Coastal protection through NbS in times of uncertainty.

A case study of Bjärred, Sweden

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LUCSUS
Lund University Centre for Sustainability Studies

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Abstract:

The global climate crisis presents significant social challenges and threatens biodiversity. Climate change is increasing the vulnerability of coastal areas, leading to more erosion and flooding. Nature-based solutions (NbS) offer a multifaceted approach to address these issues. This thesis examines the use of NbS for coastal protection in Bjärred, southern Sweden, and the municipality's strategies for planning, implementing, and monitoring sustainable solutions in the face of climate change uncertainties. Based on literature and stakeholder interviews, the analysis highlights NbS's suitability for mitigating coastal zone uncertainties. However, long-term effectiveness remains uncertain, necessitating further research and follow-up. To ensure that NbS can withstand more frequent storms and erosion, improved permit processes and enhanced community engagement in Bjärred and within the municipality are essential. This study underscores NbS's potential but emphasizes the importance of continuous evaluation and collaboration with residents for a resilient coastal future.

Keywords: NbS, Coastal protection, Uncertainty, Beach nourishment, Sustainability Science, Bjärred

Word count: 11988 words

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All interviewees from Lomma municipality and Lund University have filled this paper with interesting insights and without your contribution, the results of this thesis would not have been the same. Thank you for your time and for allowing me to gain insight into the process of coastal protection and planning behind the NbS in Lomma municipality.

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Table of Contents

List of Figures and Tables

List of abbreviations

NbS	Nature-based Solutions
CP	Coastal Protection
IUCN	The International Union for Conservation of Nature
IPCC	Intergovernmental Panel on Climate Change
EbA	Ecosystem-based Adaptation

1 Introduction

There is an urgent need to combat the major crisis of the Anthropocene: climate change, biodiversity loss and the challenges of human well-being, and humanity must try to find solutions to overcome all the challenges at once.

Coastal areas are particularly vulnerable to the effects of climate change such as erosion and flooding. A large proportion of the global population lives there, and data also show a demographic trend towards coastal areas (Baills et al., 2020; Ferro-Azcona et al., 2019). The AR5 report from the IPCC states that it is urgent to protect the coastal zones against sea level rise and the related consequences of flooding and coastal erosion (Masson-Delmotte, V. et al., 2018).

Coastal protection (CP) refers to the protection of infrastructure, people and assets that are or may be negatively impacted by flooding and erosion, as a consequence of high sea levels and waves. In such cases, there is a need for human intervention to protect nature and society (Möller, 2019). Möller (2019) argue that there are two cases when the need for coastal protection is necessary, 1) in the case where existing CP measures are insufficient or do not fit their purpose or 2) in the case when flooding and erosion have not yet caused enough threat to prevent the presence of people, assets, and housing along the coastline.

Grey coastal protection, such as seawalls, are common in coastal areas today but may become outdated due to altered external conditions caused by climate change and will no longer have the capacity to protect society (Möller, 2019). Grey infrastructure has the benefit of providing instant protection. However, seawalls are an expensive investment and do not bear the element of flexibility that is required when the projected risk exceeds expectations. In such cases, the wall can no longer hold the sea back and maintain the shoreline (Möller, 2019; Sutton-Grier et al., 2018). Given that engineered grey measures for coastal protection are not the most sustainable measure against coastal erosion in the long term (Möller, 2019; Morris et al., 2018) this thesis will address nature-based methods and solutions for building a long-term sustainable society.

Nature-based Solutions (NbS) were developed with the purpose to solve numerous societal challenges at once (Seddon et al., 2020). NbS is the umbrella term for techniques that utilize ecosystem services for addressing societal challenges and that benefit human well-being and biodiversity. NbS interventions can range from protecting natural ecosystems to creating urban solutions. The resilience of NbS depends on biodiversity support, and community participation varies across strategies (Seddon et al., 2020). NbS can be used to handle identified risks of flooding and coastal erosion through measures such as wetlands, mangroves and the refeed of sand dunes. (Baills et al., 2020; Morris et al., 2018).

However, it is important to understand that the effects that humanity will experience from climate change are uncertain. In this thesis, uncertainty should be understood as the uncertainty that can be expected in relation to climate change projections and the impacts the changing climate has on the environment. There are uncertainties related to feedback effects from the climate system (Baills et al., 2020; Roe & Baker, 2007), as well as uncertainties embedded in the scenarios and future projections (Toimil et al., 2019). There are some certainties in how the impacts of climate change will affect coastal areas within the next decades. However, the timeframe beyond is hard to predict in terms of the rate of change and to which extent global emissions can be cut, and if global tipping points can be avoided there is still uncertainty (Steffen et al., 2018). Consequently, it is uncertain what the effects of climate change will look like in a longer perspective, and how and to which extent coastal areas will be affected.

1.1 Aim and research questions

There is research addressing NbS as a promising method for coastal protection (Morris et al., 2018; O'Leary et al., 2023; Sutton-Grier et al., 2018) but there is little research about connecting NbS to the uncertainties of climate change impacts in coastal areas. Notably, there is a clear gap identified in the research field of coastal protection and climate change. Against this background this thesis aims to examine the use of NbS in coastal areas, and to what extent the solutions serve as a long-term solution, considering the aspect of uncertainty in relation to the future effects of climate change. And if the protective measures of NbS will be enough to protect the coastal zone.

Further, I aim to evaluate how uncertainty is considered using the case study of Bjärred, through analysing the process behind planning, implementation, and evaluation of NbS in the coastal area in Bjärred, in Lomma municipality, Sweden.

Bjärred is a coastal village that is starting to see the effects of increased erosion in the coastal zone, where grey coastal protections have been implemented to protect both private and public interests. In recent years the municipality has started trying new techniques within the realm of NbS and coastal protection to protect the coastal zone. Since this is my home village, I was interested to see how the municipality deals with NbS and coastal protection in relation to the uncertainty of climate change impacts.

Through an academic literature review I explore how NbS are used for coastal protection globally, and what the attributes of NbS are for dealing with uncertainty of climate change impacts. Then, through semi-structured interviews with involved actors and decisionmakers, I analyse how the municipality of Lomma has considered uncertainty in the process of planning implementing and evaluating two NbS projects in Bjärred.

The research questions are the following:

RQ1

- **In what ways are NbS used in coastal areas globally and what are the attributes of NbS for dealing with uncertainty related to climate impacts in coastal areas?**

RQ2

- **How is the municipality considering climate uncertainty during the process of planning and implementing and evaluating the NbS-projects in Bjärred?**

1.2 Contribution to Sustainability Science

This paper contributes to sustainability science through the exploration of NbS in a coastal context based in a local setting. There is a great need for coastal protection and NbS are currently being evaluated as a possible solution to prevent risk while contributing with ecosystem services. The topic connects to sustainability science in various ways and this section highlights the ideas through which this thesis contributes to the field.

By discussing NbS for coastal erosion, this thesis is 'purpose bound' and is aimed at action, one of the pillars of sustainability science research (Spangenberg, 2011). This thesis aims to analyse a municipal process to inform decision-makers and residents about the situation, and to engage and make better-informed choices in the face of climate change impacts.

Bjärred is an example of a place that is affected by coastal erosion and where Nbs is currently being implemented. This thesis takes a local approach to the governance process behind NbS and suggests a more inclusive and participatory approach for a successful solution. Partelow et al., (2018) emphasise how making the process participatory and inclusive could enhance the success of ecosystem-based projects in coastal areas. Further, this thesis has the potential to be one of several important steps in making the risks in the coastal zone visible to the citizens of Bjärred and provides information that can benefit a more inclusive process.

Inherent to sustainability science is the creation and use of climate scenarios (Mahmoud et al., 2009), especially in the case of risk assessments. The contribution of this thesis lies in how the local process has been made visible and linked it to the uncertainties of climate scenarios and climate impacts. Climate scenarios are not forecasts nor projections of the future. Rather, they can provide alternative futures and explore trajectories (Mahmoud et al., 2009). Uncertainties are embedded in scenarios in how they are created, understood, and communicated and therefore uncertainty must be considered when working with coastal protection against future threats and risks.

Sustainability science seeks to be transparent and reflexive (Spangenberg, 2011) and so does this thesis. The reflexive approach that the municipality uses to analyse the knowledge gaps that exist within the municipality's process of NbS is analysed and highlighted. Conclusively, the contribution is the communication of risks and uncertainties that exist in the coastal areas to help community participation and decision making. Further, reveals how the municipality works with NbS, and investigates whether these can be a long-term solution to climate change and the impacts they entail.

2 Background - Bjärred as a case study

2.1 Location and valuable ecosystems

Bjärred is a village with approximately 10,000 residents in the north end of Lomma municipality. Lomma municipality is situated in Lomma Bay and has a total of 12 km coastline (Lomma kommun, 2019). The maps in Figure 1 show the location of Sweden and Lomma municipality, where Bjärred is marked as the orange area in the north end, on the map to the right (ArcGIS, 2022). In the 20th century the village was a seaside resort for wealthy people and today it serves as a residential area where citizens and tourists come to enjoy the recreational areas (Lomma kommun, 2020).

Today, a major part of the coastline is reserved for outdoor activities and recreation. These include the public baths in Lomma municipality, Lomma north beach, the Habo area and the beach at Långa Bryggan in Bjärred, as well as the area between the baths. The area is extended out to the sea to a depth of three metres. Measures allowed to maintain the area include adding sand to the beach, additionally, eelgrass and seaweed may be removed during the summer months (Lomma kommun, 2020)

Several valuable ecosystems have been identified in the coastal zone in Bjärred. There are three nature reserves, and two marine protected areas, and sensitive water courses in the coastal zone. Eelgrass meadows, which are essential habitats for many marine species are to be found along the coast. Activities that could disturb flora and fauna in Lomma Bay should not be permitted, and erosion protection are not allowed to be built into the water (Lomma kommun, 2020).

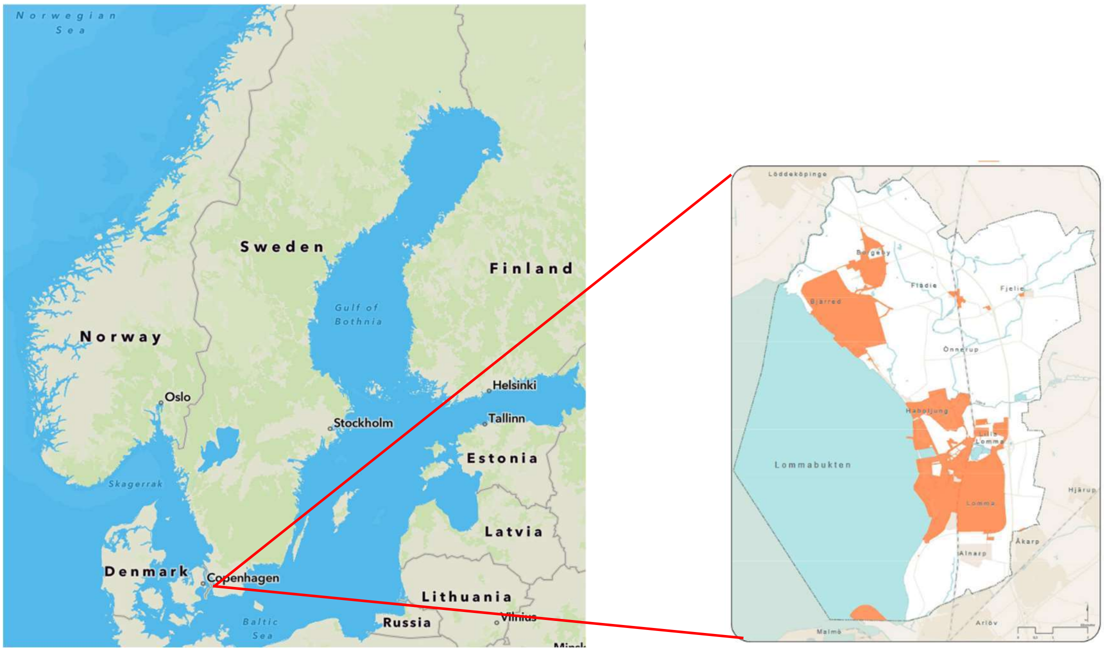

Figure 1. The map on the left side shows where Sweden and Lomma municipality are located, and the map to the right shows Lomma municipality. Bjärred is the orange area at north end. The figure is constructed by the author. The maps are used with consent (ArcGIS, 2022; Lomma kommun, 2020).

2.1.1 Coastal management

According to Swedish law, the General Plan (Översiktsplan) is a description and strategic planning document that must be in place in every municipality, showing how the municipality plans to use, develop, and preserve the physical environment (Lomma kommun, 2020). Lomma municipality's general plan is written by a working group consisting of experts in urban planning, architecture, and environmental issues. The document describes the physical planning over a decade, between 2020-2030 (Lomma kommun, 2020).

A small working group carried out the Coastal zone program (kustzonprogrammet) to deepen the understanding of the threats and the possibilities in the coastal zone in Lomma Municipality. The program was designed to provide unanimous guidance to the responsible committees and the municipal board in their work on the coastal zone. The document aims to point out how climate change and sea level rise will affect Lomma municipality in terms of flooding and coastal erosion and define the measures that need to be taken to manage the risks. The study also clarifies the division of responsibilities in the issues, between authorities and municipal citizens (Lomma kommun, 2019). The municipality oversees the management of public land, however, management on private stretches of the coast is delegated to the private owners. (Lomma kommun, 2020).

2.1.2 The Coastal zone

The coastal zone is the area defined in the Coastal zone program. The coastal zone has been defined according to three aspects: erosion, flooding, and beach protection. These aspects are important because a higher water level will affect erosion and flooding. Beach protection (strandskyddet) will also be affected, which means people's right to access the coastal area will be altered (Lomma kommun, 2019). Beach protection law (Strandskyddslagen) is legislation designed to protect beaches from settlement and exploitation and to safeguard plant and animal life in shallow coastal areas (Naturskyddsföreningen, 2023). The coastal zone is affected by a changing climate, as sea level rise affects animals and vegetation in shallow areas (Lomma kommun, 2019).

Another decisive aspect that was used to define the coastal zone are the 12 guiding principles of the international ecosystem approach, an established strategy for management, designed to ensure a sustainable use of ecosystems (Lomma kommun, 2019).

This means that the coastal zone is defined based on the areas that may be affected by the sea from a climate change perspective, and this includes both the areas closest to the sea but also valuable areas in the water, from an ecological perspective. Figure 1 shows the different colours representing the three aspects of flooding (blue), yellow (erosion) and the area of beach protection (green). The three colours represent the expected outcomes of the projections based on a scenario of a sea level rise of 4 meters by 2100 (Lomma kommun, 2019).

Blue: Flooding: The rising sea level increases the flood risk in Lomma's low-lying coastal zone (-3 to +4 meters above sea level).

Yellow: Erosion: Areas within 500 meters of the shoreline are vulnerable to coastal erosion and its indirect impacts.

Green: Beach protection: Rising sea level, erosion, and adaptation measures reduce ecosystem services, nature values, and beach accessibility. Areas protected by the Beach Protection Act (strandskyddet) are strategically important for coastal resilience and ecosystem services.

The coastal zone includes land and water areas affected by climate change. Coastal waters extend up to 3 meters deep in Lomma Bay, while the beach spans from the shoreline to 2 meters above sea level. In summary, the coastal zone encompasses flood-prone areas, erosion-vulnerable zones near the shoreline, and important beach protection areas (strandskyddsområden) with reduced ecosystem services (Lomma kommun, 2019).

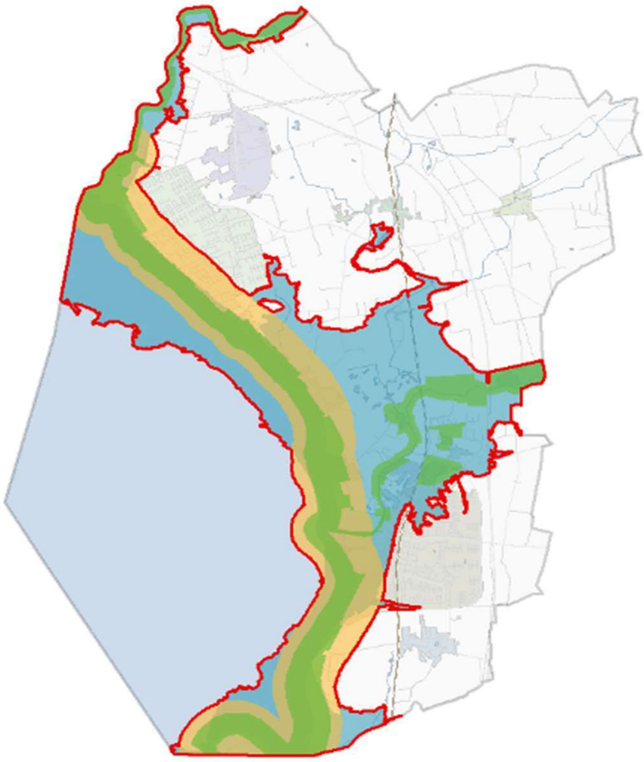

Figure 2 Definition of the coastal zone in Lomma Municipality. Risk assessment from Lomma municipality in the Coastal zone programme; blue colouring indicates the area at risk of flooding by 2100, and yellow colouring indicates the risk of coastal erosion by 2100. The green area is the land protected by the Beach Protection Act (standskyddet). (Lomma kommun, 2019). Picture used with consent.

2.2 Coastal erosion in Bjärred

The damage from beach erosion in Lomma Bay is mainly caused during storms. High waves and high-water levels contribute to a lot of sand being transported out from the coast and result in beach erosion. The southern part of the bay (the coast in Lomma) is flatter and shallower compared to the northern part (the coast in Bjärred) which means that erosion is not as severe there. In 2019, more than 3.4 km of the 12 km long coastline of Lomma municipality was protected against erosion through measures of coastal protection. In the coming years, more of the shoreline will have to be protected. The Coastal zone program states that it is difficult to predict the extent to which erosion will occur as the conditions and appearance are continuously changing as a result of a changing climate (Lomma kommun, 2019).

Today, the coast in southern Bjärred and north of Lomma beach is mainly in balance with alternating erosion/accumulation, while the beach from southern Bjärred to Lomma has moderate to significant erosion. However, with future sea level rise erosion will increase along almost the entire coastline in Lomma Bay (Lomma kommun, 2019).

According to the Special Report on the Ocean and the Cryosphere, the frequency of storms is predicted to increase in the future (Pörtner et al., 2019). The speed of coastal erosion is increasing, and chunks of the shoreline are gradually removed by waves. This disrupts the coastal nature and threatens the people living there.

The extratropical storm, named Malik, hit the Swedish west coast in late January 2022. The storm caused power cuts in southern Sweden (SMHI, 2022). The landfall of Malik had destructive effects on the coastline of Bjärred (Figure 3). In January 2023, the storm Otto made landfall on the same coast. This time the damages were even bigger than the previous year (Figure 4).

Figure 3 Coastal erosion in Bjärred after storm Malik in 2022 (Lomma kommun, 2022a).
Picture used with consent

Figure 4. The four pictures show the erosion that had taken place the previous day on the beaches in Bjärred, after storm Otto in January 2023. Pictures taken by the author. January 2023.

2.3 Coastal protection in Bjärred

Along some stretches of the shoreline, grey measures have been implemented for coastal protection, which are made from concrete tiles that together hold the coastline in place. Figure 5 shows pictures of hard coastal protection that are used at some sites in Bjärred.

Figure 5. An example of the current grey coastal protection on two sites in Bjärred. Concrete tiles holding the shoreline intact. Pictures taken by the author. January, 2023.

Through the project, '*LIFE Coast Adapt'*, the municipality of Lomma is trying out different types of Nature-based solutions against coastal erosion. The first project was initiated in 2019 (and continued until the autumn of 2021) and started by removing invasive species on the beach and proceeded by planting a salt-tolerant variety of rye that has extensive root systems to bind the sand that will naturally prevent erosion (Figure 6). This part of the project was taking place on the part of the shoreline that is referred to as the BOJK beach. Further planting of various plants will be needed to finalise the project (Lomma Kommun, 2022b).

The aim is to create natural sand dunes along the coastline, and fences were built to enhance the process and to hinder the sand from returning to the sea (Figure 7). A sand dune of seaweed and sand was constructed to help nature along (Lomma Kommun, 2022b).

Figure 6 Picture of fences and the planting of salt-tolerant rye at the LIFE Coast Adapt project on the BOJK beach. Picture used with consent (Lomma kommun, 2022b).

LIFE Coast Adapt project seeks to create the conditions for securing and strengthening coastal ecosystem services, which in turn will form natural erosion and flood protection and make coastal natural and ecosystem-based adaptation measures visible, tested, and evaluated. The results of the project will provide a basis for developing long-term sustainable strategies for the future (Lomma Kommun, 2022b).

Figure 7. The results of the LIFE Coast Adapt project in 2021, showing with beach fences and beach nourishment on the BOJK beach (Lomma Kommun, 2023). Pictures used with consent.

After the storms, the municipality declared that it is currently uncertain what can be done along the coastline within the framework of the project. In 2022, they communicated that they were working to identify and evaluate the possibilities for action in the area, starting with the removal of the fences that have been blown down and the repair of the fences that still fulfil its function, together with fences on the steepest slopes (Lomma kommun, 2022a)

Most of the sand that was refed to create wider dunes in 2021 has been moved by natural forces into the water, further south. A major part of the plantings made in 2021 was destroyed by the storm since the plants did not get enough time to grow their root systems sufficiently to bind the sand before the storm hit (Lomma kommun, 2022a).

The second initiative in the LIFE Coast Adapt project in Bjärred is to construct a wetland in the north end of the coast (LIFE Coast Adapt, 2022), (Figure 8). A water pipe has been dug up and the wetland has replaced it, to make it easier for the water to sink through the soil instead of flowing out through the pipe (LIFE Coast Adapt, 2023). The purpose of the intervention is to minimise the negative effects of erosion, and to increase the natural purification of water that flows into the sea. The aim is to both clean the water that is currently running through the pipe and reduce the force of the water flow before it reaches the sea. Possibly this will become a recreational area while also promoting biodiversity (LIFE Coast Adapt, 2023).

Figure 8. The area in the north end of Bjärred where the wetland is now constructed. The blue figure was placed on top of the original picture by the author to indicate where the wetland is currently located. Picture used with consent (LIFE Coast adapt, 2023).

Establishing wetlands has many benefits. The wetland habitat is an advanced ecosystem and attracts many birds, insects, and aquatic animals. For instance, it attracts bird species that thrive in ponds that have less vegetation. Coastal wetlands filter water and ensure that it remains nutrient rich. The wetlands reduce the flow rate of stormwater before it reaches the sea. This will be monitored and measured by researchers from Lund University (LIFE Coast Adapt, 2023).

3 Concepts and frameworks

In this section, I explain the two key concepts of this thesis, NbS and Uncertainty. Starting by introducing ecosystem services which is the basis of NbS and continuing by further explaining NbS as a concept, and its challenges within coastal management. Further, I introduce uncertainty and how it relates to coastal protection. Finally, this section ends with an overview of the frameworks used and developed for the analysis of the results.

3.1. Nature-based solutions (NbS)

Ecosystem services are the foundation of NbS. They are the services provided by nature and its ecosystems and are crucial to human well-being. Almost everything we take for granted is regulated through complex biological, chemical, and physical processes and different combinations of ecosystems are represented in the diverse processes and services. Human life and activities on Earth affect the services the ecosystems can continue to deliver (Millennium Ecosystem Assessment, 2005). Coastal areas deliver services such as food, fibre, timber, fuel, climate regulations, nutrient cycling, storm and wave protection, recreation, and aesthetic values. In addition, inland waters (e.g., wetlands, rivers and streams) provide flood regulation, sediment retention and transport, and pollution control and more (Millennium Ecosystem Assessment, 2005).

Nature-based solutions is the umbrella term for approaches that use the contribution of ecosystem services that natural systems can provide (Wamsler & Brink, 2016). The term is closely related to Ecosystem-based Adaptation (EbA), and both focus on the work of turning adaptation challenges into innovative solutions (Wamsler & Brink, 2016). Other common terms under the umbrella of NbS are ecosystem-based mitigation, green and blue infrastructure, and eco-disaster risk reduction (Nature, 2017; Seddon et al., 2020).

The formal definition of NbS was formulated by the the IUCN (the International Union for Conservation of Nature) in 2016. *"Nature-based Solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits"* page 1, (*IUCN Global Standard for Nature-Based Solutions*, 2020). Hence, the illustration by IUCN (Figure 9), demonstrates how the idea of NbS was meant to be understood and implemented internationally.

Figure 9 Illustration of NbS from the IUCN (IUCN Global Standard for NbS, 2020).

According to Seddon et al., (2020), there are three significant ways in which NbS may vary. These aspects affect the extent to which NbS can provide ecosystem services:

- NbS involve both the protection of and restoration of existing ecosystems. As well as creating manmade 'grey-green' solutions in urban spaces (Seddon et al., 2020; Sutton-Grier et al., 2018). Healthy ecosystems e.g., natural forests or wetlands store more carbon than an urban human managed ecosystem (Watson et al., 2018). NbS, such as parks and green roofs provide cooling effects and stormwater management and contribute to health enhancing services (Keeler et al., 2019).

- The level of resilience is based on the extent to which they support biodiversity (Seddon et al., 2020). NbS can continue to maintain ecosystems and provide ecosystem services for as long as they can recover from external disturbances. Ecosystems with a diversity of native species are more resilient and play a role in climate change mitigation and adaptation (Seddon et al., 2020).

- The level of community participation varies amongst the strategies under the umbrella of NbS. Ecosystem-based Adaptation (EbA) prioritises community participation in climate adaptation for a long-term sustainable approach. This approach considers social, economic, and cultural benefits (Seddon et al., 2020).

3.1.1 NbS in Coastal management

Within coastal protection, Nature-based Solutions (NbS) are often referred to as "soft infrastructure" or "living shorelines". This entails that the soft lines of the shoreline are preserved or restored. The preservation and restoration methods often involve coastal landforms e.g., where sand dunes and coastal wetlands serve as natural tidal flow and wave dissipaters, to achieve coastal protection (Narayan et al., 2017). Arguments suggest that natural coastal protection is preferable to hard-engineered coastal protection, since NbS adapt dynamically to external stresses, such as storms and waves, while hard structures do not have this ability (Möller, 2019). Further, examples of how NbS can be used in coastal protection and risk reduction in coastal areas, show that wetlands (Thorslund et al., 2017), kelp forests/kelp beds (Morris et al., 2020) sand dunes (Harris & Ellis, 2020) and dune reconstruction and revegetation (Fernández-Montblanc et al., 2020) exemplify of how hazards can be managed while also reducing risk (Fiertz, 2021).

Coastal landforms can change over time when responding to changing environmental conditions. Engineered coastal protection has no adaptive capacity and thus its resilience to changing environmental fluctuations can be better, as long as the condition does not exceed its limits (Möller, 2019). A conclusion from these arguments is that nature-based coastal protection can continue to provide ecosystem services and evolve even with a changing climate while protecting nature and society, but only if enough space for evolvement is available (Spencer et al., 2016).

Several researchers argue that it is of high importance to take a holistic approach to the benefits of coastal ecosystems (Sousa et al., 2012), such as carbon storage and sequestration (Duarte et al., 2013; Gattuso et al., 2018; Rogers et al., 2019), And provide ecosystem services together with biodiversity conservation, recreational values and provision of habitat for fish and other species (Costanza et al., 1996) All these services work together and contribute to coastal protection (Möller, 2019).

3.1.2 Challenges and advantages of NbS in Coastal areas

Natural solutions can create conflicts, as their adaptation and changing appearance require more land area than a constructed protection would, such as a sea wall (Möller, 2019). Scientists argue that soft coastal protection measures like NbS are urgently needed in order to protect coastal populations and infrastructure from flooding and erosion (Möller, 2019; Morris et al., 2018). This argument is supported by the fact that it takes several years, up to several decades, from the implementation of NBS to the realization of its full potential (Powell et al., 2019). However, the advantage of NbS over grey infrastructure, is that its capacity becomes more efficient and strengthens over time, while grey infrastructure usually degrades and needs more resources for its maintenance (Sutton-Grier et al., 2018). Equally, NbS in coastal areas have the advantage of having a short decision horizon, with a relatively low economic cost, but the measures have a non-robust tendency, meaning that it lacks the capacity to be effective over centuries, regardless of how the risk may evolve with climate change (Baills et al., 2020; Hallegatte, 2009). The definition of robustness connects to the measure's capacity to provide effective protection against flooding and erosion, regardless of the time of implementation from 2030-2300 (Baills et al., 2020). Robustness ties to life expectancy; and measures such as beach nourishment have a life expectancy of five years or less, and requires frequent refeed of sand for its maintenance (frequency depending on the erosion rate) (Baills et al., 2020). However, Morris et al., (2018) emphasize the challenge of lack of data comparing the efficacy of soft vs. hard coastal protection and suggest that the value of ecosystem services provided by both systems must be assessed in order to get an adequate comparison. Further, Morris (2019) concludes the lack of data for efficacy might be the reason why seawalls and other resolutions have been a common measure globally to tackle coastal risks of flooding and erosion. Finally, there is still a risk of maladaptation for NbS in coastal areas (Seddon et al., 2020) and the IUCB Global standard for implementation of NbS emphasizes the eight criteria to minimize the risk.

3.2 Uncertainty

In the context of this thesis, uncertainty is framed as the uncertainty that can be expected in relation to climate change projections and the impacts the changing climate has on the environment. The future change rates are uncertain; hence, the level of climate hazards, vulnerability, and risk are difficult to predict (Toimil et al., 2020). Deep uncertainty includes events that cannot be known or about which there is no consensus and which are debated (Walker et al., 2003). They include surprises and uncertainty in the expectations of global emissions and how they will impact climate ocean feedback systems, like the loss of polar ice-sheet over decades and centuries (Lawrence et al., 2019). Globally, there is a growing need for adaptation especially in the coastal zones, where the impacts of climate change are already apparent (Toimil, et al., 2020). Some researchers claim that traditional risk assessments do not consider all variables to evaluate risk (Hallegatte, 2009; Milly et al., 2008) and that contemporary coastal engineering requires non-stationary approaches to assessing risk, hazard, and vulnerability towards climate impacts.

3.2.1 Uncertainty and shoreline changes

Shoreline changes depend heavily on the processes of mean sea level, storm surges, tides and waves combined. These variables are individually affected by climate change both on a regional and a global level (Toimil et al., 2019). The certainty of future projections of these processes decreases with time, hence, developing reliable projections on how shorelines will be affected requires a deep and broad understanding of the driving forces combined (Toimil et al., 2019). Coastal protection under climate change requires projections that are reliable, long-term, and that can consider uncertainty for decades and up to centuries (Jongejan et al., 2011; Wainwright et al., 2015). However, there is a lack of consensus among scientists as to what a model should look like, that considers short term with long term processes, that could make reliable projections beyond the next few years (Toimil et al., 2019). The complexity lies in the interplay between short and long-term processes that shape the shoreline, which individually are altered by climate change, consequently adding uncertainty to the effects of coastal evolution (Jongejan et al., 2016; Wainwright et al., 2015).

3.3 Frameworks

Based on the concepts presented above, a framework was constructed to help structure my results and to analyse the data, to understand how Lomma municipality is managing NbS and how the aspect of climate change uncertainties is dealt with.

3.3.1 Analytical and Structural Framework

The initial idea for developing my own analytical and structural framework sprung from the framework for developing adaptive pathways proposed by Buurman and Babovic (2016). The framework for developing adaptation pathways was designed to provide policymakers with a step-by-step approach to develop plans that are flexible and resilient, in order to tackle future impacts of climate change and its uncertainties (Buurman & Babovic, 2016). The original framework provided the ideas that inspired me to understand that the NbS process is circular and reflexive and consists out of four parts that connect to one another. Since the framework by Buurman & Babovic is not applicable to the case of the thesis I decided to create my own to help structure my results.

Through the framework from Buurman & Babovic (2016), I drew inspiration and gained knowledge about how a decision-making process can be structured and which alternatives should be considered to find decision-making paths under the uncertainty of the impact of climate change. Figure 10 shows a simplified version of their framework, where the significant stages are picked, which were the stages that inspired the process of developing my own framework (figure 9).

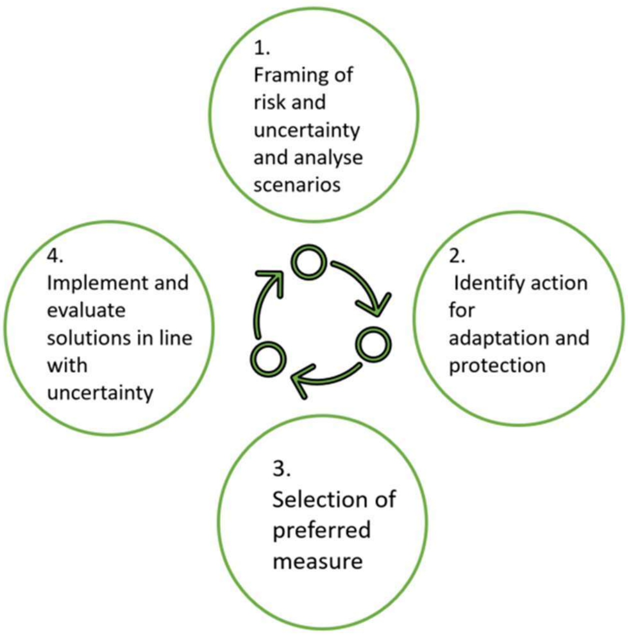

Figure 10. The figure is a simplified version of the analytical framework for adaptation pathways by Buurman & Babovic (2016). This version was created by the author and highlights relevant stages of the process that can be linked to the process of NbS in Lomma Municipality.

Figure 11 presents the structural framework that was created during the research process. During the interviews, connections between the framework from Buurman & Babovic (2016) and my research case were discovered. Using this insight, I developed my own structural framework to clarify the research process and the later part of the results. The framework clarifies the process behind coastal NbS in the municipality and how each part of the framework is connected. Further, the attributes required to deal with climate uncertainty were added when discovered during research. The framework was developed with the case of Bjärred in mind but can be applied to any similar process in the context of local coastal adaptation and NbS.

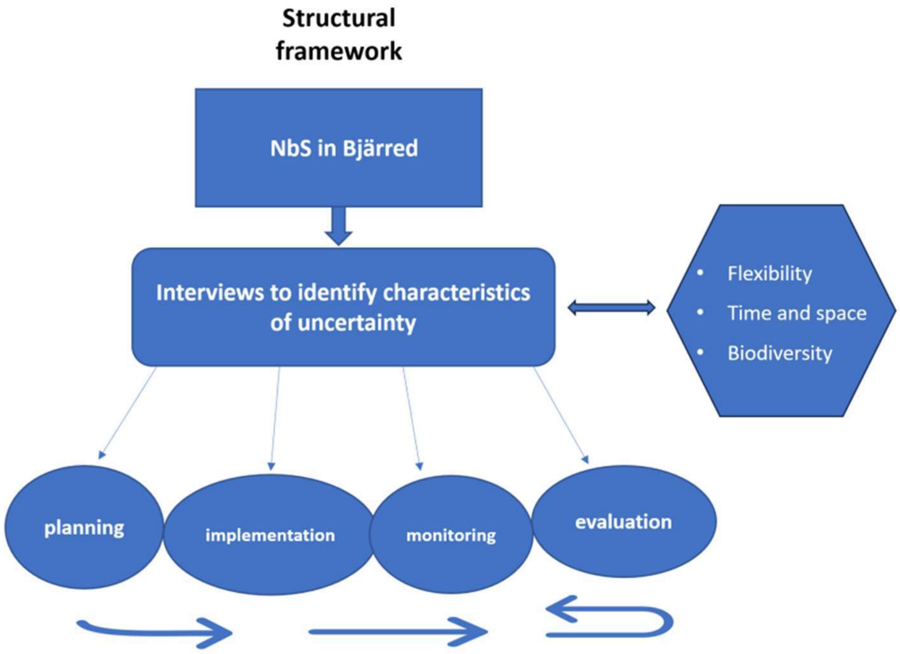

Figure 11 The structural framework created by the author. The structure indicates how the process of NbS was identified in the case of Bjärred and provides the structure of the results section. The arrows suggest that the process of coastal NbS in Lomma municipality is circular and reflexive.

4 Methodology

4.1 Research design

In this thesis, a mixed method was used. To reply to the first research question, I used a literature review with the intention to get an overview of NbS in coastal areas, and to understand how the literature mentions NbS and links them to uncertainties related to climate change in different ways.

The information gathered in the review help with constructing the structural framework, presented under Framework 3.3.

To reply to the second research question about how uncertainty is recognised in the process of NbS in Lomma municipality, I used a content analysis of key documents and interviews. The methods were used to understand how the municipality intends to work with coastal erosion in the northern part of the municipality, Bjärred.

4.2 Data collection and analysis

The data was analysed at different stages of the thesis-writing process. The literature review was necessary to understand how NbS is used in coastal adaptation, as well as to develop questions for the interview guides (Appendix A). Further, the analysis of the municipal documents took place to gain understanding of the local context and together with the literature review, were crucial for the topic of NbS and local coastal protection and adaptation.

The first interview with an official at the municipality provided insights that neither the literature study nor the document analysis could provide. The first interview clarified the process behind the NbS projects in the municipality, as well as identifying the type of expertise that was required in the other interviewees.

The framework (figure 9) represents three different stages of the data analysis:

- The first stage identified the projects of *NbS in Bjärred* and both document analysis and interviews were essential to gain this information.
- Stage two *interviews to identify characteristics of uncertainty,* was informed by the first stage together with the literature review. The literature review identified the characteristics of uncertainty connected to NbS (flexibility, time and space, and biodiversity), which led me to ask relevant questions in the interviews.
- The final stage of the analysis which is represented by *planning, implementation, monitoring, and evaluation* are replied to under RQ2 (5.2) and was informed by the stages above.

4.2.1 Academic literature review

The literature review aimed to better understand how NbS are used within coastal areas, and if NbS have the characteristics to manage uncertainties related to climate change impacts. The chosen method is the *traditional-narrative review*, which allows for a mixed methods approach, where the aim is to gain a better understanding of the previous research in the field (Efron & Ravid, 2019). Hence, there is no attempt to find all relevant literature within a certain time period, but rather to locate and select sources that could benefit my analysis of research question 2. Efron and Ravid (2019) outline several ways of approaching a literature review and for the purpose of this thesis, the “central review”-approach was chosen, since this allowed the researcher to synthesize past and current literature to gain a holistic view of the chosen topic (Efron & Ravid, 2019), which is precisely what this thesis aims to do. Databases such as Scopus and LubSerach were used to find relevant academic articles on the topic, with results limited to the years 2020-2023. Keywords such as *uncertainty*, NbS (or closely related terms) and *coastal protection* in combination with other search terms were used to find relevant literature. A snowball approach was followed, where relevant articles were selected and thereafter found useful sources in the reference lists (Eshenaur Spolarich, 2023). By looking for practices described in the articles as ecosystems for coastal protection, I was able to identify NbS that fit the description. As some practices were mentioned in more than one article, I took this as evidence that such a practice could be used for coastal protection. The articles were scanned to identify characteristics that could be associated with the NbS that were expressed as an attribute for dealing with climate change uncertainties. These attributes set the structure of my results (5.2).

4.2.2 Municipal documents

The documents of my analysis were official documents from Lomma municipality. They included the *Översiktsplan* – the General plan, and the *Kustzonprogrammet* – the Coastal zone program. Those are the documents Lomma municipality uses to communicate the plans and objectives for the municipality and its environment. Since Bjärred is the second largest society within Lomma municipality the documents were the source that could provide information about my case. The general plan provided an overview of the municipality's work, and the coastal zone program specifically addressed issues related to climate adaptation strategies in the coastal zone. The documents were selected because they were the main source to gain information about the interventions in the coastal zone and included scenarios for flooding and erosion.

4.2.3 Semi-structured interviews

I conducted interviews with actors who had insight into the different parts of the NbS process of the LIFE Coast Adapt projects in Bjärred: from planning to implementation and follow-up evaluation. Hence, I selected four interviewees with insight into the different stages of the process. The snowball method was used to find suitable interviewees, where the first person recommended the next etc. (Eshenaur Spolarich, 2023). The first interviewee, an official at Lomma municipality, recommended to contact a coastal engineer at Lomma Municipality, who has worked with the implementation of the

NbS projects. This person was able to provide further guidance and explained that the monitoring of the NbS projects is done by researchers at Lund University, among others. A researcher at Lund University who works with monitoring and inventory of flora and fauna at the project sites were the third interviewee. The last person was a researcher and coastal engineer at Lunds University (LTH) working on the monitoring of the LIFE Coast Adapt-beach in Bjärred. This person contributed with expertise on NbS and created an overall picture of different factors affecting the process, from planning and design to implementation and monitoring, as well as prospects and the potential of NbS to reflect uncertainties in all parts of the process and of NbS as a method.

I developed an interview guide (Appendix A) that could help answer the question of what the process of coastal protection and NbS looks like in Bjärred.

Table 1. List of interviewees and clarification of referencing in results

Interviewee involved in part of the project process	**Reference in text**	**Proficiency**
Planning	(1)	Official at Lomma Municipality
Implementation	(2)	Coastal Engineer at Lomma Municipality
Monitoring	(3)	Researcher and professor at Lund University
Evaluation	(4)	Researcher and coastal engineer at Lund University

Table 1 presents each interviewee which is stated by proficiency and referred to in the results using the numbers on the same row. The interviews were semi-structured and followed an interview guide with six questions (Appendix A), with room for the interviewees to elaborate and talk about aspects beyond what was asked (Bryman, 2016). The audio files were recorded and transcribed using the transcription tool in Microsoft Word.

4.2.4 Research ethics and limitations

All interviewees were sent a form of consent (Appendix B), where they were informed about the purpose of the interview and my research. They all gave consent to recording the interviews. Since one of the interviewees chose to stay anonymous, I concluded that all interviewees should be referred to by their proficiency (and all interviewees gave their consent).

The number of interviewees was intentional to limit the scope of the thesis (considering time and capacity), however, the results could have been more nuanced if more interviewees had been included.

Moreover, the analysis was meant to build on results from the two NbS projects in Bjärred, however, during the interviews, it became evident that there was little information about the wetland since the project was at an early stage. Consequently, this thesis focuses primarily on analysing the NbS at the beach.

Further, the importance of local participation for NbS is mentioned by sources (*IUCN Global Standard for Nature-Based Solutions*, 2020; Seddon et al., 2020) but was *not* identified during the literature review as an attribute of NbS for dealing with uncertainty. Rather as a factor to consider for long-term success and was therefore not included in the structural framework. However, in the latter part of the results local participation has shown to be an important aspect for the long-term success of NbS in Bjärred to deal with uncertainty but will however be debated in the discussion section instead.

5 Results

5.1 Research question 1

In the first part of the literature review nine coastal NbS methods were identified. See Table 2 two for an overview. The second part of the literature review is presented in 5.1.2.

5.1.1 How are NbS used for coastal protection?

Table 2. Methods for NbS in coastal areas

	Method
1.	Beach nourishment
2.	Dune grass
3.	Revegetation and reconstruction of dunes
4.	Sand fences
5.	Saltmarshes
6.	Wetlands
7.	Mangroves
8.	Sea grass plantation

9.	Shellfish reefs

There are various ways through which NbS can be used for coastal protection. Beach nourishment is the most common method and can be done in different ways depending on geomorphological circumstances (Kindeberg et al., 2023). It is possible to combine onshore and off-shore protection, combining seagrass and dune grass, but its effectiveness for coastal protection is yet to be investigated in practice (Kindeberg et al., 2023). However, beach nourishment and its effects are commonly researched in academic literature (Almarshed et al., 2019; Baills et al., 2020; Hanson et al., 2002).

Beach nourishment is a soft alternative to hard coastal structures and is globally used to slow down shoreline retreat and coastal erosion (Bocamazo, 2011; Hanson et al., 2002). Sediment from the sea is collected close to the shore and deposited on an existing beach to prevent and delay long-term sand erosion (Hanson et al., 2002).

Further, the establishment of dune grass is widely used, where vascular plants are planted on dunes to allow for the roots to retain the sand on the beach (Baills et al., 2020; Kindeberg et al., 2023). Revegetation and reconstruction of dunes, is an effective technique to tackle future and current sea level rise, which according to scenarios threatens coastal communities and landscapes (Fernández-Montblanc et al., 2020). There are ways through which NbS measures can be combined to enhance the effect of coastal protection, namely by using e.g., sand fences and beach nourishment (Baills et al., 2020) or seagrass, dune grass and beach nourishment (Kindeberg et al., 2023). Almarshed et al., (2019) explore how beach nourishment and grey coastal protection can be used jointly.

Another important NbS, are wetlands (Hobbie & Grimm, 2020; Möller, 2019), as they are multi-beneficial and which versatility contribute to many ecosystem services (social, environmental, and cultural) at local and global levels. Some of these services include coastal protection, flood regulation and biodiversity (Thorslund et al., 2017). Since coastal erosion and flooding threaten important coastal areas and ecosystems, these natural defences can reduce the impacts and protect them (Duarte et al., 2013).

Saltmarshes and Mangroves are ecosystems found in coastal zones and together with other plant-rich habitats, such as seagrasses, they can reduce wave height and water flow (Hobbie & Grimm, 2020; Morris et al., 2018; Spencer et al., 2016) as the water flows through dense vegetation and slows down the flow and reduces wave energy (Morris et al., 2018). The same is suggested for vegetation on shore, as the vegetated dunes are submerged by water they reduce wave energy and decrease coastal erosion (Fernández-Montblanc et al., 2020).

Conclusively, it is possible to combine hard and soft measures for coastal protection purposes and is referred to as *the Hybrid approach*, in order to get the benefits of protection from both soft and hard solutions, while simultaneously avoiding the weaknesses of the two (Sutton-Grier et al., 2015). Shellfish reefs can be installed in front of a sea wall, to prolong the lifetime of the seawall protecting it. The reef will provide water filtration and enhance biodiversity through habitat (Milbrandt et al., 2015; Morris et al., 2018). It is yet to be explored if the combined strategy of hybrid eco-engineering can provide new alternatives when NbS alone is not enough (Morris et al., 2018).

5.1.2 What are the attributes of NbS in coastal areas for dealing with uncertainty related to climate change?

The ways through which uncertainty and NbS are connected are various and through the literature review three main categories were identified: *Flexibility, Time and space* and *Biodiversity enhancement*. Additionally, a fourth heading supplements the previous tree for general advice on what to think about when implementing coastal protection that considers uncertainty. Results from the literature review show that there is a need for methods that can provide coastal protection even if the effects of climate change are uncertain and when the consequences will go beyond the projected scenarios. However, the literature review also shows that the attributes of NbS are not always to its advantage.

The following sections will guide you through the categories and how NbS measures are compliant with climate uncertainty. There is a final section where additional values to consider uncertainty in coastal protection are presented and suggested for future practices.

Flexibility – ability to adapt and self-repairing capacity

There are several ways that NbS can provide flexibility. In comparison with grey infrastructure, NbS has the advantage of flexibility when the future of climate change impacts is uncertain.

Economically there is an advantage since natural solutions are often less costly to implement than grey infrastructure (Hanson et al., 2002), hence the cost for maladaptation is less (Hallegatte, 2009). Once a measure of NbS has been implemented, it may be over dimensioned for its purpose, but it causes no damage and can be restored if the need turns out to be less than intended (Baills et al., 2020). However, the opposite is also true and there won't be any need for expensive extensions or upgrades if the coastal protection turns out to be inadequate (Fiertz, 2021).

Natural coastal ecosystems have the capacity to adapt to the effects of climate change due to their dynamic characteristics (Morris et al., 2018). However there are limits to the adaptive capacity of NbS since interventions require space to expand and space is not always available (Hobbie & Grimm, 2020).

It is important to remember that natural ecosystems have an inherent tendency to repair themselves after sudden weather events such as storms and floods, (Morris et al., 2018; Nordström, 2005) but this is where their slowness of the system lies. Although adaptation and self-repair will occur, it takes a long time, sometimes decades for it to restore itself (Almarshed et al., 2019) and the timescale is dependent on the season (Morris et al., 2020). Sandy beaches are dynamic and can self-repair and but there is often a need and a desire to refeed the dunes actively in order to maintain it (Almarshed et al., 2019; Baills et al., 2020).

Time and space

Baills et al., (2020) refer to the measures classified as "soft measures" to be reliable for short- and medium-term adaptation. Short-term is in this context referred to as 2030-2050, and medium term 2080-2100, and long term 2100-2300. A longer time frame benefits NbS in comparison to grey infrastructure that degrades with time, however, grey infrastructure will reach its full potential immediately (Powell et al., 2019). Even though the *flexibility-category* touched on the aspect of time as a factor for adaptation, time is closely linked to uncertainty and climate change impacts. Additionally, it is important for all coastal adaptation measures to be planned for and implemented on time, not too early and not too late, since the alternative will be associated with great costs (Lawrence et al., 2019). The interests and preferences of community members may change over time, hence decisionmakers must consider the long-term perspective and apply measures that can be adaptive (Lempert et al., 2006).

According to Baills et al., (2020), the time horizon for a natural solution to be put in place is also significantly shorter than a grey solution, as planning and completion for large grey engineering projects can exceed 10 years.

Providing ecosystem services and biodiversity enhancement

Prominent qualities of sea grass meadows and offshore vegetation are that they affect sediment dynamics, wave and current movement and hence have a dampening effect on coastal erosion (Kindeberg et al., 2023; Ondiviela et al., 2014). Long-living species of seagrass can provide good coastal protection when reaching maximum biomass (Ondiviela et al., 2014). The meadows are very important habitat for many marine species and therefore acts as valuable resource for biodiversity. However, the habitats currently declining globally (McKenzie et al., 2020) and need to be protected and restored (Boudouresque et al., 2021). Morris et al., (2018) state that natural coastal habitats i.e., coral reefs, sand dunes, kelp and sea grass forests, mangrove forests and shellfish reefs can provide ecosystem services such as maintenance of wildlife, provisioning of raw materials and food, nutrient cycling and water purification, carbon sequestration and recreational and educational values. However, when referring to restored and reconstructed habitats (NbS) for the same categories as mentioned, there is evidence of its ability to provide ecosystem services, yet the data is limited and for many habitats, the data is missing. The lack of data introduces uncertainties, making it challenging to measure the effectiveness of natural solutions (Morris et al., 2020). Additionally, the ecosystem services provided by NbS have global effects (e.g., biodiversity enhancement, carbon sequestration), not only bring local benefits (Davlasheridze et al., 2019).

Additional values to consider uncertainty for future practices in coastal protection.

Lawrence et al., (2019) conclude that it is of great importance to include the local community in a collaborative decision-making process to achieve an understanding of long-term risks and the importance to take early actions to shift strategy in the plans for coastal adaptation, to prevent ineffectiveness. It is suggested to put plausible scenarios of climate change impacts and coastal protection measures to stress-test; since different time perspectives and the risk of coastal hazards may give different outcomes and to include communities in the assessment of possible solutions.

Further, there is an emphasis on being prepared to change adaptation pathways and to stay open to new priorities and circumstances, as they can shift over time (Lawrence et al., 2019; Lempert et al., 2006). Finally, the unpredictability of climate change impacts affects people's ability to evaluate the costs and risks of the impacts and how to adapt to them (Lawrence et al., 2019).

5.2 Research question 2

5.2.1 How is the municipality considering climate uncertainty during the process of planning and implementing and evaluating the NbS-projects in Bjärred?

Through the interviews, four levels of the process of coastal protection through NbS were identified. These are the phases of 1) planning, 2) implementation, 3) monitoring and 4) evaluation. As previously mentioned in the methodology section (4.2.3); the four interviewees had insights in one and each of the four phases.

Planning phase

The municipality gradually evaluates which measures against erosion and flooding should be implemented. Interestingly, this is a circular process, just as the framework indicates. As new data is identified, planning for new approaches to coastal protection can be improved and refined (1).

Initially, the Coastal zone program was intended to provide knowledge about the measures needed to appropriately protect the coastal zone, but as the program evolved it became clear that the necessary data was not available, to answer the question of which measures were best suited to combat erosion and flooding. This is currently being investigated and, according to interviewee 1, they already have more data and thus can make better estimates of the necessary measures (compared to 2020, when the Coastal zone program was written) (1).

Protection of the coastal area will be prioritized depending on where the risk and the effect of climate change impacts (1) Common interest will be protected, but some areas will have to become flooded and will not be protected by the municipality (1).

In addition, to the two LIFE-projects, there are two retreat areas in the plans; along the water streams; (the valley of the Kävlingeån river and a small strip along the coast that is now beach meadows) (1). The maps from the Coastal zone program show how all coastal areas in Lomma municipality from -3 meters up to + 4 meters above current sea level are at the risk of flooding in 2100, hence new buildings will be prohibited. The purpose of retreat areas is to function as a NbS (1) (Lomma kommun, 2019).

Importantly, the private properties already located on sites that bear the risk of flooding and erosion, will not get any protection from the municipality. It is the responsibility of the municipality to inform residents that their properties will not be protected if they are built on private land and located in an area at risk of flooding and/or erosion (interviewee 1). Hence, the only option for their homes is to retreat further away from the coastline since the municipality cannot legally implement coastal protection on private land (interviewee 1).

An example of how flexibility is considered through the process of planning NbS is seen in how the municipality views a new project at another beach in Bjärred. Today the beach is renourished with sand frequently, and the plan is to continue this practice thus a flexible solution is currently practiced. However, the municipality has not yet determined a specific strategy to be implemented, and the path forward will be determined by future events. It's anticipated that as erosion intensifies due to increased storm activity and rising sea levels, the frequency of sand replenishment will also increase. However, uncertainty about the future remains, and in a worst-case scenario, it may necessitate the consideration of more conventional, non-Nature-based solutions for the entire beach. However, the interviewee expressed concern of how this potential shift may affect the desirability of coastal living in the face of such significant changes. Yet, it is currently not decided whether there will be a grey solution, or a NbS(1). To conduct a goal-focused evaluation plan for NbS takes a long time and can be very costly (4).

The Coastal zone program and the General plan refers to climate scenarios that range from 2020-2100, (Lomma kommun, 2023)(1). The scenarios from 2020 to 2100, are based on four emission pathways as per the IPCC reports. The emission scenario that the General plan refers to is the *RCP8.5 scenario* from the IPCC-report, which may result in an estimated mean temperature of 4,4 degrees above 1990's levels and the mean sea level may rise with 0,6 -1,1 meter until 2100, and with 5,4 meters until 2300 (Lomma kommun, 2023). However, interviewee 1 believes that the scenario has underestimated the potential future outcomes (1). According to the interviewee, these scenarios appear to be at the lower end of what is likely to transpire. The interviewee expressed a strong expectation of facing more substantial threats and disruptions than what the existing scenarios currently account for (1).

Further, in regards to biodiversity, both the General plan and the Coastal zone programmes state that Lomma municipality has many areas in the coastal zone with high natural values (Lomma kommun, 2019, 2020) and that the municipality shall with regards to a changing climate minimize both its impact on climate change and its consequences. When necessary, climate adaptation measures must be taken it should be done in a way where it minimizes damage to the natural environment, human health and property (Lomma kommun, 2023,). Regarding biodiversity, Interviewee 4 highlights the importance of already in the planning phase consider the dynamic that natural solutions need for the development of flora and fauna. Already, at an early stage, the municipality must account for the quantity of sand that could be eroded by a 100-year-storm event, in order to protect the values located further in, e.g., roads, nature and property (4).

Implementation phase

The NbS that have been carried out according to the municipality's plans are the LIFE project with beach nourishment and planting, and the wetland in northern Bjärred. During the interview, it became evident that the project is a pilot and that the framework for it is not clear or strict. Interviewee 2 points out that the method is to try and evaluate and then see what happens. Currently, the municipality observes how the sediment moves, the estimated time between sand replenishment is evaluated and the results are evaluated (2). If the coastline should not be entirely retreated one must refeed the dunes regularly (4).

The flexible attributes of NbS have been observed during the timeframe of the LIFE project at the beach. While NbS can show great flexibility, it has its limits. As mentioned in the previous section of the planning process, limited data were available. Hence, the consequences of Storm Otto in 2023 had the effects of spreading the deposited sediment over the boat ramp, which was an unforeseen event, and the sand had to be removed. The interviewees confirm that if the beach nourishment would not yet have taken place, the storm would result in even greater erosion (2, 4).

One challenge with beach nourishment is the unpredictability coupled with it: e.g., how often new sand needs to be added, how often the permit for excavation of sediment in Lomma harbour needs to be renewed with Länsstyrelsen (the County Administrative Board), and which time frames to give to the contractors responsible for maintenance (2). All mentioned factors reflect uncertainties in the phase of implementation.

In this sense the aspect of time is reflected in the project, since the action of beach nourishment requires sand to be moved from the seafloor in Lomma harbour, the municipality needs permission from Länsstyrelsen before actions may be taken. This permission process may take time and can possibly delay the process of implementation (2). However, there are some contradictive results in this regard and the third interviewee said this does necessarily not hinder the process if the permit was applied for a long time in advance (4). Further, in all climate adaptation work, one must be proactive and permits need to be in place in advance. There is time to do that, but we need to be able to predict the need within the next 3 years (4).

A significant constraint impacting the LIFE-beach project revolves around the necessity to secure approval from the Mark- och miljödomstolen, commonly known as the Land and Environment Court, for any measures affecting an area exceeding 3,000 square meters of the seabed. Regrettably, the application process associated with this regulatory body is long, often spanning a duration of approximately 2 to 3 years (3).

In response to the time limitations imposed by the LIFE project's framework, the municipality has made the strategic choice to seek permission from Länsstyrelsen, exclusively for measures falling below the 3,000 square meter threshold. It's noteworthy that the effectiveness of erosion protection is inherently linked to the volume of sand that can be deposited on the beach. In the context of this limitation, the reduced efficacy of coastal protection measures could be attributed to this regulatory constraint (4).

Monitoring and evaluation phase

The evaluation work consists of three parts: two working groups from Lund University (one looking at the ecology of the coast and a technical group of engineers that measure how the topography changes and measure the profile with GPS) (4) and a third working group from Region Skåne (3).

There are some flexibility characteristics noted from this phase that have been observed by the interviewees. The flexible feature of the technique of beach nourishment prevents the coastline from moving, even though the erosion continues (4).

The researchers have observed that because of the shallow water in Bjärred, the wave energy is broken before it reaches the shore, except during extreme weather events and storms when the water level is higher than normal, and the storm surges overflow the dune and that creates erosion. This happened during storms Mallik in 2022, and Otto in 2023 (4). Nature-based protections are dynamic and will never look the same as when the measure was implemented. After a storm, natural dynamic build-up processes are expected to occur on a sandy beach. However, the powerful wave energy that is required for building up the dune is missing in Bjärred, hence there is not enough self-repairing capacity. This is evidenced by the absence of sandy beaches in Bjärred, where the vegetation grows all the way down to the sea, indicating very little wave energy (4).

Further, some areas will be very difficult to protect in a scenario of high sea level rise and even more frequent extreme weather events. A risk model is used to calculate the frequency of high-water levels and strong storms and includes the aspect of sea level rise. Extreme scenarios may already soon be occurring and the NbS has the ability to protect the coastline even during extreme events. There is flexibility built into the protection and its ability to buffer for more than expected (3).

Regarding the aspect of time, the researchers can already now draw conclusions from the project and its long-term effects. The interviewee emphasizes that after the storms (Otto and Mallik) that have occurred since the start of the project, the beach nourishment measures have been destroyed by the storms, which further confirms the importance of its function (4). If the measure had not been in place, the coastal strip would have suffered even more damage and the nature and properties behind would have been affected instead. This measure is continuous and needs to be replenished regularly (4). Thus, it is concluded that the knowledge of how to create a long-term project can be drawn from the experience of observing the project and the dynamics of the solution (3,4).

As the results from RQ 1 indicate it is of great importance to include the local community in a collaborative decision-making process to achieve an understanding of long-term risks and the importance to take early actions. However, the aspect of community communication was not considered during the process of planning and implementation. In retrospect, the municipality was self-critical about how this was handled. Interviewee 4 said that they have been poor at communicating the purpose and expected outcome of NbS on the Life beach. "*People thought it was a failure after storm Mallik, but if we hadn't added more sand, the erosion would have taken more of the coastline. Without that solution, the erosion would have been worse"* (4).

High biodiversity levels quickly emerged on the west coast of Skåne during similar NbS trials. Some introduced plant species help to build up the dunes quickly. The zone between water and land is very important for many rare species and their establishment has been seen in several places on the west coast of Skåne (3). One of the problems with the coast in Bjärred is that there is no place for the plants to spread; instead, there is a green environment that ranges almost all the way down to the shore (3).

Interviewee 3 concluded from his research after having followed the NbS project in Bjärred that the coast and the beach have come a long way from their natural state and are now covered with hard surfaces and bicycle paths, as well as dense vegetation with alien and to some extent invasive plant species. The results of the observations show that biodiversity responds quickly to the measures taken via the NbS, with vegetation playing an essential role in binding the sand moving in the bypass (3).

Multifunctionality is mentioned as an important aspect by the researchers. Biodiversity is to some extent dependent on the dynamic aspect and the movement of the sand. Similarly, the effect of the protection is enhanced by the dynamics created, and over-fixing the sand with, for example, plant roots is also not preferable. They conclude that the management of coastal protection needs to be flexible and adapted to the storms and stresses to which the coastal protection is exposed (3,4).

Finally, interviewee 3 believes that the long-term potential of NbS is short-term in Bjärred given the limited space on the coast. In the long term, they may be difficult to maintain and, given the current scenarios, a hardened solution is probably the most effective protection in the long term. Conclusively, emphasizes that there is a lot of uncertainty (3).

6 Discussion

To reply to the aim of this thesis, if the measures of NbS will be enough to protect the coastal zone in the long term; the answer is not yet. Further coastal interventions and research are required. The results indicate that NbS have many attributes to deal with the uncertainties of climate change impacts e.g., flexibility, the aspect of time and space and biodiversity enhancement. In the municipality of

Lomma NbS is still in its infancy. From the two ongoing projects of NbS in the municipality it is evident that there are ambitions, but data collection, monitoring and stakeholder engagement are still lacking to meet future needs.

Beach nourishment, which is a commonly used NbS technique has proof of its efficacy (Morris et al., 2018) on a global scale (Bocamazo, 2011; Hanson et al., 2002). However, a limiting factor for beach nourishment may be its ability to be flexible to deal with the uncertainties of climate change impacts. Meaning, that the self-repairing capacity requires space and takes time (Almarshed et al., 2019). This is time that we need but might not have, and space that does not exist, at the current location of the NbS- beach. As seen in the results, the space for the location of the beach is one of the limiting factors for its long-term success (Hobbie & Grimm, 2020). There are currently bicycle paths and houses hindering the expansion of the sand dunes. This means that the dunes must expand out towards the sea in order to grow and provide protection. The results show that there is currently no other option.

In the General plan, the municipality states that the northern coastline in Bjärred is considered to have high marine values, and thus no coastal protection will be implemented there (Lomma kommun, 2020). However, in the same area, there is a nature reserve bordering the sea. The nature reserve is commonly used for recreational purposes and has valuable flora and fauna. Hence, those values will be lost when the area is allowed to be flooded and the sea level rises.

Stakeholder engagement is repeatedly mentioned in the literature about NbS as something that must be considered for long-term success (Bennett et al., 2016; *IUCN Global Standard for Nature-Based Solutions*, 2020; Powell et al., 2019; Seddon et al., 2020), and to better deal with both climate uncertainties, and the uncertainties of how the local's priorities might change over time (Lempert et al., 2006). This thesis shows evidence that a local dialogue is currently lacking in the process of NbS in Bjärred. However, the municipality expresses self-reflection and stresses the aspect of developing citizen dialogue about the coastal and climate change adaptation issues, with those living on or visiting the coast (Lomma kommun, 2019). According to my analysis, the dialogue with stakeholders and residents seems to be a challenging part of the long-term success of NbS in Bjärred.

Then, what will be the implications for lack of space, time, and stakeholder engagement in Bjärred? Ultimately, there will be no more space for the beach to expand onto and too little time between storm events that may cause severe erosion. Major parts of the coastline in Bjärred are lined with private properties and those will not have a chance to protect themselves against flooding and erosion in case the scenarios for climate change impacts are underestimated. The final solution is to retreat. The municipality will not protect private properties and that is one important reason why the information about climate change and its impacts must reach the residents. Still, the municipality bears the responsibility of communication risk to its citizens (Lomma kommun, 2019). Yet, to understand the risk of climate impacts, monitoring and evaluation of results must be a continuous process, so that people, natural values and homes can stay safe. However, it is a problematic issue and the official from the municipality mentioned that even if the municipality wanted to protect individual properties, they do not have the right to do so.

A hinder to the future development of NbS in Bjärred is the process of applying for permits regarding activities in Lomma harbour to enable beach nourishment. The process may be hindering and slowing down the intervention. However, as intense storms and hurricanes are expected to become more frequent in the future (Pörtner et al., 2019) the application process can be difficult to predict. It will become important to stay ahead of the trend of erosion and review current time intervals of renourishment to not hinder the maintenance of the coastal protection.

6.1 Contribution to the knowledge of NBS

Through this thesis, new knowledge about NbS has been discovered. The information of how limited knowledge the municipality had about suitable coastal defences has never been made available. The information on the municipality's plans has only been presented through public documents by the municipality but rarely communicated to its citizens. This thesis contributes not only by confirming what previous research has already found, that flexibility, time and space and an active local dialogue are necessary for the success of NbS (Powell et al., 2019) but also highlights the local management process of NbS in Lomma municipality and summarises its shortcomings but also what can be done better for sustainable coastal protection. For local purposes, this paper can have high values and be of great importance.

The limitations of my findings are that they mainly discover the circumstances of a certain project of NbS in a coastal village in Sweden. Literature confirms that NbS are site-specific (Cohen-Shacham et al., 2019) and consequently, it is not certain that my findings apply to any case of NbS. It would be interesting to evaluate if and how the future NbS interventions in Lomma municipality have learnt from the shortcomings and experiences of the LIFE-coast adapt projects. If they further will consider aspects of uncertainty throughout the management process. The official from the municipality mentioned that the knowledge gaps of the Coastal zone program were many and that these had to be identified before the next step of identifying appropriate coastal measures. However, to take part in the current planning process in the municipality while sharing the results and insight from this study could have the potential to contribute to long-term solutions for coastal protection locally.

Working across boundaries to solve the complex issues of coastal protection connects to the importance of transdisciplinary for sustainability science (Spangenberg, 2011). Conclusively, all perspectives are needed to learn about NbS and how to solve the complex issues. The importance of looking at NbS on a large scale is reflected in a final quote by one interviewee: *"In the long term, the exchange of knowledge needs to spread to where there is a need and not primarily to where the resources are. But if we don't work across professional boundaries, we won't be able to solve anything* "(3).

Finally, future research is required to explore how onshore and offshore measures can be combined to enhance the protective capacity in Bjärred or in other coastal areas (Kindeberg et al., 2023). What function do the seagrass beds serve in terms of coastal protection? The complexity of coastal ecosystems needs further study.

One of the interviewees suggested that sand is the limiting factor to beach nourishment. As long as sand is available, beach nourishment has the ability to adapt to any sea level in theory. Since the process of applying for permits may be hindering access to sand, and since the frequency of storms is likely to increase, this is an issue that needs to be addressed. However, is the problem acknowledged within academia, legal courts or among politicians? This calls for further exploration and research.

7 Conclusion

The future of NbS in the coastal zone of Bjärred is uncertain and unspoken. With the information from a literature review and interviews this thesis aimed to examine the use of NbS in coastal areas, and if they can function as a long-term solution, considering the aspect of uncertainty in relation to the future effects of climate change. Further, I aimed to evaluate how uncertainty is considered in Bjärred, by analysing the process behind planning, implementation, and evaluation of NbS.

The results show that we cannot yet evaluate the effectiveness of the projects. The main project, the LIFE-beach, could potentially be the first step in a series of nature-based actions in the municipality, or it could be nothing more than this single project. Despite the uncertainties of the future, both in consideration of the effects of climate change and for the future of NbS, the results from this study suggest that NbS both in Bjärred but also around the world has many advantages over grey solutions and is highlighted as multifunctional measures.

However, the advantages of NBS are not to be taken for granted and measures of monitoring and evaluation as well as an active dialogue with citizens, are important elements for the long-term success of NbS in Bjärred. Beach nourishment requires space and time for flexibility in order to provide biodiversity enhancement and local and global benefits.

This thesis asks for a more transparent planning and decision-making process regarding the risks, barriers, and solutions in the coastal zone. Through an active dialogue with residents, NbS could be more sustainable and protect the coastal zone. Currently, not all residents and land areas have suitable protection against the identified risks of flooding and coastal erosion.

The realm of NbS and the qualities it provides have the potential to meet an uncertain future of climate change impacts for the short-to-medium time span. In the longer time frame, we do not yet know and continuous work of the reflective process of planning, implementing, and monitoring and evaluation must continue until there is a certain answer.

8 References

Almarshed, B., Figlus, J., Miller, J., & Verhagen, H. J. (2019). Innovative Coastal Risk Reduction through Hybrid Design: Combining Sand Cover and Structural Defenses. *Journal of Coastal Research*, *36*(1), 174–188. https://doi.org/10.2112/JCOASTRES-D-18-00078.1

ArcGIS. (2022). *Karta—Lomma kommun* [Text]. Kävlinge Kommun, Lantmäteriet, SDFI, Esri, HERE, Garmin, Foursquare, GeoTechnologies, Inc, METI/NASA, USGS | Lomma kommun. https://lomma.se/ovriga-sidor/karta.html

Baills, A., Garcin, M., & Bulteau, T. (2020). Assessment of selected climate change adaptation measures for coastal areas. *Ocean & Coastal Management*, *185*, 105059. https://doi.org/10.1016/j.ocecoaman.2019.105059

Bennett, N. J., Kadfak, A., & Dearden, P. (2016). Community-based scenario planning: A process for vulnerability analysis and adaptation planning to social–ecological change in coastal communities. *Environment, Development and Sustainability*, *18*(6), 1771–1799. https://doi.org/10.1007/s10668-015-9707-1

Bocamazo, L. (2011). *Beach Nourishment, Shoreline Change, and Dune Growth at Westhampton Beach, New York, 1996-2009 on JSTOR*. https://www-jstor-org.ludwig.lub.lu.se/stable/29783115

Boudouresque, C., Blanfuné, A., Pergent, G., & Thibaut, T. (2021). *Water | Free Full-Text | Restoration of Seagrass Meadows in the Mediterranean Sea: A Critical Review of Effectiveness and Ethical Issues*. https://www.mdpi.com/2073-4441/13/8/1034

Bryman, A. (2016). *Social research methods* (Fifth edition). Oxford University Press.

Buurman, J., & Babovic, V. (2016). Adaptation Pathways and Real Options Analysis: An approach to deep uncertainty in climate change adaptation policies. *Policy and Society*, *35*(2), 137–150. https://doi.org/10.1016/j.polsoc.2016.05.002

Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., Maginnis, S., Maynard, S., Nelson, C. R., Renaud, F. G., Welling, R., & Walters, G. (2019). Core principles for successfully implementing and upscaling Nature-based Solutions. *Environmental Science & Policy*, *98*, 20–29. https://doi.org/10.1016/j.envsci.2019.04.014

Costanza, R., d'Arge, R., Groot, R., Farber, S., Grasso, M., Hannon, G., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J., Raskin, R., Sutton, P., Belt, M., & Belt, H. (1996). The value of the world's ecosystem services and natural capital. Nature. *Report of Workshop Organised by NCEAS, Santa Barbara, Calif. (1996).*, *387*.

Davlasheridze, M., Atoba, K. O., Brody, S., Highfield, W., Merrell, W., Ebersole, B., Purdue, A., & Gilmer, R. W. (2019). Economic impacts of storm surge and the cost-benefit analysis of a coastal spine as the surge mitigation strategy in Houston-Galveston area in the USA. *Mitigation and Adaptation Strategies for Global Change*, *24*(3), 329–354. https://doi.org/10.1007/s11027-018-9814-z

Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I., & Marbà, N. (2013). The role of coastal plant communities for climate change mitigation and adaptation. *Nature Climate Change*, *3*(11), Article 11. https://doi.org/10.1038/nclimate1970

Efron, S. E., & Ravid, R. (2019). *Writing the Literature Review: A Practical Guide*. The Guilford Press. https://ludwig.lub.lu.se/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,uid&db=nlebk&AN=1824703&site=eds-live&scope=site

Eshenaur Spolarich, A. (2023). Sampling Methods: A guide for researchers. *Journal of Dental Hygiene*, *97*(4), 73–77.

Fernández-Montblanc, T., Duo, E., & Ciavola, P. (2020). Dune reconstruction and revegetation as a potential measure to decrease coastal erosion and flooding under extreme storm conditions. *Ocean & Coastal Management*, *188*, 105075. https://doi.org/10.1016/j.ocecoaman.2019.105075

Ferro-Azcona, H., Espinoza-Tenorio, A., Calderón-Contreras, R., Ramenzoni, V. C., Gómez País, M. de las M., & Mesa-Jurado, M. A. (2019). Adaptive capacity and social-ecological resilience of coastal areas: A systematic review. *Ocean & Coastal Management*, *173*, 36–51. https://doi.org/10.1016/j.ocecoaman.2019.01.005

Fiertz, E. (2021). *An Examination of Nature-based Solutions for Coastal Adaptation in Southern Sweden*. http://lup.lub.lu.se/student-papers/record/9073297

Gattuso, J.-P., Magnan, A. K., Bopp, L., Cheung, W. W. L., Duarte, C. M., Hinkel, J., Mcleod, E., Micheli, F., Oschlies, A., Williamson, P., Billé, R., Chalastani, V. I., Gates, R. D., Irisson, J.-O., Middelburg, J. J., Pörtner, H.-O., & Rau, G. H. (2018). Ocean Solutions to Address Climate Change and Its Effects on Marine Ecosystems. *Frontiers in Marine Science*, *5*. https://www.frontiersin.org/articles/10.3389/fmars.2018.00337

Hallegatte, S. (2009). Strategies to adapt to an uncertain climate change. *Global Environmental Change*, *19*(2), 240–247. https://doi.org/10.1016/j.gloenvcha.2008.12.003

Hanson, H., Brampton, A., Capobianco, M., Dette, H. H., Hamm, L., Laustrup, C., Lechuga, A., & Spanhoff, R. (2002). Beach nourishment projects, practices, and objectives—A European overview. *Coastal Engineering*, *47*(2), 81–111. https://doi.org/10.1016/S0378-3839(02)00122-9

Harris, M. E., & Ellis, J. T. (2020). A holistic approach to evaluating dune cores. *Journal of Coastal Conservation*, *24*(4), 42. https://doi.org/10.1007/s11852-020-00760-w

Hobbie, S. E., & Grimm, N. B. (2020). Nature-based approaches to managing climate change impacts in cities. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*(1794), 20190124. https://doi.org/10.1098/rstb.2019.0124

IUCN Global Standard for Nature-based Solutions: First edition. (2020). IUCN. https://doi.org/10.2305/IUCN.CH.2020.08.en

Jongejan, R., Ranasinghe, R., Wainwright, D., Callaghan, D. P., & Reyns, J. (2016). Drawing the line on coastline recession risk. *Ocean and Coastal Management*, *122*, 87–94. Scopus. https://doi.org/10.1016/j.ocecoaman.2016.01.006

Jongejan, Ranasinghe, R., Vrijling, J. K., & Callaghan, D. (2011). A risk-informed approach to coastal zone management. *Australian Journal of Civil Engineering*, *9*(1), 47–60. https://doi.org/10.1080/14488353.2011.11463968

Kindeberg, T., Almström, B., Skoog, M., Olsson, P. A., & Hollander, J. (2023). Toward a multifunctional nature-based coastal defense: A review of the interaction between beach nourishment and ecological restoration. *Nordic Journal of Botany*, *2023*(1), e03751. https://doi.org/10.1111/njb.03751

Lawrence, J., Bell, R., & Stroombergen, A. (2019). A Hybrid Process to Address Uncertainty and Changing Climate Risk in Coastal Areas Using Dynamic Adaptive Pathways Planning, Multi-Criteria Decision Analysis & Real Options Analysis: A New Zealand Application. *Sustainability*, *11*(2), Article 2. https://doi.org/10.3390/su11020406

Lempert, R. J., Groves, D. G., Popper, S. W., & Bankes, S. C. (2006). A General, Analytic Method for Generating Robust Strategies and Narrative Scenarios. *Management Science*, *52*(4), 514–528. https://doi.org/10.1287/mnsc.1050.0472

LIFE Coast Adapt. (2022). *LIFE Coast Adapt | Vi testar nya metoder mot kusterosion*. LIFE Coast Adapt. https://lifecoastadaptskane.se/

LIFE Coast Adapt. (2023). *LIFE Coast Adapt | Våtmark i Norra Bjärred*. LIFE Coast Adapt. https://lifecoastadaptskane.se/location/vatmarker-vid-karstorp/

Lomma kommun. (2019). *Kustzonsprogram—Lomma kommun* [Text]. https://lomma.se/bygga-bo-och-miljo/klimat-miljo-och-hallbarhet/klimatarbete/kustzonsprogram.html

Lomma kommun. (2020). *Samtliga dokument till Översiktsplan 2020—Lomma kommun* [Text]. https://lomma.se/bygga-bo-och-miljo/oversiktsplan-och-detaljplaner/oversiktsplan/samtliga-dokument-till-oversiktsplan-2020.html

Lomma Kommun. (2023, January 5). *Erosionsskydd i Bjärred—Lomma kommun* [Text]. https://lomma.se/bygga-bo-och-miljo/byggprojekt/fardiga-byggprojekt/erosionsskydd-i-bjarred.html

Lomma kommun. (2022a). *Erosionsprojektet vid BOJK efter stormen—Lomma kommun* [Text]. https://lomma.se/arkiv/nyheter/nyheter/2022-02-08-erosionsprojektet-vid-bojk-efter-stormen.html

Lomma Kommun. (2022b). *Erosionsskydd i Bjärred—Lomma kommun* [Text]. Erosionskydd i Bjärred. https://lomma.se/bygga-bo-och-miljo/byggprojekt/norra-kommundelen/erosionsskydd-i-bjarred.html

Mahmoud, M., Liu, Y., Hartmann, H., Stewart, S., Wagener, T., Semmens, D., Stewart, R., Gupta, H., Dominguez, D., Dominguez, F., Hulse, D., Letcher, R., Rashleigh, B., Smith, C., Street, R., Ticehurst, J., Twery, M., van Delden, H., Waldick, R., … Winter, L. (2009). A formal framework for scenario development in support of environmental decision-making. *Environmental Modelling & Software*, *24*(7), 798–808. https://doi.org/10.1016/j.envsoft.2008.11.010

Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield. (2018). *IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (AR 5; pp. 3–24). https://www.ipcc.ch/sr15/chapter/spm/

McKenzie, L. J., Nordlund, L. M., Jones, B. L., Cullen-Unsworth, L. C., Roelfsema, C., & Unsworth, R. K. F. (2020). The global distribution of seagrass meadows. *Environmental Research Letters*, *15*(7). https://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-184536

Milbrandt, E. C., Thompson, M., Coen, L. D., Grizzle, R. E., & Ward, K. (2015). A multiple habitat restoration strategy in a semi-enclosed Florida embayment, combining hydrologic restoration, mangrove propagule plantings and oyster substrate additions. *Ecological Engineering*, *83*, 394–404. https://doi.org/10.1016/j.ecoleng.2015.06.043

Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., & Stouffer, R. J. (2008). Stationarity Is Dead: Whither Water Management? *Science*, *319*(5863), 573–574. https://doi.org/10.1126/science.1151915

Möller, I. (2019). Applying Uncertain Science to Nature-Based Coastal Protection: Lessons From Shallow Wetland-Dominated Shores. *Frontiers in Environmental Science*, *7*. https://www.frontiersin.org/articles/10.3389/fenvs.2019.00049

Morris, R. L., Boxshall, A., & Swearer, S. E. (2020). Climate-resilient coasts require diverse defence solutions. *Nature Climate Change*, *10*(6), Article 6. https://doi.org/10.1038/s41558-020-0798-9

Morris, R. L., Konlechner, T. M., Ghisalberti, M., & Swearer, S. E. (2018). From grey to green: Efficacy of eco-engineering solutions for nature-based coastal defence. *Global Change Biology*, *24*(5), 1827–1842. https://doi.org/10.1111/gcb.14063

Naturskyddsföreningen. (2023). *Värna vårt strandskydd – stränderna är till för alla*. Naturskyddsföreningen. https://www.naturskyddsforeningen.se/artiklar/varna-vart-strandskydd-stranderna-ar-till-for-alla/

Nordström, K. F. (2005). *Beach Nourishment and Coastal Habitats: Research Needs to Improve Compatibility—Nordstrom—2005—Restoration Ecology—Wiley Online Library*. https://onlinelibrary-wiley-com.ludwig.lub.lu.se/doi/full/10.1111/j.1526-100X.2005.00026.x

O'Leary, B. C., Fonseca, C., Cornet, C. C., de Vries, M. B., Degia, A. K., Failler, P., Furlan, E., Garrabou, J., Gil, A., Hawkins, J. P., Krause-Jensen, D., Le Roux, X., Peck, M. A., Pérez, G., Queirós, A. M., Różyński, G., Sanchez-Arcilla, A., Simide, R., Sousa Pinto, I., … Roberts, C. M. (2023). Embracing Nature-based Solutions to promote resilient marine and coastal ecosystems. *Nature-Based Solutions*, *3*, 100044. https://doi.org/10.1016/j.nbsj.2022.100044

Ondiviela, B., Losada, I. J., Lara, J. L., Maza, M., Galván, C., Bouma, T. J., & van Belzen, J. (2014). The role of seagrasses in coastal protection in a changing climate. *Coastal Engineering*, *87*, 158–168. https://doi.org/10.1016/j.coastaleng.2013.11.005

Partelow, S., Glaser, M., Solano Arce, S., Barboza, R., & Schlüter, A. (2018). Mangroves, fishers, and the struggle for adaptive comanagement: Applying the social-ecological systems framework to a marine extractive reserve (RESEX) in Brazil. *Ecology and Society*, *23*(3). https://doi.org/10.5751/ES-10269-230319

Pörtner, H.-O., Roberts, D. C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama, B., & Weyer, N. M. (2019). *IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* ((eds.)]. In press.). https://www.ipcc.ch/srocc/

Powell, E. J., Tyrrell, M. C., Milliken, A., Tirpak, J. M., & Staudinger, M. D. (2019). A review of coastal management approaches to support the integration of ecological and human community planning for climate change. *Journal of Coastal Conservation*, *23*(1), 1–18. https://doi.org/10.1007/s11852-018-0632-y

Roe, G. H., & Baker, M. B. (2007). Why Is Climate Sensitivity So Unpredictable? *Science*, *318*(5850), 629–632. https://doi.org/10.1126/science.1144735

Rogers, K., Kelleway, J. J., Saintilan, N., Megonigal, J. P., Adams, J. B., Holmquist, J. R., Lu, M., Schile-Beers, L., Zawadzki, A., Mazumder, D., & Woodroffe, C. D. (2019). Wetland carbon storage controlled by millennial-scale variation in relative sea-level rise. *Nature*, *567*(7746), Article 7746. https://doi.org/10.1038/s41586-019-0951-7

Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*(1794), 20190120. https://doi.org/10.1098/rstb.2019.0120

SMHI. (2022). *Malik—Årets första namngivna storm | SMHI*. https://www.smhi.se/bloggar/vaderleken-2-3336/malik-arets-forsta-namngivna-storm-1.179810

Sousa, A. I., Lillebø, A. I., Risgaard-Petersen, N., Pardal, M. A., & Caçador, I. (2012). Denitrification: An ecosystem service provided by salt marshes. *Marine Ecology Progress Series*, *448*, 79–92. https://doi.org/10.3354/meps09526

Spangenberg, J. H. (2011). Sustainability science: A review, an analysis and some empirical lessons. *Environmental Conservation*, *38*(3), 275–287. https://doi.org/10.1017/S0376892911000270

Spencer, T., Möller, I., Rupprecht, F., Bouma, T. J., van Wesenbeeck, B. K., Kudella, M., Paul, M., Jensen, K., Wolters, G., Miranda-Lange, M., & Schimmels, S. (2016). Salt marsh surface survives true-to-scale simulated storm surges. *Earth Surface Processes and Landforms*, *41*(4), 543–552. https://doi.org/10.1002/esp.3867

Steffen, W., Rockström, J., Richardson, K., Lenton, T. M., Folke, C., Liverman, D., Summerhayes, C. P., Barnosky, A. D., Cornell, S. E., Crucifix, M., Donges, J. F., Fetzer, I., Lade, S. J., Scheffer, M., Winkelmann, R., & Schellnhuber, H. J. (2018). Trajectories of the Earth System in the Anthropocene. *Proceedings of the National Academy of Sciences*, *115*(33), 8252–8259. https://doi.org/10.1073/pnas.1810141115

Sutton-Grier, A. E., Gittman, R. K., Arkema, K. K., Bennett, R. O., Benoit, J., Blitch, S., Burks-Copes, K. A., Colden, A., Dausman, A., DeAngelis, B. M., Hughes, A. R., Scyphers, S. B., & Grabowski, J. H. (2018). Investing in Natural and Nature-Based Infrastructure: Building Better Along Our Coasts. *Sustainability*, *10*(2), Article 2. https://doi.org/10.3390/su10020523

Sutton-Grier, A. E., Wowk, K., & Bamford, H. (2015). Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. *Environmental Science & Policy*, *51*, 137–148. https://doi.org/10.1016/j.envsci.2015.04.006

Thorslund, J., Jarsjo, J., Jaramillo, F., Jawitz, J. W., Manzoni, S., Basu, N. B., Chalov, S. R., Cohen, M. J., Creed, I. F., Goldenberg, R., Hylin, A., Kalantari, Z., Koussis, A. D., Lyon, S. W., Mazi, K., Mard, J., Persson, K., Pietro, J., Prieto, C., … Destouni, G. (2017). Wetlands as large-scale nature-based solutions: Status and challenges for research, engineering and management. *Ecological Engineering*, *108*, 489–497. https://doi.org/10.1016/j.ecoleng.2017.07.012

Toimil, A., Camus, P., Losada, I. J., Cozannet, G. L., Nicholls, R. J., Idier, D., & Maspataud, A. (2019). Climate change-driven coastal erosion modelling in temperate sandy beaches Methods and uncertainty treatment | Elsevier Enhanced Reader. *Earth-Science Reviews*. https://doi.org/10.1016/j.earscirev.2020.103110

Toimil, A., Losada, I. J., Nicholls, R. J., Dalrymple, R. A., & Stive, M. J. F. (2020). Addressing the challenges of climate change risks and adaptation in coastal areas: A review. *Coastal Engineering*, *156*, 103611. https://doi.org/10.1016/j.coastaleng.2019.103611

Wainwright, D. J., Ranasinghe, R., Callaghan, D. P., Woodroffe, C. D., Jongejan, R., Dougherty, A. J., Rogers, K., & Cowell, P. J. (2015). Moving from deterministic towards probabilistic coastal hazard and risk assessment: Development of a modelling framework and application to Narrabeen Beach, New South Wales, Australia. *Coastal Engineering*, *96*, 92–99. https://doi.org/10.1016/j.coastaleng.2014.11.009

Walker, W. E., Harremoës, P., Rotmans, J., van der Sluijs, J. P., van Asselt, M. B. A., Janssen, P., & Krayer von Krauss, M. P. (2003). Defining Uncertainty: A Conceptual Basis for Uncertainty Management in Model-Based Decision Support. *Integrated Assessment*, *4*(1), 5–17. https://doi.org/10.1076/iaij.4.1.5.16466

Wamsler, C., & Brink, E. (2016). *Promoting nature-based solutions: Guideline for integrating ecosystem-based adaptation into municipal planning and governance: Vol. Disaster Studies and Management Working Paper No. 32*. University College London (UCL) Hazard Centre.

https://www.ecosystemservices.se/download/18.29aef808155c0d7f050946/1473856990895

/Guideline.EbA.12.09.2016.pdf

9. Appendices

9.1 Appendix A. Interview guides

Intervjuguide för intervjuer med Lomma kommun angående Naturbaserade lösningar:

Svenska:

1. Vilka Naturbaserade lösningar har ni implementerat för att skydda kustzonen mot översvämningar och erosion, framför allt i Bjärred?
2. Vilka naturbaserade lösningar planerar ni för framtiden i kustzonen?
3. Hur och när följer ni upp arbetet för de naturbaserade lösningarna? Beskriv gärna hur förloppet och arbetsprocessen går till från design till implementering och uppföljning?
4. Vilka scenarion ligger till grund för planeringen och designen av de naturbaserade lösningarna?
5. Har ni övervägt osäkerheter i samband med scenariots utförande och de osäkerheter som finns i klimatförändringars effekter i kustzonen?
6. Hur speglar sig hänsynen till framtida osäkerheter kring klimatförändringarna i er implementering och design av de naturbaserade lösningarna?

Interview guide for interviews with Lomma municipality regarding Nature-based Solutions.

English:

1. What nature-based solutions have you implemented in order to protect the coastal zone from flooding and erosion?
2. What Nature-based solutions do you plan for the future in the coastal zone?
3. How and when do you follow up on the Nature-based solutions? Please describe the work process from design to implementation and follow-up?
4. Which climate scenarios/risk scenarios form the basis for the planning and design of the Nature-based solutions?
5. Have you considered the uncertainties associated with the development of the scenario and the uncertainties of the effects of climate change in the coastal zone?
6. How are the considerations of uncertainties of future climate change reflected in your implementation and design of the Nature-based solutions?

Intervjufrågor till forskare vid Lunds universitet

1. På vilket sätt arbetar du med de naturbaserade lösningarna i Bjärred? LIFE och våtmarken.
2. Vad är din uppfattning om Life-projektets långsiktighet (och flexibilitet) i relation till osäkerheter kring klimatförändringarnas effekter? Vilken potential har lösningen som skydd?
3. På vilket sätt har projektets följts upp och utvärderats och vad är resultaten av detta?

4. Hur kommer den naturbaserade lösningen att förändras över tid och hur kommer kommunen behöva arbeta för att bevara den?
5. Hur är denna typ av lösning överlägsen en hårdgjord grå lösning mot kusterosion? Vilka värden/fördelar bidrar den med?
6. Ser du några utmaningar med lösningen med tanke på dess potential som erosionsskydd?

9.2 Appendix B. Consent form

<u>CONSENT FORM</u>

Name of the interviewer: *Anna Nohed*

Contact information of the interviewer:

Date and time of interview:

Purpose of the study
Thank you very much for taking the time to talk to me. I have asked you for an interview as part of a master thesis that I carry out in the last term of the International Master Program in Environmental Studies and Sustainability Science at Lund University.
The aim of the interviews is to better understand how the work with Nature-based Solutions and coastal protection has been implemented and will continue to be applied, in Bjärred and Lomma Municipality.

I am getting in touch with you since I am conducting research regarding Nature-based solutions and coastal protection in times of uncertainty. I have a few questions that I would like to ask you. All information is confidential and will not be revealed or associated with your name unless you agree to it. If you do not want to answer a question please tell me, the interview is entirely voluntary, and you can discontinue it at any moment. Please let me know if you want me to explain a question.

Do you consent that I can use your answers for the thesis project?

*Authorization for using the information/responses (Yes / No) yes*________________

*The respondent wants to stay anonymous (Yes / No) yes*____________

I consent that this meeting is recorded (audio) without the right to publish, distribute, or edit through any medium by the interviewer (Yes / No) ___*yes*____________

Name of the interviewee (if anonymous write anonymous here)

Position of the interviewee (if the respondent agrees to it being noted down and used)