tablets or paper questionnaires, intercepts in public venues (libraries, markets, senior centres, bars), and QR-code distribution through local associations and social media. Before the actual fieldwork, we ran a rapid pretesting survey with around ten residents and gathered feedback from Odsherred planner Ella Cadee. This allowed us to refine our questions until completion time was under 15 minutes. Several questions were deleted, and terminology was altered. The survey was made using the UGent Qualtrics license. For the specific content of the survey, see Appendix.

3.2 Cluster analysis

We applied k-means clustering to uncover naturally occurring socio-demographic profiles within the respondent population, rather than imposing predefined groupings (e.g., by age alone). Each respondent was represented as a vector in a high-dimensional feature space, derived from four categorical survey variables: residency status, age group, household composition, and transportation modes. Residency was encoded as a binary variable (1 = resident, 0 = non-resident). Age group was treated as an ordinal variable, mapped to integers from 0 ("under 21") to 6 ("70+"). Household composition was one-hot encoded into categories: “Household: Alone”, “Partner”, “Partner & Children”, and “Other Family”. Transportation modes were also one-hot encoded. Respondents selecting multiple modes activated multiple binary indicators. Each respondent’s vector was then pairwise compared using Euclidean distance, defined as:

$$d(A,B) = \sqrt{\sum_{i=1}^{n}(x_i^A - x_i^B)^2}$$

Where x_i^A and x_i^B are the values of feature for respondents A and B. This Euclidean distance metric quantifies dissimilarity between individuals across all encoded features. The k-means algorithm uses these distance calculations to group respondents with similar socio-demographic characteristics by iteratively assigning each point to the nearest cluster centroid and updating centroid positions until they converge. The algorithm's objective is to minimize the within-cluster sum of squares (WCSS), also known as inertia, which is mathematically defined as:

$$WCSS = \sum_{i=1}^{k}\sum_{x \in C_i} \| x - \mu_i \|^2$$

where k is the number of clusters, C_i represents cluster i, μ_i is the centroid of cluster i, and $\| x - \mu_i \|^2$ is the squared Euclidean distance between data point x and its cluster centroid. In this formula, WCSS measures the total compactness across all clusters. Lower values indicate tighter, more homogeneous groupings where respondents within each cluster share more similar profiles.

However, minimizing WCSS presents an inherent trade-off. While increasing the number of clusters will always reduce WCSS (as points become closer to their centroids), excessive clustering can lead to results where groups become too distinct and lose practical interpretability. To balance cluster quality with meaningful segmentation, we employed the elbow method, plotting WCSS against the number of clusters (k). This approach identifies the optimal k by locating the "elbow" point where the rate of WCSS reduction begins to plateau, indicating that additional clusters yield diminishing returns in terms of improved homogeneity. To determine the optimal number of clusters for our analysis, we plotted WCSS values for k ranging from 2 to 10.

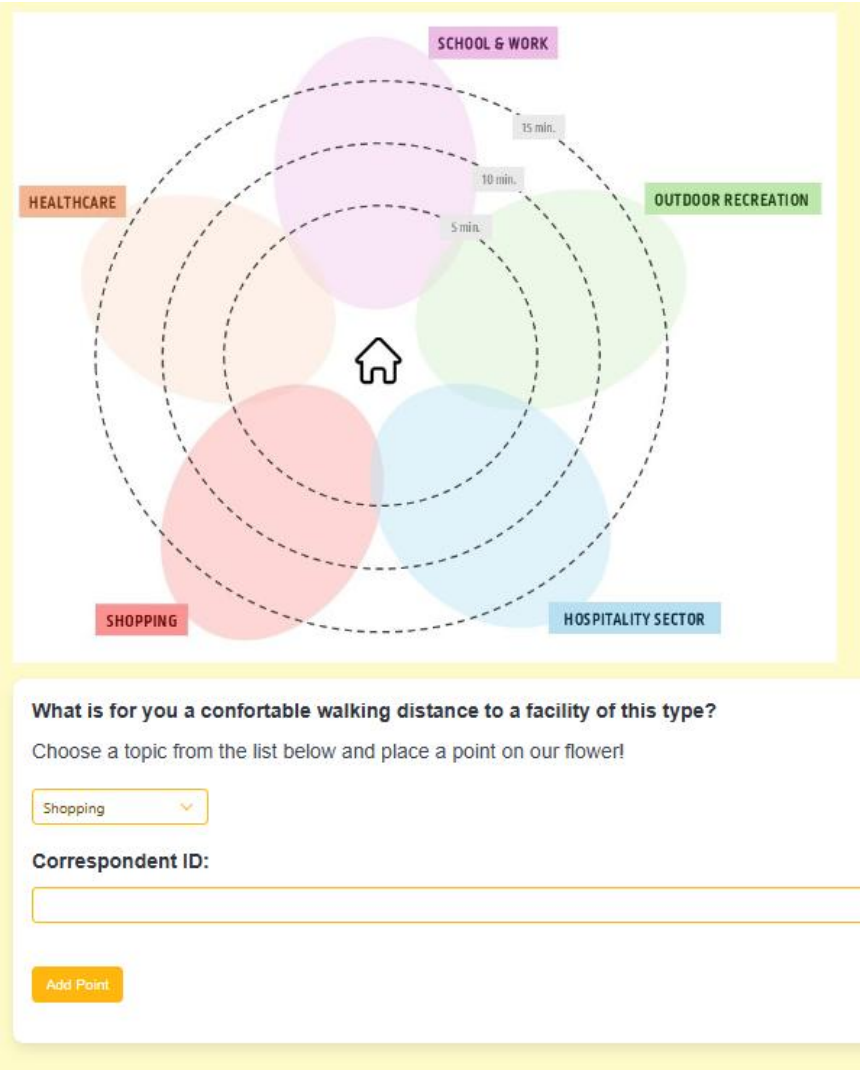
3.3 GIS analysis

As described above, we built two survey tools. Our first survey tool uses the Flower of Proximity, a flowerlike diagram with five petals. Each petal represents one of the service categories we identified in our desktop research. At the centre sits a house icon, marking the respondent's home location. Concentric circles radiating outward serve as reference lines for walking-time intervals. Respondents select a service type from a dropdown menu and then click on the flower to indicate their ideal walking distance in minutes to that service (Figure 10). Each click records x- and y-coordinates in our database, which we convert into a walking-time value. If a service doesn't apply, respondents click the centre, yielding a negative time; we filter these entries afterward. Crucially, this exercise captures a hypothetical ideal scenario, not the current state of access. The application can be visited through this link:

https://we12s016.ugent.be/student/student_lefrerik/denemarken/denmark_flower.html

Figure 10

The flower of proximity application

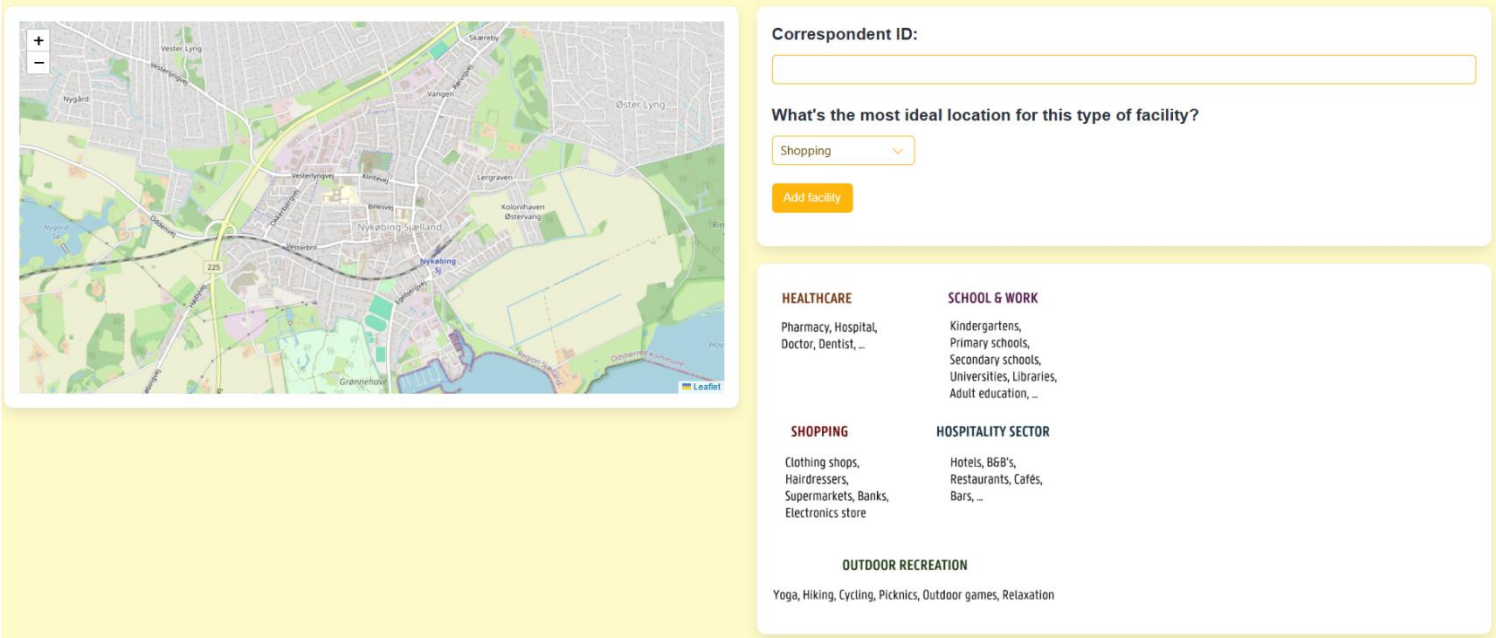


The second survey tool captures respondents' home locations and their top-ranked service area preference. On an interactive map of Nykøbing with adjustable zoom, participants first select the single service category they value most (based on an earlier ranking question). They then point out on the map to mark where they would like a new facility of that type to be located, answering: "What's the most ideal location for this type of service?" Households could choose to mark either a general neighbourhood or a precise address; most opted to pinpoint their exact home. Each click records latitude and longitude in our database, allowing us to outline individual service-area catchments. Below is a screenshot of this tool in action (Figure 11). You can visit this application through this link:

https://we12s016.ugent.be/student/student_lefrerik/denemarken/denmark_point.html

Figure 11

Application for specific locations



We began with six linked tables: five "flower" tables (health, hospitality, shop, school, outdoor), each containing respondents' ideal walking-time values per service category, and one "map_point" table holding each respondent's home location and their chosen site for the service type they ranked highest. All records share a persistent respondent ID (c_id), so any c_id that drops out of the updated datasets, because it never intersected with another service area, is simply excluded from further analysis. The same was done for any ID of which the residence location fell out of our pre-defined study area.

Next, we computed a unified walking-time value, t, for each flower table. In QGIS, a custom Python script (see Figure 12) reads the x–y point coordinates, recentres them on the flower's origin, converts to polar coordinates to derive a radius, translates that radius into minutes of walking, and rounds to the nearest whole minute. The new 't' column then lets us compare temporal preferences directly across all facility types.

Figure 12

Python function

```
import math

def pool(value1, value2):
    x = int(value1)
    y = int(value2)
    return round(float(((math.sqrt((x-404)**2+(y-336)**2)-94)*4.285714286)/60))
```

Next, service areas are generated for each residence point using the QNEAT3 plugin, specifically the *"Iso-Areas as Polygons from Point"* tool. The parameter input is the following:

- Maximum area coverage: 1200 meters
- Time interval: 60 seconds
- Average travel speed: 4 km/h
- Path type: Fastest, based on travel time

Because we need the intersection of each correspondent's service areas at intervals of 5, 10, and 15 minutes, we generate service areas manually for each residence. After creating a service area, we add a c_id column to that layer, so we know which correspondent it belongs to.

Once all service areas are created, we merge them into a single polygon layer that contains every isochrone for every correspondent and service type. We also merge the separate thematic tables (health, outdoor, hospitality, school, and shop) into one unified attribute table. Next, we use QGIS's "Join attributes by field value" tool to link the spatial and tabular data. We join the merged service-area layer (with c_id) to the merged attribute table (with id) on c_id = id, specifying a one-to-many relationship so that each correspondent's ID can link to multiple service-area polygons. A one-to-one join would wrongly restrict each correspondent to a single service type.

From the joined layer, we select features where cost_level = t, that is, the cost_level field (in minutes) matches the respondent's walking-time preference t. These selected polygons represent each correspondent's ideal service area and are exported, retaining only the columns c_id, cost_level, t, and theme. We then apply thematic symbology to visualize the maximum preferred walking distance per service theme. To identify overlapping service areas of the same type, we create a Virtual Layer using a custom SQL query (Figure 13) that finds intersections within the layer's own attribute table. We then filter for theme_a = theme_b, ensuring we only keep overlaps where both polygons represent the same service theme. The resulting overlapping zones, showing

where multiple correspondents share ideal walking distances to the same service, are exported as a new layer for further analysis.

Figure 13

SQL query to self-intersect

```
SELECT
  a.c_id AS c_id_a,
  a.thema AS thema_a,
  b.c_id AS c_id_b,
  b.thema AS thema_b,
  intersection(a.geometry, b.geometry) AS geometry
FROM
  joined_layer AS a,
  Joined_layer AS b
WHERE
  a.c_id <> b.c_id
  AND intersects(a.geometry, b.geometry)
```

We then used the map_point table, which records each respondent's preferred facility location and implicitly weighs its importance, to calculate mean target areas. For each service type, we generated a minimum enclosing circle (minimum bounding geometry) around all relevant points. Next, we intersected these circles with our merged service-area zones (from the previous step). This produced broad consensus areas that combine "where people want a service" with "how far they're willing to walk." We then overlaid these consensus zones onto Nykøbing's cadastral parcels to see exactly which plots fall inside each area.

Finally, we examined the c_ids linked to those parcels to distinguish preferences between demographic clusters. From our k-means analysis, we know which c_ids correspond to which certain profile group. We selected the parcels favoured by the elderly group into one layer and placed the remaining parcels into another. The result is two distinct parcel sets: one reflecting the preferred areas of older respondents and another reflecting those of the younger cohort.

4 RESULTS

4.1 Qualitative

The history and overall findings of residents were all written down. Out of these notes, several key contextual insights emerged. First, Nykøbing offers a broad mix of everyday services: a dentist, childcare, a swimming pool, a health centre, and sports clubs (badminton, boxing, etc.). You'll also find several hairdressers, a fishmonger, and a bakery that's been in operation for 130 years. Grocery shopping is well covered "we have every kind of supermarket," one resident remarked, pointing to chains like REMA and Lidl. In fact, there are five large supermarkets, which feel excessive outside the tourist season, when up to 90,000 summerhouse visitors arrive. Specialty shops like bakeries, butcheries, and small convenience stores have closed in winter due to low demand, and the closure of the local Aldi left convenience stores to dominate. Tourists tend to seek out the few remaining specialized shops (art supplies, local crafts). Overall, the retail sector struggles. "We're used to businesses changing constantly," said one local, frustrated by the turnover.

Restaurants are plentiful but often criticized: "We want local products instead of another pizzeria," said a resident, lamenting how empty the centre feels in the evenings. Café Nokken by the harbour and the Michelin-starred restaurant in the old psychiatry building are notable exceptions that draw praise.

For essential services in the context of a hospital, secondary school, or cinema, residents must travel to Holbæk, Asnæs, or Vig. Local public services are limited to a 'borgerservice' desk (citizen service) and four library computers. One woman complained that repeated reports of potholes went unheeded. On the positive side, the renovated theatre has made its neighbourhood feel safer after dark: "Old people were afraid to walk here before; now they're not."

Opinions on healthcare vary. Some appreciate the health centre's unhurried appointments, but many complain about the rotating staff "every time it's a different doctor" and note that complex procedures still require a trip to Holbæk. Public transport runs largely on school schedules; off-peak service is sparse, leaving non-drivers stranded. There are no dedicated bike or walking paths to nearby villages, and roads are riddled with potholes. Still, many locals use small, three-wheeled mini-cars (e.g., Lindebjergs) to navigate narrow lanes. This mode of transport seemed to be quite popular with elderly residents.

Nature remains a major draw "the forest is cheaper than the gym" said an elderly resident, but green spaces in the town centre are scarce. As Denmark's largest summerhouse region, Nykøbing sees its population swell seasonally, which supports five supermarkets but means many tourists bring their own supplies and don't

contribute much locally. Looking ahead, residents hope for fewer supermarkets and more local food shops, plus additional clothing stores. Currently many choose to shop online or in Roskilde and Copenhagen. Other suggestions included more recycling points on the outskirts and even extra ice-cream stands.

In summary, locals express a pragmatic resignation: "I don't use it, so it's fine," and "We can hope for better, but there aren't the people or the money." While services are generally "sufficient, but vulnerable," the community remains realistic about the limits and possibilities of village life.

We included four open-ended questions to root our spatial analysis in residents' lived experience and to answer our sub-questions directly. First, by asking "*Thinking about the last few decades in Nykøbing, please list up some of the positive and negative changes in availability of services*?" We pinpointed which services have strengthened over time (e.g., leisure and retail) and which have eroded (e.g., healthcare and small businesses).

Table 1

"Thinking about the last few decades in Nykøbing, please list up some of the positive and negative changes in availability of services." Total answers: 27

Perception of change	Positive	#	Neutral	#	Negative	#
Commuting	Train station Better road connection	2 1			Overall decrease in quality of public transport	2
Shopping	New supermarkets	2			Small businesses don't survive long, shops closing down	6
Leisure	Improved cultural activities, especially in the harbour area, Theatre Resting spaces (benches, park)	3 2 2			Nightclub disappeared	1
Healthcare			Psychiatry (now museum)	1	Hospital closed	1
Food & beverage			A lot of new cafés	1	Bars such as the Irish pub closed	2
Other	Buildings	2	Summerhouses	1	Summerhouses Highschool displaced	1 1

Secondly, the question in table 2 highlighted current service gaps by showing that residents now journey to Holbæk, Copenhagen, and Vig for essentials and leisure; outlining these destinations revealed the voids our redevelopment could plug.

Table 2

"In the past month, to which other towns did you travel to obtain services you could not find in Nykøbing? Additionally, please give the reason of your visit." Total answers: 30

City	#	Reason	#
Holbæk	10	Shopping (total)	13
Copenhagen	10	groceries	1
Vig	3	clothing	4
Højby	3	City trip, cultural visit	4
Asnæs	2	Musical venue, concert or orchestra	2
Roskilde	2	Cinema	2
		Museum	2
		Sport	2
		Restaurant	1
		High school	1

Next, by asking why people came to Nykøbing in the past decades, this uncovered the town's historical pull-factors: tourism, shopping, and nature. These factors were then overlaid on our base map to locate legacy services and understand how the spatial structure evolved.

Table 3

"Thinking back ten or twenty years ago, for which services did people come to Nykøbing? Why?" Total answers: 24

Attraction	#
Tourism (summerhouses, vacation)	11
Shopping	8
Nature (beaches, outdoor activities)	5
Calm & quiet	3
Clubs and bars	2
Art workshops	2
Cosiness	1
Cheap housing	1
History	1
Restaurants	1
Sommerland	1

Finally, the prompt of table 4 below paired positives (e.g., nature, affordable housing, quiet) with negatives (e.g., lack of specialist healthcare, poor public transport), pinpointing exactly which amenities we need to preserve or introduce, to ensure our target population both want to stay and can stay. Together, these qualitative insights shaped our understanding of Nykøbing's past, present, and the specific needs driving its future redevelopment that were impossible to derive from a desktop study.

Table 4

"Do you see yourself staying in Nykøbing as a pensioner? What would make the decision easier?"
Total answers: 34

Yes	**21 (62%)**
No	**8 (24%)**
Maybe	**5 (15%)**

+	#	- (improvement areas)	#
Nature	5	Lack of specialist healthcare	2
Cheap housing	3	Already having a home in a bigger city	2
Family & friends	2	Unwelcoming towards young people	1
Quiet	2	Public transport	1
Summerhouse	1		

4.2 Quantitative

4.2.1 Descriptive statistics

The age-distribution histogram shows a clear skew toward older age groups. Most respondents fall in the 61–70 and 70+ brackets, reflecting Nykøbing's reputation as a town of retirees. However, there is also a surprisingly large cluster of under-21 respondents, suggesting that our mixed-mode outreach (shop visits, online QR-code) succeeded in engaging young people as well.

Figure 14

Age distribution histogram

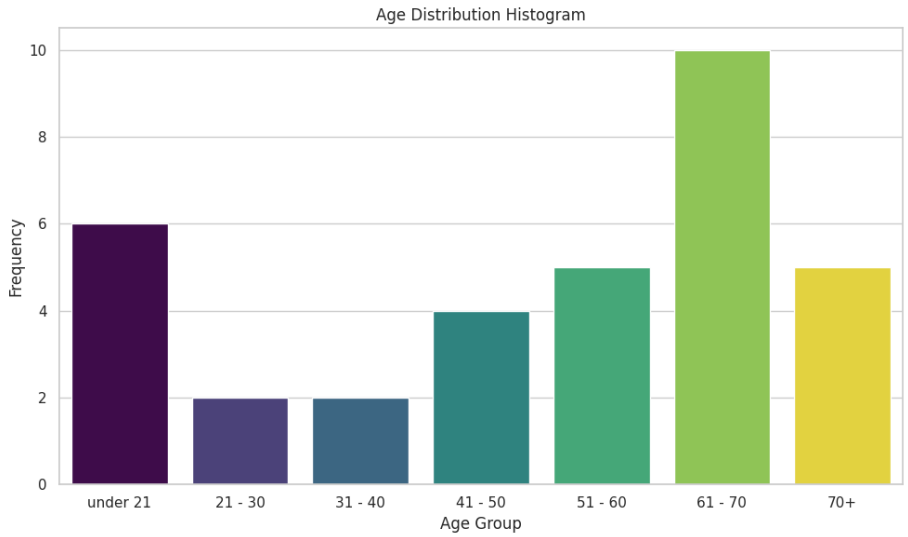
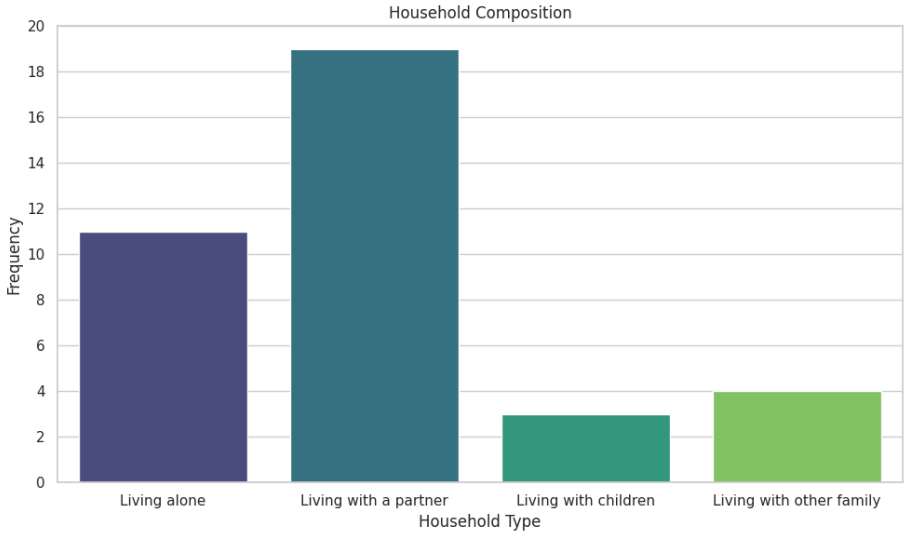


Figure 15 shows that most of our respondents live either alone or with a partner, together accounting for roughly four-fifths of all households. This pattern mirrors demographic studies of Nykøbing, where an aging population and out-migration of younger families have left many seniors living alone or as couples. By contrast, households with children or other family members are comparatively rare. This skew toward single and paired elder households highlights the need to prioritize services like accessible healthcare, small-scale retail, and social venues within walking distance of these predominant household types.

Figure 15

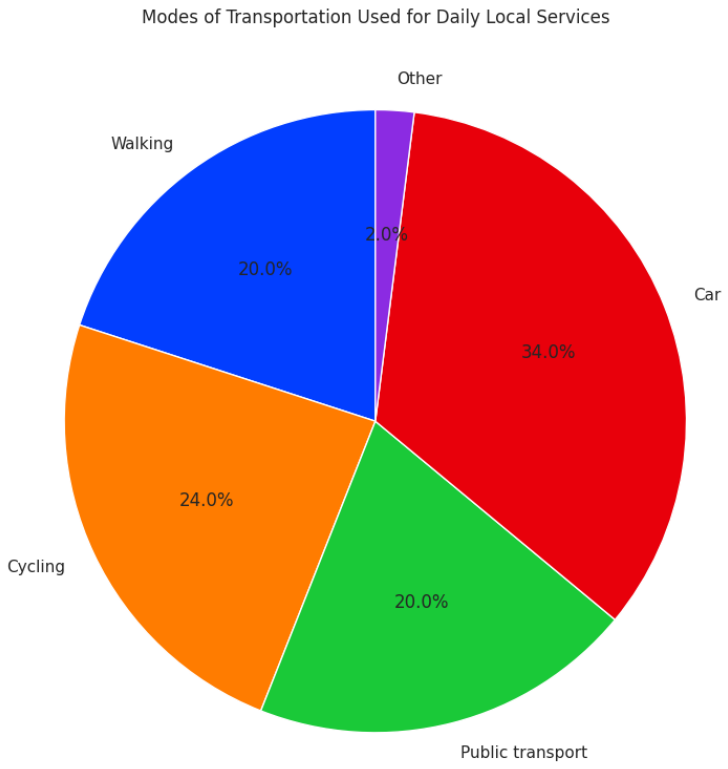
Household composition



Although rural Denmark is often dominated by car travel, our sample shows a more balanced mix. Cars remain the most common mode at 34 %, but cycling isn't far behind at 24 %. Walking and public transport each account for 20%, with only 2% using other modes. These results suggest that encouraging a shift toward active transport, especially cycling and walking, could be a realistic and well-supported strategy in Nykøbing.

Figure 16

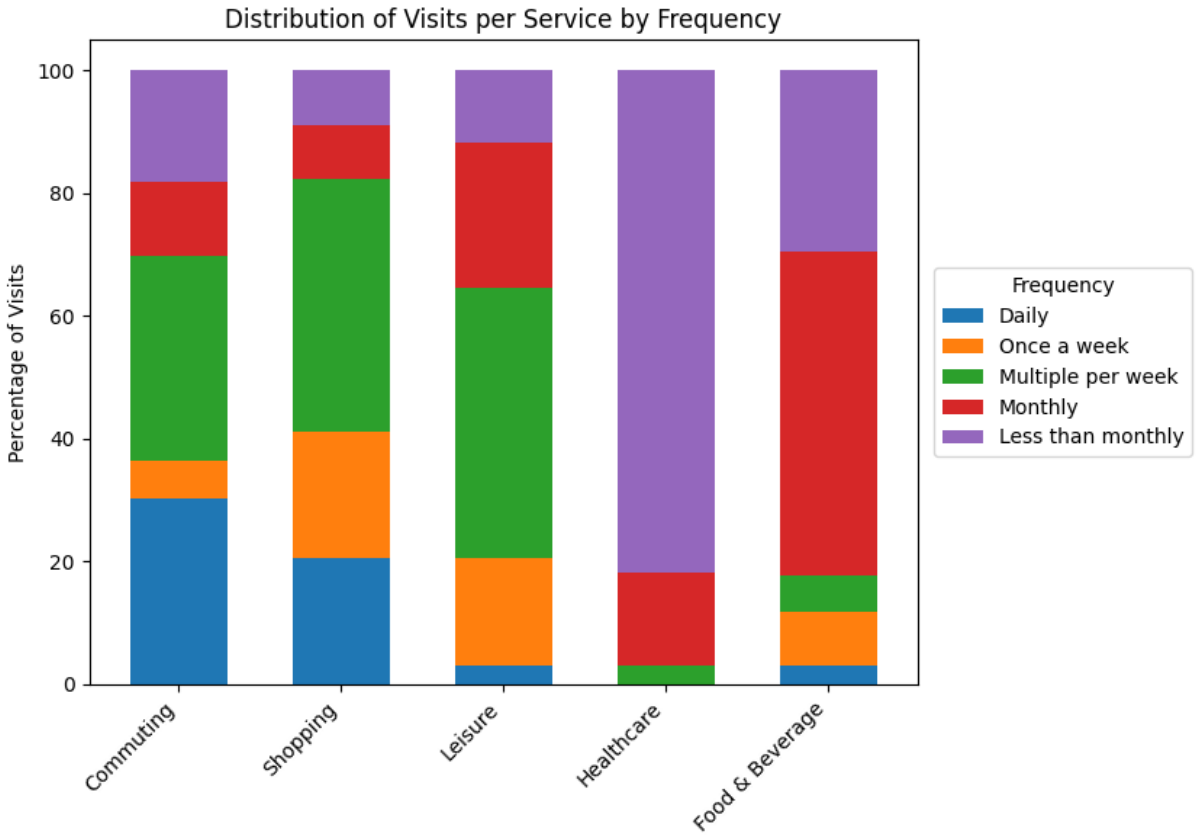
Transportation mode distribution



Respondents' visit frequencies vary by service type. Commuting and shopping dominate weekly routines, 30% commute daily and another 34% commute multiple times per week, while 21% shop every day and 41% shop multiple times weekly. Leisure activities also occur frequently, with 44% of participants enjoying them several times a week and a further 23% on a monthly basis. In contrast, healthcare is largely infrequent: 67% of respondents visit medical services less than once a month, and only 3% do so weekly. Food and beverage outings similarly skew toward occasional trips, with 53% going monthly. These patterns suggest that daily-and-weekly necessities (like groceries and transit) must lie within a very short walk, ideally five minutes or less, while less-frequent services (healthcare, restaurants) can be clustered in central, mixed-use nodes that remain comfortably accessible.

Figure 17

Frequency distribution of facility visits

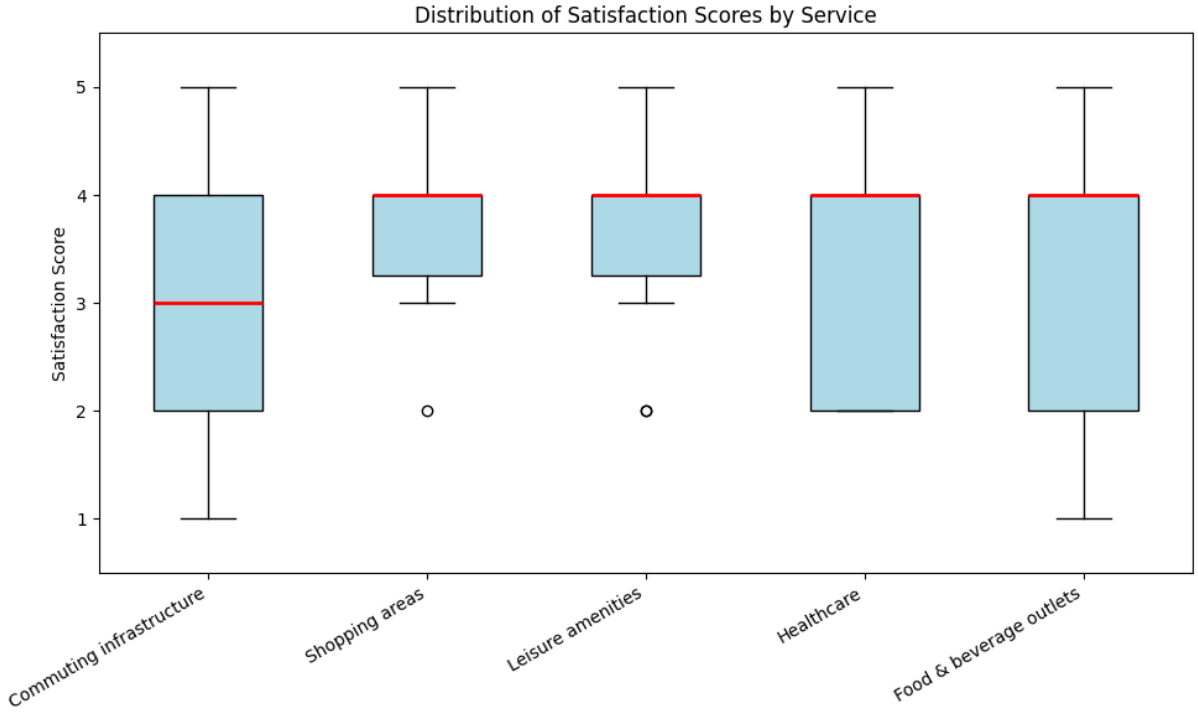


4.2.2 Cluster profiles and satisfaction scores

Figure 18 presents respondents' average satisfaction scores for five service categories, with error bars showing one standard deviation around each mean (overall mean = 3.50). Commuting infrastructure received the lowest average rating (3.12 ± 1.12), followed by food and beverage outlets (3.29 ± 1.22) and healthcare services (3.38 ± 0.97). Leisure amenities scored higher at 3.83 ± 0.79, while shopping areas topped the list with 3.92 ± 0.80. These results highlight that everyday needs like transport, groceries, and medical care are seen as only moderately satisfactory and exhibit greater variability in perceptions, whereas leisure and retail spaces generally meet or exceed residents' expectations.

Figure 18

Distribution of satisfaction



With mean satisfaction scores in hand, we turned to our k-means cluster analysis (Section 3.2) to segment respondents into five concise profiles: Cluster 0 comprises young adults (21–30) living alone or with partners, half walking and the rest split between public transport and car/bike; Cluster 1 includes older singles (61–70) who rely chiefly on cars and bikes; Cluster 2 consists of under-21 residents living with family and highly dependent on public transport; Cluster 3 covers older couples (61–70) who predominantly drive but also cycle and walk; and Cluster 4 represents middle-aged adults (41–50) in mixed households (some with children), balancing car travel with cycling, walking, and transit. These profiles will help us select the most relevant target group for tailored policy recommendations.

Table 5

Cluster identification

Cluster	# Respondents	Age Group	Household Type	Primary Transport Mode	Profile Summary
0	4	21-30	Living alone or with partner	50 % walking; 25 % public transport; 25 % car/bike	Young adults with mixed living situations, moderate mobility but varied mode use.
1	5	61-70	Living alone	Mainly car and bike; some walking & public transport	Older singles relying on personal transport (car + bike) with limited transit use.
2	6	Under 21	Living with family	83 % public transport; 17 % car/bike/other	Very young residents in family households, highly dependent on public transport.
3	10	61-70	Living with partner	60 % car; 40 % cycling; 30 % walking	Older couples with a strong preference for cars, supplemented by cycling and some walking.
4	9	41-50	Mixed (some with children)	67 % car; 33 % cycling & walking; 33 % public transport	Middle-aged families, mixed transport use but a clear lean toward car travel.

If we then proceed towards the specific satisfaction scores for each service type for each cluster, we see the following. Across all five clusters, commuting infrastructure consistently registers the lowest satisfaction scores, while shopping and leisure amenities perform best. No group rates transport above a 3.33 average, underscoring widespread frustration with getting around. In contrast, shopping satisfaction never falls below 4.0 for most clusters, and leisure scores peak at 4.29 among middle-aged families, suggesting that retail and recreation meet residents' expectations more often than basic mobility.

Digging deeper, the oldest, single-resident cohort (Cluster 1, ages 61–70) reports the greatest overall discontent: they rate commuting at just 2.83 and food & drinks at 2.67, well below the town's average. Their comparatively moderate scores for shopping (4.00) and leisure (3.50) indicate that even where services exist, accessibility remains a barrier. Older couples (Cluster 3) share similar concerns about transport, 3.20 for commuting, but express stronger satisfaction with shopping (4.10) and food & beverages (3.70), hinting that partnership may have a buffering effect on some mobility challenges.

By contrast, younger adults (Cluster 0, ages 21–30) appreciate the town's shopping options most (4.25) and give leisure a solid 3.67, though they too feel the pinch on commuting (3.00) and healthcare (3.25). The under-21 group (Cluster 2) delivers the most balanced profile, with all category scores between 3.17 and 3.83, suggesting a uniform, but unexceptional, level of service satisfaction. Middle-aged families (Cluster 4) mirror this equilibrium but stand out for their high leisure score (4.29). Taken together, these patterns point to transport enhancements and more accessible dining options as priorities, with single older residents, who report the lowest satisfaction overall emerging as the most critical target for policy interventions.

Figure 19

Satisfaction heatmap

Cluster	Commuting	Shopping	Leisure	Healthcare	Food & Drinks
0.0	3.0	4.25	3.67	3.25	3.33
1.0	2.83	4.0	3.5	3.17	2.67
2.0	3.33	3.17	3.83	3.83	3.33
3.0	3.2	4.1	3.75	3.44	3.7
4.0	3.13	4.0	4.29	3.13	3.17

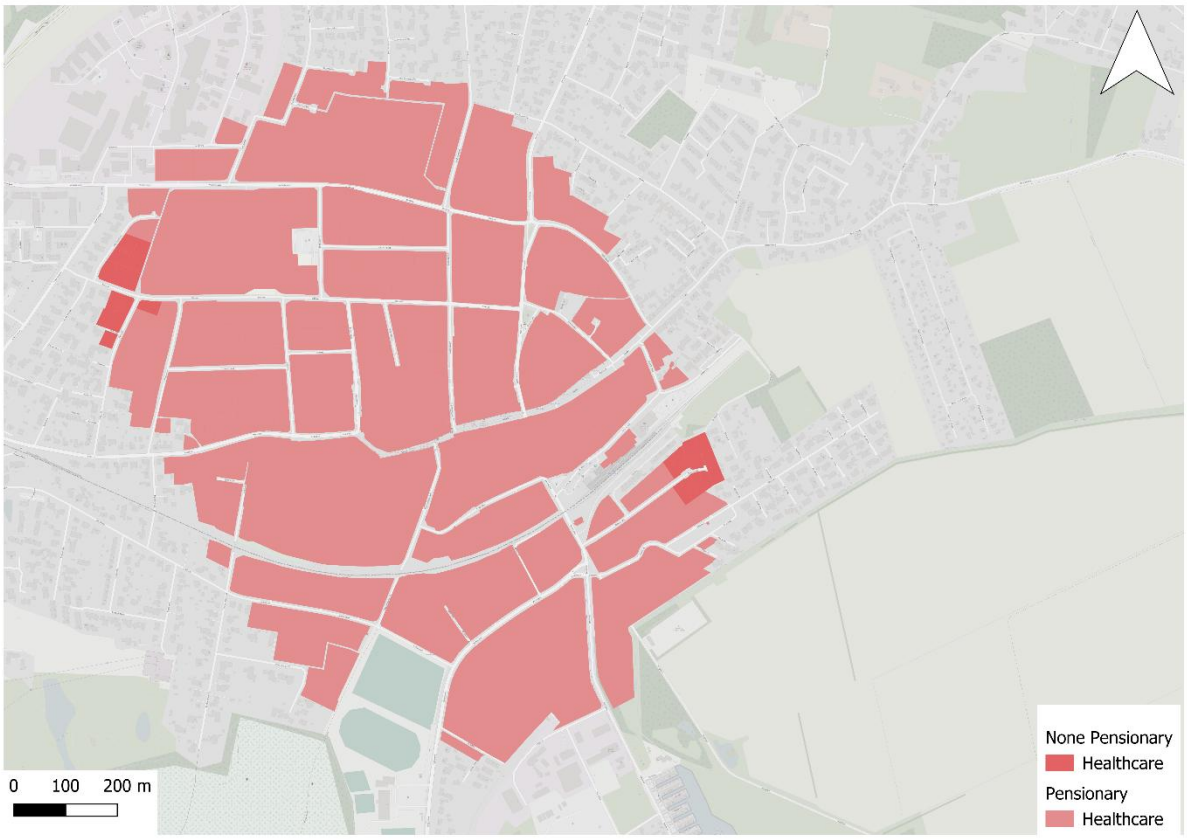
4.2.3 Spatial outcome

As a result, from our spatial and temporal analysis we got 5 different maps. Those maps show for each service type the preferred plots based on walking distance for each service type from each correspondent's home and the mean area of the specific wanted locations of the most important service of each correspondent. Considering the two groups, elderly and younger people, there was only a difference for healthcare facilities and work or school facilities. On the first map (Figure 20) the dark and the light-coloured plots are the preferred plots for the younger people. But only the lighter plots are the preferred plots for the elderly. This is the same case for map 2 (Figure 21) for work or school. The other three types showed no difference between groups, so those plots all got the same colour.

For healthcare you clearly see that some outlying plots fall out. This is because elderly people value healthcare more than younger people and so there was more input for healthcare so more specific, and closer, service areas. It is not so surprising that elderly would walk less for a doctor's office or a hospital. The same case for work or school. The few people that still worked valued almost always their work above healthcare. If they still worked, they pointed out that it could be way closer just to have it closer and they could work for maybe longer.

Figure 20

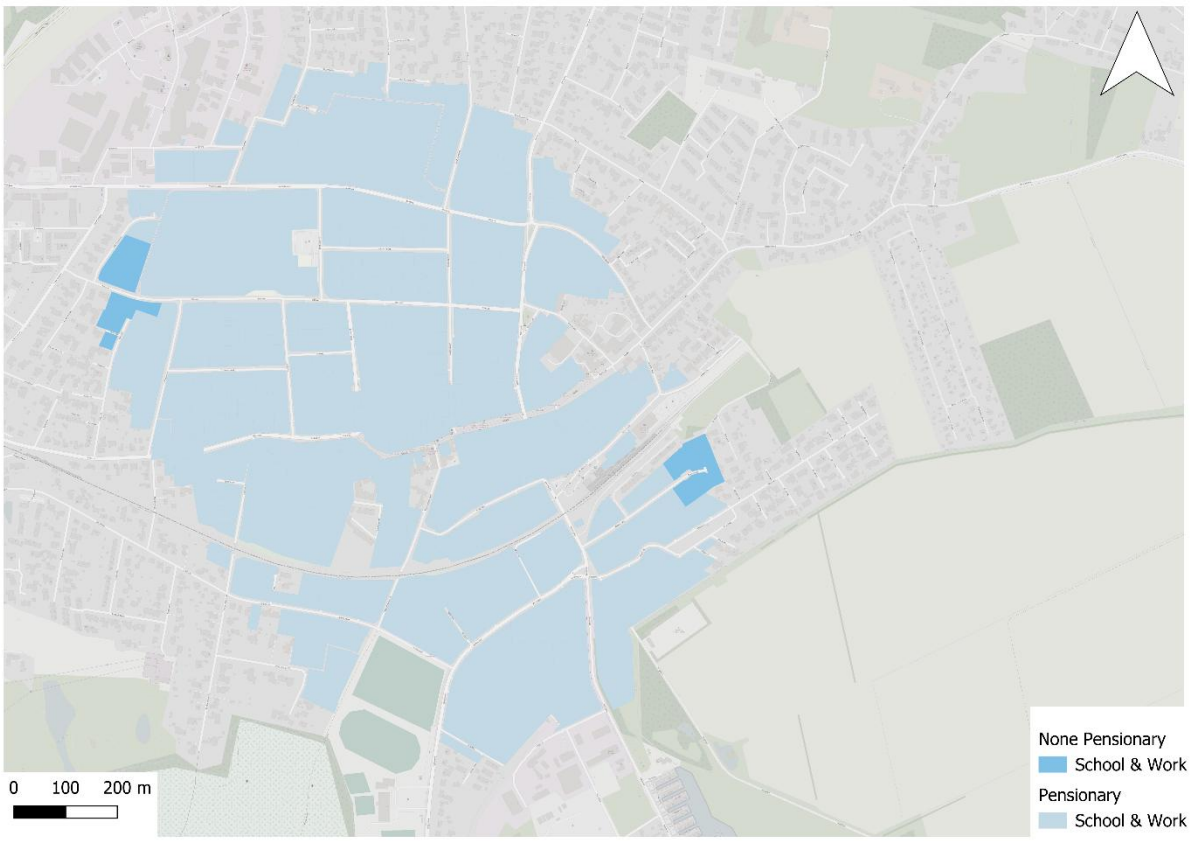
Healthcare suitable plots



Above is shown the healthcare map where the plots clearly stand out for the elderly. Beneath is shown the map for school or work. It is clearly that those results are roughly the same.

Figure 21

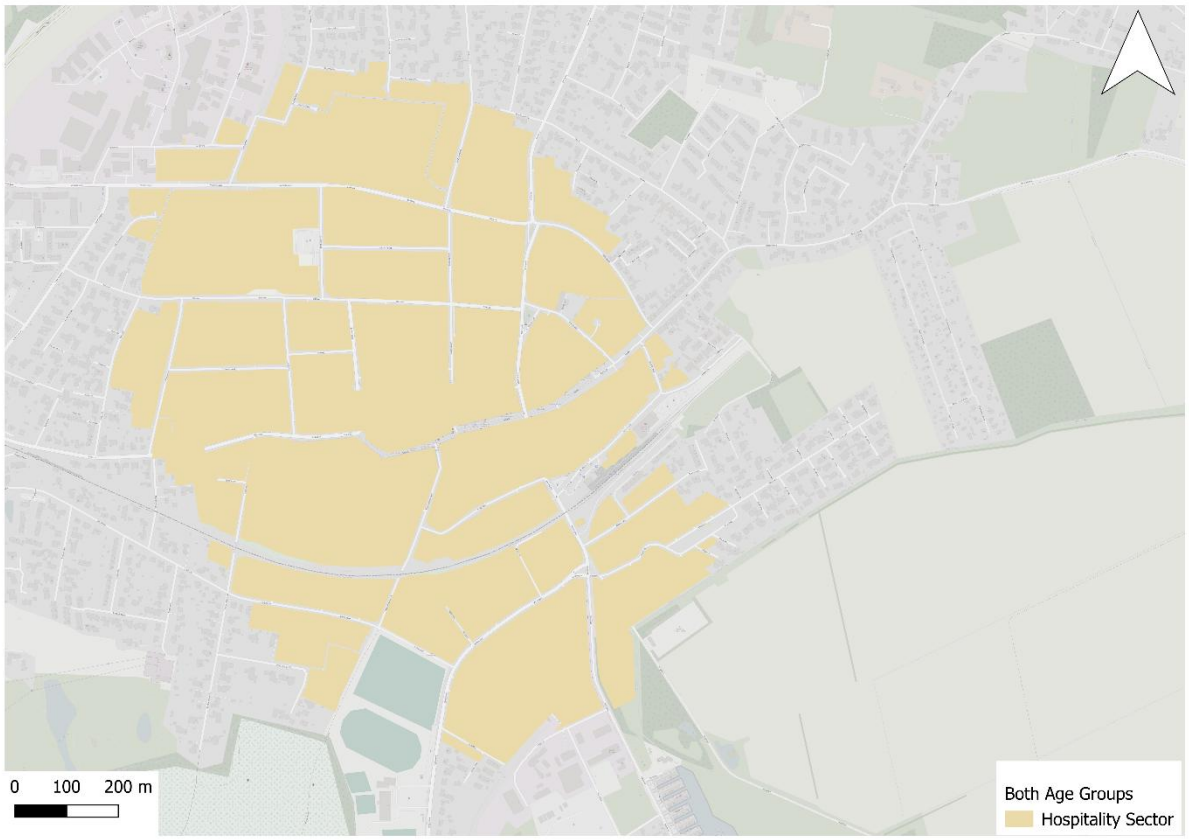
School and work suitable plots



For the other three themes there is not a distinction between groups but there is surely an important result. For the hospitality sector the whole region of Nykøbing is coloured. This means that overall, there is need for new restaurants, especially for diverse kitchens, cafés and bars. Those cafés and bars are severely needed for younger people. Those facilities attract the younger people to Nykøbing and maybe make them stay. Beneath you see the results for this service type.

Figure 22

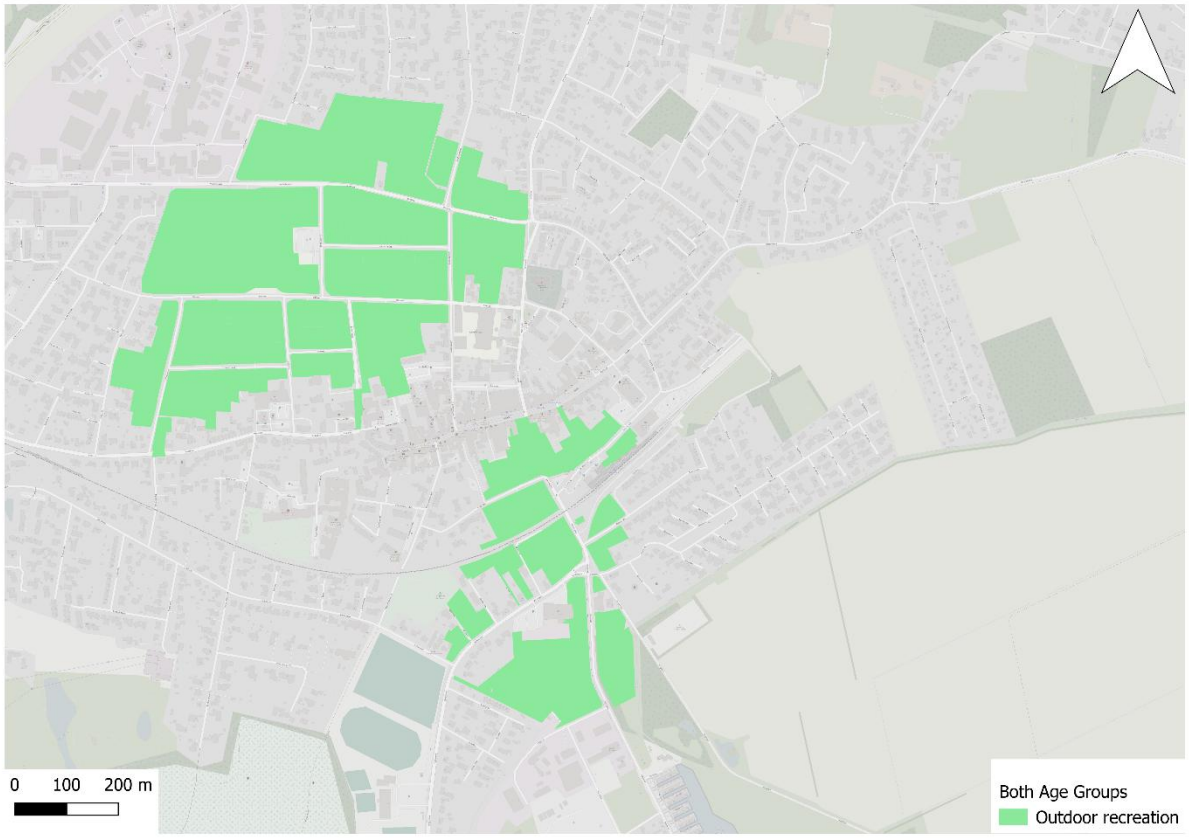
Hospitality sector suitable plots



The outdoor recreation facilities in Nykøbing are present but not well spread. It is always a beach, park or small woodland that is located around Nykøbing that tries to serve the people. On the map (Figure 23) you clearly see that a region on the south of Nykøbing is highly preferred for a new recreational facility. This is because it is made from the connection between the harbour and the centre of Nykøbing. If there would come a new facility of that kind in that specific location, the connection between the city centre and the harbour would be better and Nykøbing would feel more as a whole. Now it feels like two separate parts, the centre and the harbour. A new facility could make this new feeling. There is also need for green areas in the centre of Nykøbing as seen on the map. This is a common goal or problem in cities. A green area or more green areas are important and needed in a city centre. If these are absent, the green and living feeling of the city is gone. Take New York City for example, without its lungs (Central Park) this city would not be liveable.

Figure 23

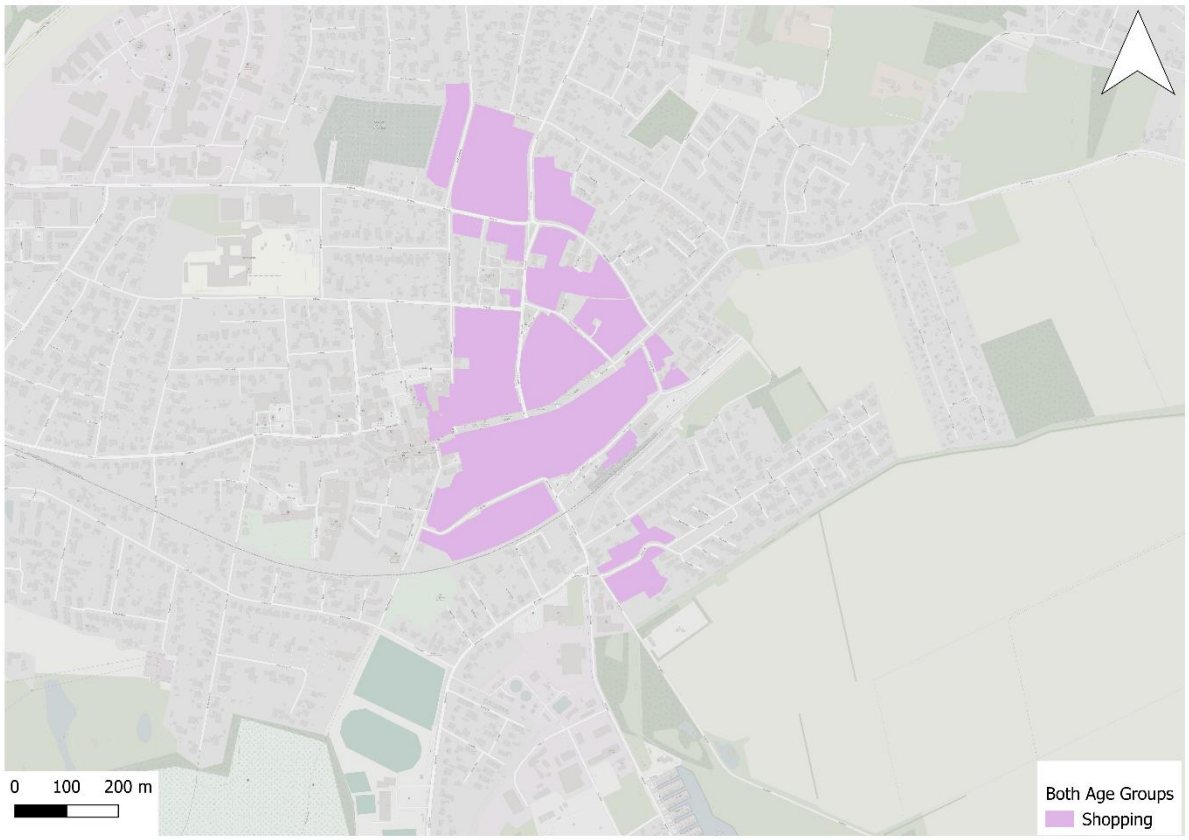
Outdoor recreation suitable plots



Lastly there is a result for the shopping areas in Nykøbing. There is known that there are five supermarkets in Nykøbing. People who got their summerhouse are satisfied with that but people who are a resident are not. Five supermarkets to serve few people are too much. It is said by residents that there could be more local shops with local specialties. This considers the general plots that are shown on the map. It is also clearly that there must be more shops on the north-east side of Nykøbing. Now the shops are centred around the centre of Nykøbing but people living up north must walk a greater distance to get to a supermarket and other shops. Nykøbing is also not known for clothing stores. People who live here in the summer would not buy their clothes in Nykøbing. This could be solved with new shops located on these plots showed on the last map (Figure 24).

Figure 24

Shopping suitable plots



Overall there is clearly a great need for each type of service. Width these results in mind the local policy makers could transform Nykøbing to serve all needs of the residents and the summer house owners. If we look back to the current zonal plan of Nykøbing, there is clearly a consensus. The areas that are covered by these results and the current situation say that there is a need for a different type of that service or a renovation or just a new service in that area. Zones that are only covered by the current zonal plan are zones that are already matching the needs of the people. Zones that are only covered by the results are zones where a big need is for new development of specific services.

5 DISCUSSION

5.1 Survey

In hindsight, we should have begun the survey with a concise eligibility screener to immediately filter out ineligible participants. A single question "Are you a permanent resident of Nykøbing?" would have set clear expectations from the outset and prevented respondents who didn't meet our criteria from proceeding, saving everyone's time. Next, the questionnaire should have been reorganized into clearly numbered, thematic sections. For example, grouping usage-pattern questions as Q1–Q3, satisfaction ratings as Q4–Q6, priority rankings as Q7–Q8, mapping tasks as Q9–Q10, retrospective reflections as Q11–Q12, and demographic items as Q13–Q15 would have created a logical flow. This structure reduces cognitive load and helps respondents understand exactly where they are in the process. Every question about satisfaction or priorities ought to have been anchored in a concrete context, such as a "15-minute walk" radius, and paired with an explicit "N/A" option for services a respondent hasn't used. By eliminating vague prompts like "How satisfied are you overall?" and respecting non-users with an N/A choice, we would have avoided confusion and ensured more accurate responses. Finally, all demographic and household questions should have been moved to the very end, once the substantive data were collected, and any specialist jargon replaced with plain language. Keeping these items until after the core questions would have made the survey feel shorter and more engaging, thereby maximizing completion rates and improving the reliability of our insights.

5.2 Sample size and statistical significance

These changes to boost response rates bring us to the question of statistical significance. With roughly 35 completed surveys, our current sample is far too small to support reliable descriptive statistics. In an ideal scenario, we would aim for a precision of ±5 (E) percentage points at 95 (Z) percent confidence level. Using the standard infinite-population formula with a p-value of 1:

$$n_0 = \frac{Z^2 p(1-p)}{E^2} \approx 384$$

and then applying the finite-population correction for N ≈ 5 000 residents gives:

$$n_0 = \frac{n_0}{1 + \frac{n_0 - 1}{N}} \approx 357$$

So, we would need about 357 completed surveys to hit ±5 percent. However, our 10–12-minute questionnaire, with open-ended items and an online mapping tool, will almost certainly limit our response rate. To obtain 357, we'd have to send out roughly 1 428 invitations (at a 25% response rate), which would be nearly 29 percent of the town. That scale is simply impractical in the field.

To strike a more realistic balance, we can relax our precision to ±8 percentage points. Repeating the calculation with E = 0.08 yields 146 responses. Only by reaching our target sample size could we perform truly robust statistical analyses. With just 35 responses, any descriptive or inferential results would lack sufficient power and reliability.

5.3 Spatial questions

That initial confusion around the Flower of Proximity tool almost certainly skewed our walking-time estimates. If some respondents clicked their current walk instead of their ideal walk, our dataset would understate true preferences, biasing means downward and compressing the variance. In practical terms, any isochrone or service-gap analysis built on those raw "t" values must be treated with caution. At the very least, we need to acknowledge this systematic error in our discussion and interpret all walking-distance findings as conservative estimates of people's true willingness to walk.

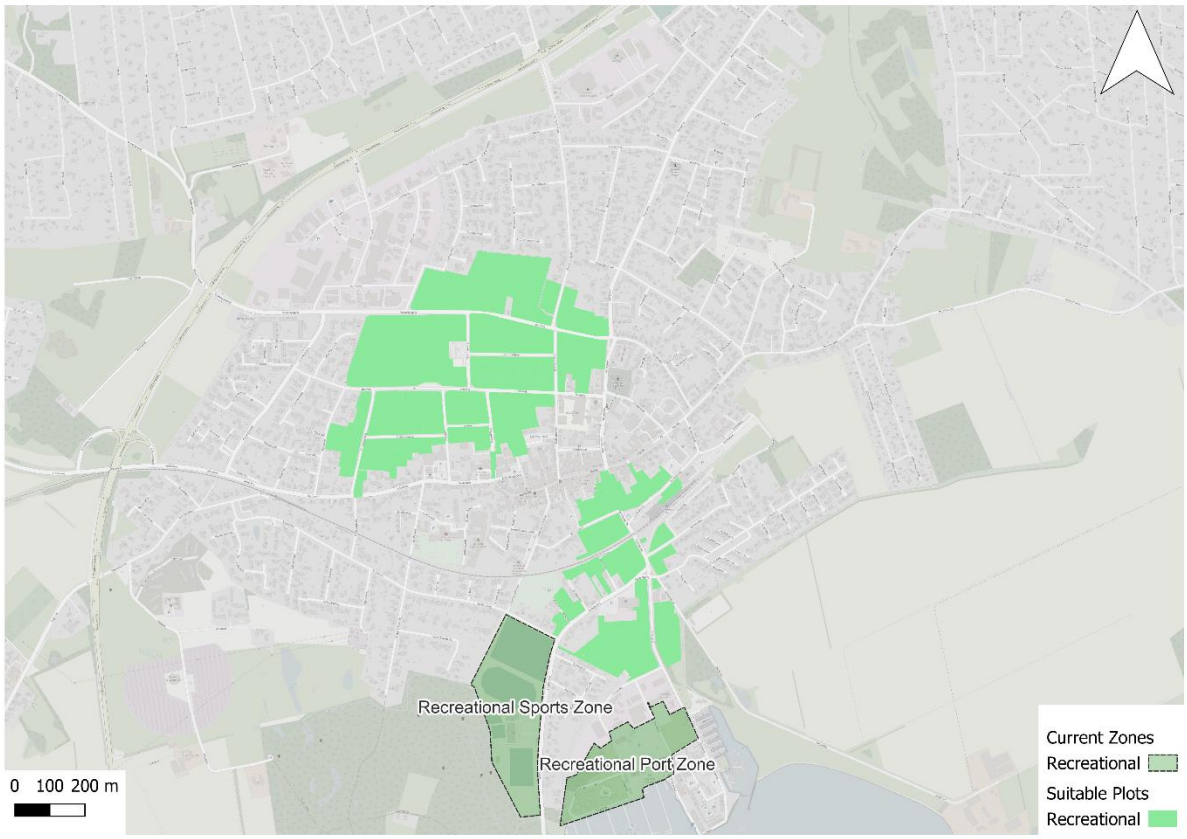
Similarly, because we asked respondents to mark only a broad neighbourhood rather than their exact addresses, both to respect privacy and minimize drop-out, their mapped home locations are approximate. As a result, our spatial analyses (isochrones, service-area intersections, parcel targeting) carry an inherent locational uncertainty. All findings based on residence points should therefore be interpreted with appropriate caution.

5.4 Difference between current situation and results

It is very useful to compare our results with the current situation. Therefore, following maps were made. On figure 25 the current recreational zones are only in the south of Nykøbing. It would be better (considering the needs of the people) that recreational zones would appear more up north and more at the connection between the centre and the harbour.

Figure 25

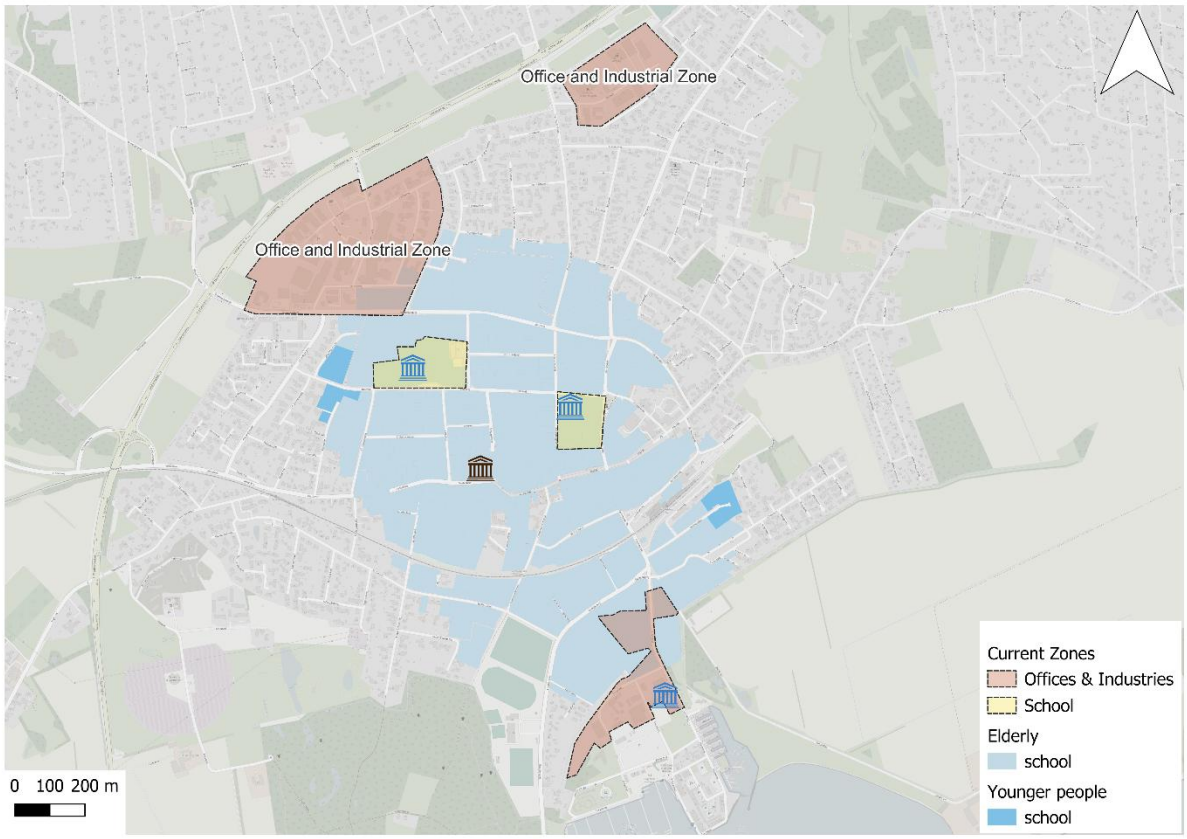
Comparison of recreational zones



School and work zones are also differentiated around Nykøbing. School zones are in the centre and that matches roughly our results. But the work zones are all outside the centre. Considering our results it could be a good solution to take these work zones to the centre.

Figure 26

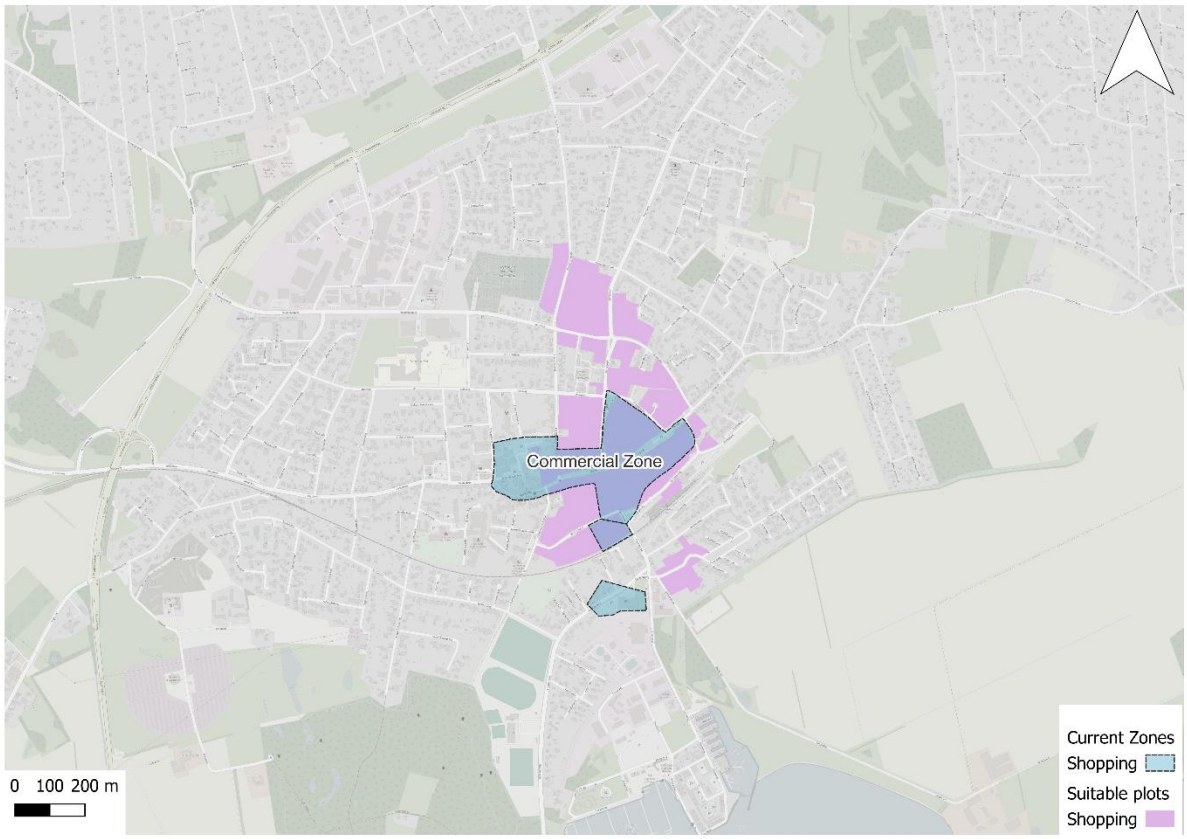
Comparison school and work zones



The commercial zones overlap around the centre of Nykøbing. Here could you say that the shop's location is great, but the diversity is not what it could be. A new commercial development plan up north could meet the overall needs of the people.

Figure 27

Comparison commercial zones



6 CONCLUSION

In this study, we examined how Nykøbing Sjælland might leverage the walking preferences of its ageing population to guide urban redevelopment. We began with a desktop review of historical land use, current zoning, and future local plans (Lindely and Havnevej), then designed a mixed-mode survey, combining closed-ended questions, open prompts, and interactive PPGIS mapping to capture both "what" services people need and "where" they want them. Through k-means clustering, we distilled five demographic/mobility profiles, each with distinct service priorities and travel habits.

Our analysis of mean satisfaction scores revealed consistent patterns across clusters: daily necessities (commuting, grocery shopping) scored only moderately and varied widely, whereas retail and leisure amenities generally met expectations. Older singles (Cluster 1) reported the lowest overall satisfaction, particularly with transport and food & beverage, identifying them as a priority group. Frequency-of-use data underscored that services visited multiple times per week demand very short walking distances (5–10 minutes), while less-

frequent services (healthcare, dining) can be sited slightly further away in mixed-use nodes. Spatially, we converted Flower of Proximity clicks into preferred walking times and generated enclosing circles around preferred facility locations. Intersecting these with cadastral parcels, and then disaggregating by cluster, yielded two parcel sets of interest: one serving mobility-constrained elderly respondents and another favoured by younger groups. Notably, healthcare emerged as undersupplied in peripheral areas, while hospitality and outdoor recreation showed broader opportunity zones, especially along the underutilized harbour–centre corridor.

Reflecting on our fieldwork, we learned that a sharper screener, thematic question grouping, "15-minute walk" anchors, and mid-survey tutorials for mapping tasks would shorten completion time and reduce misinterpretation. Moreover, with only 35 responses, statistical power was insufficient: achieving ±8 pp precision at 95 percent confidence would require about 146 completed surveys. A mixed-mode rollout (door-to-door, intercepts, QR scans) at that scale is feasible and would improve representativity.

Our findings suggest several policy actions. First, enhance commuting infrastructure and introduce targeted shuttle services in zones where older residents report low transport satisfaction. Second, infill small-scale retail and healthcare facilities within 5–10-minute walking bands to reduce reliance on neighbouring towns. Third, activate the harbour–centre transition with mixed-use developments. Finally, diversify the commercial base by supporting local food shops and boutiques, stabilizing year-round retail beyond the five large supermarkets. These recommendations must be tempered by our study's limitations. The small sample size limits the precision of descriptive statistics, and the locational uncertainty of broadly indicated home points introduces spatial error. Initial misinterpretations of the Flower tool likely biased walking-time estimates downward, so our findings represent conservative estimates of true preferences. Looking ahead, a two-phase approach could solidify these insights. Short-term pilots such as a pop-up health kiosk or waterfront café can test feasibility in identified consensus areas. Concurrently, a larger-scale survey with expanded outreach should be conducted to capture underrepresented groups. In the longer term, a participatory planning process involving residents, planners, and local businesses will refine site-specific proposals, ensuring redevelopment aligns not only with quantified walking preferences but also with qualitative values like "cosiness" and inter-generational community.

By integrating residents' self-expressed needs and mobility limits into a data-driven, walkability-focused framework, Nykøbing can pursue inclusive, sustainable redevelopment—transforming itself into a more accessible, vibrant town for all ages.

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8 APPENDIX

8.1 Survey

ID number: _____

Hello,

We are students from the University of Ghent, Belgium. We are conducting a survey to get a better understanding of the perception of services in Nykøbing. This way we create a framework for policymakers for possible future redevelopment of the city centre. Thank you so much for your cooperation!

Demographic and behaviour context

1. Are you a resident of Nykobing?
    - Yes, permanent resident
    - Yes, but only as a summer house owner
    - No

2. What is your age group?
    - Under 21
    - 21 - 30
    - 31 - 40
    - 41 - 50
    - 51 - 60
    - 61 - 70
    - 70+

3. What best describes your household composition?
    - Living alone
    - Living with a partner
    - Living with children
    - Living with friends / roommates
    - Living with other family (except for partner and children)
    - Other

4. Which mode(s) of transportation do you typically use to reach daily local services during a typical week? (Please select all that apply)

    Definition local services: Any neighbourhood facilities you visit in person (e.g. shops, cafés, healthcare practices, sports venues, public offices, banks). Online-only visits do not count.

    - Walking

- Cycling
- Public transport: please specify _____
- Car
- Other : please specify _____

5. Approximately how many of those typical weekly visits are for each purpose?

(Enter a whole number; if none, write "0". The numbers do not have to sum perfectly.)

	daily	Once a week	Multiple times a week	monthly	Less than monthly
Commuting (work or study)					
Shopping (groceries, retail)					
Leisure (sport, culture, recreation)					
Healthcare (hospital, pharmacy)					
Food and beverage outlets (bar, café)					

Overall satisfaction with the urban layout

6. For each service of Nykøbing listed below, please indicate your overall level of satisfaction.

service of Nykøbing	Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very satisfied	I don't use this sevice
Healthcare facilities (hospitals, doctors, pharmacies)						
Commuting infrastructure (roads, public transport organization, cycling routes)						
Leisure amenities (parks, sports, cultural venues)						
Shopping areas (variety, accessibility, convenience)						
Food & beverage outlets (cafés, bars, restaurants)						

Evaluation of town functions

7. Which of the following essential services within a 15-minute walk from your home would most improve your day-to-day life in Nykøbing? Please tick up to three that you consider the highest priority and add a comment on why you would like them improved.

☐ Neighbourhood grocery / fresh-food store _____

☐ Pharmacy or basic healthcare clinic _____

☐ Frequent public-transport stop or shuttle hub _____

☐ Safe pedestrian crossings and wider footpaths _____

☐ Secure bicycle parking or bike-share station _____

☐ Pocket Park or small green space with seating _____

☐ Child-care or after-school facility _____

☐ Waste-sorting / recycling point _____

☐ Community meeting room or co-working space _____

☐ Is there an essential service not listed above you feel is missing within walking distance? Please specify:

Retrospect & future oriented questions

8. Thinking about the last few decades in Nykøbing, please list some of the positive and negative changes in the availability of services. Please briefly state the service/facility and why it matters to you.

_____

(Examples of services/facilities: a new bus line, closure of a local supermarket, extension of cycling paths, removal of a car park, opening of a health centre, etc.)

9. Do you feel you need something entirely new, just an improvement, or is it fine? For each category, tick one statement. Then rank the three categories that matter most to you (1 = highest priority).

Category	I need new facilities	I need better or more of what already exists	What is available is sufficient	Rank 1 – 3
Healthcare (clinic, pharmacy)				
Commuting (bus/rail stop, bike-share, safe crossings)				
Leisure (park, sports venue, cultural space)				
Shopping (grocery, convenience store)				
Food & beverage (café, bar, restaurant)				

10. In the past month, to which other towns did you travel to obtain services you could not find in Nykøbing? Additionally, please give the reason why you went to this town.

_____

11. Thinking back to ten or twenty years ago, which shops or facilities brought people in from surrounding villages? Are they still operating? Why/why not?

    _____

12. For each service below, tick if you normally use it inside Nykøbing, in another town, or *online*."

    - major grocery
    - DIY store
    - clothing retail
    - general practitioner
    - specialist doctor
    - cinema
    - public office
    - bank

14. Do you see yourself staying in Nykøbing as a pensioner? What would make the decision easier?

Your responses were recorded, thanks for your time!

FACULTEIT WETENSCHAPPEN

Master of Science in Geography and Geomatics

ALL PATHS LEAD TO NATURE

PGIS SURVEY ANALYSIS OF FRILUFTSLIV IN ODSHERRED

Word count: 10 602

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Course: Geïntegreerd Internationaal Projectwerk

Academic year: 2024 - 2025

UNIVERSITEIT GENT

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1 INTRODUCTION

In recent years, the COVID-19 pandemic has profoundly reshaped our relationship with public space and nature. As restrictions confined people indoors, the outdoors regained importance as a place of refuge, recovery and connection. This renewed societal awareness of the mental and physical health benefits of being in nature highlighted the enduring value of outdoor practices. Particularly in Scandinavian countries, where nature engagement is deeply embedded in their cultural identity, such practices have long existed under the umbrella of *friluftsliv.* Friluftsliv is a broad and often ambiguous concept that emphasizes a simple, harmonious life in the open air. While friluftsliv has been central to Scandinavian life for over a century, its meaning and practice remain difficult to pin down. It is not defined by a single activity, location or social group, but rather by a mindset rooted in simplicity and a deep connection with nature. Despite its cultural prominence, academic research has yet to fully capture how friluftsliv is experienced differently across space and population groups, especially in contexts where tourism and local life intersect.

This study seeks to contribute to that understanding by focusing on the municipality of Odsherred in Denmark, a coastal region known for its rich natural landscapes, its designation as a UNESCO Global Geopark and its large number of summerhouses. These characteristics make Odsherred a unique setting where the boundaries between permanent residents and temporary visitors often blur. Because friluftsliv is not only shaped by personal attitudes and motivations, but also by access, seasonality and social identity, it is important to investigate how different groups inhabit and interpret this shared landscape.

The aim of this research is to explore how friluftsliv is understood and practised in Odsherred. More specifically, it examines how spatial patterns of outdoor life may vary between locals and visitors, considering socio-economic and temporal factors. In doing so, this study not only seeks to clarify what friluftsliv means in practice but also provides insights into the spatial and social dimensions of activities in nature. These findings may inform future planning, policy and landscape management by highlighting the everyday value of friluftsliv and the need to support accessible and inclusive outdoor spaces for all. This leads us to the central research question of this study: **'What does friluftsliv mean as a concept and practice in Odsherred, and how do its spatial patterns differ between locals and visitors considering socio-economical and temporal factors?'**

2 THEORETICAL FRAMEWORK

2.1 What is friluftsliv?

Friluftsliv is a well know concept in Scandinavian countries, since it is been deeply rooted in their culture. For outsiders it is harder to understand, since there is no direct translation for the term. Friluftsliv literally means free-air-life and can thus be seen as outdoor life. But it is not just a term, it is a whole philosophy, a way of life, a method, a tradition and much more. The word is inherently complex (Henderson, 2002b; Visit Norway, n.d.).

2.1.1 Friluftsliv history

The word friluftsliv was first used by the playwright Henrik Ibsen in the poetic drama Paa Vidderne (On the heights) in 1859, where he described a philosophical connection between the human spirit and wild nature. However, the practice is older than the term. The phenomenon is as old as the species of homo sapiens, since hunter-gatherers always lived in nature and of the land. Biophilia states that humans genetically inherent the need for contact with nature. Three 'green waves' of development of friluftsliv can be distinguished. During the first wave in the mid-19th century, modern friluftsliv began to take shape because of the romantic 'back-to-nature'-movement, as a reaction against the growing urbanisation and industrialization. Mostly upper-class society, who did not have a natural connection to nature unlike hunters, fishers or farmers, reconnected with nature and the old Scandinavian outdoor tradition in their free time. In the 1860's the first tourist organisations emerged to nurture urban people's health through nature experiences. These organisations strongly influenced the development of friluftsliv. The second wave, during the first part of the 20th century, made the general public aware of the benefits of being in nature. The working class started to practise friluftsliv, since they gained free time. After World War II the third wave started to emerge. Increasing environmental awareness led to legal protections, including Norway's 1957 Friluftsliv Act, securing public access to nature. By the late 20th century, friluftsliv became institutionalized within education and politics. Friluftsliv becomes a part of the lifestyle and identity of Scandinavians (Friluftsrådet, 2018; Gelter, 2000; Nerland, 2022).

2.1.2 Definitions of friluftsliv

First and foremost it is important to note that there is no such thing as a 'one size fits all' definition for friluftsliv. Every individual approaches the concept differently. A definition given by the Norwegian outdoor brand Amundsen (2025) encompasses a lot of aspects of what friluftsliv means today for many people:

> Friluftsliv is a state of mind, not an activity, nor a competition. It embodies the values of what nature gives in return. A sense of detachment from the daily grind that empowers and re-energizes us to enable longevity and stability in our lives. Friluftsliv, regardless of activity, is simply being in harmony with nature. (Amundsen Sports, 2025)

The complexity and the wideness of friluftsliv is depicted in some definitions:

- Friluftsliv is a Norwegian tradition for seeking the joy of identification with free nature. (Faarlund, 2002, p. 18)
- Health, wealth and joy are encapsulated in that one word: friluftsliv. (Mikkjel Fønhus, n.d.)
- Staying outdoors and being physically active during leisure hours to have a change of environment and experience nature. (Det kongelige klima- og miljødepartementet, 2015, p. 10)
- A philosophical lifestyle based on experiences of the freedom of nature and the spirituals connectedness with the landscape. (Gelter, 2000)
- Friluftsliv is about harmonizing with nature, not disturbing or destroying it. Friluftsliv is not about consuming experiences, places, or resources, although just by being in a place will change it and resources consumed. Friluftsliv is not to actively seek adventures, although adventures and adrenaline kicks may be a natural part of friluftsliv. In friluftsliv you don't change nature to gain experience or take control of it, you don't build artificial racetracks, or boulder cliffs. In friluftsliv you may use nature for food and shelter or for your survival, but not modify nature to suit the outdoor activity. Friluftsliv is not an activity or activity program with a narrow goal; it is a lifestyle and a philosophy. (Gelter, 2000, p. 82)
- I believe that friluftsliv, first and foremost, is about feeling the joy of being out in nature, alone or with others, feeling pleasure and experiencing harmony with the surroundings—only being in nature and doing something that is meaningful for me—here and now. (Dahle, 2023, p. 248)
- Friluftsliv is about seeking a deeper relationship between people and nature by going into nature in simple and self-sufficient ways, and it is lined to cultural practice and identity. It denotes outdoor activity that is both informal and appropriately unfolding. (Henderson, 2002, p. 26)

2.1.3 Sorts and characteristics of friluftsliv

From these definitions some characteristics of friluftsliv become clear. Friluftsliv can be divided into two big main groups, the so called 'genuine friluftsliv' or 'woodcraft' and the more modern superficial, activity-oriented concept of friluftsliv or 'leave no trace'. These forms differ significantly in their goals, practices, and impacts (Gelter, 2000; Turner, 2002). Over the years, various blends of these two kinds of friluftsliv have emerged.

Genuine friluftsliv or woodcraft, represents the original, philosophical understanding of the concept. Henderson (2002a) stated that the focus is on 'being', rather than on 'having' and 'doing'. It is not defined by specific outdoor activities, but rather by a lifestyle and mindset of simplicity, presence, and harmony with nature. It is about the joy one feels while being in nature. This type of friluftsliv is rooted in the human evolution of surviving of the land. It needs a profound understanding and working knowledge of the surrounding nature. It often included masculine activities like hunting, building shelters, making open fires..., but also self-sufficiency, like picking berries. Arne Naess (1982) emphasized that friluftsliv is about "richness in ends, simpleness in means". Genuine friluftsliv does not need technology, consumer goods, fancy outdoor gear or motorized forms of travel. Therefore, everybody can take part in friluftsliv. It typically takes place in open-air environments and in relatively free nature, away from the constraints of urban life. The focus lies not on performance or competition, but on personal experience, reflection and connection with the land. It involves all sides of human beings, all parts of body and mind are needed. It also embraces a social dimension, encouraging shared experiences with family and friends and depending on one another during activities. Gelter (2000) stated that "by doing this we learned more about ourselves, each other, the surrounding landscape, and our place in the world. This is the true essence of friluftsliv". By practising friluftsliv, one creates more responsibility towards nature and others, which leads to more environmental awareness and a more biophilic lifestyle (Dahle, 2003; Gelter, 2000; Henderson, 2002a; Nerland, 2022; Turner, 2002).

In contrast, activity-oriented friluftsliv, or 'leave no trace' reflects a more contemporary and commercialized interpretation. It emerged in the second half of the 20th century as a response to the enormous growth of outdoor recreation and as a result of the growing ecological awareness but also the growing consumerism. Here, nature often serves as an arena for recreation and physical challenge: camping, hiking, kayaking, mountain biking and even extreme sports are common examples. By using modern equipment, they aim to have as little impact on nature as possible, literally leave no trace, and therefore do not use land as in woodcraft. The friluftsliv-practitioners want to protect the nature from themselves. But the promotion of outdoor gear indicates

consumption, which is again not good for the environment. The famous Scandinavian quote 'there is no such thing as bad weather, only bad clothes', reflects that. As a result, the traditional low-key outdoor activities are being commercialized and sport-oriented. While this kind of activities also do take place outdoors, the connection to nature is often secondary to the activity itself. As a result, the experience becomes more superficial, potentially undermining the original intention of friluftsliv. It also risks excluding individuals without access to resources, and erodes the idea of spontaneous, self-directed encounters with nature (Dahle, 2003; Dixon, 2023; Gelter, 2000; Henderson, 2002a; Turner, 2002).

Even though there are differences, some common values can be discerned between the two forms of friluftsliv. Friluftsliv-experiences, as the word itself denotes, takes place outdoors and have a nature aspect to it. It is not linked to a specific activity. Some examples of experiences are canoeing, hiking, cycling, picking berries, cross-country skiing, searching for sea animals, quietly watching the landscapes, swimming, reading a book on a bench in the park, going troll-hunting with children… and so much more! It can be anything as long as it fosters enjoyment in nature. Preferably there is no competition-aspect linked to it, allowing all attention to go to the connection with nature, the environment, others and yourself. Friluftsliv can be enjoyed alone or with others. The experiences are not bound to a season, it is done year-round! At the end, friluftsliv should promote the physical, mental and social health and should build environmental awareness, which all lead to a higher quality of life.

2.1.4 Benefits of friluftsliv

Friluftsliv has a lot of benefits across physical, mental and social health domains. Physically, engaging in outdoor activities such as hiking or ice bathing is associated with increased energy expenditure, reduced body mass index, improved cardiovascular risk profiles and enhanced immune system function. Even low-intensity activities in green spaces can contribute to better physical health outcomes. Mentally, friluftsliv promotes reduction in stress and anxiety, improved cognitive function and emotional well-being. Passive activities such as sitting quietly in a forest can be as beneficial as more vigorous exercises, fostering relaxation and cognitive restoration. Socially, friluftsliv fosters interaction, cooperation and community development. Outdoor activities facilitate stronger interpersonal relationships, mutual trust and leadership skills (Bratman et al., 2015; Lousen & Andkjær, 2025; Mygind et al., 2019; Straume & Løvoll, 2020).

2.2 Friluftsliv in Denmark

Although friluftsliv is a concept that is big in the Scandinavian countries, yet some differences between them can be discerned. Gelter (2000) states that friluftsliv is deeply embedded in the Norwegian and Swedish culture, but in Norway friluftsliv is still an important part of people's everyday life compared to Denmark and Sweden where it has obtained a more technical meaning in outdoor activities and has lost its philosophical dimension. This can be seen in the law: friluftsliv was included in the constitution of Norway as early as 1957 and only in 2015 in Denmark (Klima- og miljødepartementet, 2025; Miljøstyrelsen, 2023). The Danish Nature Agency proposed eight guidelines that form the basis of their friluftsliv (Naturstyrelsen, n.d.-b). First of all, everyone, both in the countryside and in the city, should have access to friluftsliv-experiences. Linked to this, the Danes must create exciting and attractive cities where there is room for friluftsliv, since most of them live in the city. Thirdly, both children and adults should learn in and from nature. Furthermore, friluftsliv should not only create engagement and a sense of community, but can also be used as a social lever. It can help in providing opportunities to support vulnerable and socially disadvantaged groups in society. Sixthly, a life with friluftsliv strengthens both mental and physical public health. Lastly, activities in nature can be a starting point for entrepreneurship and new jobs, and innovation for societal problems, like climate change, can lead to new opportunities for outdoor experiences.

Friluftsrådet distinguished three dominant forms of friluftsliv that are prevalent in Denmark: friluftsliv as sport, as tourism and as a simple outdoor lifestyle (Friluftsrådet, 2018). They state that all types are equal and that people can practice and combine multiple types. Friluftsliv as sport and as tourism can be compared to the more modern activity oriented type of friluftsliv. Sport activities needs advanced materials, and emphasizes performance and physical challenge. They focus on mastering the natural elements, so they compete 'against nature'. In friluftsliv as tourism, they focus on recreation 'in' nature. They enjoy nature in an easy and comfortable way, together with family and friends. Friluftsliv as simple outdoor life, can be compared to genuine friluftsliv, because it is about identification 'with' nature. During these kind of experiences, they use as minimal equipment as possible and if some equipment is needed, it is often handmade. Respect for nature is key, so one can experience harmony and peace in nature and feel a connection with the environment.

One of the biggest differences between friluftsliv in Denmark and the other Scandinavian countries is the absence of the right to roam, also called the *allemansretten* or all man's right. This law states that everyone can access, explore and enjoy public and private owned uncultivated land (SUSTON, 2024). The absence is mainly

because of the higher population density and greater amount of farmland. This does not mean that the general public cannot access anything! Publicly owned land, like the beaches, dunes and some forests are open for roaming. Yet, most of the private grounds cannot be entered, unless it is uncultivated, unfenced and during daytime (Riis, 2021). Andkjær (2005) also shows that friluftsliv is subject to change. Friluftsliv is introduced into pedagogy, for example multiple degrees are offered that specialise in friluftsliv, and hereby it also becomes professionalised. Overall there is more activity in nature, and the focus shifts towards risk, challenge and personal development.

2.2.1 Important organisations regarding friluftsliv in Denmark

Friluftsliv in Denmark is supported and promoted by a range of actors and initiatives. Among the most prominent actors is Naturstyrelsen, the Danish Nature Agency, a governmental body under the Ministry of Environment. Naturstyrelsen is responsible for managing approximately 210,000 hectares of state-owned natural areas and wants to enhance biodiversity so that nature will become wilder and richer in species and with good opportunities for both nature experiences and active outdoor life (Naturstyrelsen, n.d.-a). Friluftsrådet, the Danish outdoor council, plays a critical role as well, as an independent and non-governmental umbrella organisation representing over 80 smaller and local member organisations engaged in friluftsliv. Founded in 1942, the council's vision is 'friluftsliv for everyone, in a rich nature, and on a sustainable basis'. They inspire the people to do more friluftsliv and improve the opportunities, conditions and framework through political advocacy, projects, labelling schemes and campaigns. They want to create better outdoor experiences, but take in consideration the environmental needs and needs for nature protection (Friluftsrådet, n.d.). They also assign quality labels to larger coherent natural areas, thereby creating *Danske Naturparker* or Danish Nature Parks, where care, protection and use of nature are combined. In these areas they want to develop nature, outdoor activities and local identity in a sustainable way (Danske Naturparker, n.d.). Besides these, there are many other places suitable for friluftsliv. Denmark has five national parks, each preserving unique natural habitats, landscapes, and cultural heritage. Additionally, Geoparks, highlight the geological, cultural, and ecological history of landscapes shaped by natural forces over millennia. Denmark has three Geoparks, of which one is Geopark Odsherred. All these places serve as a unique backdrop for all kinds of friluftsliv experiences (Visit Denmark, n.d.). Digital initiatives like Udinaturen.dk support friluftsliv by providing an accessible online platform where citizens can find information about shelters, hiking trails, campfire sites and other outdoor facilities throughout Denmark. Finally, Foreningen Dansk Friluftsliv, the Association of Danish Friluftsliv, enhance contact between professionals and educators who work in nature and friluftsliv. They want to strengthen nature education and

the friluftsliv-tradition in Denmark and also the cooperation with other Scandinavian countries (Foreningen Dansk Friluftsliv, n.d.).

2.3 Existing research on spatial patterns of friluftsliv

While friluftsliv is a well-established concept in Scandinavian contexts and widely studied in terms of participation patterns and health benefits, there is a notable lack of research that explores the spatial differentiation of friluftsliv practices between locals and visitors, especially in coastal municipalities like Odsherred. In such areas, summerhouse owners and tourists significantly impact the use and meaning of outdoor spaces (Anneberg Kulturpark, 2022).

2.3.1 Locals versus visitors: spatial preferences and behaviours

Existing studies (Kaae *et al.*, 2018; Westphalen & Pedersen, 2023) show that locals and visitors engage with nature in distinct spatial ways, shaped by proximity, accessibility and infrastructure. Locals tend to integrate friluftsliv into everyday routines, preferring nearby green areas such as neighbourhood forests or quiet beaches. Their visits are often shorter and more frequent. In contrast, visitors, mostly studied as tourists, typically seek out iconic or curated locations such as nature parks, marked trails and scenic viewpoints; especially during weekends and holidays. These visitors are more dependent on infrastructure and tend to display a more concentrated and seasonal use of space (Westphalen & Pedersen, 2023).

Interestingly, summerhouse owners often fall somewhere in between: while they are technically visitors, their repeated and longer stays foster more localised spatial practices. They develop familiarity with less crowded spots and tend to avoid peak periods (Gernow *et al.*, 2024).

2.3.2 Temporal and aesthetic dynamics

Temporal patterns also shape spatial practices. Local use is relatively stable throughout the year, while visitor activity peaks in summer and on weekends, creating temporary congestion at coastal and high-profile nature spots. Seasonal shifts are also visible: coastal areas attract more visitors in spring and summer, while inland areas see more consistent year-round use (Gernow *et al.*, 2024).

Aesthetic and emotional factors influence spatial preferences as well. Open coastal landscapes and panoramic viewpoints are particularly attractive for visitors due to their associations with peace, escape and connection. While place meanings are broadly shared between locals and visitors, coastal areas are more often linked with feelings of healing, wildness and vacation (Løvoll *et al.*, 2020; Gernow *et al.*, 2024).

2.3.3 Infrastructure, access and equity

Accessibility, both physical and perceived, is a major determinant of participation. Areas that are easy to reach by foot, bike, or public transport, or that offer signage, parking and maintained trails, see significantly higher usage. Legarth (2025) and Friluftsrådet (2013) highlight that proximity to residential areas strongly correlates with participation levels, especially for people without car access. Motorists enjoy more freedom to visit diverse and distant areas, whereas pedestrians and cyclists rely on local green spaces.

Preferences across all user groups consistently include forests, beaches, biodiversity and trail networks. Legarth (2025) argues for better spatial distribution of accessible nature areas, particularly near urban centres and for stronger integration between recreation and transport planning to overcome structural barriers.

Finally, the national mapping study by Gernow *et al.* (2024) confirms that nearly half of all friluftsliv visits take place in public areas, while the other half occur on private land; despite the limited access rights. Conservation areas that explicitly allow public recreation, such as beaches and protected forests, are particularly popular and are visited by 76% of Danes. These findings further reinforce the need for well-managed, accessible and equitably distributed nature areas across Denmark.

2.3.4 Emerging trends in outdoor recreation

Recent national surveys (Friluftsrådet, 2013; Westphalen & Pedersen, 2023; Gernow *et al.*, 2024) indicate notable shifts in friluftsliv practices. Nature visits are becoming shorter, more localised and more common on weekdays. Children are spending less time outdoors due to competition from digital media and organised sports. Meanwhile, walking and cycling are replacing car travel for everyday friluftsliv. Forests and coasts remain the most popular destinations, but urban green spaces are also gaining importance.

Friluftsrådet (2013) reports that 91% of Danes visit nature at least once a year, with significant variations by age, income, education and pet ownership. For example, people with dogs or higher education levels are much more likely to engage in regular friluftsliv.

2.3.5 The case of Odsherred and planning needs

The municipality of Odsherred stands out as a prime example of overlapping local and visitor engagement (Anneberg Kulturpark, 2022). Due to its combination of coastline, forests and summerhouse zones, the area experiences intense seasonal variation in friluftsliv use. Gernow *et al.* (2024) highlight that visitor densities in Odsherred during weekends and summer months exceed the local population, especially along the north and west coasts. This concentration creates both opportunities and pressure: while natural areas attract diverse user groups and foster seasonal economic activity, they also raise questions around crowding, landscape wear and the equitable distribution of recreational infrastructure. Odsherred's dual identity, as both a residential and recreational landscape, makes it a compelling case study for understanding the spatial dynamics of friluftsliv in Denmark.

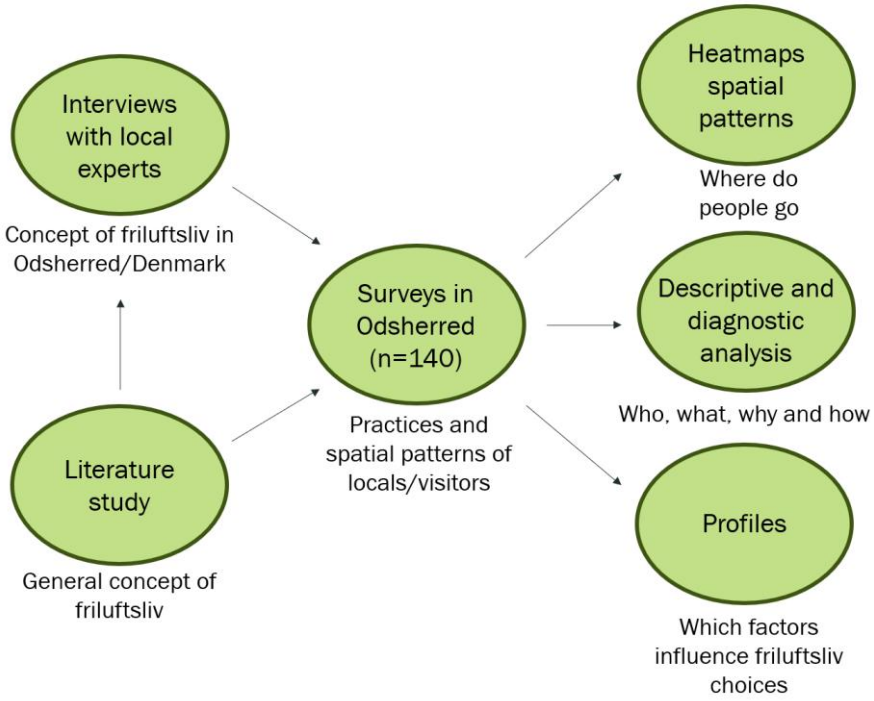
Despite strong participation, several areas remain under-researched. Friluftsrådet (2013) calls for improved mapping of outdoor facilities and urban green spaces, greater insight into unorganised forms of friluftsliv, and more attention to social inequalities in access and use. There is also a need to explore the health-economic benefits of friluftsliv and the role of voluntary organisations in supporting participation.

3 METHODOLOGY

In the next chapter of our report the methodology that was used for this research, will be discussed. To give a clear overview of the steps that were conducted, a general workflow is shown in Figure 1. The first step consisted of doing a literature study to get a good understanding of the general concept of friluftsliv. With this information as a basis, interviews were conducted with various local and Danish experts of friluftsliv to get a better understanding of the local context. The output of these two steps was used to construct a participatory GIS (PGIS) survey. The goal of this was to get better insights in the spatial patterns of friluftsliv in Odsherred. In the end, a total of 140 respondents completed the survey at various locations. This data was analysed and used to get three main outputs. First of all, heatmaps were created to get an understanding of **where** people go to experience friluftsliv. Next, diagnostic and descriptive analyses were done to understand **what** people do and **why** and **how** they do these things. To summarise these results, profiles were made by doing a cluster analysis to see which types of respondents could be found. This clarifies the socio-economic factors that influence choices in the experience of friluftsliv.

Figure 1:

Flowchart methodology



3.1 Interviews with key (local) experts

After the literature study interviews were conducted, prior to the trip to Denmark, with (local) experts in the field of friluftsliv in Denmark, and, if possible, specifically regarding to how it is organized in Odsherred. The aim of these interviews was twofold. On the one hand, the interviews could serve as input for the survey, allowing the multiple-choice options to reflect the local reality in Odsherred as accurately as possible. On the other hand, the interviews can also be considered as a separate component of data collection, which makes it interesting to compare the processed interviews with the results of the survey.

The structure of the interview consisted of four parts. The first part included questions about the general concept of friluftsliv. Next, questions were asked about the local context of friluftsliv in Odsherred. This was followed by a section focusing on the spatial patterns related to the practice of friluftsliv, and finally, interviewees were asked about the type of infrastructure that may or may not be necessary, as well as their vision for the future of friluftsliv. At the end of each interview, additional insights were also requested, such as useful sources or other individuals who might be relevant for further interviews. The questions and structure of the interview can be found in detail in the appendix.

After drafting the interview questions, relevant experts were contacted. The following professors with specific knowledge of friluftsliv were approached: Anton Stahl Olafsson, Søren Andkjær, and Erik Mygind. Additionally, organisations such as the *Foreningen Danske Friluftsliv*, a forum for friluftsliv, and the *Danish Friluftsrådet* were contacted. Among the local experts that were approached for interviews were representatives of the Geopark, the Municipality of Odsherred, and *Det Vilde Køkken*, a local restaurant whose owner was considered to have relevant knowledge.

Despite several reminders to the experts and organisations, some did not respond and others declined the offer because they did not see themselves valuable for the research. In the end only Søren Andkjær, Jakob Walløe Hansen from the Geopark, and Anton Stahl Olafsson agreed to be interviewed. Søren Andkjær is an associate professor at the University of Southern Denmark. He contributes academic expertise on friluftsliv as a cultural phenomenon and its role in health and education. Jakob Walløe Hansen is the head of education and communication at the UNESCO Global Geopark in Odsherred and combines geological knowledge with local, practice-based insights into nature education and friluftsliv initiatives. Anton Stahl Olafsson is an associate professor at the University of Copenhagen, specialised in landscape planning and sustainable recreation, and is

familiar with the Odsherred region through regular visits. Together, their profiles provide a well-rounded foundation for understanding both the national framework and local practices of friluftsliv. During the analysis of the results, the most relevant insights of the different interviews will be synthesized to provide a clear and structured overview.

3.2 PGIS surveys with locals and visitors

For the third part of the methodology, a PGIS survey was conducted. The survey was divided into two parts: questions about friluftsliv and questions where respondents had to indicate locations on a map. The full survey can be found in the appendix, but in general, five important questions were explored: who, what, why, how and where do people experience friluftsliv? The first question asked whether people were familiar with the concept of friluftsliv. If not, a brief explanation was provided, for example: friluftsliv is connecting with nature and can be done in many different ways, such as walking or biking, but also camping. Respondents were then asked what activities they engage in, also where, why, and how often they do these activities. This provides insight into the perception of friluftsliv in Odsherred. At the end of the survey, respondents were also asked to indicate whether they were locals or visitors, where summerhouse owners were also considered to be visitors, and to state their age. All participants took part in the survey on a voluntary basis and all data was collected anonymously and processed in accordance with GDPR-regulations to ensure ethical handling and confidentiality. In order to reach an as large and diverse group of people as possible in a relatively short period of time, supermarkets were visited to conduct the surveys. A good geographical spread of supermarkets was chosen in order to obtain the most representative results possible. These supermarkets are shown in Figure 2. The surveys were conducted using tablets or mobile phones, with people receiving guidance while completing the questions. Figure 3 is a picture taken during fieldwork at the Daglibrugsen Egebjerg supermarket. Finally, Figure 4 provides additional context about Odsherred. The location of forests and the biggest summerhouse areas are shown and will be important later when discussing the results.

Figure 2:

Overview of the survey locations (supermarkets)

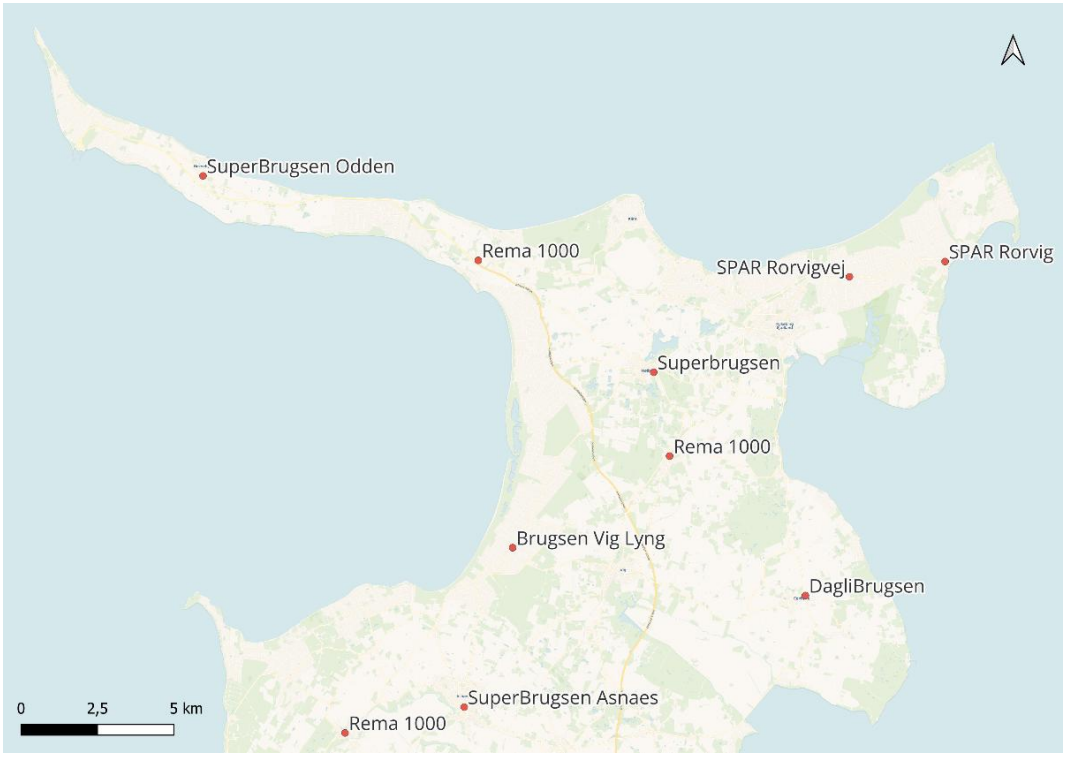
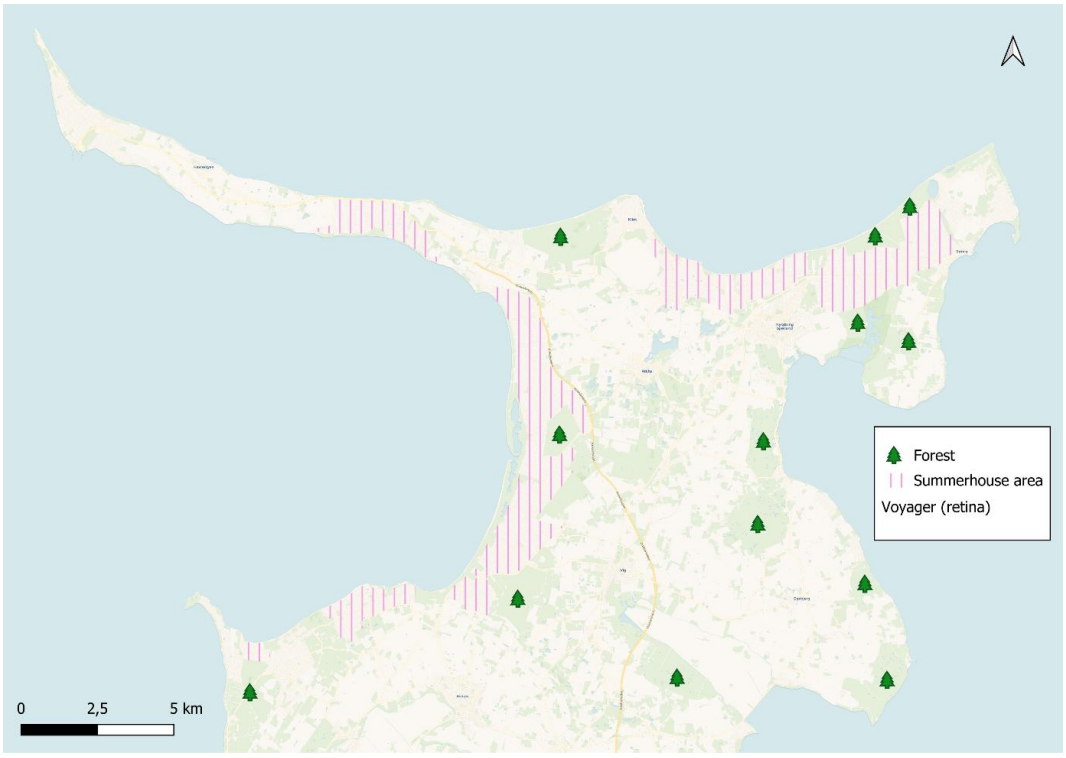


Figure 3:

Picture during fieldwork

Figure 4:

Context map with summerhouse areas and forests in Odsherred



3.2.1 Analysis of the survey questions

Questions without a spatial component were analysed separately. The who-, what-, why- and how-questions formed the descriptive and diagnostic part of this study. Firstly, the dataset was cleaned and made usable via ChatGPT. Each variable was converted to multiple binary dummy variables. Secondly, in SPSS the frequencies of each answer to the questions were calculated. Via Excel the percentages were calculated and charts were made from this data. This made it clear which answers were popular and made the prominent view discernible. Thirdly, the results were examined to see whether there were significant differences in responses between age groups, gender and locals/visitors via SPSS. For this, cross tables were made between the possible answers to questions and the different groups. The chi²-value and the corresponding p-value made it clear whether the outcome was significant or not. Tests were conducted two-sided with a significance α of 0.05, which indicates a 5% chance on a type I-error (false positive). The file with the SPSS output of these analyses can be found together with the other submitted documents.

After that, a cluster analysis was conducted to analyse the data across multiple dimensions. This analysis is capable of extracting specific groups of responses from the dataset, allowing certain profiles to be identified within the data. The cluster analysis was performed using the software program SPSS and a hierarchical cluster analysis was chosen, given that the data consisted mainly of binary and thus nominal variables. As a result, a K-means cluster analysis was not suitable. Ward's method was selected as the clustering technique and the squared Euclidean distance was used as the distance measure. Since hierarchical cluster analysis does not automatically determine the optimal number of clusters, three clusters were chosen based on an evaluation of the icicle diagram (see appendix). To preserve the integrity of the results, not every variable could be included in the cluster analysis because if too many variables are used in relation to the number of respondents, overfitting may occur, whereby the clustering algorithm detects random patterns in the data. This can result in clusters that are not robust and difficult to reproduce when new data are added.

After preparing the dataset for use in SPSS, the dataset contained 93 columns for 140 responses. Therefore, a selection was made based on relevance: only questions related to motivation, activities, company and socio-demographic characteristics were included. The full list of included variables can be found in the appendix. After the cluster analysis and the assignment of each data entry to a specific cluster, the clusters were analysed using the Compare Means-tool offered by SPSS. This tool computed the mean value for each variable in the dataset, but grouped by the different clusters. As the 'prepared' dataset only contained binary dummy variables, these means directly correlate to the percentage of positive responses to a variable per cluster. This allowed to determine the different profiles within the clusters.

3.2.2 Analysis of PGIS

During the survey the respondents were asked how they experience friluftsliv. This could be an activity like hiking or biking, but also just enjoying nature, sitting down and relaxing, camping… After that, the respondents were asked to show where they go in Odsherred for these experiences. Therefore a map was shown and people could draw wherever and how they wanted. This led to three different kinds of shapes as seen in Figure 5 on the left side. People could draw a closed circle, a half open circle or a line going back and forth to indicate the area that they go to. In order to get polygons that show the whole area that they use, the convex hull function was used. The result is seen in Figure 5 on the right side. After getting the polygons for each experience/type of activity, heatmaps were made using the Count overlap-method. Multiple heatmaps were made, one that shows every

experience, another that filtered on visitor or local and lastly heatmaps that filtered on the type of activity/experience.

Figure 5:

Data showing experiences before and after convex hull function

In addition, there was also a question in the survey where people had to indicate where they live if they are a local, or where they stay if they are a visitor. This could be a point or an area that they mark on the map of Odsherred. Convex hull was used again to make sure every indicated area was a polygon. In this way, the experiences and region of stay of each respondent were known. Using the centroids of both layers and combining them on respondent id, the distance was calculated for each experience to the region of stay.

4 RESULTS

4.1 Interviews with key (local) experts

4.1.1 National context of friluftsliv in Denmark

In contrast to countries like Norway or Sweden, the interviewed experts underline the conceptual openness of friluftsliv in Denmark, as it lacks a strict definition or formal tradition. Søren Andkjær highlights its fluid and culturally embedded nature, which is shaped by educational, commercial, therapeutic and other purposes. Jakob Walløe Hansen, who has more practical hands on experience, notes that this conceptual flexibility allows Danes more freedom in how they engage with nature. Anton Stahl Olafsson emphasizes friluftsliv as a source of well-being and intrinsic motivation, especially in contrast to competitive or performance-oriented approaches. All three experts stress the link between friluftsliv and health, as well as the absence of legal rights like the right to roam, which shapes how Danes access and experience nature.

4.1.2 Local context of friluftsliv in Odsherred

At the local level, the designation of a UNESCO Geopark in 2014 illustrates how friluftsliv takes shape in practice. Hansen, closely involved in local initiatives, describes a diverse landscape of outdoor practices supported by infrastructure such as trails, campsites and swimming zones. He notes a growing interest in quieter, peripheral areas and highlights how infrastructure often mediates site preference. Olafsson, a frequent visitor to the region, focuses on multifunctional land use, where outdoor recreation overlaps with farming and coastal activities, sometimes leading to tensions among user groups. He also stresses that motivations vary, some seek solitude and nature, while others seek social or physical engagement. Furthermore he mentions that site choice is often shaped by familiarity and accessibility. Andkjær, while less familiar with Odsherred itself, draws attention to broader spatial relationships, such as place attachment and the coexistence of formal and informal forms of friluftsliv. Activities like foraging or gardening reflect a more personal, non-institutional engagement with nature. He also notes that avoidance of crowds or discomfort is a meaningful driver of behaviour.

4.1.3 Spatial patterns and differences between locals and visitors

The interviews provide a nuanced understanding of how friluftsliv in Odsherred is shaped by spatial patterns, seasonal dynamics and user differences. Jakob Walløe Hansen highlights the coastal zones as key hotspots for outdoor activities such as swimming, fishing and kitesurfing. These activities are often made possible by well-developed infrastructure. These concentrated areas coexist with more distributed, everyday practices like walking or gardening, which typically occur near people's homes or summerhouses. As Anton Stahl Olafsson points out, these practices are often more informal and closely tied to the rhythms of daily life. Søren Andkjær adds that such spatial preferences are deeply influenced by place attachment such as personal memories, experiences and emotions linked to specific places. Walløe Hansen draws attention to the interplay between formal and informal uses of space. While some infrastructures, like mountain bike trails or kayak routes, are clearly marked and maintained, others such as foraging areas or unofficial picnic spots remain unregistered. Yet, they are still heavily used. These informal patterns are harder to monitor but crucial to understanding actual usage, which underlines the potential value of participatory GIS tools.

An important factor related to the spatial patterns is the seasonality, as it plays a major role in shaping friluftsliv. According to Walløe Hansen, the summer months bring an 'explosion' of activity, with tourists and second-home owners flooding the area. This seasonal crowding often prompts local residents to adapt their behaviour, either by visiting places at off-peak times or avoiding them altogether. Andkjær emphasizes that these adaptations reflect not only practical concerns but also deeper emotional ties to the landscape. In contrast, Olafsson notes that spring and autumn see more varied yet lower-intensity use, often by locals or off-season visitors. Winter usage is limited but steady, shaped by both weather and cultural routines.

According to the experts, a clear difference emerges between how locals and visitors engage with friluftsliv. Olafsson explains that for many locals, outdoor practices are woven into daily life, for example walking the dog, cycling to the store, or gardening, often without being labelled as friluftsliv at all. Visitors, by contrast, treat nature as a destination, seeking peace, novelty, or escape from urban life. Andkjær notes that these visitors are more reliant on infrastructure and tend to navigate based on tourism promotion materials rather than local knowledge. Although tensions occasionally arise, for example when locals avoid overcrowded spots during peak season, conflict is generally avoided through spatial and temporal adjustment. Walløe Hansen points out that, in many cases, visitors help justify investments in infrastructure that ultimately benefit both groups. Still, Andkjær warns that current policies often prioritise the economic potential of tourism while overlooking the

more subtle and long-term needs of residents. The expectations of the two groups also diverge. Visitors, according to Olafsson, tend to look for clear signposting, facilities and easy parking. Locals, meanwhile, depend more on local knowledge and unmarked paths. These different expectations likely influence how space is used and perceived, and should therefore be carefully considered when interpreting PGIS data.

4.1.4 Future perspectives for friluftsliv in Odsherred

Looking ahead, all three experts express concern about growing pressure on open space. Walløe Hansen warns that the increase in tourism, summerhouse development and mobility could lead to the erosion of landscape quality and identity unless clear spatial planning is implemented. Andkjær highlights the political reluctance in Denmark to actively steer friluftsliv, despite increasing environmental and social challenges. He advocates for a more deliberate and inclusive approach to spatial regulation. At the same time, Olafsson observes the rise of new outdoor practices. On one hand, faster, performance-oriented activities like trail running and gravel biking are gaining popularity and on the other hand, slower, more reflective activities such as foraging or mindfulness in nature are also on the rise. This growing diversity puts new demands on the landscape and its infrastructure and calls for more nuanced, locally informed planning.

Ultimately, the experts agree that future policies must strike a balance between tourism, ecological sustainability and local well-being. Walløe Hansen argues for stronger zoning and targeted protections of vulnerable areas. Meanwhile, Andkjær and Olafsson emphasise the need for participatory planning and grounded, empirical knowledge, the kind of insight that PGIS-based studies like this one can provide.

4.2 PGIS surveys with locals and visitors

The results of the PGIS survey try to sketch the story of how people in Odsherred experience friluftsliv. First the paper looks at **who** the respondents are, so these are the kind of people that experience friluftsliv. Secondly, the **what**-question is answered: do the respondents know the concept of friluftsliv, how would they describe it and what type of friluftsliv and which activities do they do? Linked to that is the question: '**where** do they go for these activities?'. Furthermore it is important to research **why** they do it and to look at which factors motivates them to go outside. Finally, this part discusses **how**, in which way, people practice friluftsliv. For example, do they need any infrastructure or transportation and who do they involve in the activities? To complete the picture, some profiles of typical friluftsliv-practitioners were made based on the survey data.

4.2.1 Who? Overview respondents

During the two and a half days of fieldwork, 140 valid survey responses were collected throughout the whole municipality of Odsherred. An even distribution across different groups was aimed for. In the sample, there are roughly equal numbers of men and women, with slightly more men (Figure 6). Mainly seniors answered the survey (41%), followed by middle aged people. The adults and the young adults formed the smallest groups (Figure 7). Since most people are thus retired, 44% had no job. People that had a job, worked mostly indoors and hardly outside (Figure 8). Although it was not an official holiday in Denmark, 44% of the respondents were visitors and the other 56% were locals that lived in Odsherred (Figure 9).

Figure 6:

Gender

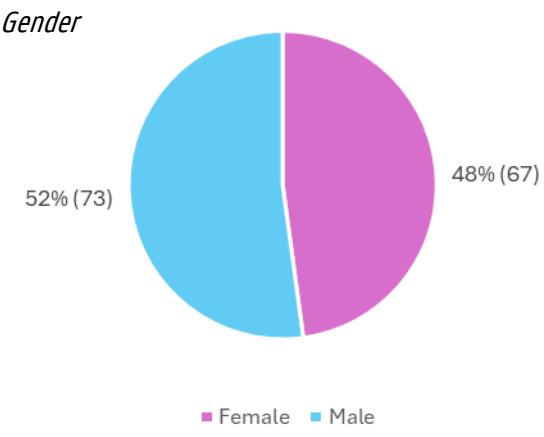


Figure 7:

Age

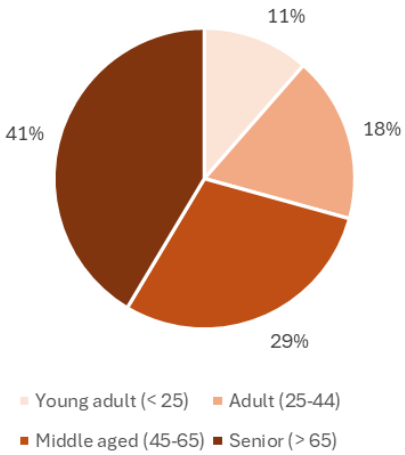


Figure 8:

Type of job

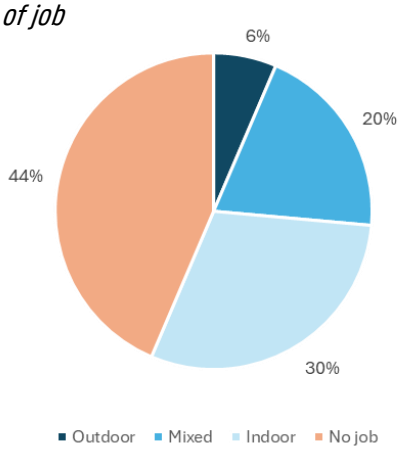


Figure 9:

Local or visitor

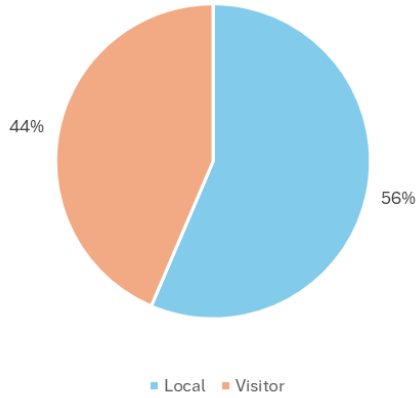
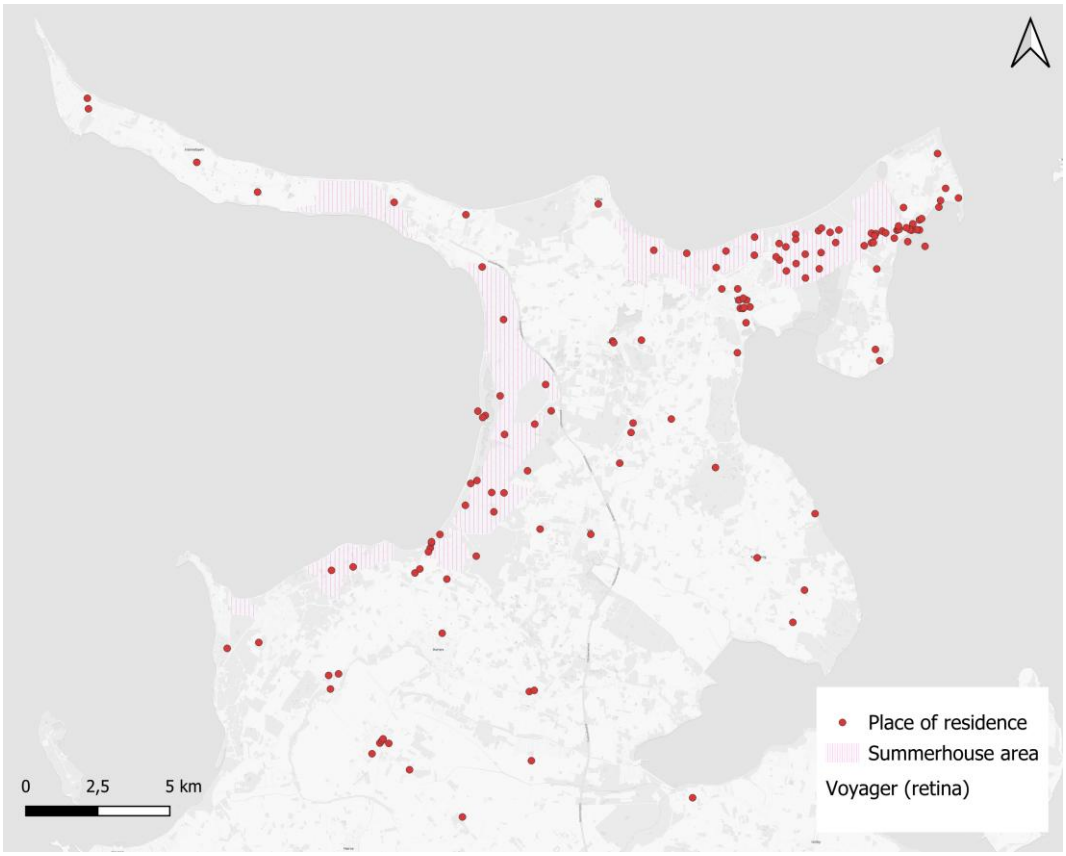


Figure 10 shows the geographical distribution of the respondents, specifically where the locals live or the visitors stay. The most important summerhouse areas are also visible on the map. Two zones have the highest density of respondents, these are also the zones where most of the surveys were conducted, this should be handled carefully when interpreting the results.

Figure 10:

Map with places of residence of all respondents

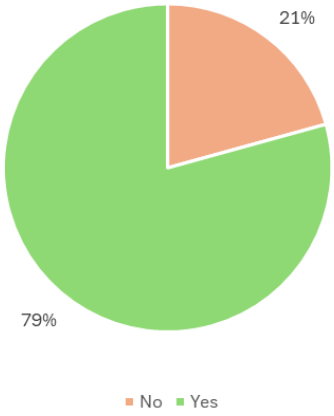


4.2.2 What?

Friluftsliv is a very important part of the Scandinavian culture and lifestyle, but does this also apply to the people in Odsherred? More than three quarters of the surveyed persons mentioned that they know the concept of friluftsliv (Figure 11). When tested, visitors knew the concept of friluftsliv significantly ($p = 0.024$) less than locals. 29% of visitors answered no to the question, whereas only 14% of the locals said no. Strikingly, three times more men did not know the concept compared to women (30% men vs. 10% women) ($p = 0.004$). Overall it can be said that friluftsliv is a familiar concept in Odsherred.

Figure 11:

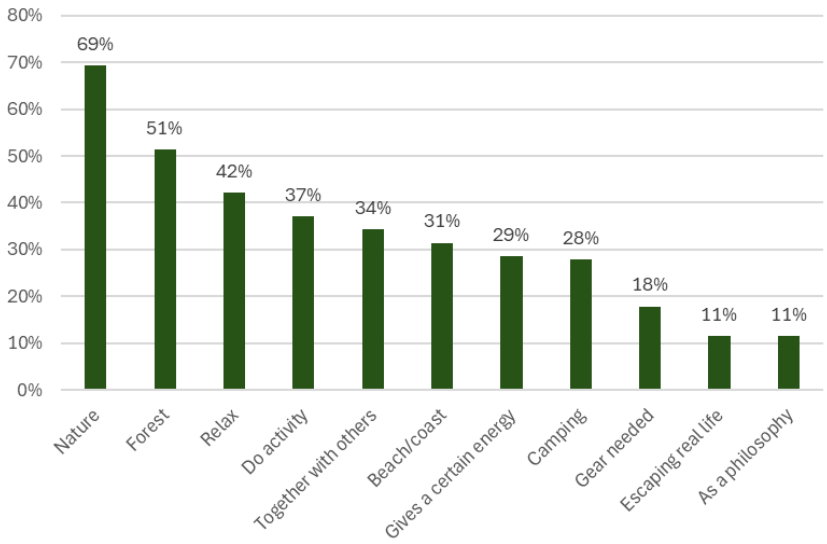
Answers to the questions 'Do you know the concept of friluftsliv?'



When the respondents needed to describe what friluftsliv means for them, they linked it mostly to nature (Figure 12). They also mentioned specific places in their definition like the forest or the beach/coast. It is also about doing activities, sometimes together with others, that bring relaxation. Between the locals and the visitors, there were no significant differences, which means that they perceive friluftsliv in similar ways. Between the genders there were some interesting significances. Women mentioned the word 'nature' more ($p < 0.001$), but also 'relax' ($p = 0.02$), 'together with others' ($p = 0.012$), 'forest' ($p = 0.004$) and 'beach/coast' ($p = 0.011$). This outcome could also be due to the fact that women indicated more words.

Figure 12:

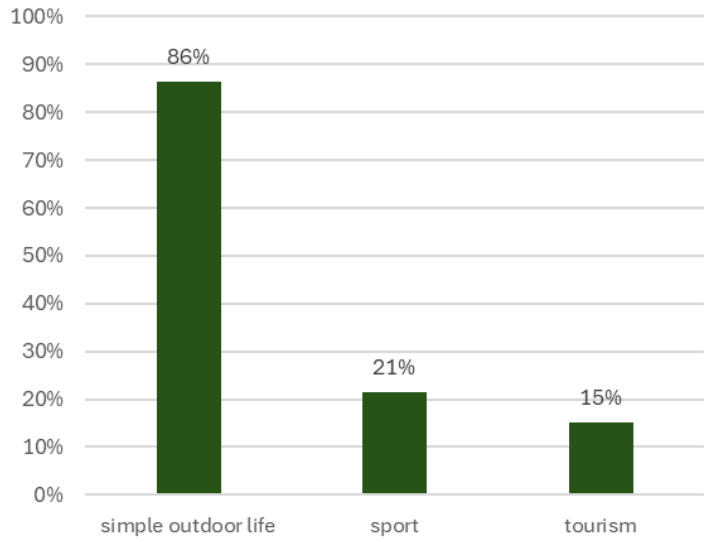
Answers to the question 'How would you describe friluftsliv?'



As described in 2.2, Friluftsliv in Denmark, there are three major types of friluftsliv practised in Denmark. Most people in Odsherred like to keep it simple, 86% indicated they prefer friluftsliv as a simple outdoor life (Figure 13). A lower number of people use nature as an arena for sports (21%) or as a place for tourism (15%). Locals and visitors share this opinion, since there were no significant differences.

Figure 13:

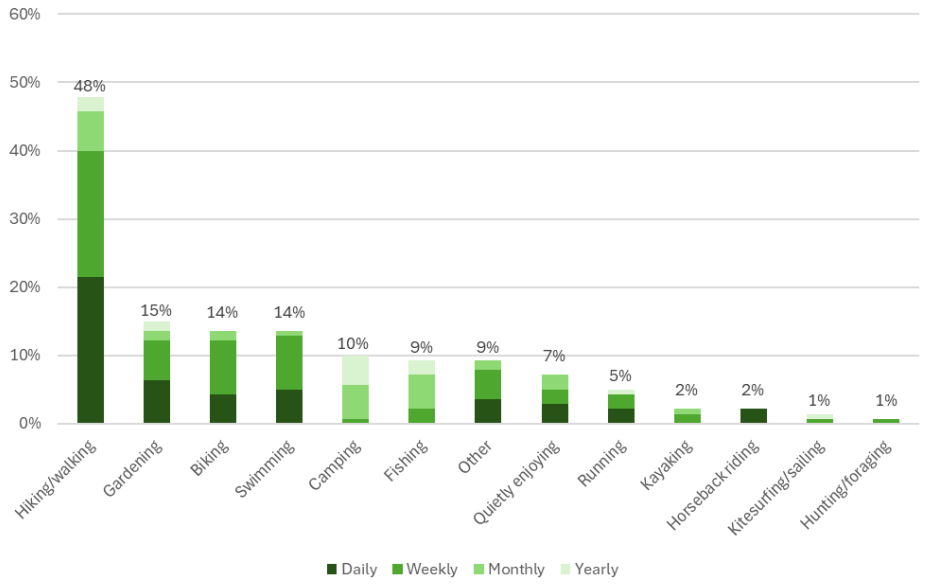
Answers to the question 'What type(s) of friluftsliv do you do yourself?'



Within these three big types, a lot of different practices and experiences could be done (Figure 14). One result stands out in Odsherred, namely hiking and walking. 48% of the respondents denoted doing this, where almost half of them go for a walk on a daily or weekly basis. Furthermore, around 14-15% enjoys daily or weekly gardening, biking or swimming. Camping, fishing or quietly enjoying is the preferred friluftsliv-experience of 7-10% of the respondents. Running, kayaking, horseback riding, kitesurfing/sailing, and hunting/foraging is less often done by people in Odsherred. Important to note is that all the types of activities offered as an option in the survey where chosen at least once. It is striking that there is no significant difference in experiences between locals and visitors. That means that the people who visit Odsherred, seek out the same activities that locals do. Yet, women preferred to go swimming ($p = 0.015$) and men to go fishing ($p = 0.002$). No significant differences were distinguishable between the age groups, only the activity of fishing was done more often by young adults ($p < 0.001$).

Figure 14:

Answers to the question 'Which type of friluftsliv-experiences do you do'

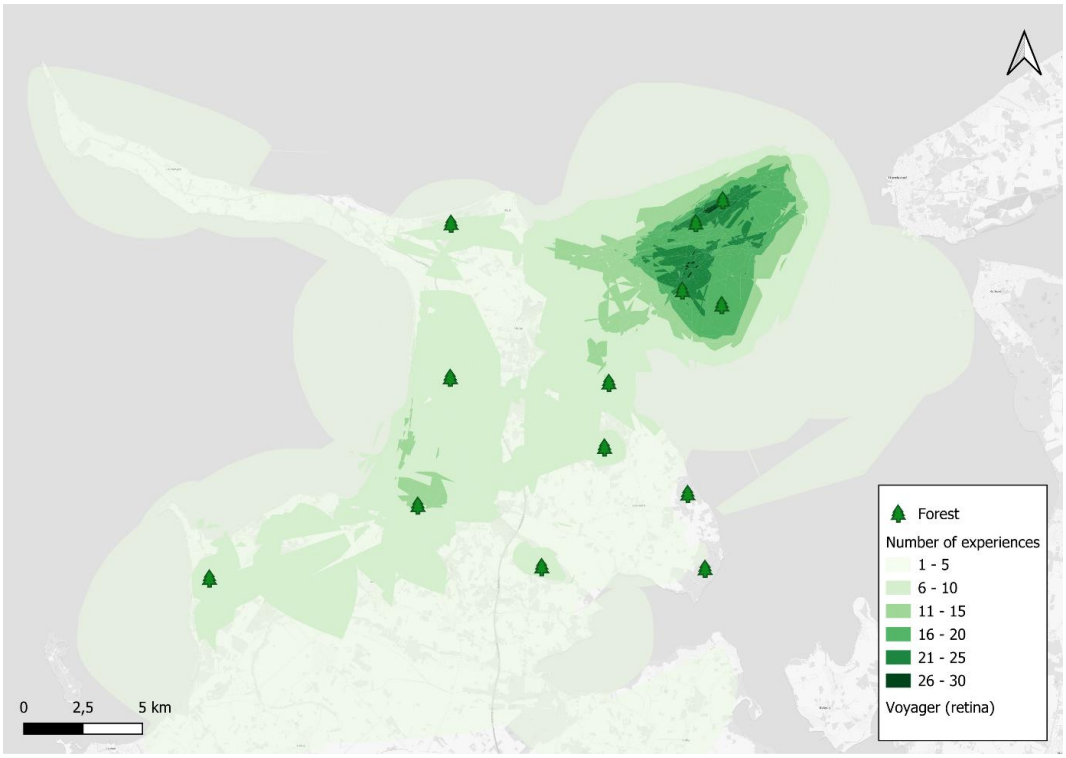


4.2.3 Where?

To be able to answer where people experience friluftsliv, a series of heatmaps were made using the data derived from the PGIS-survey. The first heatmap (Figure 15) shows the overlap of all the experiences, so using the whole dataset. This map shows that most people experience friluftsliv in and around Nykøbing. There is a dark green area in the city centre, but also in the northeastern corner of Odsherred. As shown on the map, these areas roughly overlap with forests nearby. Another area that is visited a lot is the west coast of Odsherred. The big light green area of 6-10 experiences overlaps a lot with the summerhouse area on the west coast. There is also a dark green area of 11-15 experiences that overlaps with a forest nearby. So in general this map shows that people tend to go near the coast or a forest to experience friluftsliv in Odsherred.

Figure 15:

Heatmap of all experiences (locals and visitors)



To be able to look at the differences between local and visitors, as described in the research question, these experiences were filtered. Figure 16 shows the friluftsliv experiences of visitors. Again the centre of Nykøbing is very popular as well as the northeastern corner of Odsherred with dark areas overlapping or being near to forests. Also, the west coast with the summerhouses turned out to be popular with an overlap count between 5-7 and 8-10. This is pretty similar to the general heatmap.

Figure 16:

Heatmap with all experiences of visitors

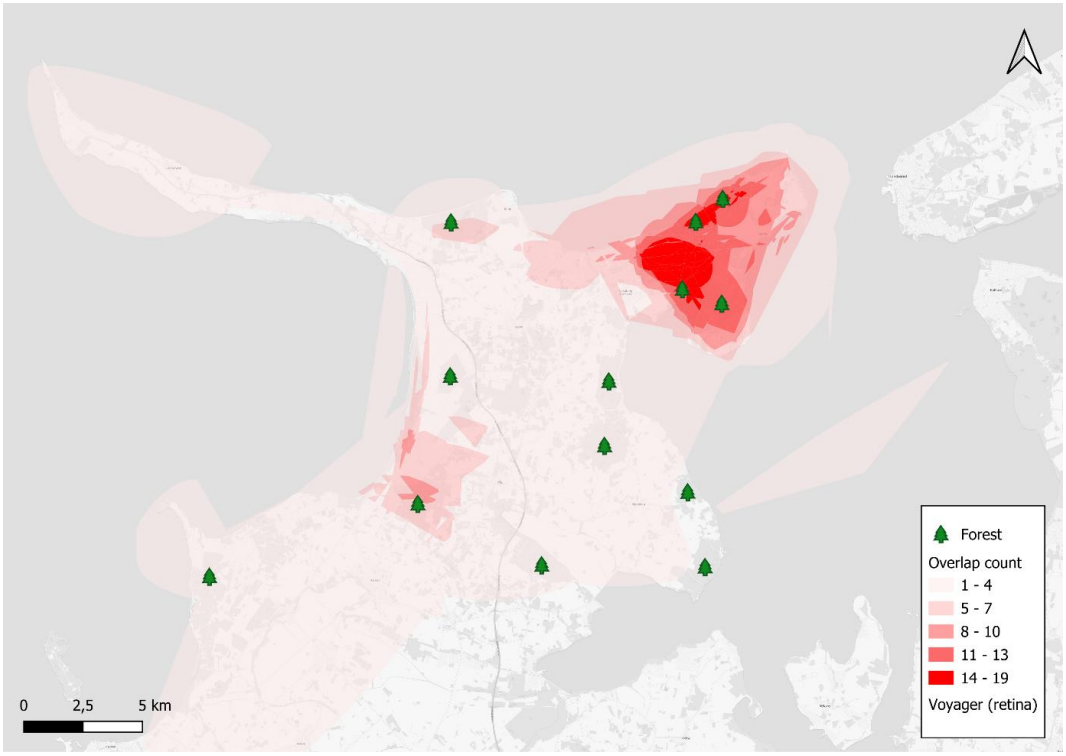
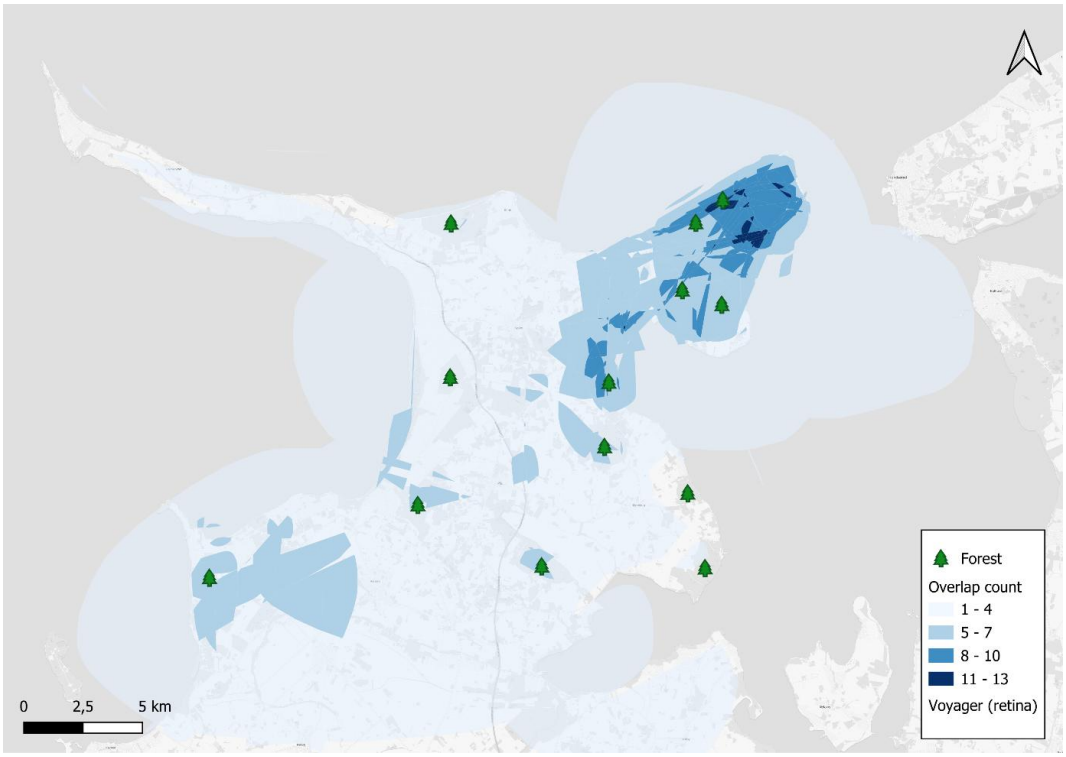


Figure 17 shows the friluftsliv experiences of locals. Compared to the heatmap of visitors, the centre of Nykøbing is less used and the tip of the northeastern corner is a lot more popular. Also a lot of the dark blue areas correspond to forests, this is a little bit more clear than the heatmap of visitors. Lastly the southwestern part of Odsherred is used more by locals than visitors.

Figure 17:

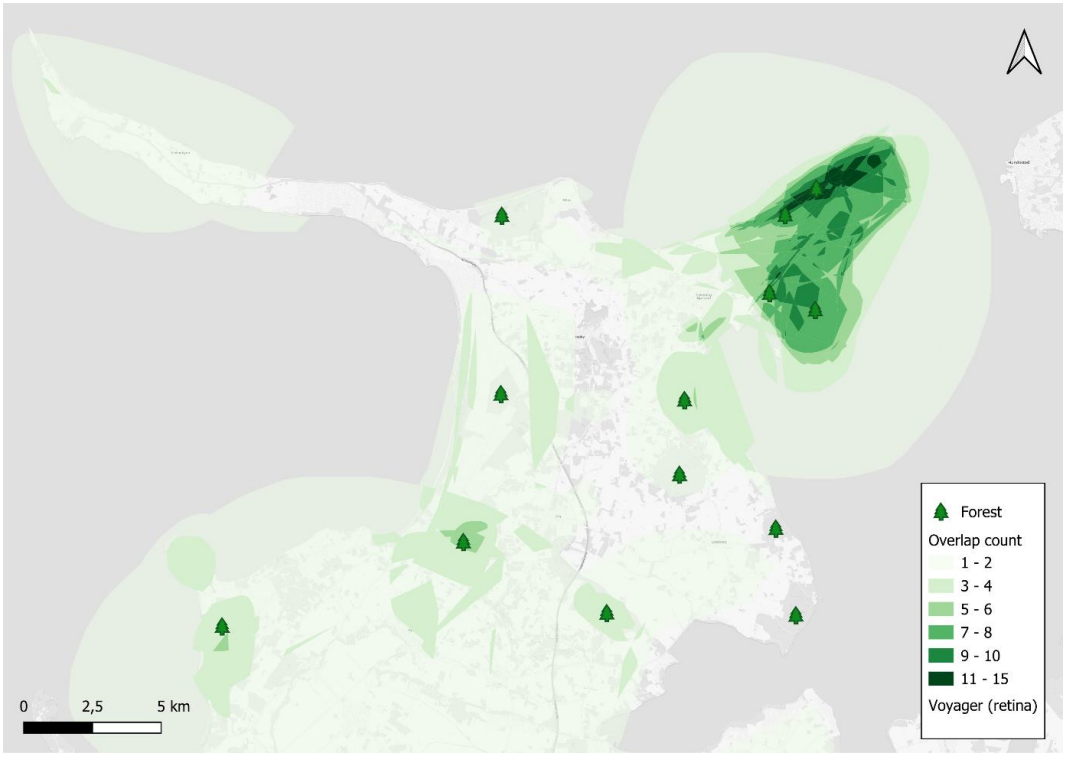
Heatmap with all experiences of locals



Lastly, other heatmaps were made filtering on the activity/experience, so locals and visitors were both included. In this report the two most popular activities will be discussed namely walking/hiking and biking. The heatmaps of the other activities can be found in the appendix. For walking/hiking (Figure 18) almost every forest coincides with a dark(er) green area. So people tend to look for forests when they are going for a walk. Also the northeastern corner is used a lot for walking/hiking.

Figure 18:

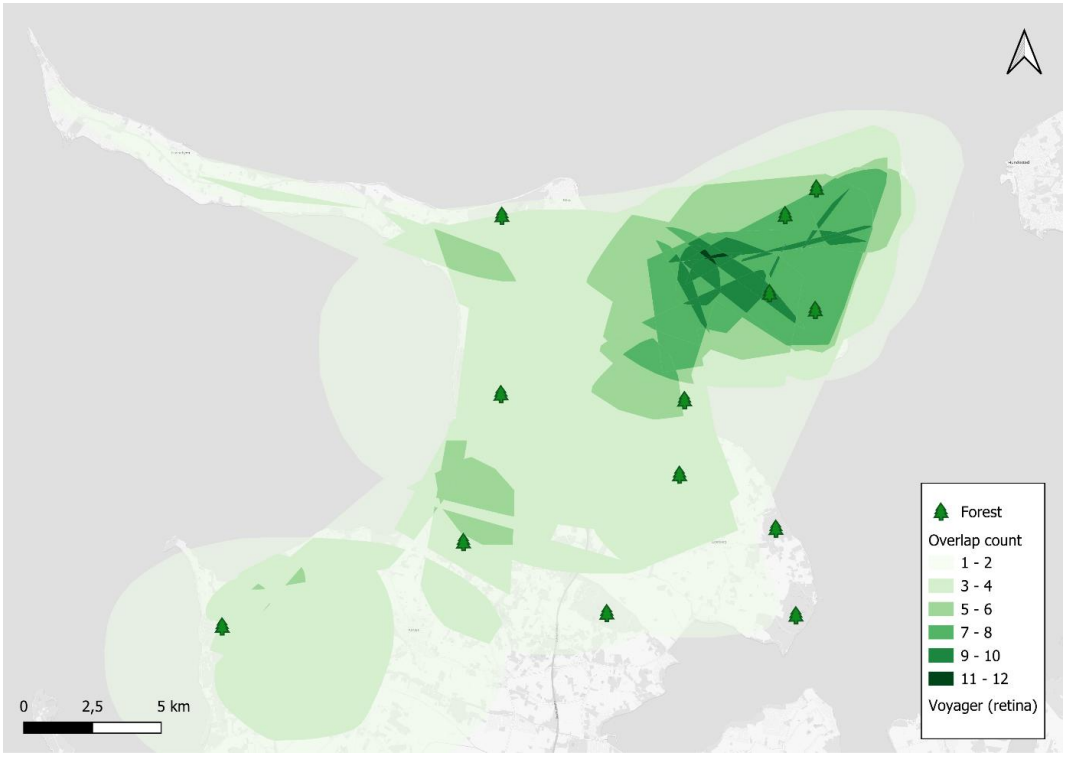
Heatmap showing walking/hiking



When the heatmap of biking (Figure 19) is compared to the heatmap of hiking/walking, biking is much more spread out in Odsherred. People can cover a much bigger area and this shows in the results of the survey. The respondents indicated bigger areas, often the whole region. That is why the centre of the region lights up, but also the area near Nykøbing is still very popular.

Figure 19:

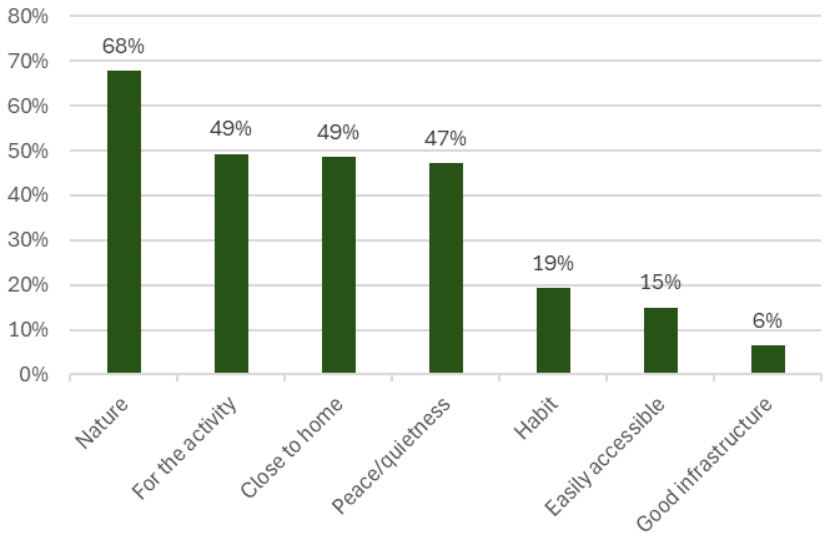
Heatmap showing biking



The survey asked a few more questions about their specific experiences such as 'Why do you go there exactly?'. This was a multiple choice question where people could choose multiple answers. The answers and their percentages are shown in Figure 20. This figure shows that nature is very important for the respondents as the heatmaps already showed with the forests, but also 'close to home', 'for the activity' and 'peace/quietness' were chosen a lot. So people look for quiet places in nature close to home where they can do the activity they want.

Figure 20:

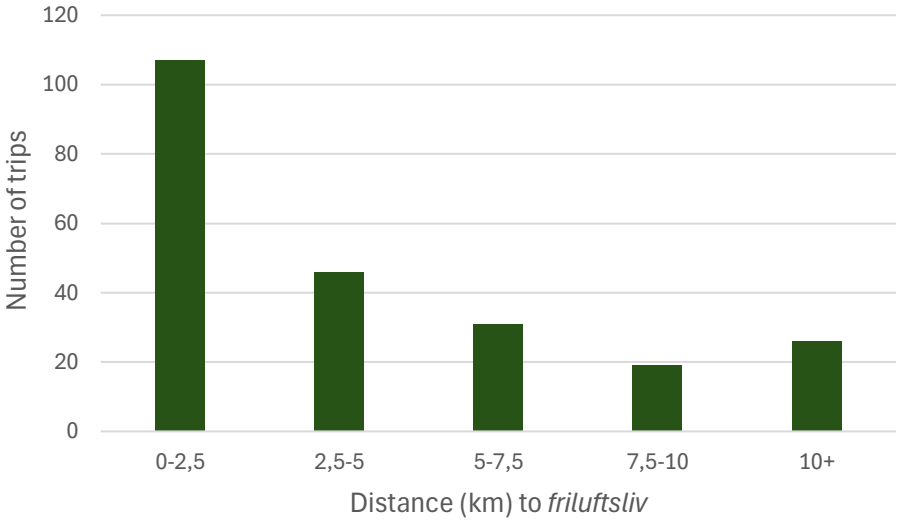
Answers to the question 'Why do you go there exactly?'



In addition, the place of residence of a respondent was linked to the specific experiences of this person, so the distance between both places could be calculated. Figure 21 shows for each experience how far the respondent travelled from their home or summerhouse. This is in line with Figure 20 where the answer 'close to home' was chosen a lot. Here a distance between 0 and 2.5 km was the most frequent, with the amount of trips steadily declining the further the experience is.

Figure 21:

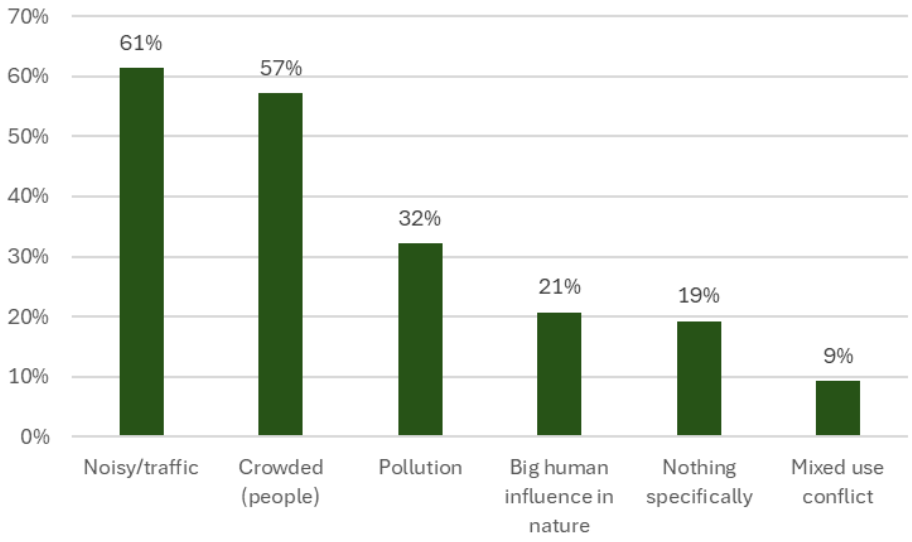
Relationship between the distance from home to the experience and the number of trips



People definitely avoid certain places or some factors while practising friluftsliv. Figure 22 shows that 61% of the respondents do not like places with a lot of noise or traffic. Besides that, 57% of people stay away from places that are too crowded. This links back to the fact that people look for peace and quietness while doing friluftsliv. Furthermore, places that are polluted or influenced a lot by humans are avoided.

Figure 22:

Answers to the question 'Which places/What factors do you try to avoid while doing these experiences?'

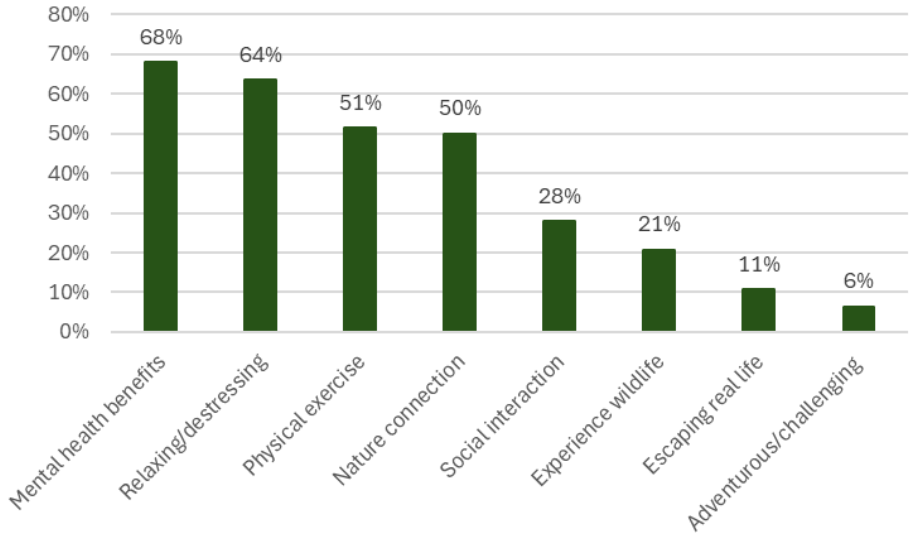


4.2.4 Why?

A lot of factors motivate people to go outside and experience friluftsliv (Figure 23). The biggest motivations are the benefits for their mental health (68%). The advantages that nature and being outside brings to the table is backed up by science. Significantly more women (76%) point out these benefits ($p = 0.045$). Linked to this is the feeling of relaxing and destressing that 64% of the respondents experience. This is mentioned mostly (85%) by middle aged people ($p = 0.006$). A possible hypothesis for this is that they already work for a long time and thus feel a higher need to destress. This group also mentions more 'nature connection' (66%) in their answer ($p = 0.028$). Besides mental health, physical health is also a very important aspect for people that do friluftsliv (51%). Seniors in particular (62%) find it very important to stay mobile ($p = 0.004$). Connecting with others during friluftsliv is important for 28% of the respondents. This motivates more women (36%) than men (20%) ($p = 0.044$). Between locals and visitors no significant different motivational factors were found.

Figure 23:

Answers to the question 'What motivates you the most to have outdoor experiences?'

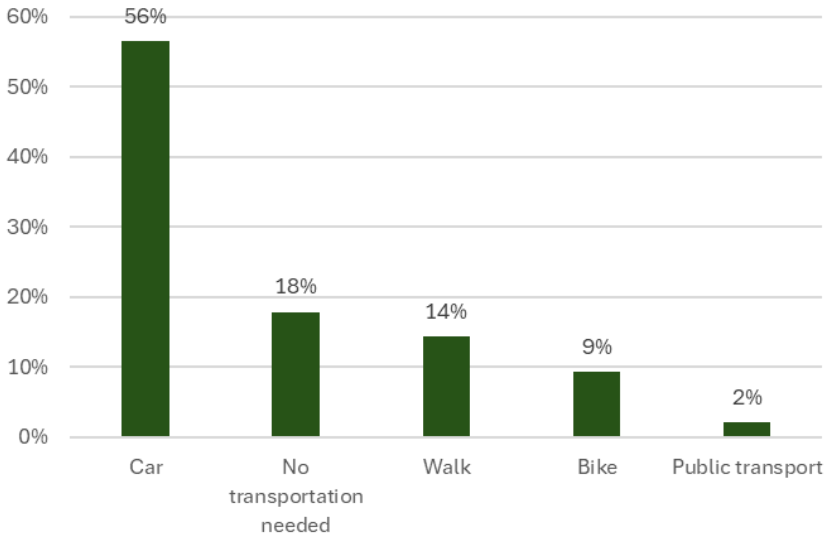


4.2.5 How?

Although friluftsliv is often experienced close to home (Figure 20 and 21), most people still use a car (56%) to get to that specific location (Figure 24), like the beach or a forest. In addition, 18% do not require any form of transportation, which also points to the fact people stay in their neighbourhood and friluftsliv starts at their doorstep. Public transport is hardly used.

Figure 24:

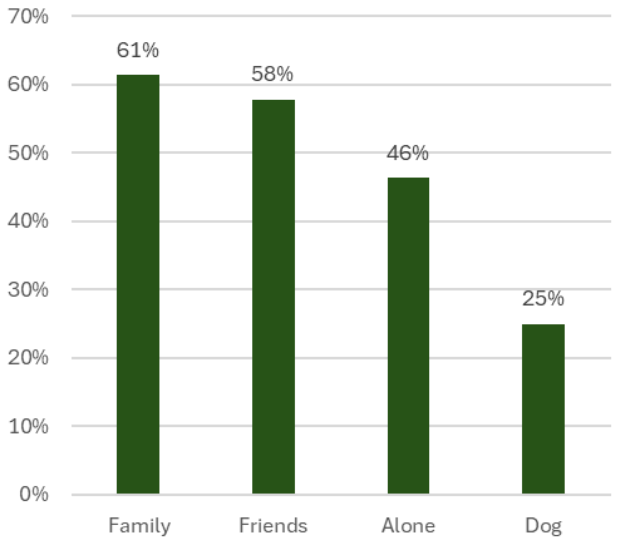
Answers to the question 'Which mode of transport do you mostly use to get to the place where you experience friluftsliv?'



Most of the time people do outdoor activities with their family (61%) and friends (58%) (Figure 25). The respondents mentioned that they often do friluftsliv with their partner. This links back to the fact that friluftsliv is not only about connecting with nature, but also with others. 34% of the respondents indicated 'together with others' in their definition on friluftsliv (Figure 12). Nevertheless, people also enjoy being on their own. They talked about how personal time let them properly destress and relax. People who have a dog, took the dog with them on their friluftsliv-experiences, especially on daily walks. Significantly more women (34%) went out to walk the dog ($p = 0.015$). Between other factors, like age groups or local/visitor, there were no significant differences in who they practise friluftsliv with.

Figure 25:

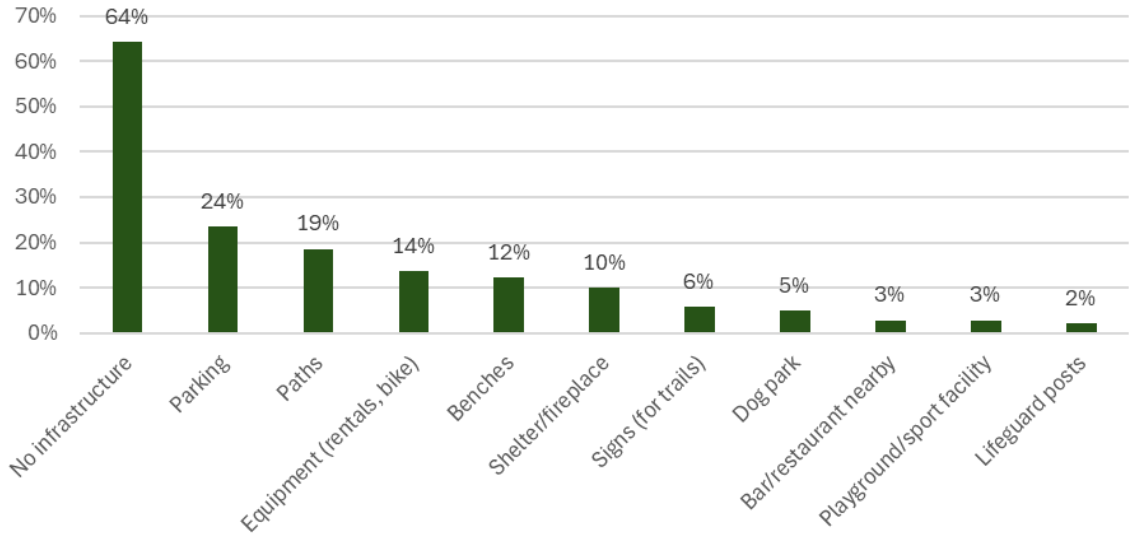
Answers to the question 'With whom do you do these things?'



On the question 'Which infrastructure do you need?' (Figure 26), people clearly stated they do not need any kind of infrastructure for their experiences. This is related to the 'simple outdoor life'-style of friluftsliv that people prefer to practice. They do not need fancy gear or infrastructure to feel connected to nature. On the question 'Why do you go there exactly?', the answer 'good infrastructure' was the least popular (Figure 20). It can be concluded that a good friluftsliv-spot is not defined by its infrastructure. Yet, 24% of the respondents reported that a parking lot is useful, especially for those who come by car.

Figure 26:

Answers to the question 'Which infrastructure do you need?'



4.2.6 Profiles of friluftsliv-users

The analysis of friluftsliv-practices among respondents revealed three distinct clusters, each reflecting different motivations, social contexts and activity patterns. These clusters are labelled the Relaxation-Oriented Enjoyers, the Nature-Oriented Allrounders, and the Family-Oriented Tranquillity Seekers, based on their dominant characteristics. All descriptive statistics and percentages mentioned below, as well as additional numerical details not discussed in this section, can be found in the appendix.

The Relaxation-Oriented Enjoyers constitute a group primarily characterized by their social orientation and preference for alternative outdoor practices. This cluster consists of 66% men, and shows a clear tendency to engage in friluftsliv with friends (84%) rather than with family (32%). This cluster is also the least likely to pursue such activities alone. Their dominant motivator is relaxation, which scores highest among all clusters, while mental health is cited far less frequently (45%) compared to the average of 85% in the other groups. Hiking is uncommon in this cluster, with only 16% participation, yet they are more active than average in less mainstream outdoor activities. While 61% of this group is familiar with the concept of friluftsliv, their overall conceptual engagement is somewhat limited. A slight majority are local residents (57%), suggesting that their outdoor practices are embedded in a known, social environment rather than exploratory or nature-focused in the traditional sense.

In contrast, the Nature-Oriented Allrounders display the most holistic and ideal-typical interpretation of friluftsliv. This group is the most female-dominated, only 42% men, and scores exceptionally high on a broad range of motivational dimensions. Physical activity (67%) and contact with nature (100%) are key drivers, and interest in wildlife (52%) is also considerably higher than in the other clusters, where this motivator averages just 12%. Mental health (94%) and social interaction (58%) are also strong motivating factors. Moreover, this cluster stands out for its universal familiarity with the concept of friluftsliv (100%). In terms of activity, hiking is very prominent (73%), and this group appears to enjoy a wide range of social contexts, as they frequently engage in friluftsliv both alone, with friends, and with family. Only 45% of this group are locals, indicating a more exploratory or visitor-based orientation to outdoor recreation.

The third group, labelled Family-Oriented Tranquillity Seekers, shows a more domesticated and intimate approach to friluftsliv. With a near even gender distribution (52% men), this cluster stands out for its strong family orientation: 79% undertake friluftsliv with family, whereas only 24% do so with friends. This is the lowest among all clusters. Additionally, only 43% engage in activities alone, compared to 50% on average in the other groups. Despite scoring around the average on motivators such as relaxation, nature, wildlife, and mental health, this cluster places almost no emphasis on social interaction (8%) as a motivating factor. Their familiarity with the concept of friluftsliv is relatively high (81%), and 57% participate in hiking. Notably, gardening is also a more prominent activity here, reflecting a preference for routine, home-based forms of outdoor engagement. With 62% of members being local residents, this group likely reflects a lifestyle where friluftsliv is closely tied to everyday domestic rhythms rather than recreational novelty.

5 DISCUSSION

This study provides valuable insights into how friluftsliv is experienced in Odsherred. First of all, most respondents (79%) knew the concept of friluftsliv, which emphasises that it is a well-known and important practice. Important to mention is that some of the people who indicated no did not fully understand the question because later on in the survey some said they actually knew friluftsliv. So the actual percentage is even higher. The visitors significantly knew friluftsliv less then locals, this could be due to foreign visitors. While the concept is often described in literature as shifting towards a technical or recreational framework in Denmark, the results of this research show that its core values remain largely intact. Most respondents engage in friluftsliv in a simple and accessible way, close to home and with minimal infrastructure. This contradicts the idea that the philosophical dimension of friluftsliv has been lost. On the contrary, the practice appears deeply embedded in everyday life, where people are motivated to go outside and into nature because of all the benefits it gives. There is less focus on commercial or sport-related ambitions. Friluftsliv in Denmark can be interpreted as open, flexible and inclusive. Numerous forms of outdoor activities, from walking and biking to gardening or simply sitting in nature, are considered as possible friluftsliv experiences. This aligns closely with the simple outdoor life, the genuine form of friluftsliv, which emphasises simplicity, connection with nature and emotional well-being. Furthermore, a clear majority of participants preferred this simple outdoor life. The absence of a need for infrastructure or material equipment was found a lot in the survey, and many activities took place in forests or coastal areas without facilities. This confirms that the essence of friluftsliv does not lie in infrastructure development but in the quality and accessibility of natural environments. Similarly, transport patterns reinforce the local nature of the practice. Many respondents did not require transportation at all, or used active modes such as walking and biking. While a car was used by some, distances remained short. The simplicity of both infrastructure and mobility supports the Danish national friluftsliv policy's emphasis on equal and daily access to outdoor spaces for everyone, as outlined in the national guidelines. This policy advocates that friluftsliv should be for everyone, in every season, and not dependent on costly equipment or transport.

The connection between friluftsliv and mental health is one of the most significant outcomes. Almost 70 percent of respondents stated that their primary motivation for going outside was their mental health and to relax or reduce stress. These motivations strongly align with existing research which confirms the benefits of being in nature for psychological well-being. Furthermore, respondents frequently mentioned peace and quietness as preferred environmental characteristics, while noise, traffic and overcrowding were identified as reasons to avoid certain areas. These preferences highlight the importance to preserve and protect calm, undisturbed

nature areas and make them accessible to avoid overburdening and damaging a limited number of well-known sites.

The social aspect of friluftsliv also emerged as an important theme. Many respondents indicated that they practised outdoor activities together with partners, friends or family. Interestingly, a big group also engaged in activities with dogs. Given that around one in four respondents appeared to be dog owners, walking the dog was a frequent and routine form of nature engagement. This underlines the role of pets as facilitators of daily friluftsliv, a dimension that has received relatively little attention in literature and deserves further exploration.

One unexpected outcome concerns the limited distinction between locals and visitors. Literature and expert interviews often assert a clear divide, with locals engaging in frequent, informal friluftsliv, while visitors are believed to rely on structured destinations and tourism infrastructure. However in this study, few significant differences were found in activity type, location preference or motivation. A possible explanation is the presence of summerhouse owners within the visitor category. These individuals, although not permanent residents, have a repeated and long-term interaction with the area and often develop habits and preferences similar to those of locals. This may blur the distinction and needs further research. Additionally, the structured nature of the survey may have been insufficient to detect deeper social, emotional or cultural differences. Future research using qualitative methods could explore these more subtle layers of identity, connection to nature and temporality of friluftsliv in more depth.

Methodologically, the use of participatory GIS provided valuable insights into where friluftsliv takes place. The resulting heatmaps revealed consistent hotspots in forests and coastal zones, confirming that these environments are key settings for outdoor life in Odsherred. However, several limitations must be acknowledged. The convex hull method used to process the spatial data may have expanded the areas indicated by respondents, especially for activities with a limited spatial extent such as walking loops. A better approach could be to make a distinction between point, line, and area-based inputs, or integrating data from GPS-based platforms such as Strava to get a better insight into movement patterns. While such refinements were not feasible within the scope of this project, their potential for improving future spatial analysis should not be overlooked.

Other methodological concerns include sampling bias. Surveys were conducted mainly at supermarkets and during weekday working hours, which likely skewed the dataset toward older residents and people living near urban centres such as Nykøbing. Also the amount of surveys could have been more equally spread out among

Odsherred. Now a lot of the surveys were done at one supermarket near Nykobing. These flaws may have influenced the results both demographically and spatially. Moreover, some questions may not have been fully understood by all respondents. For example, certain terms like 'mixed-use conflict' or infrastructure-related items may have lacked clarity, limiting the interpretive value of these responses. Greater care in survey design and a broader sampling strategy could help mitigate these issues in future studies.

Despite these limitations, the findings of this study have practical relevance for spatial planning and policy development. They suggest that investments should prioritise the protection and accessibility of quiet, undeveloped nature areas close to where people live. Infrastructure is not always necessary, but ensuring legal access, basic maintenance of trails and protection from overuse remains essential. Particularly in Denmark, where the legal right to roam is absent, the creation and preservation of public access zones such as beaches and state forests becomes critical. The results also highlight the importance of decentralised planning that supports friluftsliv not only in popular destinations but in everyday neighbourhoods. This aligns with the values expressed in the Danish national friluftsliv strategy and supports broader goals related to sustainability, mental health and community well-being.

In terms of broader implications, this study invites several new research directions. The blurred boundary between locals and visitors calls for a more refined division between social groups and a deeper understanding of place-based behaviours. Emotional connections to specific locations, as well as seasonal variation in use, are topics that would benefit from more qualitative investigation. The role of pets, gender differences in perception and motivation, and barriers for disadvantaged populations also offer promising opportunities for further research. Additionally, the relationship between friluftsliv and shifting forms of mobility, including the growing popularity of walking, gravel biking, and micro-experiences like gardening, raises questions about how outdoor practices are evolving and what planning policies are needed to respond to this.

6 CONCLUSION

This research is set out to better understand what friluftsliv means in the specific context of Odsherred, and how the ways in which people engage with outdoor life differ between locals and visitors. By combining literature, expert interviews and participatory spatial data, insights were gained in both the conceptual depth and the practical realities of friluftsliv. The results show that friluftsliv in Odsherred is not a narrowly defined activity, but a broad and inclusive practice that reflects a deeply rooted cultural relationship with nature. Most respondents (both locals and visitors) engaged in simple, low-threshold forms of outdoor recreation, such as walking, biking, gardening or swimming, often close to home or in natural areas like forests and coastlines. These practices are not primarily driven by infrastructure or performance, but by the need for relaxation, mental well-being and a sense of connection with the landscape.

While differences between locals and visitors were expected to occur, no significant differences could be found. Summerhouse owners appeared to navigate outdoor spaces in ways that resembled local behaviour. According to the interviews, seasonal patterns also shaped spatial use: visitor intensity normally peaks during summer months, prompting subtle forms of avoidance or temporal adjustment among locals. Nevertheless, both groups largely shared the same values, places and motivations.

This research not only answers the question of how friluftsliv is understood and practised in Odsherred, but also shows why such knowledge matters. As pressure on open space increases through tourism, urbanisation and changing lifestyles, it becomes more important to plan for accessible, inclusive and resilient nature experiences. These findings can help inform spatial planning, recreational infrastructure and public health policy by highlighting what people actually value in outdoor environments: not necessarily more facilities, but quality, calmness and proximity. Moreover, this study demonstrates the usefulness of participatory GIS methods for mapping informal and emotionally meaningful landscape use, which are types of knowledge that are often overlooked in formal planning. By visualising where people go and why, planners and policymakers can make more grounded and equitable decisions, supporting friluftsliv as a public good.

In short, friluftsliv in Odsherred is not just an activity, but a living relationship between people and place, shaped by culture, context and everyday choices. Friluftsliv is a simple act, which gives people a lot of richness in return. Understanding the dynamics of friluftsliv is essential for the preservation and strengthening of outdoor life in Denmark for future generations.

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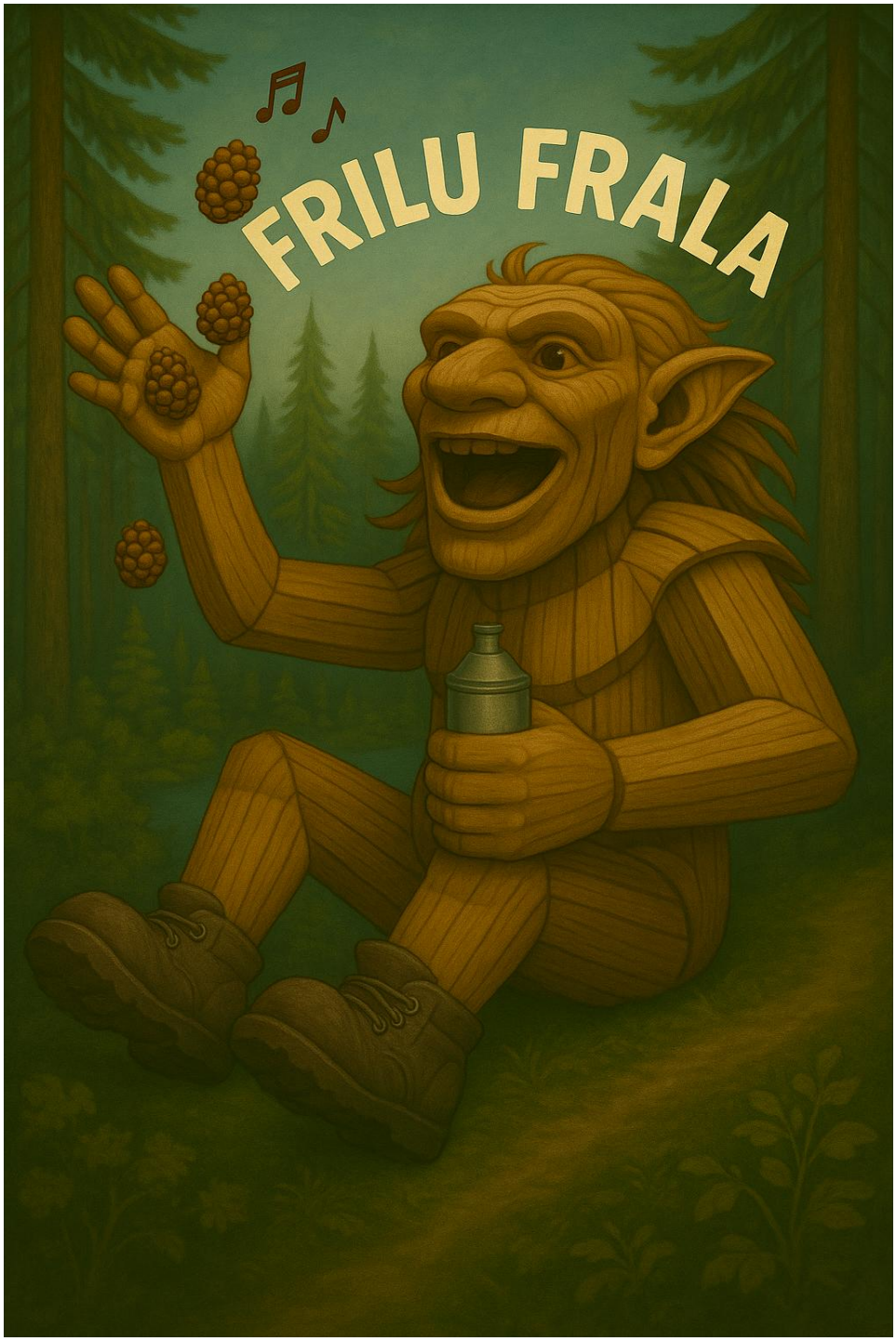
8 APPENDIX

8.1 Frilu Frala

Figure 27:

Frilu Frala, the embodiment of friluftsliv.



🌲 ✨ friluftsliv nel cuore, la natura mi chiama e io rispondo col cuore aperto 🍄 💚

8.2 Interview questions

A. General definition and context of friluftsliv

1. How would you describe friluftsliv within the Danish context?

2. To what extent does the interpretation of friluftsliv in Denmark differ from other Scandinavian countries (certain other values and/ or principles)?

3. How does the absence of the Right to Roam (Allemansretten) in Denmark impact friluftsliv?

4. Are there any specific cultural or historical elements that have shaped the Danish view of friluftsliv?

B. Friluftsliv in Odsherred

5. How important is friluftsliv in Odsherred (compared to other regions in Denmark)?

6. What forms of outdoor experiences typically fall under friluftsliv here? (e.g. hiking, kayaking, camping, swimming, cycling, …) Do you have an idea about what people do most often to experience friluftsliv in Odsherred?

7. How is friluftsliv promoted by the local government or other organisations in Odsherred (policy measures, guidance to certain places, infrastructure, …)?

C. Spatial patterns and use of outdoor space

8. Are there certain areas in Odsherred where people are more likely to engage in friluftsliv? If not, why do you think so? And if so, why exactly there? What is the role of the geopark in this? And is there an important link to the distance to their accommodation/house?

9. Do people engage in friluftsliv alone, with family or friends, and how does this impact spatial patterns?

10. Are there (marked) differences in how locals and visitors (tourists as well as people with a summerhouse) experience friluftsliv and explain why you think that there are (no) differences.

11. Do you see differences in experiencing friluftsliv between different ages, genders…? (explain your answer)

12. To what extent do seasonal factors play a role in the use of outdoor spaces for friluftsliv?

13. What challenges or bottlenecks exist in the preservation and accessibility of outdoor spaces for friluftsliv? Do places sometimes get too popular to experience friluftsliv?

D. Infrastructure and future vision

14. What infrastructure do you think is essential to support friluftsliv? Or absence of it? (make link to woodcraft (minimal gear/materials/infrastructure) vs leave no trace (with more gear/materials/infrastructure) friluftsliv)

15. How do you see the future of friluftsliv (in Odsherred)? Do you expect changes in how people use outdoor spaces, are there already trends/changes visible compared to the past, and if so, what changes/trends?

E. Additional insights

16. Do you have any recommendations for literature or other experts we could consult?

17. Is there anything else you think is important to mention regarding friluftsliv in Odsherred?

8.3 Survey questions

1) As which gender do you identify? (radio)
    a. Male
    b. Female
    c. X

2) Do you know the concept of friluftsliv? (radio)
    a. Yes
    b. No

3) If yes, how would you describe it? (checkbox)
    a. Nature
    b. Relax
    c. Beach/coast
    d. Escaping real life
    e. Do activity
    f. Camping
    g. Gear needed (bike, shoes, tent)
    h. As a philosophy
    i. Gives a certain energy
    j. Forest
    k. Together with others

4) What type(s) of friluftsliv do you do yourself? (checkbox)
    a. Sport
    b. Tourism
    c. Simple outdoor life

Questions 5-11 can be done multiple times per activity

5) Which type of experiences do you do? (radio)
    a. Hiking/walking
    b. Camping
    c. Biking
    d. Horseback riding
    e. Swimming
    f. Fishing
    g. Kitesurfing/sailing
    h. Quietly enjoying
    i. Kayaking
    j. Running
    k. Hunting/foraging
    l. Gardening
    m. Other

6) If other, what is the activity you do? (open answer)

7) Indicate on the map where you do this. (map)

8) How often do you do this? (radio)
    a. Daily
    b. Weekly
    c. Monthly
    d. Yearly

9) Which infrastructure do you need? (checkbox)
    a. Paths
    b. Shelter/fireplace
    c. Signs (for trails)
    d. Lifeguard posts
    e. Equipment (rentals, bike)
    f. Playground/sport facility
    g. Parking
    h. Dog park
    i. Benches
    j. Bar/restaurant nearby
    k. No infrastructure needed

10) With whom do you do these things? (checkbox)
    a. Alone
    b. Friends
    c. Family
    d. Dog

11) Why do you go there to experience friluftsliv? (checkbox)
    a. Peace/quietness
    b. Nature
    c. Close to home
    d. Good infrastructure
    e. For the activity
    f. Easily accessible
    g. Habit

12) Do you experience friluftsliv in another way? (radio)
    a. Yes (if yes, back to question 5)
    b. No

13) Which places/What factors do you try to avoid while doing these experiences? (checkbox)
    a. Crowded (people)
    b. Mixed use conflict
    c. Big human influence in nature
    d. Noisy/traffic
    e. Pollution
    f. Nothing specifically

14) What motivates you the most to have outdoor experiences? (checkbox)
    a. Mental health benefits
    b. Physical exercise
    c. Relaxing/de-stressing
    d. Social interaction
    e. Nature connection
    f. Experiencing wildlife
    g. Escaping real life
    h. Adventurous/challenging

15) What is your age? (open answer)

16) Are you a local or a visitor? (radio)
    a. Local
    b. Visitor

17) Indicate your region of stay on the map. (map)

18) What type of job do you have? (radio)
    a. Indoor
    b. Outdoor
    c. Mixed
    d. No job

19) Which mode of transport do you mostly use to get to the place where you experience friluftsliv? (radio)
    a. Car
    b. Bike
    c. Walk
    d. Public transport
    e. No transportation needed

8.4 Other results PGIS survey

Figure 28:

Heatmap quietly enjoying (locals and visitors)

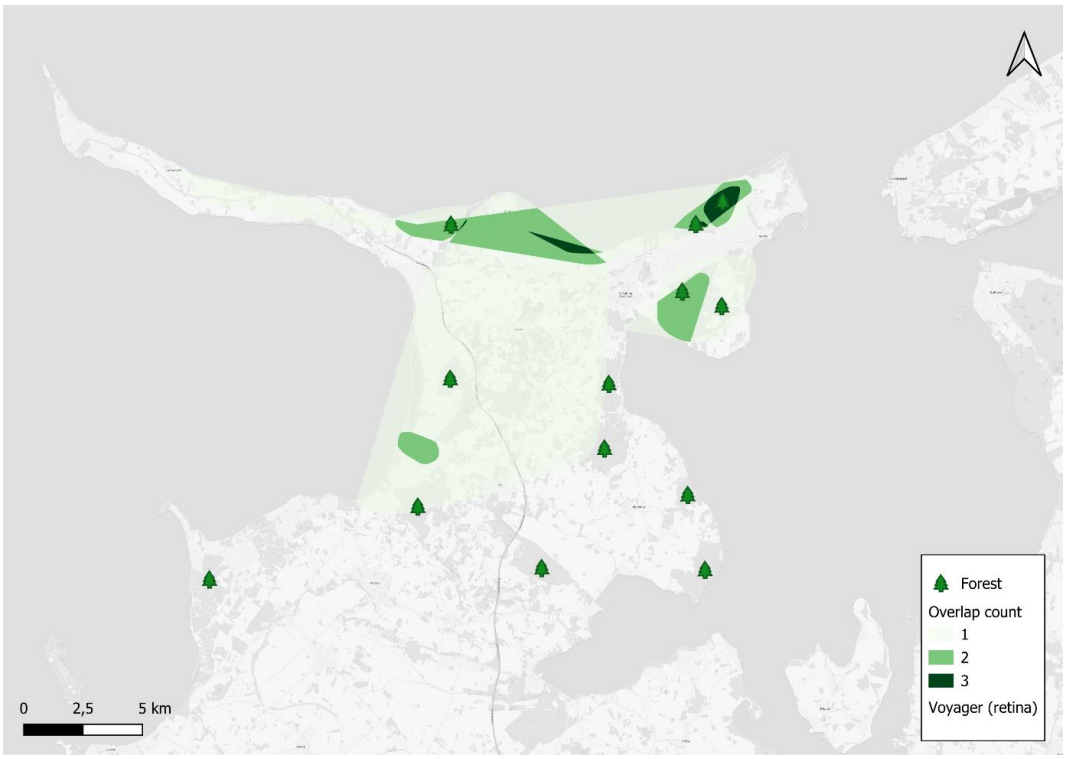


Figure 29:

Heatmap camping (locals and visitors)

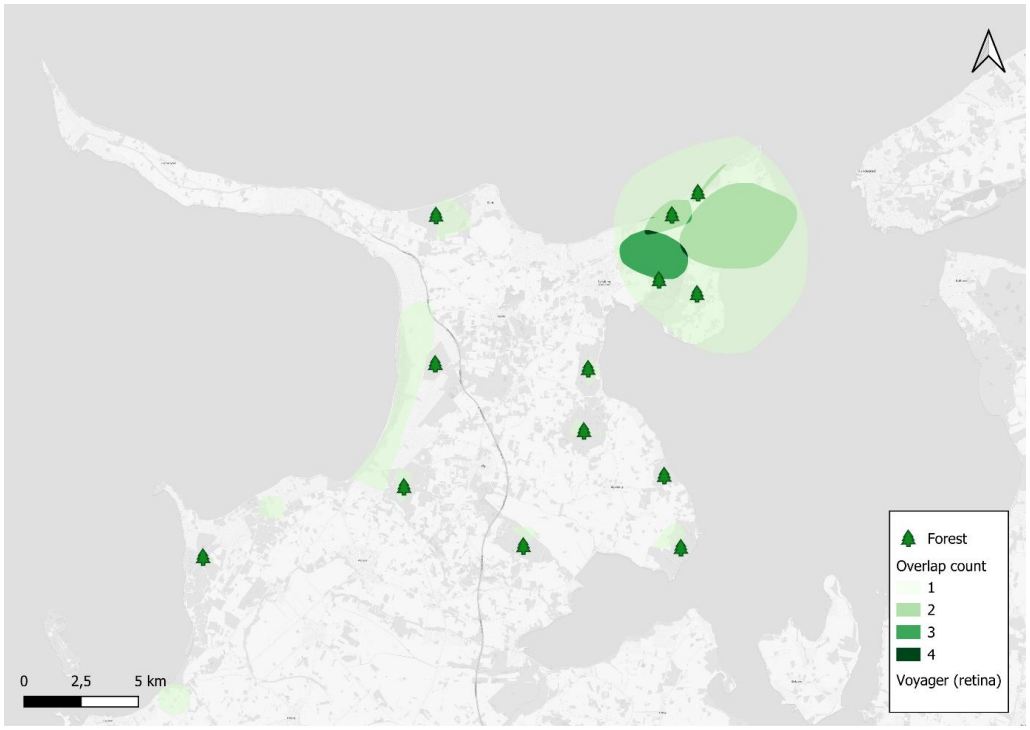


Figure 30:

Map fishing (locals and visitors)

Figure 31:

Heatmap swimming (locals and visitors)

Figure 32:

Heatmap horseback riding (locals and visitors)

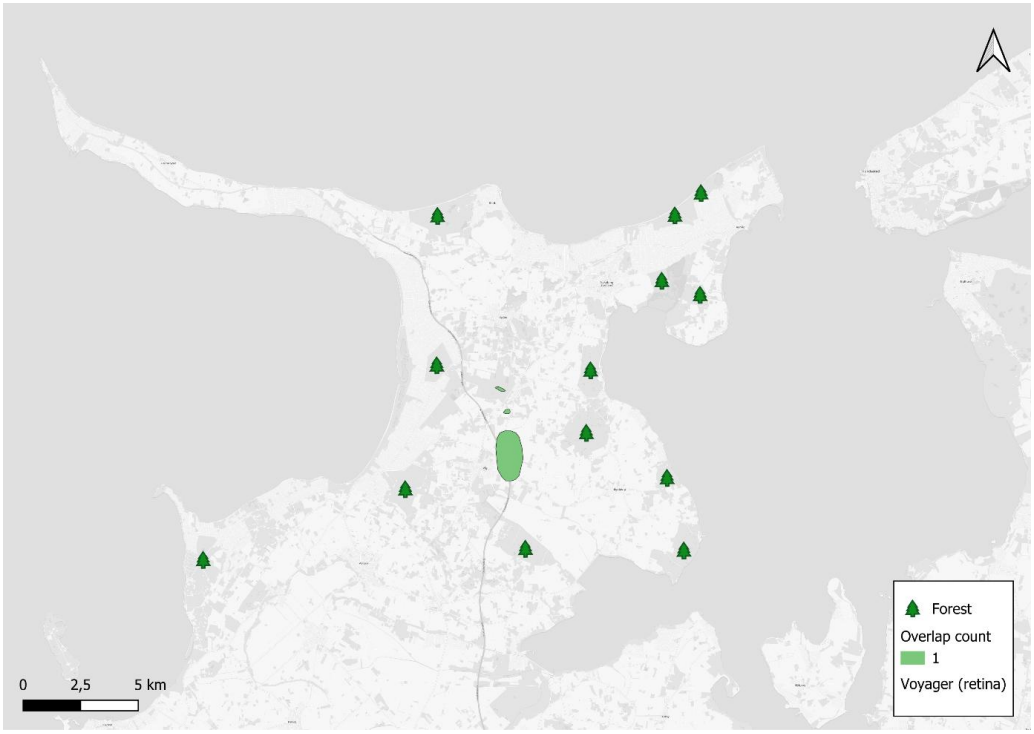


Figure 33:

Heatmap kitesurfing/sailing (locals and visitors)

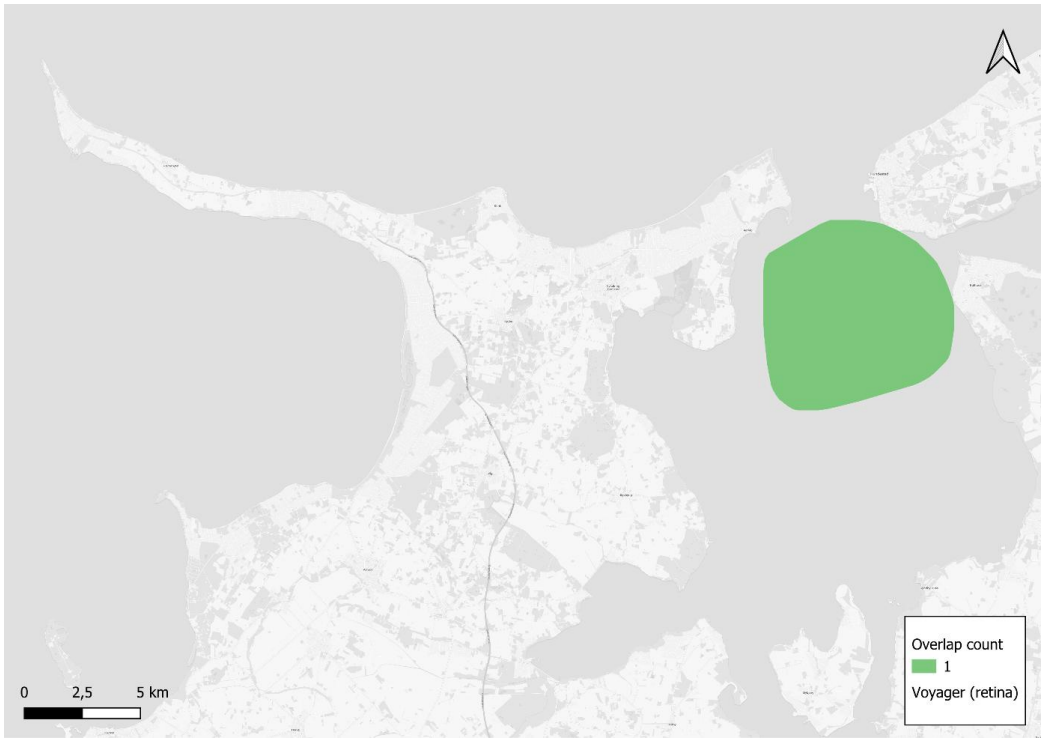


Figure 34:

Heatmap kayaking (locals and visitors)

Figure 35:

Heatmap running (locals and visitors)

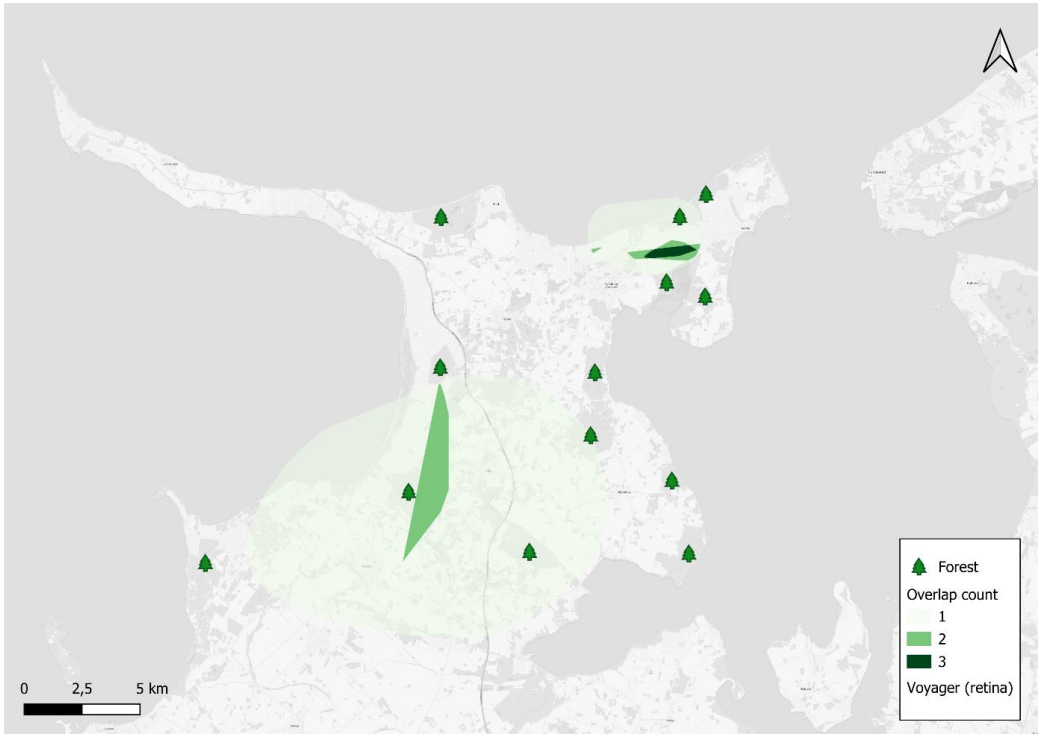


Figure 36:

Heatmap hunting/foraging (locals and visitors)

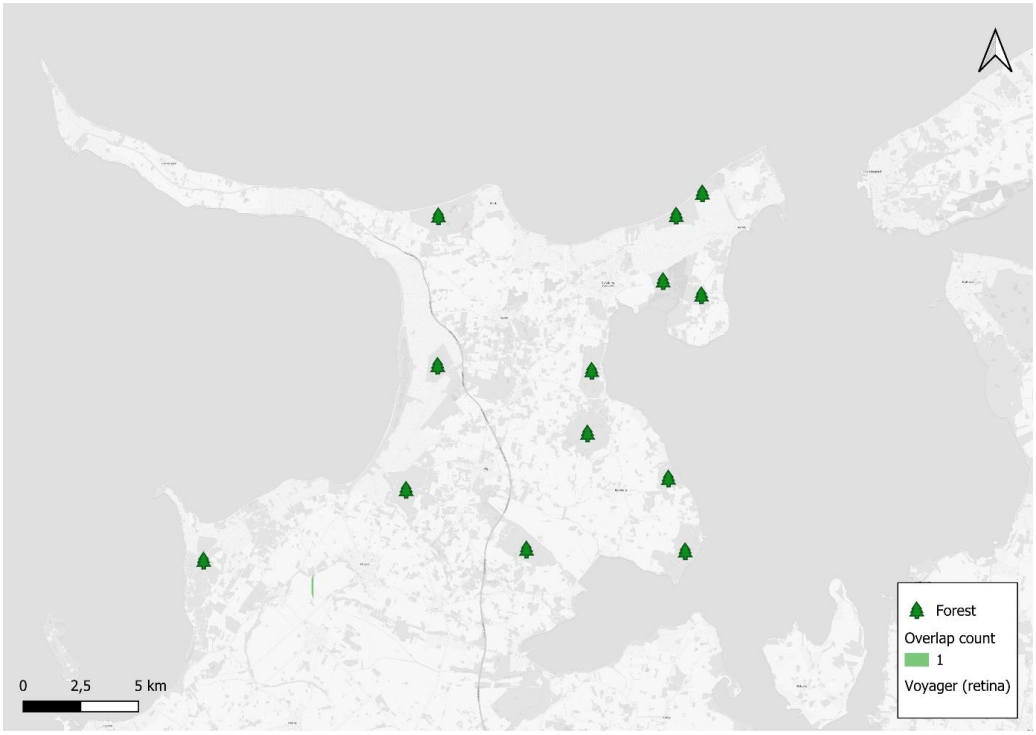


Figure 37:

Heatmap gardening (locals and visitors)

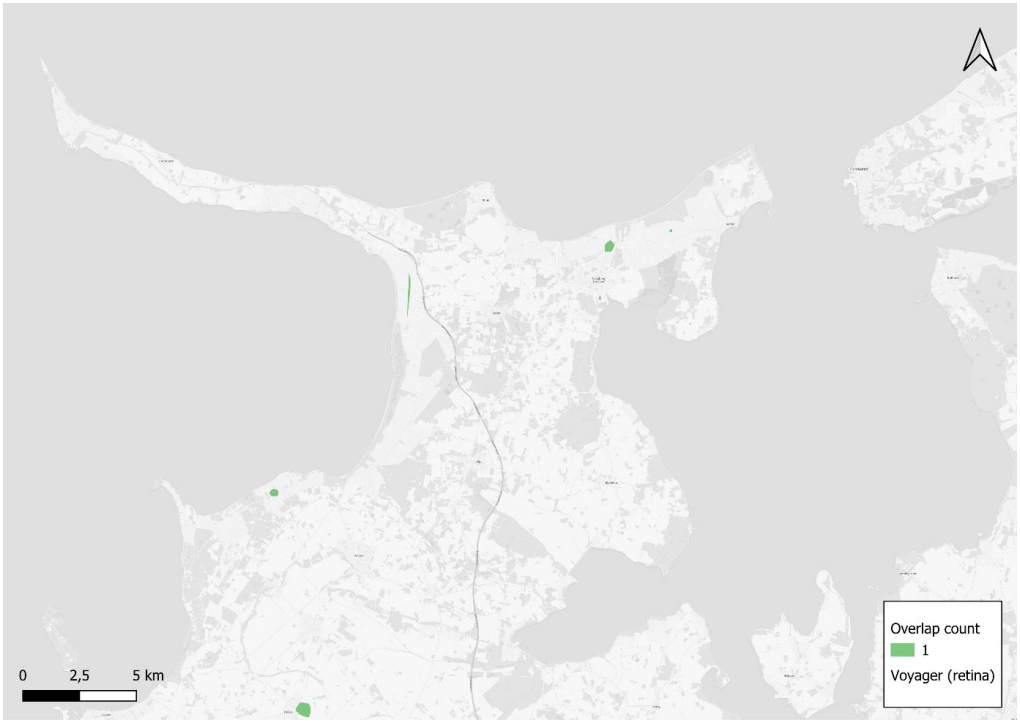
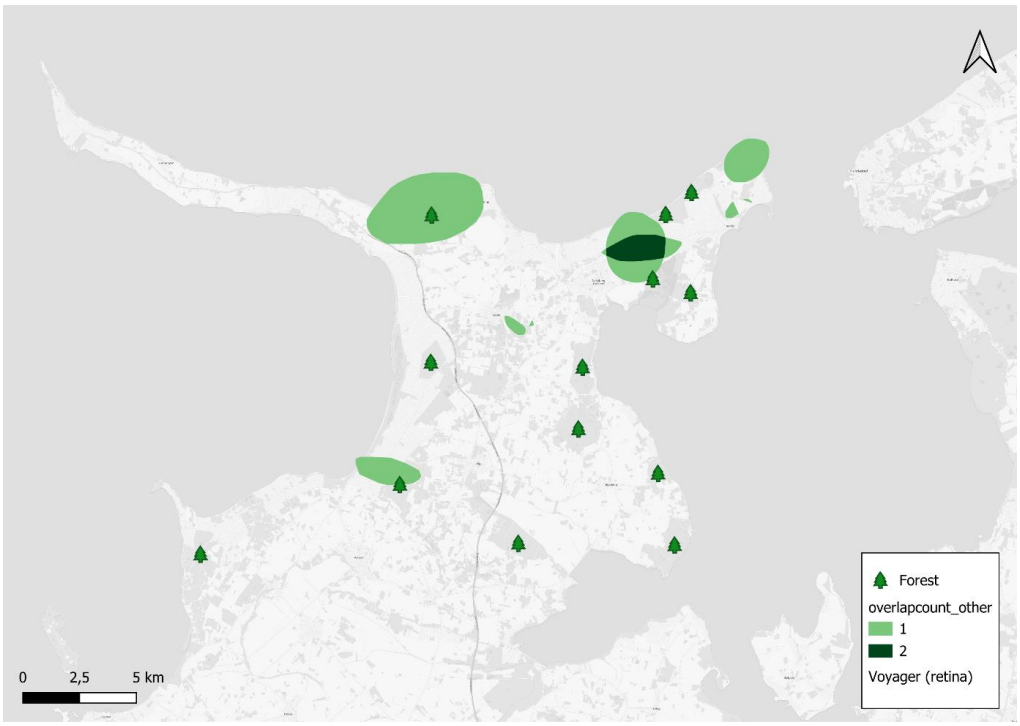


Figure 38:

Heatmap other (locals and visitors)



8.5 Cluster analysis results

Table 1:

Structure of clusters

Ward Method		601 - Gender_binair	613 - What is your age?	608 - With whom do you do these things? - Friends	608 - With whom do you do these things? - Family	608 - With whom do you do these things? - Dog	608 - With whom do you do these things? - Alone	612 - What motivates you the most to have outdoor experiences? - Physical exercise	612 - What motivates you the most to have outdoor experiences? - Relaxing/de-stressing	612 - What motivates you the most to have outdoor experiences? - Nature connection	612 - What motivates you the most to have outdoor experiences? - Experience wildlife	612 - What motivates you the most to have outdoor experiences? - Mental health benefits	612 - What motivates you the most to have outdoor experiences? - Social interaction	Biking (ja of nee)	Hiking/walking (ja of nee)	Camping (ja of nee)	602 - Description - Nature	602 - Description - Relax	614 - Are you a local or a visitor?_Local	612 - What motivates you the most to have outdoor experiences? - Escaping real life	612 - What motivates you the most to have outdoor experiences? - Adventurous/challenging
1	Mean	,66	52,09	,84	,32	,09	,50	,45	,70	,32	,14	,45	,34	,23	,16	,14	,48	,18	,57	,07	,07
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
	Std. Deviation	,479	22,210	,370	,471	,291	,506	,504	,462	,471	,347	,504	,479	,424	,370	,347	,505	,390	,501	,255	,255
2	Mean	,42	60,79	,88	,67	,27	,48	,67	,61	1,00	,52	,94	,58	,24	,73	,09	1,00	,82	,45	,09	,06
	N	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
	Std. Deviation	,502	18,019	,331	,479	,452	,508	,479	,496	,000	,508	,242	,502	,435	,452	,292	,000	,392	,506	,292	,242
3	Mean	,48	53,89	,24	,79	,35	,43	,48	,60	,37	,10	,70	,08	,02	,57	,08	,68	,38	,62	,14	,06
	N	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63
	Std. Deviation	,503	18,630	,429	,408	,481	,499	,503	,493	,485	,296	,463	,272	,126	,499	,272	,469	,490	,490	,353	,246
Total	Mean	,52	54,95	,58	,61	,25	,46	,51	,64	,50	,21	,68	,28	,14	,48	,10	,69	,42	,56	,11	,06
	N	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
	Std. Deviation	,501	19,833	,496	,489	,435	,501	,502	,483	,502	,407	,469	,450	,344	,501	,301	,463	,496	,498	,310	,246

age groups_Adult	age groups_Middle aged	age groups_Senior	age groups_Young adult	Swimming (ja of nee)	Gardening (ja of nee)	Fishing (ja of nee)	Andere (ja of nee)	Kayaking (ja of nee)	Running (ja of nee)	Kitesurfing/sailing (ja of nee)	Running (ja of nee)	Kitesurfing/sailing (ja of nee)	Quietly enjoying (ja of nee)	Hunting/foraging (ja of nee)	Horseback riding (ja of nee)
,18	,23	,39	,20	,14	,07	,25	,23	,05	,07	,02	,07	,02	,05	,00	,02
44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
,390	,424	,493	,408	,347	,255	,438	,424	,211	,255	,151	,255	,151	,211	,000	,151
,12	,30	,55	,03	,15	,15	,00	,03	,00	,06	,00	,06	,00	,06	,03	,00
33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
,331	,467	,506	,174	,364	,364	,000	,174	,000	,242	,000	,242	,000	,242	,174	,000
,21	,33	,37	,10	,13	,21	,03	,03	,02	,03	,02	,03	,02	,10	,00	,03
63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63
,408	,475	,485	,296	,336	,408	,177	,177	,126	,177	,126	,177	,126	,296	,000	,177
,18	,29	,41	,11	,14	,15	,09	,09	,02	,05	,01	,05	,01	,07	,01	,02
140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
,384	,457	,494	,319	,344	,358	,291	,291	,145	,219	,119	,219	,119	,258	,085	,145

Figure 39:

Icicle Diagram