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Faculty of Landscape Architecture, Horticulture
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Climate adaptation for coastal zones

Benefits and tradeoffs in a southern Swedish case

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CLIMATE ADAPTATION FOR COASTAL ZONES

Benefits and tradeoffs in a southern Swedish case

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ABSTRACT

Climate change in coastal areas implies sea level rise and more frequent extreme weather events causing floods. Floods cause property damage and risk to people as the coastal zones many times are built and developed environments. Besides from this, the coastal zones have high ecological values connected to the coastal dynamics. 'Coastal squeeze' occurs when ecological values are obstructed to migrate inland by built environments, currently a common situation. In Bunkeflostrand and Klagshamn in southern Sweden, coastal squeeze is a fact, and as sea levels rise, much of the ecological values could be lost by year 2100.

Conventional and traditional methods to control water are being questioned, the integration of natural features is gaining attention and innovation is advocated in the aspiration to a sustainable development for our common future.

Following reading will take you through the outlook of coastal planning and management, and display international approaches to address climate adaptation for coastal zones. Thereafter, some examples will be applied to the Bunkeflostrand and Klagshamn context with the ambition to identify benefits and tradeoffs from the sustainability aspect.

The results show that conventional methods may not always be the worst solution, and that natural features may not be the better - the combination of various structures and methods may constitute a sequential line of defense. Other results show that ecological benefits many times imply socio-economic tradeoffs, and vice versa. Sometimes an ecological long-term benefit even implies ecological tradeoffs. The results also show that sustainability may conflict with the Sustainable Development Goals, depending on the focus.

To assess the best possible solutions, climate adaptation for coastal zones require multidisciplinary collaboration and investigations between agencies, the state, municipalities, planners and designers.

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ACRONYMS

CAB	County Administrative Board
CBD	Secretariat of the Convention on Biological Diversity
EbA	Ecosystem-based Adaptation
EC	European Commission
EU	European Union
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GMSL	Global Mean Sea Level
HCE	Historical centennial events
HaV (Havs och Vattenmyndigheten)	Swedish Agency for Marine and Water Management
ICAADE	International Conference on Amphibious Architecture, Design and Engineering
ICE	Institution of Civil Engineers
ICZM	Integrated Coastal Zone Management
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
MSB (Myndigheten för samhällsskydd och beredskap)	The Swedish Civil Contingencies Agency
NbS	Nature-based Solutions
PBL (Plan- och bygglagen)	Swedish Planning and Building Act
RCP	Representative Concentration Pathways
RDI	The Resilient Design Institute
SDG	Sustainable Development Goals
SGI (Statens geotekniska institut)	The Swedish Geotechnical Institute
SGU (Sveriges Geologiska Undersökning)	Geological Survey of Sweden
SMHI (Sveriges meteorologiska och hydrologiska institut)	Swedish Meteorological and Hydrological Institute
SLR	Sea Level Rise
UN	United Nations
USACE	U.S. Army Corps of Engineers
WCED	World Commission on Environment and Development
WMO	World Meteorological Organization

Introduction

1

1.1 BACKGROUND

Climate change and sea level rise

Signs of a changing climate are several and the World Meteorological Organization (WMO) states that the highest global average temperatures were recorded during 2013-2017 of approximately 1°C higher than the period 1850-1900, which is a dramatic increase in the climate context (WMO 2018). With this, the cryosphere is continuing to decrease (WMO 2018; IPCC 2019a). Even if the Paris Agreement goal to keep temperature rise below 1,5°-2°C (compared to preindustrial levels) is reached and the global temperature rise is slowed down or even reversed, the global mean sea level (GMSL) will continue to rise due to thermal expansion of the oceans, and the delayed effects from glacial melt and loss of ice sheets (IPCC 2019a).

Other signs of a changing climate are precipitation anomalies, more frequent extreme weather, and a change in wind patterns that influence high sea water levels (IPCC 2019a; SMHI 2019c). According to IPCC (2019a) a study indicates a 2,3 meters sea level rise (SLR) per Celsius degree rise for the next 2000 years and that a 100-year event will be common by 2100.

Development in coastal zones

Populating coastal zones have always been attractive for humans and has increased much in modern times (Neumann et al. 2015). Around 11% of the world population is estimated to live in Low Elevation Coastal Zones, i.e. coastal areas below 10 m elevation (IPCC 2019a). The world population density is considerably higher in coastal zones compared to non-coastal zones (Neumann et al. 2015).

Globally, Europe, North America and Oceania have the lowest urban land conversion of the coastal zones whilst an extensive coastal urbanization is occurring in e.g. China and Southwest Asia (ibid.). Despite, the European Union (EU) states that the coastal zones in Europe are more densely built up compared to hinterland areas (EU 2011).

The dynamic coast

Coastlines are, and have always been, shaped and reshaped by natural forces. The last 100 years, human urge and desire to live adjacent to the water has been made simpler through technological advancements, although commonly with constructions that have restricted natural dynamics; sometimes even exacerbating unwanted effects, such as erosion (Tol, Klein and Nicholls 2008; Davis, Krüger and Hinzmann 2015). Such conventional/traditional structures for coastal defense not only restrict natural dynamics or generate negative side-effects, they are also ineffective to adapt to a rising sea level meaning that they will require frequent maintenance and structural reinforcements (Davis, Krüger and Hinzmann 2015).

False sense of security and coastal squeeze

Another disadvantage of conventional structures is the false sense of security provided to and perceived by the inhabitants. A recent event showing this is the Hurricane Katrina in August 29th, 2005 – one of the deadliest and costliest natural disaster in American history. Levees constructed to protect several areas in New Orleans were overflowed in more than 50 locations leading to the mass spreading of floodwaters. The false sense of security was one of the major causes to the devastation, but also the mismanagement of both urban systems within the flood walls, and the natural systems outside of them – severely damaged by the hurricane.

Globally, natural systems and wetlands that provide defense against storm surge and wave effects are in risk of being marginalized or lost from eroding effects or being submerged due to SLR. IPCC (2019a, ch. 4, pp. 68-69) call the phenomenon 'coastal squeeze', which occurs when natural systems are impeded by built up human development (see Figure 1).

To address such issues, Seddon (2018) calls for adaptation methods that reach beyond traditional defensive solutions in order to preserve and protect essential ecosystems.

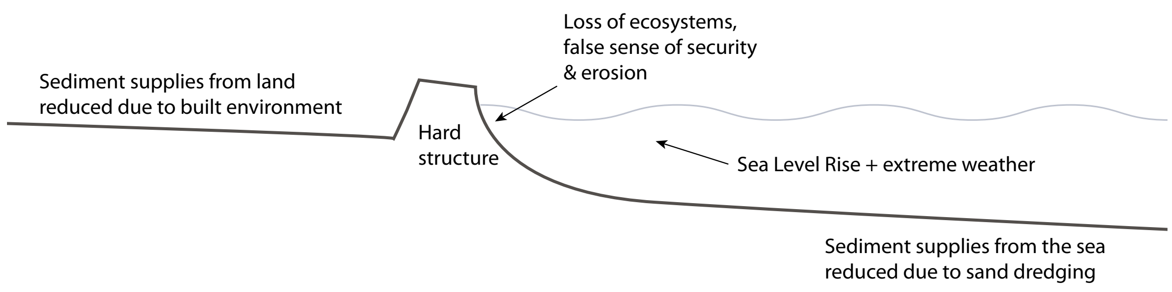

Figure 1: Simplified illustration of coastal squeeze (Borner 2020).

A paradigm shift towards sustainability and resilience

As a result from Hurricane Katrina, it was acknowledged that hard structure flood control measures (e.g. levees) were deficient and that the mismanagement of the surrounding natural systems enhanced the severe impacts, leading to a paradigm shift of realizing the relevance of a "floodplain management" (Nordenson, Nordenson and Chapman 2018, p. 76). The shift from conventional and established flood control practices (resistance) to an integrated floodplain management (resilience) can be traced to the incorporation of "natural and nature-based features" in the U.S. Army Corps of Engineers (USACE) palette of flood risk reduction measures, in which four categories are defined:

1. **Natural features** – "created through the action of physical, biological, geologic, and chemical processes operating in nature".
2. **Nature-based features** - created by humans mimicking natural features.
3. **Nonstructural measures** "are complete or partial alternatives to structural measures, including modifications in public policy, management practices, regulatory policy, and pricing policy".
4. **Structural measures** "are traditional structures including levees, storm surge barrier gates, seawalls, revetments, groins, and nearshore breakwaters".

(USACE 2013)

With the aspiration of reducing coastal flooding and increase resilience, USACE imply that combinations of the listed categories above form the "integrated approach". The integrated approach is a proper flood protection which constitutes a series or sequential measures that together amplify the defense. Nordenson, Nordenson and Chapman (2018, pp. 76, 79) complement this with an urge for also adding a governance approach to the technical solutions by stating: "truly resilient and adaptable coastal regions will demand the collaboration of state and municipal agencies, private developers, property owners, planners and designers.

To address the challenges of climate change and the adversities of coastal developments, loss of biodiversity, and deterioration of ecosystems, new and innovative approaches are sought after (Denton et al. 2014; Moosavi et al. 2017). Nordenson, Nordenson and Chapman (2018) argue that new infrastructural strategies and fundamental knowledge about the relationship between human settlement and water are required in order to achieve coastal resilience.

Therefore, it can be concluded that new approaches to coastal adaptation is needed, and that solutions should be holistic in order to achieve resilient coastlines. Even though working with landscapes are situational tasks that generate site specific solutions (improper to copy from one site to another), and that the magnitude of Hurricane Katrina might not be the case in southern Sweden, we can still speculate and learn from the experience and knowledge generated by USACE based on this event.

By incorporating natural and nature-based features into coastal defense infrastructure, new and resilient urban and recreational spaces that both reduce flood risk and preserve and improve ecosystems can be created – turning threats from climate change into opportunities (Nordenson, Nordenson and Chapman 2018). Simultaneously, the approach is also incorporating social, ecological and economy aspects – being the core values of sustainability (see Figure 2). Also, a wider collaboration underlined by Nordenson, Nordenson and Chapman (2018) is crucial, although they do not necessarily suggest further exploitation of coastal zones – regulation of land use or even discouraging development should not be excluded in the adaptation discourse.

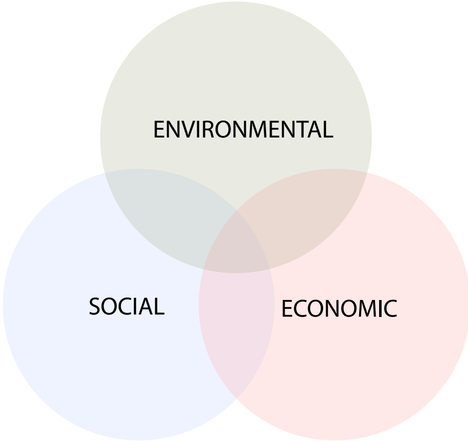

Figure 2: The three core values of sustainability (Borner 2020).

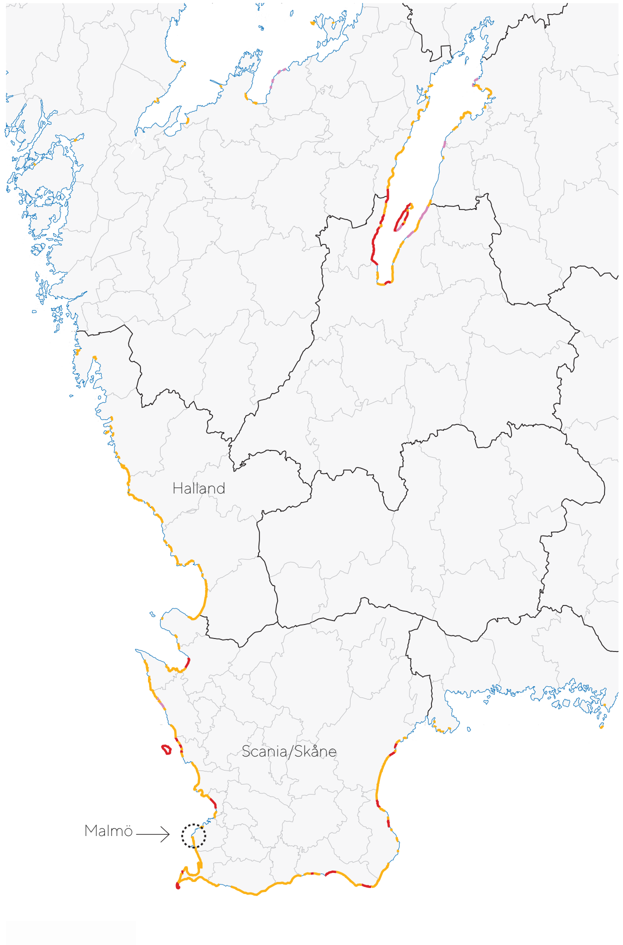

Figure 3: Erosion assessment (SGU 2017).

Adaptation in Sweden

Mentioned earlier, much developed areas, globally, can be found in the coastal zones, which is also the case in Sweden. Boverket (2006) defines 'coastal zones' as the area between the shoreline and 5 km inland. Boverket claims that 38% of the Swedish population live here, and that 32% of the country's buildings are located here as well. Boverket also describe that the general development rate in Sweden has decreased compared to the 1970's and 1980's, although with an increase along the coastal zones, where approximately 50% of the developments occur in southern Sweden[1], indicating that much developments need and will need adaptation.

The choice of coastal adaptation measures to climate change largely depend on the level of vulnerability to combinations of SLR, erosion, floodings, and/or land slide occurring at a specific site (Tol, Klein and Nicholls 2008). In Sweden, the two counties Scania (Swe. Skåne) and Halland are considered to have the most vulnerable coastlines (Länsstyrelsen et al. 2019).

Sveriges Geologiska Undersökning (SGU) assessed and identified areas susceptible to and affected by erosion throughout Sweden (SGU 2017). The erosion assessments are based on topography, field visits and the area's soil type and its sensitivity to eroding effects. The outcome for the Scanian and Halland situations can be seen in Figure 3.

The erosion assessments are currently being complemented as the Swedish government in 2019 delegated Statens geotekniska institut (SGI) and Myndigheten för samhällsskydd och beredskap (MSB) a mission to 'identify particular risk areas' prone to erosion, flooding and landslide, but also to assess the socio-economic consequences, and to grade the identified risk areas linked to climate change. The mission will be executed in four parts, and the results will be delivered in May 2021[2].

Climate adaptation in Malmö

The erosion assessment map in Figure 3 indicates significant threats to also the Malmö area. Climate adaptation strategies regarding high sea water levels are described in the Malmö comprehensive plan from 2018. The strategies found there encompass long-term planning measures advocating multidisciplinary collaboration in planning processes as well as in financial models, and design proposals. A general guideline is to prescribe a +3,0 meters above sea level as a 'lowest elevation level' for new development. Eventually, Malmö will develop a long-term strategic plan dealing with SLR problems now and in the future (Malmö stad 2018a).

[1] Southern Sweden is defined as the counties of Värmland, Örebro, Västmanland, Uppsala and all counties to the south of these (Boverket 2006).

[2] Kerstin Konitzer, Strategist Climate Change, SGI, presentation 2020-01-21

Problem definition

At present, nature-based features are gaining popularity, conventional methods are being questioned, and innovation is advocated (Denton et al. 2014), making it essential to investigate different coastal protection structures and methods, compare them and try to predict the outcomes before implementing them in full scale.

Remarkable is that, in the climate adaptation discourse, socio-economic values seem to get more attention before ecological. This is noticeable in the mission to 'identify particular risk areas' delegated by the Swedish government, in which one of the four parts concerns 'Socio-economic impact assessments of the risk areas' – with no equivalent part concerning ecological values (SGI 2020).

Therefore, the research questions are:

A. What are the benefits and tradeoffs from different coastal protection structures and methods, and from the Sustainable Development Goals (SDGs) standpoint?

B. How can different coastal protection solutions be applied to achieve coastal resilience?

Aims and objectives

The aims and objectives of the thesis are:

1. to describe climate adaptation in coastal zones in relation to SLR and storm surge, including the effects from coastal measures, structures and methods utilized or applicable for coastal flood protection.
2. to evaluate specific applications in a Scanian context, with Bunkeflostrand and Klagshamn in southern Malmö as project site.

Delimitations

In this thesis, the term 'coastal' refers to coastlines connected to oceans, which are the types of coastlines that will be explored, first on an international level and later within the Bunkeflostrand and Klagshamn context.

Even though a holistic approach is encouraged, another delimitation is having the main focus on evaluating the benefits and tradeoffs from the selected coastal flood protection structures and methods. Therefore, this thesis will not handle non-structural aspects, e.g. policy, governance, financial aspects or benefit-cost analyses to any greater extent.

In this thesis, a fragment of available flood protection structures and methods will be presented (in section 2.4), from which an excerpt will be tested and evaluated (in section 7). The selected structures and methods are sometimes based on the combination between existing flood protection plans and the current trend towards nature-based features. Another example leans towards a radical change relating to innovative and novel thinking methods and approaches.

Method and process

This work is a general exploration of what climate change implies in coastal zones; initially, from a global perspective and then to a southern Swedish context – Bunkeflostrand and Klagshamn.

The work process can be divided into six segments:

1. Research and knowledge base
2. Mapping and modelling
3. Analysis and comparison
4. Visualizations, assessments and evaluations

1. The **research and knowledge base** was acquired by, and consist of:

- Up-to-date reports and contemporary peer reviewed articles on climate change and various adaptation approaches were initially gathered from the IPCC and from Google Scholar. From the acquired literature, further reports and articles were retrieved from reference lists.

  Policy documents, assessment reports, publications and articles were retrieved from various national agencies, Region Skåne, municipality homepages, the consultant company SWECO, supervisor Thomas B. Randrup, a guest lecturer Liao Kuei-Hsien, and Google Scholar – in-text citations and reference lists lead to additional relevant literature.

  The in-text citations and references also lead to various project examples. With a focus on novel ideas and innovative methods.

  The literature was reviewed and analyzed in relation to (i) both established and conventional flood control practices, and new approaches - from both an anthropocentric and an ecological viewpoint, (ii) adaptation and resilience, (iii) relevant laws and regulations for the specific site Bunkeflostrand and Klagshamn.

- A study visit with the EU funded project 'LIFE Coast Adapt' in November 21st-22nd, 2019.

- A two-day conference 'Regional Kustsamverkan' (Eng. Integrated Regional Coastal Zone) between 21st -22nd January 2020.

2. Selected data used for **mapping and modelling**:

- CO_2 emission and SLR
  Several components need to be taken into consideration when forecasting future local sea level, such as: isostasy and subsidence, wind, waves, thermal expansion, water salinity, and ocean currents (von Oelreich et al. 2015). The forecasted sea level for the project site is based on information from the IPCC (2019a) and SMHI (2018b).

  Representative Concentration Pathways (RCP) are scenarios for future greenhouse gas concentrations divided into four scenarios: RCP2,6, RCP4,5, RCP6,0 and RCP8,5 (SMHI 2018d). The latter RCB8,5 – translated as 'continued high CO_2 emission rate' – is the scenario that will be used in this thesis, based on the statement that it, till year 2100, is the scenario that represent the current trend (SMHI 2019a).

  A 1,1 meter SLR will be used for the project site as studies done by the IPCC (2019a) have concluded a GMSL between 0,61–1,10 m is likely to occur with the RCP8,5 scenario. They also claim that any RCP-scenario implies a high confidence that current 100-year events will be common by 2100.

- Storm surge and recurrence intervals
  Storm surge is high sea water levels pushed onshore by strong winds, causing floods. Several factors affect the storm surge amplitude, such as bathymetry, wind power and storm duration (NOOA 2019; SMHI 2019b). As storm surge relates to the mean sea level, SMHI (2019b) underlines that storm surge will reach even further on land as sea levels continue to rise. Therefore, a specific recurrence interval will not be focused, instead three scenarios will be presented and discussed.

- Threat maps
  The MSB (2018) threat maps, produced accordingly to the EU 'Directive 2007/60/EC on the assessment and management of flood risks' (further presented in section 5.1.1) will be used for the project site. Three end of the century scenarios depicting a 100-year, 200-year, and an estimation of a 10 000-year event are made available. The 10 000-year event, which will be called 'extreme event' in this thesis, is the highest predicted water level by year 2100.

- **Mapping and modelling** sea level scenarios was executed through Geographic Information System (GIS) analyses in ArcMap by 'bathtub modelling'. This means that the current sea level has been 'raised' to a chosen level. This type of modelling does not only raise the sea level but also all water tables inland, which is misleading. The raised inland water tables are called 'artefacts' and have been lowered to the current water level.

  The next step in the GIS-analyses entailed using the MSB threat maps.

  Subsequently, the project site was built up as a 3D model in SketchUp according to scale. Buildings and architecture were simplified although similar to the actual on-site buildings and layout.

3. The **analysis and comparison** process comprise taking the acquired knowledge basis into consideration when reviewing maps and models, and from project site visits. By adding buildings and infrastructure to the maps and models, areas that will be flooded at different sea levels will be identified.

   Furthermore, contemporary as well as innovative structural measures addressing climate adaptation for coastal zones was inspected and then a selection were applied to the Bunkeflostrand and Klagshamn context.

4. Viewpoints and locations for **visualizations** were selected from the 3D SketchUp model together with Google Earth street views - facilitating the understanding of the structural and visual impacts on the landscape. Then, the benefits and tradeoffs of the examples were **assessed and evaluated** based on the literature studies, and then from an SGD standpoint.

The coastal picture

2

While exploring the subject 'climate adaptation for coastal zones' it is essential to both understand the threats that climate change pose to the coastal zones, and what the concept 'adaptation' implies. Not only does the subject interrelate with numerous other subjects, a list of terminology emerges in addition.

Experiences from conventional methods to control water have exposed both benefits and tradeoffs. It even resulted in a paradigm shift to an 'integrated floodplain management approach' implementing natural and nature-based features, aiming to achieve resilience – yet another frequently used term in risk of being misunderstood if used perfunctorily. Simultaneously, the United Nation (UN) member states joined forces to achieve sustainability and sustainable development, which evoke the interest to investigate how it relates to the aspiration of resilient climate adaptation for coastal zones.

The following section will help clarify some of the frequently used terms and concepts in order to analyze and assess different solutions and their impacts for the project site accordingly (section 6). For example, the word 'threat' is generally perceived and defined similarly, although the term itself has nuances, and definitions vary much. Therefore, this section will start with the definitions of some common threat terms used in this thesis.

2.1 THREAT TERMINOLOGY AND DEFINITIONS

The three terms 'hazard, vulnerability and risk' are in general intuitively understood by the public, although the definitions might differ between scientific fields and disciplines, and they might also change over time (EEA 2017). The definitions sometimes even vary within a scientific field.

Hazard

According to IPCC (2012, p. 560) hazard is defined as:

> *"A **potential** occurrence of a natural or human-induced physical event that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources"*

Vulnerability

The UNISDR (2009, p. 17) defines the term as:

> *"Characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard".*

Risk

The UNDRR (2019) highlights the complexity of the term but it can be summarized as:

> *"Risk is the **probability** of combined effects from hazards and vulnerability having a negative effect on people, systems or assets".*

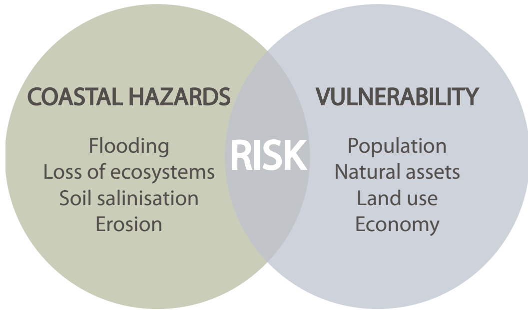

Figure 4: Hazard, vulnerability and risk diagram (Borner 2020).

2.2 IMPACTS AND COASTAL HAZARDS

The impacts from SLR are multiple, although regarding flooding effects it implies two types of impacts:

1. A changed coastline as permanent flooding occurs.

2. Temporary flooding from the combination of specific weather events such as heavy precipitation and increased stream and river flows.

(Simonsson et al. 2017)

The IPCC (2019) pinpoint six coastal hazards due to SLR and impacts due to both SLR and other climate-related effects (see Figure 5).

The hazards and impacts may interact themselves but might also co-react with other climate-related effects, causing even greater problems – an example could be increased erosion due to SLR, another could be SLR blocking the outflow from streams and rivers with increased flows due to heavy precipitation events (Simonsson et al. 2017).

The direct impacts (see Figure 5) might destroy built environment, essential transportation links and businesses, disrupt ecological values etc. (Bhattachan et al. 2018; Klimatanpassning.se 2019b; Länsstyrelsen Skåne et al. 2019; IPCC 2019).

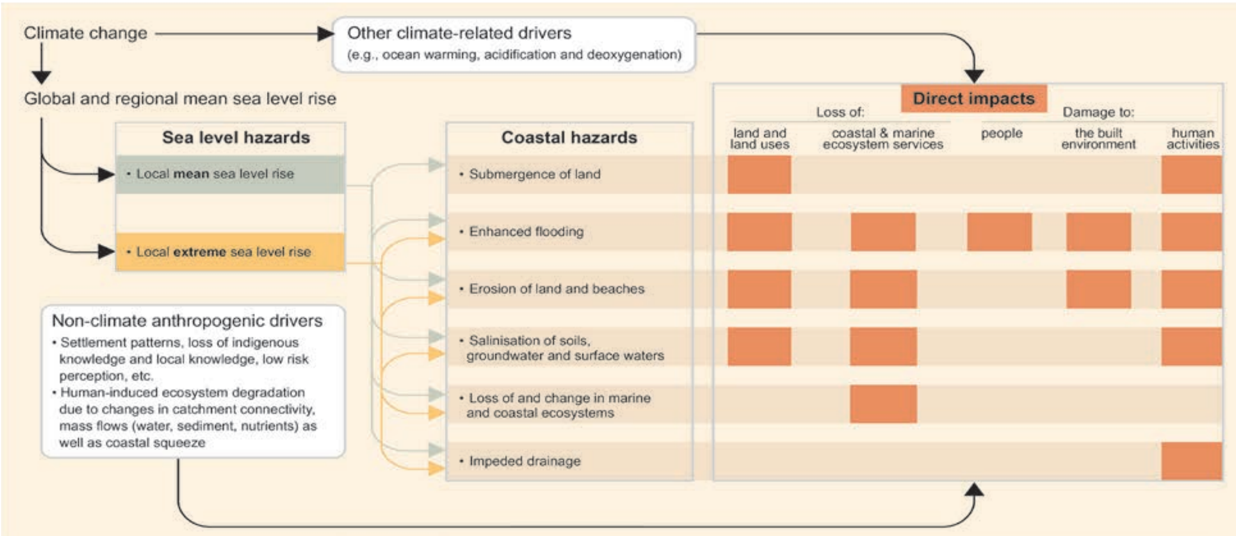

Figure 5: Overview of the main cascading effects of sea-level rise (IPCC 2019b, ch. 4 p. 375).

2.3 ADAPTATION

In this section, the term adaptation will be investigated in three steps from a climate adaptation in coastal zones perspective.

Firstly, a clear definition to the term is needed.

Secondly, a short discussion about 'what and why' adaptation for coastal zones is necessary – from both the ecological and anthropocentric viewpoints.

Lastly, among numerous adaptation measures, four have been selected, briefly summarized, described and compared.

2.3.1 What is it?

In the IPCC Third Assessment Report (2001, p. 982) adaptation is defined as:

> *"Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation."*

IPCC explains that 'anticipatory adaptation' is when adaptation measures are implemented before impacts are observed, and that 'reactive adaptation' as impacts have been observed. IPCC stress the importance of adaptation to make our societies prepared for SLR and flooding (e.g. extreme sea level events), or else the potential risks and impacts will increase significantly; Wong et al. (2014) advocate anticipatory adaptation, as it might be more costly and less effective if implemented in retrospect.

Though, as the above definition indicate, it is important to understand that adaptation is not bound to technical and physical means but is also applied and practiced by gathering and spreading information and knowledge, and by being innovative in the processes (Klimatanpassning.se 2019b).

2.3.2 What and why?

The attractiveness in populating and utilizing coastal zones implies that a great extent of social, cultural and economic values can be found here (Simonsson et al. 2017).

Health aspects connected to SLR in terms of deterioration of living standards e.g. leading to changes in disease transmission and increased landslide risks are aspects connected to human settlements (Wong et al. 2014; Simonsson et al. 2017). Besides from that, the coastal zones many times consist of industries with supporting infrastructure (e.g. ports, roads and railways, other technical infrastructure, etc.); fishing industries or small-scale fisheries, aquaculture and agriculture; and recreational values (ibid.; ibid.).

The coastal zones also consist of biological and ecological values in great risk of being marginalized or even disappear as human settlement and built up areas form barriers preventing inland migration (Simonsson et al. 2017; IPCC 2019a).

Since climate change and SLR either will completely change the coastline by constant submergence, or by temporarily flooding, adaptation measures need to be implemented.

2.3.3 How?

Multiple adaptation concepts have been developed and are available. Depending on the source, different descriptive terms are used, such as 'approaches', 'principles', 'strategies', and 'responses'. In this thesis the term ***measures*** will be used in order to distinguish it from the various measures that will be described below. Four measures will be listed as A-D and summarized shortly afterwards. They are listed in a chronological order as they were developed:

A. The Institution of Civil Engineers (ICE) (2007) describe three broad approaches:

1. Retreat
   Moving infrastructure and buildings to avoid being affected.

2. Defend
   Ensuring that water will not enter built environments.

4. Attack
   Advancing seaward.

B. Nordenson, Nordenson and Chapman (2018, p. 81) claim to complement the USACE's four categories of flood risk reduction measures by three principles:

1. Attenuation
   Dissipation of wave energy offshore reduces the demands on nearshore structures.

2. Protection
   Improving flood protection structures (e.g. levees and seawalls) as well as nonstructural measures (e.g. relocation and evacuation strategies).

3. Planning
   Planning for and allowing controlled flooding in in urban and landscape design and management.

The principles are applied between the offshore and as upland features, and the in between.

C. Sveriges geotekniska institut[3] (SGI) (2019) recommend and describe five strategies in total:

1. Do nothing
   No negative consequences identified - natural erosion processes are allowed.

2. Retreat
   Relocating settlements, infrastructure or other essential services.

3. Hold the line*
   Preserve and/or reinforce the current shoreline and the protection provided. Implemented in situations where adaptation measures can be placed in front of or behind already existing protection structures.

4. Move seaward*
   New coastal protections are constructed closer to the shoreline in front of already existing protective structures. Rarely used in Swedish situations.

5. Limited intervention*
   Accepting natural processes in a controlled manner to secure and protect identified values.

[3] The Swedish geotechnical institute is "an expert agency that works for a safe, efficient and sustainable development and sustainable use of land and natural resources" (SGI 2016).

** The English translations are found in Hanson, Rydell and Andersson (2006).*

D. Lastly, the IPCC (2019a) describe six responses to SLR:

1. No response

2. Protection
   Stopping the water to spread further inland by:
   - *Hard protection measures* (e.g. dikes, seawalls, breakwaters and barriers).
   - *Sediment-based protection*, a.k.a. soft structures (e.g. beach nourishment and dunes).
   - *Ecosystem-based Adaptation*

   Combining the three subcategories above are so called 'hybrid measures' (ibid.).

3. Accommodation
   The use of biophysical and institutional responses in order to mitigate vulnerability of coastal residents, human activities, ecosystems, and built environment – allowing for coastal habitability despite increased levels of hazard. (Building codes, house elevation measures, floating houses and gardens, use of vegetation tolerant to saline environments, warning systems and emergency planning are different examples of accommodation responses.)

4. Advance
   Building seaward by land filling supported by vegetation to facilitate natural accretion of land and reducing coastal risks for the hinterland.

5. Retreat
   Moving exposed people, assets and human activities from the coastal hazard zone, categorized into three forms:
   - *Migration* (voluntary movement)
   - *Displacement* (involuntary movement)
   - *Relocation*, a.k.a. resettlement, managed retreat or managed realignment.

   Retreat measures can be avoided by avoiding new developments in areas in risk of SLR and coastal hazards (ibid.).

6. Ecosystem-based Adaptation (EbA)
   Combinations of protection and advance responses based on sustainable management, conservation, and restoration of ecosystems (e.g. wetlands and reefs). EbA protect the coastline by:
   - Attenuating waves and flows as it can act as obstacles.
   - Raising elevation and reducing erosion by trapping and stabilizing sediments and organic matter.

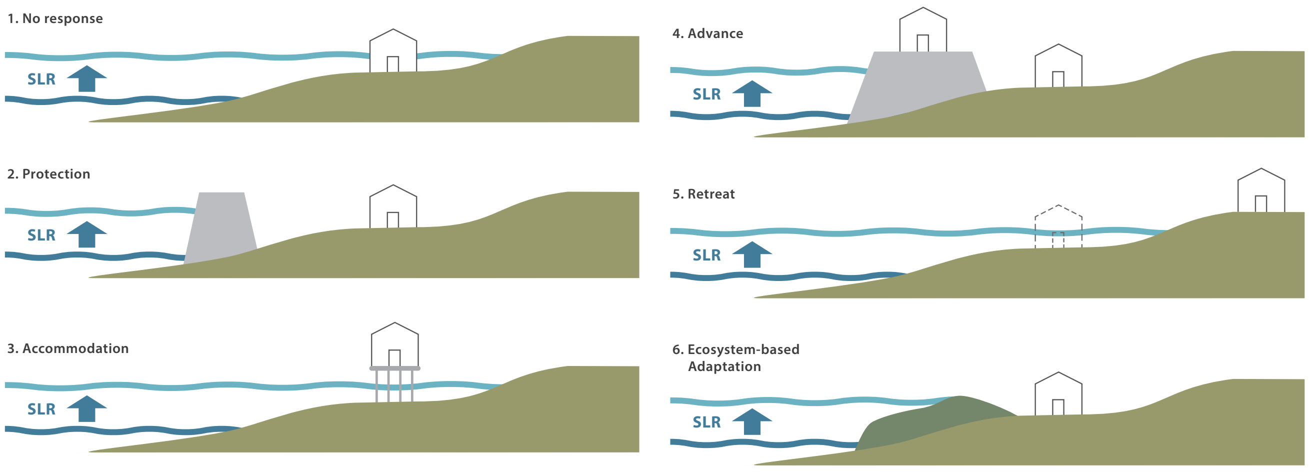

Figure 6: The IPCC six responses to SLR. (Borner 2020).

2.3.4 Summary

By summarizing the four selected adaptation concepts (see Table 1), it is visible that several share more or less the same ideas, forming nine measures in total.

The 'attenuation' measure in the Nordenson, Nordenson and Chapman column, could to some extent be regarded as a defense/ protection measure as its purpose is to reduce wave energy, although the definition does not correspond to the defend/ protection/hold the line-measures.

The 'planning' and 'limited intervention' are other examples of measures that overlap, though being different by definition. They incorporate "allowing controlled flooding" and "accepting natural processes in a controlled manner" (further described in section 2.3.3).

The IPCC stand alone with the EbA measure, making a clear distinction of a paradigm shift to incorporate natural features in the adaptation efforts. Yet, this does not mean that natural features are excluded in the three other adaptation concepts.

Stated earlier, some measures are more or less similar. The IPCC (2019a) draws a parallel between Ecosystem-based Adaptation (EbA) and *Nature-based Solutions (NbS), although nuances in their definitions are debatable. As a result of this, the NbS is added to the EbA measure in Table 1, and the two concepts will be further explained in section 2.4.4 and 2.4.5.

In this thesis, Bunkeflostrand and Klagshamn have been selected as the project site. The area is susceptible to storm surge and SLR flooding scenarios for year 2100. Therefore, the 'Do nothing / No response' measure s not applicable, which means that all other measures (highlighted in green) will be involved in the project site examples.

SOURCE / MEASURES	ICE (2007)	Nordenson, Nordenson & Chapman (2018)	SGI (2019)	IPCC (2019)
Accommodation				✓
Attack / Advance / Move seaward	✓		✓	✓
Attenuation		✓		
Defend / Protection / Hold the line	✓	✓	✓	✓
Do nothing / No response			✓	✓
EbA + * NbS				✓
Limited intervention			✓	
Planning		✓		
Retreat	✓		✓	✓

Table 1: Summary of four selected adaptation concepts, together forming a total of nine measures. The highlighted measures will be involved in the project site examples.(Borner 2019).

2.4 CORE PRINCIPLES OF COASTAL STRUCTURES AND METHODS

Coastal structures are and have been utilized for different reasons, e.g. to prevent erosion or flooding, but they have also been used to claim land, or to provide passage for marine transportation (USACE 2011).

In general, they can be divided into *hard, soft* and *hybrid* structures and methods. Novel approaches and concepts such as *Nature-based Solutions* (NbS) and *Ecosystem-based Adaptation* (EbA) are gaining attention and will be explained in the same order below.

Taking the landscape in consideration partly implies designing coastal zones in a way to not disrupt the connection between land, people and the ocean. A goal is to retain the possibility to "see, hear, and smell the water" (Nordenson, Nordenson and Chapman 2018, p. 5).

2.4.1 Hard structures

Here, the term 'hard structures' will be used although it may be referred to differently depending on the source, some examples are:

- *Built infrastructure* (Sutton-Grier, Wowk and Bamford 2015)
- *(Modified) hard engineering structures* (Moosavi et al. 2017)
- *Hard (flood) infrastructure* (CBD 2009; Nordenson, Nordenson and Chapman 2018).

Hard structures can be site-specific and do give an immediate effect of reducing or stopping water hazards or risks – in other words, these structures are often used to *control* and *resist* natural processes (CBD 2009; Moosavi et al. 2017).

Mentioned earlier, Nordenson, Nordenson and Chapman (2018) described the devastating effects from Hurricane Katrina when multiple flood protection levees were overtopped; underlining that hard structures are not completely reliable and may even worsen the effects and damage if or when they fail; potentially dangerous to people. They are also, many times, costly and studies have shown their negative impacts on coastal habitats (Moosavi et al. 2017; Seddon 2018).

The potential disbenefits from hard structures are several as they can disconnect ecologically related habitats, disrupt the dynamics of temporary inundated land and obstructing sediment and nutrition flows among others (CBD 2009; Sweco 2017). Hard structures might even create new or worsen erosion adjacent to the structure (LIFE Coast Adapt n.d. a; Davis, Krüger and Hinzmann 2015; Sweco 2017).

Another limitation to hard structures is that they solely may provide protection, sometimes only during storm events (Sutton-Grier, Wowk and Bamford 2015). They are also static in terms of not being able to adapt to a continuously rising sea level. This implies that such structures need to be regularly reworked and reinforced (Davis, Krüger and Hinzmann 2015); a matter described by the IPCC (2019a, ch. 4, p. 6) as "unaffordable before technical limits are reached".

However, there are situations where hard structures might be a solution. An example by Sweco (2017) is situations with strong currents - natural conditions making sand replenishment or beach nourishment unfavorable. Yet, Sweco also call for careful investigations and assessments prior to construction due to the possibility to create new erosion problems adjacent to these types of structures.

Examples of hard structures:

Figure 7: A metal bulkhead at low tide showing water levels by Unknown (CC0 1.0)

Bulkhead

Bulkheads are smaller seawalls having the primarily function to retain fill masses in locations with mild currents and little wave action. They are not used to reduce erosion.

(Coastal Wiki 2019a)

Figure 8: Breakwaters (Steve Simon 2012)

Detached breakwater

Breakwaters protect the coastline by reducing wave action, slowing tidal forces, and reduce erosion. Breakwaters encourage sedimentation and help build up beaches. Detached breakwaters are the most common type of breakwaters.

(Moosavi et al. 2017; Coastal Wiki 2017)

Figure 9: Maeslant storm surge barrier by John McQuaid (CC BY-NC 2.0)

Flood barrier

(a.k.a surge barrier)

Flood and surge barriers are barriers that closes when storm surge is forecasted.

Figure 10: Groyne (Monika Schröder (monika1607) n.d.)

Groynes

A series of structures made of concrete blocks, wooden piles or armoring rubble-mounds. Mostly aligned perpendicularly to the shoreline to reduce erosion, and stabilize the shoreline by trapping sediment, forming a saw-tooth-shaped shoreline.

(USACE 2011; Coastal Wiki 2019c)

Figure: 11: Revetment to Rock armour by Sharon Loxton (CC BY-SA 2.0)

Revetment

(see also Seawall)

Revetments are sloping structures, normally with beach in front of it, that reduce wave energy. They can be constructed of various materials with different protective benefits. Though, they hinder sedimentation from the land it protects. In practice, revetments and seawalls are functioning equally.

(Coastal Wiki 2019e)

Figure 12: The Dutch sea-dike by Uber Prutser (CC-BY_NC-SA 2.0)

Sea-dike

(a.k.a levee, embankment, floodbank)

An artificial (usually) earthen wall to prevent flooding by separating the shoreline from the hinterland, mostly without or hardly any beach in front.

(USACE 2011; Coastal Wiki 2018b)

Figure 13: Stepped seawall by N Chadwick (CC-BY-SA 2.0)

Seawall

(see also Revetment)

Seawalls are often large structures protecting urbanized coastlines from storm surge, flooding, and erosion. They can take different forms: curved, stepped or be made of rubble-mound. In practice, seawalls and revetments are functioning equally.

(Moosavi et al. 2017; Coastal Wiki 2019f)

2.4.2 Soft methods

As for hard structures, soft methods for coastal protection have many names:

- *Natural* (Sutton-Grier, Wowk and Bamford 2015)
- *Sediment-based protection* (IPCC 2019a, p. 169)
- *Green* (Nordenson, Nordenson and Chapman 2018, p. 5)

Methods where natural features are used to prevent flooding or erosion along coastlines are considered as soft methods.

Seddon (2018) states that soft methods such as the maintenance and preservation of natural habitats are gaining evidence of being cost effective. Seddon claims that, during Hurricane Sandy in 2012, much property values were saved from damage because of surrounding wetland habitats. Wetlands work as a buffer zone between developments and the ocean as they reduce wave energy, slow storm surge, and absorb water (Nordenson, Nordenson and Chapman 2018). Though, it should not be forgotten that vegetated areas can have a reduced defense capacity during winter as they typically have lower canopy densities (IPCC 2019a).

Soft methods have the capability to be multifunctional and to create multiple co-benefits by allowing natural processes and not disrupting them. This includes enhancing biodiversity and pollination, carbon sequestration, natural sedimentation among others (ibid.).

Examples of soft methods:

Figure 14. Barrier islands Erin (164)editcrop by Bering Land Bridge National Preseve (CC BY 2.0)

Barrier islands

Barrier islands are ridges of sand running parallelly to the coastline, separated by water.Barrier islands reduce wave energy and provide habitat for both flora and fauna.

(Coastal Wiki 2008a)

Figure 15. Beach replenishment by Mark Gadsby (CC BY-SA 2.0)

Beach nourishment

(a.k.a. beach/sand replenishment, beach renourishment)

Beach nourishment is the action to refill or replace sand to a beach in order to prevent or reduce erosion and to mitigate wave energy.

(Coastal Wiki 2008b)

Figure 16. Sand dune by hudsoncrafted Pixabay License

Dunes

Dunes are ridges of accumulated wind-blown sand. They act as coastal sand reservoirs and reduce wave energy and stabilize the shoreline.

(Coastal Wiki 2008c)

Figure 17: Eelgrass meadow in Ramsey Marine Nature Reserve by Tony Glen (CC BY 2.0)

Natural barriers

(e.g. maritime forests, shrub communities, wetlands, salt marshes) Natural barriers help reduce wave energy, flooding, and erosion.

(Coastal Wiki 2019d)

Figure 18: Oyster reef (Airman 1st Class Sarah Hall-Kirchner 2013)

Reefs

Reefs generally cover a wide area and arise from the sea bed. They can be overgrown with e.g. mussels or oysters and provide much ecological functions.

(Coastal Wiki 2018a)

2.4.3 Hybrid methods

Hybrid methods are described by the IPCC (2019a) as solutions that are combinations of five of their previously described responses: *protection, accommodation, retreat, advance* and *EbA*. Though, Sutton-Grier, Wowk and Bamford (2015) describe hybrid methods as the combination between hard structures and soft methods.

Hybrid methods can exploit the best characteristics from both hard structures and soft methods allowing for design innovation (Sutton-Grier, Wowk and Bamford 2015). Sutton-Grier, Wowk and Bamford also mention that hybrid methods generally require less space to implement than soft methods alone, that they can provide a higher sense of security, and that they deliver co-benefits besides from coastal defense.

In situations with limited space, which is common in developed coastal zones, the combination of hard structures and natural features can be beneficial, e.g. a wetland or salt marsh that reduce wave energy to an inland levee, or by integrating ecological functions into hard structures (IPCC 2019a).

Examples of hybrid methods:

Figure 19: Building oyster reef breakwater structures or castles at Gandy's Beach by Adrianna Zito-Livingston-The Nature Conservancy (Public Domain Mark 1.0)

Artificial reefs

Reefs generally cover a wide area and arise from the sea bed. Artificial reefs can be overgrown with e.g. mussels or oysters, and they provide much ecological functions. They constitute of different types of armoring units.

(Coastal Wiki 2018a)

Figure 20: Worth am Main (Salino01 2010)

Dry floodproof

This method implies making a building impermeable to water, though to no more than approximately 10 cm over a 24-hour period. Such measures require structural robustness in order to handle pressure on exterior walls during a flood.

(DCP 2014)

Figure 21: FEMA - 22840 - by Robert Kaufmann Public Domain

Elevating structures

A way to protect structures from water is to elevate the ground floor above estimated water levels.

(DCP 2014)

Figure 22: Yet another Floating House by Not4rthur (CC BY-SA 2.0)

Floating architecture

(a.k.a. amphibious architecture)

Floating architecture adapt to the water level, both low and high floods. By using a buoyancy system, the structure returns to the same position at lower water levels.

(Nilubon, Veerbeek and Zevenbergen 2016)

Figure 23: Floating Breakwater by Anne Burgess (CC BY-SA 2.0)

Floating breakwaters

Floating breakwaters are structures that reduce wave energy and erosion.

(Coastal Wiki 2019b)

Figure 24: Tidal waters in Chesapeake by U.S. Army photo–Patrick Bloodgood (Public Domain Mark 1.0)

Wet floodproof

Wet flood proofing can be used when the structure or building cannot be physically elevated. It implies allowing water to enter and exit a building in order to release the water pressure to the structure.

(DCP 2014)

2.4.4 Nature-based Solutions (NbS)

The term Nature-based Solutions has been defined differently and is still used in various ways (Cohen-Shacham et al. 2016), acknowledging the wide amplitude of the concept and its components (Pauleit et al. 2017).

One of the European Commission (EC) description of NbS is: "actions which are inspired by, supported by or copied from nature" (EC 2015, p. 4). To this, Pauleit et al. (2017, p. 32) add "with goals for sustainable and climate resilient development". The International Union for Conservation of Nature (IUCN) describes NbS as an umbrella concept for ecosystem-related approaches addressing societal challenges, with the definition:

> "Actions to **protect**, sustainably **manage**, and **restore** natural or modified **ecosystems**, that address societal challenges effectively and adaptively, simultaneously providing **human well-being and biodiversity benefits**"
>
> (IUCN 2019)

In their attempt to define a precise definition of the concept, Cohen-Shacham et al. (2016) give examples of societal changes such as food security, climate change, water security, human health, disaster risk, and social and economic development. Besides societal changes, they also highlight that NbS should support cultural values, stressing that environmental challenges are not the only focus.

The multifunctionality and adaptability of NbS create numerous co-benefits for people, the environment, and financially (as they have the possibility to be more efficient and cost-effective than conventional solutions) - simultaneously contributing to landscape resilience (Davis, Krüger and Hinzmann 2015; EC 2015; Pauleit et al. 2017).

Seddon (2018, p. 3) states that hazards generally occur simultaneously or "in cascade", and seldomly in isolation – further emphasizing the co-benefits acquired from NbS with the example of coastal forests preventing coastal and inland flooding and simultaneously attenuating strong winds.

Additionally, other co-benefits are the potential to help mitigating climate change effects by carbon sequestration, or to reduce pollution, and to provide recreational values and economic opportunities (EC 2015; Davis, Krüger and Hinzmann 2015).

As EC (2015, p. 14) state that NbS can "provide more advantages than conventional methods" they also advocate NbS to be utilized as a component of the various arrays of measures. An advantage could be the example of synergetic effects of NbS - handling multiple challenges in one solution, e.g. both drought and floods (ibid.).

By supporting sustainable and climate resilient development with multiple benefits and advantages, tradeoffs when implementing NbS should be avoided or minimized (Pauleit et al. 2017). It is also important to underline that NbS "embrace nature conservation and its principles", although are not a substitute for nature conservation and nonetheless are all conservation efforts to be considered NbS (EC 2015; Cohen-Shacham et al. 2016, pp. 6-7).

Another aspect to the use of NbS compared to engineered structures is that, initially, NbS tend to be less effective - for example when establishing vegetation that require some seasons before reaching a considerable volume (Seddon 2018). Seddon also mention that, as the concept uses ecosystems it can become vulnerable by itself as ecosystem themselves are vulnerable to climate change, and that NbS also might demand more space than conventional solutions.

Instead of using conventional and traditional methods for coastal protection, NbS can be an attractive alternative, attenuate wave energy and protect from erosion and by that stabilizing the shorelines (Davis, Krüger, Hinzmann 2015). Some NbS can also co-develop/adapt effectively and sustainably with/to SLR or be easily redesigned (ibid.).

Within the subject of coastal defense structures against SLR, storm surge, and erosion, some examples of NbS can be:

- Removing artificial/hard structures that hinders natural dynamics and increase erosion
- Creating wetlands and revegetating riparian areas
- Removing and controlling exotic plant species
- Creating (artificial) reefs

(Cohen-Shacham et al. 2016)

Incorporating geological, ecological, and biological systems into coastal infrastructure is important not only for mitigating flood risk and preserving vulnerable ecosystems but also for creating novel urban spaces that can withstand change (Nordenson, Nordenson and Chapman 2018, p. 5).

2.4.5 Ecosystem-based Adaptation (EbA)

Measures that provide ecosystem services and favor climate adaptation are what Pauleit et al. (2017) describe as Ecosystem-based Adaptation (EbA). Pauleit et al. mean that the concept is people-centered as it covers socio-economic aspects as well as environmental benefits.

Naumann et al. (2011) describe the concept as:

> *"...an overall adaptation strategy that uses the sustainable management, conservation, and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change. It aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change"*

Agreeing with above, the CBD (2009) mention co-benefits such as being both cost-effective, that it contributes to the conservation of biodiversity, and facilitate the work towards resilient coastal zones.

The suggestion that EbA can be cost-effective is because they, to a certain extent and under the right conditions, are free of maintenance costs as they gradually adapt to coastal changes, though likely in need of maintenance after some events (e.g. heavy storms or human activities) (IPCC 2019a). IPCC also state that there is high confidence that EbA help sequestering carbon.

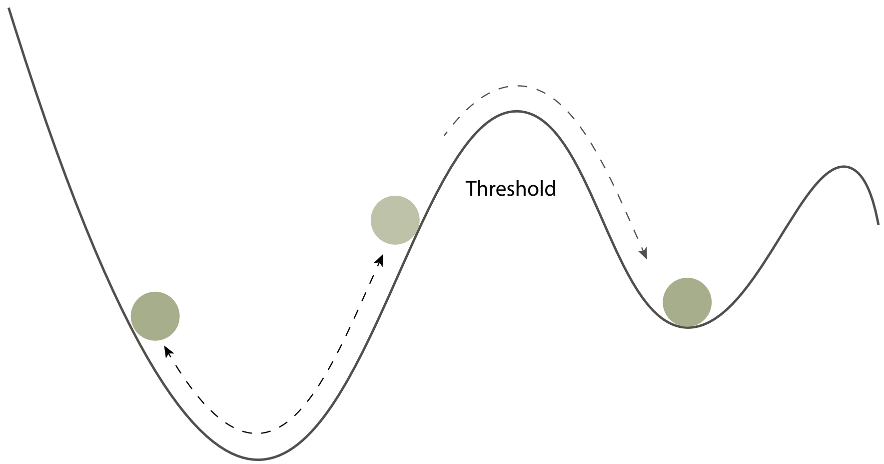

Figure 25: Resilience (Borner 2020)

2.5 RESILIENCE – A FLEXIBLE AND ADAPTIVE SYSTEM

Resilience is being advocated in several sources. In the effort to investigate how coastal protection solutions can be applied to achieve coastal resilience – the term and its essence needs to be defined. Nordenson, Nordenson and Chapman (2018) explain that the term, historically, have been used in the fields of engineering, psychology and ecology.

In the context of urban resilience to floods, the term has been described by Adger et al. (2005), Berkes (2007) and Liao (2012) as having the capability to tolerate flooding and absorb impacts, and subsequently be reorganized if damage or disruption has occurred.

Another way to define resilience is having the capacity to 'bounce back' and adapt to a new state, still providing the intended and essential functions after an event of disturbance (Walker et al. 2004; RDI 2012). This definition is in line with ecological resilience; recognizing the complexity and multiple states and processes of ecosystems, underlining that ecological resilience is the capability to adapt to a new state after being disrupted.

Nordenson, Nordenson and Chapman (2018) strictly encourage coastal resilience by developing dynamic coastal systems capable to transform and evolve after a flood – not being restored to the preflood condition.

2.6 INTEGRATED COASTAL ZONE MANAGEMENT (ICZM)

As have been mentioned before, coastal zones are valuable in multiple ways. It has attracted human activities since long as it is among the most productive areas in the world, which also is the reason why these zones have been heavily developed (EC 2020). It is also the coastal zones that are threatened of being heavily affected by climate change (Denton et al. 2014; EC 2020), whereupon assessments on how human activities and ecosystems possibly can coexist in the future have surfaced. Consequently, in 2013, the EC (2019a) launched an initiative with the goal to establish a planning framework that promotes and incorporates sustainability for the EU member states (section 5.1.2).

2.6.1 Regional kustsamverkan Skåne/Halland

The heading can be translated as Integrated Coastal Management - Skåne/Halland. The County Administrative Boards (CAB) of Skåne and Halland, SGI, SGU, among others, joined forces in 2018 to address coastal nuisances and threats from climate change, and the goal is to investigate and find sustainable solutions adjusted to the cultural heritage (SGI n.d.).

Our Common Coast

3

In this two-part section, sustainable development will be explained and how climate change pose risk of not achieving it. The Sustainable Development Goals (SDGs) connected to development in coastal zones have been selected and presented briefly. Later, these will be applied to different measures.

Sustainable development

Clearly, the concept builds upon sustainability which is achieved when its three levels are acquired: environmental, social and financial (Dessein et al. 2015). Sweden aims to be an international role model concerning 'sustainable development' (Regeringskansliet 2015). The United Nations (UN) state that the term and concept integrate actions that are beneficial for both people and planet, such as finding new innovative technologies that will not harm our environment (UN 2015). 'Sustainable development' was coined in the Brundtland report – Our Common Future – in 1987 with the definition:

> *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*
>
> (WCED 1987)

It is argued that climate change will increase coastal vulnerability and impede current and future sustainable development (Denton et al. 2014). Denton et al. also underline the importance to profoundly assess adaptation measures before being implemented as they can both support and weaken sustainable development. An example would be adaptation measures that provide immediate but short-term protection to a community, though hindering natural hydrology and disrupting adjacent ecosystems.

The Sustainable Development Goals

In 2015, 193 UN member states, including Sweden, adopted the 17 SDGs (see Figure 26) and their 169 targets, as part of the 2030 Agenda for Sustainable Development.

The risk of not achieving the SDGs is emphasized by the IPCC (2019a) if mitigation of greenhouse gas emissions or adapting to SLR and erosion are ignored. Moreover, it highlights that adaptation in beforehand (anticipatory adaptation) will be less challenging and costly, even arguing that adaptation could become impossible if overlooked.

Figure 26: Sustainable Development Goals (UN n.d.)

Below, the SDGs that relate to climate adaptation in coastal zones will be presented and shortly summarized below. (Text in *italic* is the SDG description according to the UN):

Ensure healthy lives and promote well-being for all at all ages

Climate change threaten to marginalize coastal zone ecosystems. By preserving and protecting ecosystems people can benefit from them in both recreational ways, but also from the services they provide.

Take urgent action to combat climate change and its impacts

Raising awareness and knowledge about climate change adaptation in coastal zones will engage and educate the public and facilitate sustainable and resilient adaptation strategies to be incorporated in national policies. Strategies could incorporate new tree plantings that sequestrate carbon.

Ensure availability and sustainable management of water and sanitation for all

Ecosystems connected to the coastal zones help mitigate climate change threats. By allowing natural hydrology, they can also serve as a natural filter between developed areas and the runoff recipient.

Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Raising awareness about the importance of life below water and how it is affected by climate change will help incorporate it in the planning stages of coastal zones. Sustainable climate adaptation for coastal zones can improve ecosystems and reduce threats to the coastline.

Make cities and human settlements inclusive, safe, resilient and sustainable

Knowledge about climate adaptation in coastal zones will both help and promote sustainable coastal communities and enhance resilience, and increase public acceptance to novel methods.

Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt reverse land degradation and halt biodiversity loss

Integrating biodiversity in climate adaptation in coastal zones will promote life on land and ecosystem services.

Figure 27, 28, 29, 30, 31, 32: Sustainable Development Goals (UN n.d.)

International perspectives & reference projects

4

Previously, various adaptation measures, and structural examples of conventional, novel and innovative methods have been described. In the following section, brief descriptions of current examples that can contribute to the work towards climate adaptation of resilient coastal zones will be presented. Some of the examples include a box showing what adaptation measures (section 2.3.4) it correlates with.

4.1 AN AMPHIBIOUS APPROACH

The word *amphibious* or *amphibian* relates to animals or something else that can operate both in water and on land (Cambridge Dictionary n.d. a). Amphibious, in terms of adapting to flood, can be applied on both buildings as well as larger areas such as urban areas. According to Best Climate Solutions (n.d.) amphibious buildings implies buildings that are capable of floating when needed. The International Conference on Amphibious Architecture, Design and Engineering (ICAADE) describe amphibious architecture, construction, design and engineering as a flood mitigation strategy that involves floating structures, hybrid solutions and planning aspects (ICAADE 2019).

4.1.1 The United States, Atlantic City – Chelsea Heights

Nordenson, Nordenson and Chapman (2018) describe that Hurricane Sandy resulted in general discussions about future storm surge protection, involving Chelsea Heights – "Would higher bulkheads and seawalls be proper solutions for the suburb, or would a planned retreat be better?" are questions that were asked. According to Nordenson, Nordenson and Chapman, both solutions were judged to have high financial and social impacts, leading to the planning of transforming the community to an 'Amphibious Suburb' as an alternative to both defensive and retreat measures.

The Amphibious Suburb depend on three core vertical transformations being implemented gradually:

1. Lifting existing and new homes
2. Elevating roads - working as an array of barriers, attenuating storm surge
3. Lowering and converting back alleys into canals – encouraging wetland migration

(Nordenson, Nordenson and Chapman 2018)

4.1.2 Denmark, Copenhagen - Sluseholmen

In the southern part of the Danish capital city Sluseholmen emerges from the water. The area was previously an industrial site, extended by landfill upon which the neighborhood now stands. The neighborhood consists of eight islands with channels in between, inhabited since 2006 (By and Havn n.d.; Københavns kommune n.d.)

Correlating adaptation measures (see Table 1):
Attack/advance/move seaward

Figure 33: Sluseholmen canal scene 2 by Payton Chang (CC BY 2.0)

4.1.3 Germany, Hamburg - HafenCity

After a competition in 1999, the winning masterplan for the urban redevelopment project – HafenCity – was approved in 2000. The specific character of the masterplan was the distinct interaction between the built environment and the surrounding water (HafenCity n.d. b).

Since HafenCity is located to the south and outside of an existing dike, it would not be protected by it - being an area regularly affected by high water and floods. Surrounding the area with defensive dikes was evaluated to create several disadvantages (both financial and social), e.g. by disrupting the connection to the area's principal asset – the water. Therefore, to secure the area from floods all new buildings are constructed on mounds of compacted fill materials 7.5–8 meters above mean sea level, elevating almost all roads. New roads and bridges are constructed 7.5–8.3 meters above sea level (HafenCity n.d. a)

The area's edges, around 4.5–5.5 meters above sea level, are appreciated public urban spaces with walks (HafenCity n.d. a).

Correlating adaptation measures (see Table 1):
Accommodation
Defend/protection/Hold the line

Figure 34: Hamburg – Hafencity by Pikrepo (CC0 1.0)

Figure 35: Hamburg Hafencity Sandtorkai by Ludger (CC BY-SA 3.0)

4.2 SWEDEN, SCANIA - LIFE COAST ADAPT

The regional council of Scania County applied for funding through the EU funding instrument 'LIFE programme', which was accepted in 2017. It is rooted in ecosystem-based measures addressing coastal erosion and SLR, with the objectives to reduce coastal vulnerability that simultaneously benefit biodiversity and ecosystem services (EC 2017; LIFE Coast Adapt n.d.b). Both EC and LIFE Coast Adapt explain that the project aims to generate greater knowledge about sustainable and resilient coastal adaptation measures, and to contribute to the work of developing a maritime spatial planning framework according to the EU directive (see section 5.1).

Some of the methods that will be used:

- Restoration of beach and dune formation
- Establish reefs
- Plant eelgrass
- Create wetlands
- Beach nourishment
- Removing hard structures

(LIFE Coast Adapt n.d. b)

The project duration is between June 2018 – December 2022 with a budget of 45 million Swedish Crowns (EC 2017).

Correlating adaptation measures (see Table 1):
Accommodate
Attenuation
Protection
EbA

4.3 THE NETHERLANDS

Traditionally, Dutch coastal policy has relied on large hard engineered structures in terms of flooding protection (e.g. sea dikes, groynes, and barriers, although Nolet and Riksen (2019, p. 129) claim that the "focus has widened to also include preserving spatial qualities and natural values of the coastal zone".

Being a country known for its large engineered structures (e.g. the Maeslantkering storm surge barrier (see Figure 9), Nolet and Riksen underline that as much as 75% of the coastline's most seaward sand dunes work as a primary defense against the sea, consequently making beach nourishment (frequently utilized since the early 1980's) the main management method since 1990.

Even though the 'Room for the river' project (implemented by the Dutch government between 2007–2015) concerned floods adjacent to the country's three major rivers – and not coastal adaptation, the project's principles are inspirational in the coastal context. Room for the river constituted several spatial redevelopments that addressed floods, helped restoring ecological values and improved the landscape and the recreational values (Roomfortheriver.nl n.d.). Relocating dikes, reinforcing dikes, lowering floodplains and removing obstacles are examples of approaches incorporated in the project period (Roomfortheriver.nl n.d.).

Figure 36: Zandmotor by Rijkswaterstaat/Jurriaan Brobbel 2016 (Public Domain Mark 1.0)

4.3.1 Zandmotor

"Building-with-nature" by utilizing natural processes is, according to Nolet and Riksen, a fundamental component in the Zandmotor experiment; an approximately 15 km long mega-scale beach nourishment along the Delfland coastline between the cities Rotterdam and The Hague, finalized in 2011 (see Figure 36). Its main objective is to stimulate natural dune growth to cope with rising sea levels and, concurrently, create space for nature, leisure and recreation, but also to gain knowledge about the conjunction possibilities between coastline maintenance and enhancing social values (Taal et al. 2016; Nolet and Riksen 2019). The Zandmotor hook-shape aims to mimic the natural migration of an intertidal sandy shoreline, the at times tall construction height aims to support aeolian reworking forces (Taal et al. 2016). Taal et al. state that the dynamic approach is amplified by establishing European marram grass (*Ammophilia arenaria*) (see Figure 37) in and around the dunes that help stabilizing and to trap sand.

Correlating adaptation measures (see Table 1):
Attack/Advance/Move seaward
Attenuation
Protection/Hold the line
+ NbS

Figure 37: Ammophila arenaria M1 by Jerzy Opioła (CC BY-SA 4.0)

4.3.2 Maasbommel

The Climate ADAPT (2016) claim that 60% of the Netherlands is below sea level, making it easy to understand why adaptation measures are essential. Boiten and Factor Architecten (2011) explain that the Maasbommel project comprise two types of houses: 14 permanently floating houses (see Figure 38), and 32 houses resting on a concrete hull (see Figure 39) construction that will adapt in flooding events – the actually amphibious houses.

Correlating adaptation measures (see Table 1):
Accommodation
Attack/Advance/Move seaward

Figure 38: Gouden Ham watervilla's by Marion Golsteijn (CC BY-SA 4.0)

Figure 39: Floathouse mounting by Tarrakaner (CC BY-SA 4.0)

4.3.3 Scheveningen

The western district of The Hague – Scheveningen – was a 'weak link' in the Dutch coastal flood protection line (Voorendt n.d.). Voorendt explain that the existing boulevard was fundamentally upgraded, incorporating flood protection and simultaneously enhancing spatial qualities. Karlsson (2020) claim that the municipality planned the area for a 10 000-year recurrence interval storm surge by broadening the beach in combination with a dike, upon which the boulevard was designed.

Correlating adaptation measures (see Table 1):
Attenuation
Defend/Protection/Hold the line

Figure 40: Promenade along the beach at Scheveningen, The Hague by Guilhem Vellut (CC BY 2.0)

4.3.4 Overdiepse Polder – 'Room for the river'

Communities along the Bergsche Maas river are susceptible to floods threatening more than four million people, greatly reduced by actions made in the Overdiepse Polder[4]. Instead of reinforcing and elevating the existing dike surrounding the polder, it was lowered in order to allow flooding (Roomfortheriver.nl n.d.). The polder was inhabited by farmer families with livestock, therefore eight sand mounds were created and new facilities (housing, livestock buildings, etc.) were constructed on top of them – so called 'terps' (Roomfortheriver.nl n.d.; Längengrad filmproduktion 2018). From the dredging of sand, the pond 'Westplas' was created, claimed by Roomfortheriver.nl as bringing ecological values.

Correlating adaptation measures (see Table 1):
Accommodation
Attenuation (for upstream communities)
EbA
Limited intervention
Planning
+NbS

[4] A polder is a dry low-lying land surrounded by embankments/dikes with pumps that keep them from flooding (Cambridge Dictionary n.d. b).

Swedish regulation

5

In the Swedish context, 'regulations' is an umbrella term for laws, regulations, provisions, and general recommendations (Boverket 2018b). Boverket state that not all regulations are binding - laws, ordinances and mandatory provisions are. In Figure 41 a hierarchical order to the Swedish regulations, and how the EU-directives influence them, is illustrated.

Currently, Swedish legislation is more or less aligned with the physical boundaries between water and land - the same boundaries appear between agencies and their areas of responsibility, causing great complexity for planners (Thiere et al. 2019b).

Due to the lack of specific climate adaptation legislation, multiple laws, regulations and directives needs to be taken into consideration in the climate adaptation planning processes (see Figure 49) (Thiere et al. 2019a).

In this section, information about main regulations that relate to climate adaptation in coastal zones will be presented with brief explanations on what they encompass and handle.

5.1 EU DIRECTIVES

The EU sets goals for Sweden (the member states) through directives that must be implemented in the legal framework (see Figure 41) (Naturvårdsverket 2019b; EU 2019). Naturvårdsverket (2019b) state that the EU do not interfere in how the directives are implemented.

5.1.1 Flood directive 2007/60/EC

In 2007 'Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks' was enforced with the intention to reduce flood impacts to people, the environment, cultural heritage, and economic activity, implemented in Sweden as an ordinance – Översvämningsförordningen (2009:956) (MSB 2019).

The aim with Översvämningsförordningen is to map flood risk areas, and to develop risk management plans that, in a sustainable manner, reduce coastal vulnerability and to facilitate planning processes (Thiere et al. 2019a; MSB 2019).

5.1.2 Maritime spatial planning directive 2014/89/EU

'Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning' was enforced in 2014.

In 2021, every member state must have developed a maritime spatial planning framework for the sustainable utilization, preservation, and exploitation of the maritime space, in line with a sustainable development (HaV 2019; Thiere et al. 2019a).

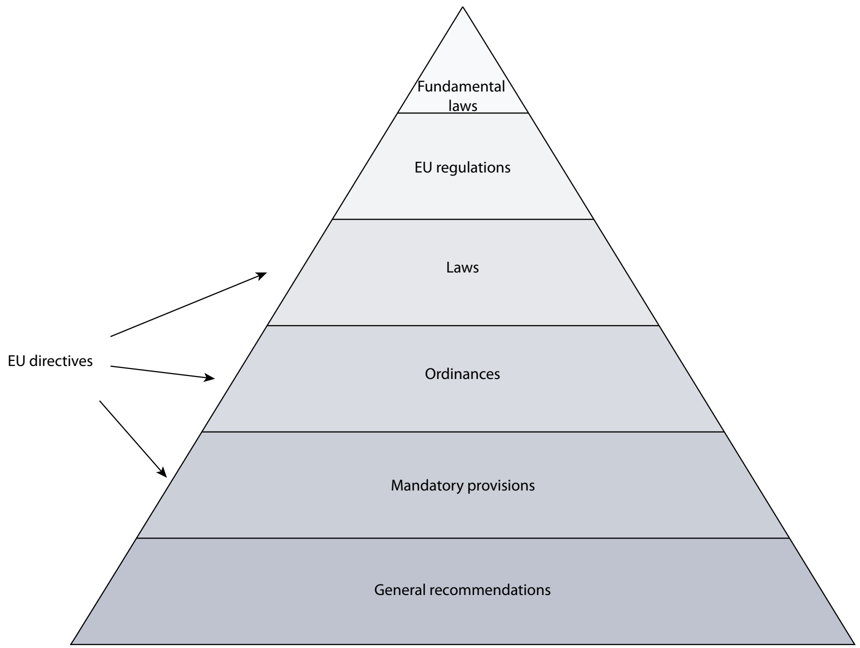

Figure 41: Hierarchical order to Swedish regulation (Borner 2020).

5.2 LAWS

5.2.1 The Swedish Environmental Code (1998:808)

Since 1999, the Swedish Environmental Code has been enforced in order to support sustainable development and encourage circular systems, e.g. reusing materials (SFS 1998:808; Naturvårdsverket 2019c). It consists of approximately 500 paragraphs with regulations and directives (Lerman and Rydell 2003).

Nature reserves

Nature reserves serve to protect biodiversity, preserve valuable nature, provide recreational environments or to restore natural areas (Lerman and Rydell 2003; Hansson, Rydell and Andersson 2006). Lerman, Rydell and Andersson (2006) also state that every nature reserve has different and specific rules depending on the values being protected, such as if or when the area can be visited, or what is allowed or prohibited to do there. Prohibited activities require dispensation. Permission and/or dispensation applications are initially made at the concerned regional CAB; accepted in specific cases, although with demands of ecological compensation within the reserve or in another area (Hansson, Rydell and Andersson 2006).

Shoreline protection

The shoreline protection is a part of the Swedish Environmental Code with two specific aims: to ensure public access to riparian zones, and to preserve healthy environments for flora and fauna on land and in water (Lerman and Rydell 2003).

Typically, the regulation stretches 100 meters in both directions from the shoreline (see Figure 49), but it can be extended to a maximum of 300 meters in some situations to safeguard the purpose of the regulation (Hansson, Rydell and Andersson 2006).

It is prohibited to build new structures or to rebuild existing structures within a shoreline protection area, or other activities that impair the flora and fauna environments - although dispensation can be allowed in specific situations (Hansson, Rydell and Andersson 2006; Boverket 2018c). Permission and/or dispensation applications within a shoreline protection area are made at the agency of urban planning of the concerned municipality (Malmö stad 2019c).

Water resource management

Chapter 11 in the Swedish Environmental Code contains the regulations for water resource management. In section 2 §, a water catchment area is defined as "an area covered by water at the highest predictable level of water" (SFS 1998:808). Some examples of water resource management activities are:

- constructing new or changing existing structures within a water catchment area
- protecting an area by drainage
- changes of water level

(Naturvårdsverket 2008b)

Water resource management activities require a formal notification to the concerned CAB, permission and/or dispensation applications are made at the Land and Environment Court (Länsstyrelsen Skåne n.d. b).

5.2.1.1 National interest

National interest provisions are found in chapter 3 in the Swedish Environmental Code, with the aim to support sustainable development on land, in water and the physical environment (Boverket 2017c). Areas of national interest consist of nationally important natural, cultural and/or recreational values and qualities (Boverket 2017b).

The areas are designated for either preservation or exploitation, and the provisions are operative in situations that potentially change the land use (Boverket 2017b; Naturvårdsverket 2019d). Areas of national interest are listed in the municipal comprehensive plans (Boverket 2017b). When producing detailed development plans, a dialogue between the municipality and the CABs make sure that the national interests have been taken into consideration and will not be damaged (Boverket 2017a).

5.2.2 Swedish Planning and Building Act (2010:900)

The Swedish spatial planning system consists of regional plans, comprehensive plans, area regulations, and detailed development plans, thereof the comprehensive plan and detailed development plan will be further described below (SFS 2010:900). Municipal planning of land and water, and on construction is regulated by provisions in the Swedish planning and Building Act – 'Plan- och bygglagen' (PBL) (Boverket 2018d).

In 2018, the PBL added demands on incorporating evaluations regarding built environment in risk of being damaged due to climate change in the municipal comprehensive plans (Boverket 2018a).

The comprehensive plan

Every Swedish municipality have their own comprehensive plan, centralized in the municipal's aspiration towards sustainable development (Boverket 2018e). It encompasses information about how the municipality will reach and accomplish different goals, and as a guidance on how to preserve and plan existing and new development, though the goals are not legally binding SFS 2010:900; Boverket 2018d).

The detailed development plan

In Sweden, a detailed development plan regulates the land and water usage, and the developed areas and buildings (SFS 2010:900). Every municipality develop their detailed development plans designated a specific area, therefore, areas that do not have such will likely need to produce one in order to get either a site improvement permit, or a building permit (with exceptions) (Boverket 2016). Boverket also explains that the detailed development plan is valid until it is either withdrawn, changed or replaced.

5.2.3 Additional information

Natura 2000

In order to preserve biodiversity and to protect valuable and threatened species and habitats, the member states of the European Union have undertaken the 'Birds Directive' and 'Habitats Directive' (EC 2019b; Naturvårdsverket 2019e). This means that every member state has identified particularly important areas – Natura 2000 – to form a coherent ecological network. The Natura 2000 areas must be managed in a sustainable manner according to the directives (EC 2019b).

Naturvårdsverket (2019e) explains that, in Sweden, the CAB are responsible of identifying Natura 2000 areas, of which Sweden has more than 4000 that showcase diverse natural environments. Activities that jeopardize the identified values need specific permission (Lerman and Rydell 2003; Hansson, Rydell and Andersson 2006). Lerman, Rydell, Hansson and Andersson mention earthworks and beach nourishment as such activities, but they also mention indirect impacts such as noise pollution and water contamination.

Legal protection of Natura 2000 areas is not delimited to their physical borders. Exploitation outside of a Natura 2000 area that risk affecting the protected area may be stopped (Naturskyddsföreningen 2010).

Previously described laws are summarized in Table 2, mainly showing the responsible agencies for permission and/or dispensation applications, and the supervising agency.

Law	Notification	Permission and/or dispensation	Supervision and guidance
Swedish Environmental Code (1998:808) *Nature reserve*		CAB	
Swedish Environmental Code (1998:808) *Shoreline protection*		Municipality (sometimes CAB)	CAB
Swedish Environmental Code (1998:808) *Water resource management*	CAB	Land and Environment Court	
Swedish Environmental Code (1998:808) *National interest*		Municipality	Municipality + CAB
Swedish Environmental Code (1998:808) *Natura 2000*		CAB	
Swedish Planning and Building Act (PBL) (2010:900)		Municipality	

Table 2: Responsible agencies handling permission and/or dispensation applications.

Project site

Bunkeflostrand & Klagshamn

6

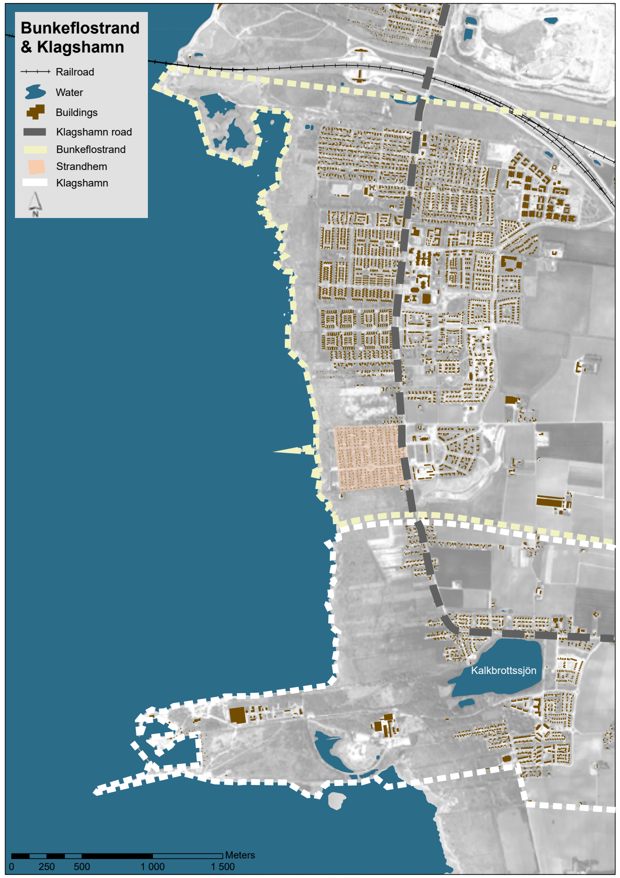

Figure 42: The project site - Bunkeflostrand & Klagshamn. Strandhem is marked in orange.

The project site - Bunkeflostrand and Klagshamn - is situated in the southern parts of Malmö municipality. The area stretches from the Öresund bridge in the north, down south to the Klagshamnsudden peninsula (see Figure 42).

The road 'Klagshamnsvägen' form a division between the low-lying lands to the west, and the eastern areas. The focus is put on the area to the west of Klagshamnsvägen as the area to the east are not, as yet, in risk of being flooded, and according to the data used.

The project site section will first describe the data and scenarios selected in the thesis, followed by a brief summary of the Malmö comprehensive plan and its coastal zone related topics. Subsequently, information about the site, risks, and concerned laws and regulation will be presented. Finally, the three core principles hard, soft and hybrid (described in section 2.4) will be applied to the project site – further structure to the examples will be described.

6.1 THE MALMÖ 2018 COMPREHENSIVE PLAN

6.1.1 Climate adaptation and high sea levels

Buildings, infrastructure, nature values, and cultural and historical values are pointed out as being in risk for floods in the section 'climate adaptation of high sea levels' in the Malmö comprehensive plan (Malmö stad 2018a).

According to the section's strategies, restrictions to develop areas below +3,0 m above current sea level are set, though with exceptions if flood prevention can be assured. Another strategy is aiming to develop multifunctional solutions to cope with SLR and flooding.

Regarding maritime spatial planning for Malmö municipality, the entire territorial water (22 km seaward from the shoreline) is incorporated in the comprehensive plan (Malmö stad 2018a).

6.1.2 Biodiversity

In this section of the Malmö comprehensive plan, the values of and benefits from high biodiversity is highlighted. The strategies describe the importance to protect and preserve biodiversity, and how areas with certain values can be protected and conserved either by classifying them as nature reserves, or through restrictions in the detail plan. Ecological compensation is enforced to all exploitation or development.

In the 'Naturvårdsplan för Malmö stad' (Eng. Malmö Nature Conservation Plan) from 2012, the most important valued areas in the municipality are identified. Information about the nature conservation plan in relation to the project site will be summarized in section 6.2.2.

6.1.3 Detailed development plans

Bunkeflostrand and Klagshamn consist of several detail development plans, some covering housing areas, and some both housing areas and parts of the surrounding nature reserves. It is possible that climate adaptation solutions will cross one or several areas with different detail development plans (see Figure 43).

Figure 43: Detailed development plans in the project area (Malmö stad 2018b).

6.2 PROJECT SITE INFORMATION

The Klagshamnsvägen road is somewhat elevated, forming a threshold between the low-lying area to the west of it – the project site. The topography of the area is, more or less, sloping evenly from the Klagshamnsvägen road towards the ocean.

The architectural styles and sizes of the buildings vary in the area. For the most part the residential buildings are detached and freestanding. The construction materials vary as well, from bricks to wooden buildings. A few areas have small and simpler weekend or secondary residences.

The Strandhem area also has a mixture of building styles and materials, though smaller and more commonly wooden compared to the rest of the project area. The Strandhem area is also the only area with an existing embankment surrounding almost the whole area.

6.2.1 Coastal protection investigations

The current information about future coastal planning and adaptation for the project site is as follows (Malmö stad 2018b):

Bunkeflostrand

Eventually, the area might be protected by a 1150 meters long embankment with vegetation. The existing pathway can be on either side of it, although the recreational values connected to the open nature reserve should be taken into consideration when designing the embankment. Stormwater will be pumped out from the protected area.

Klagshamn

To prevent sea water inflow to Kalkbrottsjön (see Figure 42) and the settlements around it, embankments with grass may be constructed.

Photo 1: Embankment around Strandhem showing the division between the settlement and the water (Borner 2020).

Photo 2: Embankment around Strandhem (Borner 2020).

Photo 3: Embankment around Strandhem. The ocean is visible to the right. (Borner 2020).

6.2.2 The nature reserves

In the Malmö Nature Conservation Plan a nature values evaluation was carried out dividing the values into four nature values classes: 'N1 – Highest nature value', 'N2 – Very high nature value', 'N3 – High nature value', 'P – park' (Malmö stad 2012).

The two nature reserves in the project area are evaluated 'N1 – Highest nature value' consisting of a variation of biotopes and findings. Malmö stad describes 'N1 - Highest nature value' as:

> *"N1 areas are important environments for threatened or rare species, or has a vital ecological function as wintering ground or as a resting place for many migrating birds. These areas can be of national and international interest."*

Bunkeflo beach meadows

Bunkeflo beach meadows was in 2006 the first area in Malmö made a nature reserve, by which the area's uniqueness has been formed by the interaction between grazing animals (more or less since the bronze age) and temporary saltwater inundations, creating a rich flora and fauna with several rare species – even endangered and threatened species (Länsstyrelsen Skåne (n.d. a); Malmö stad 2019b). The rich fauna consist of various small and unique insects but also bigger animals.

The nature reserve in Bunkeflostrand also include the sandy and shallow sea bed populated by the seagrass *Zostera maritima* – important and vital for biodiversity (Länsstyrelsen Skåne n.d. a; Malmö stad 2019b). At some places, Länsstyrelsen Skåne (n.d. a) state that the water depth reaches 3 meters first some 2 kilometers offshore.

Klagshamnsudden

Located to the south of the Bunkeflo beach meadows nature reserve, is an artificial peninsula constructed by landfill from chalk and limestone quarries with interesting and rare flora and fauna – Klagshamnsudden – converted to a nature reserve in May 2019 (Malmö stad 2019a).

Figur 44. The nature reserves in the project site.

6.2.3 Site threats

Both the natural and built environments in Bunkeflostrand and Klagshamn are in risk of temporary as well as permanent flooding. The impacts between the 2100 SLR scenario and the threat maps from MSB show different scenarios.

The built environment is vulnerable in sense of being below the current development restrictions of +3,0 m above current sea level, according to the comprehensive plan for Malmö stad (2018a).

The embankment around Strandhem can also be viewed as a vulnerable spot if or when the embankment will be overtopped, implying a sudden inflow of water. Strandhem also rely on pumps that lead water from the area out to the ocean, the capacity of the pumps are also a vulnerability in high water flow events.

The natural values are vulnerable by being subject to a 'coastal squeeze' situation, impeded to migrate inland. Loss of the natural values is connected to social values as it implies loss of recreational areas.

SLR

In the case of a 1,1 m SLR, the GIS-analysis show that some of the built environment in Strandhem will be flooded, though with much of the on-land nature reserve permanently flooded (see Figure 45).

Figure 45: Bunkeflostrand and Klagshamn land loss at a SLR of 1,1 meter.

Storm surge

The 100-year event map (see Figure 46) show that much of the area to the west of Klagshamnsvägen will be flooded. The water levels between the three events (100, 200, extreme) do not vary very much in depth: from 2,23 meters in the 100-year scenario, to 2,91 meters for the extreme event scenario.

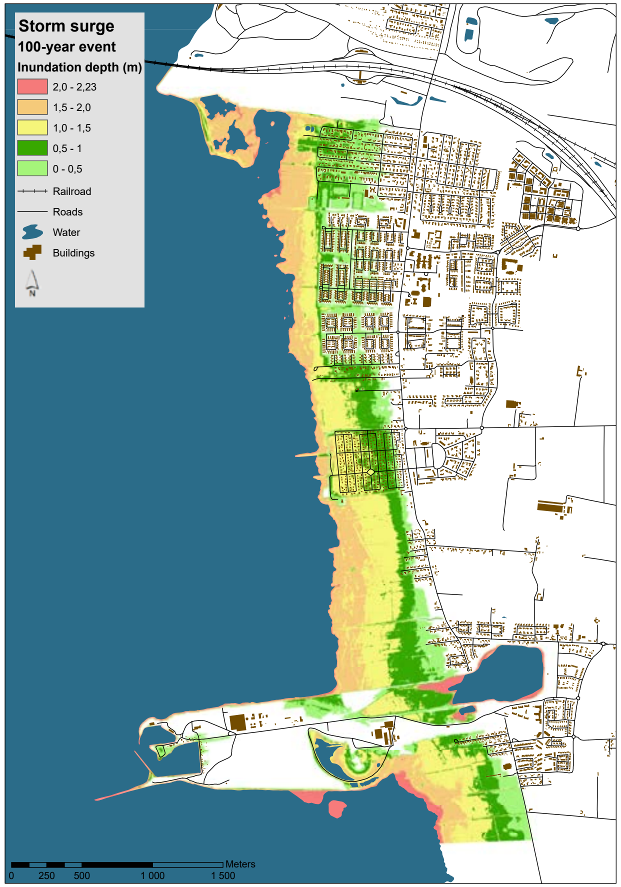

Figure 46: Inundation depth at a 100-year event.

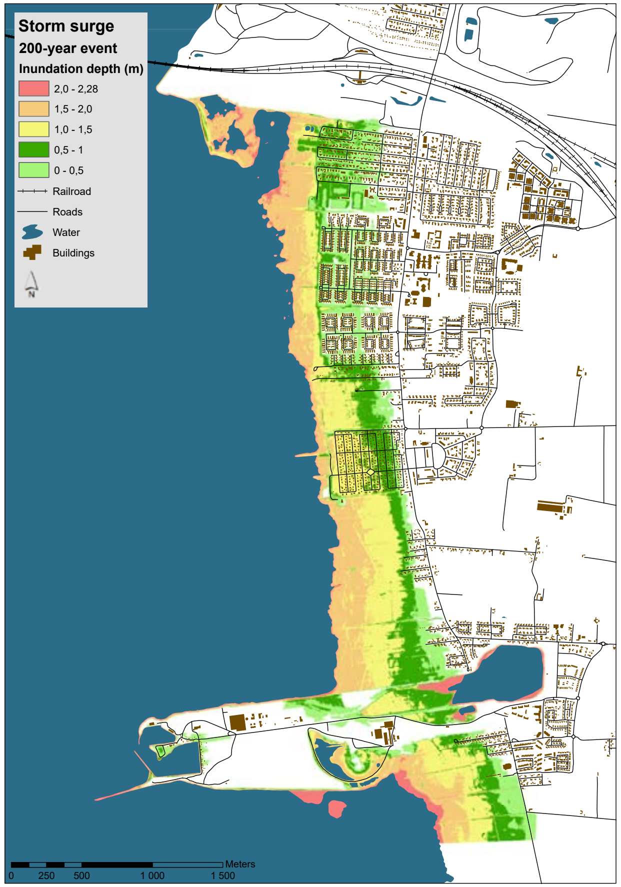

Figure 47. Inundation depth at a 200-year event.

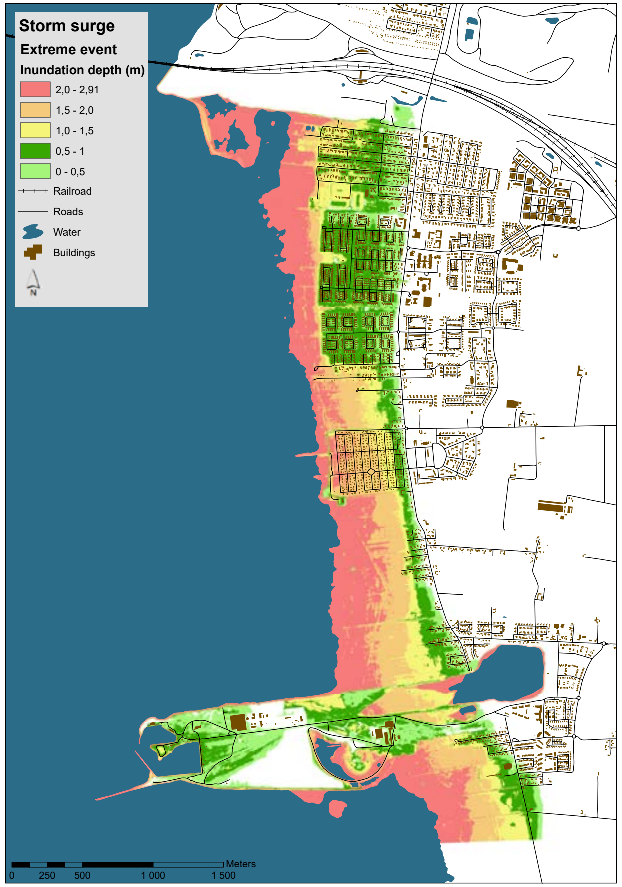

Figure 48 Inundation depth at an extreme event.

6.3 SITE LAWS AND REGULATIONS

Previously described, planning coastal zones implies much regulation to take into consideration. Regulation applied to the Bunkeflostrand and Klagshamn context will be briefly presented in this section.

Nature reserves

The Bunkeflo beach meadows and the Klagshamnsudden peninsula are protected with support by the Environmental Code.

Shoreline protection

The shoreline protection applies to much of the project area as it stretches 100 meter in both seawards and inland from the shoreline. In the parts of the area where the settlements reach closer to the shoreline, the shoreline protection border runs all the way up to the built environment.

In the Malmö comprehensive plan it is stated that the protection will be applied properly, ensuring public access and the preservation of the nature values by protecting it from exploitation. Though, it is also mentioned that preservation of natural values is in conflict with making the area more accessible (Malmö stad 2018b).

Water resource management

Any construction or reconstruction of existing structures, water drainage, or changes of the water level within 'an area thas is covered by water at the highest predictable level of water' implies water resource management, regulated by the Environmental Code.

National interests

Landscape conservation of national interest
Provisions in the Swedish Environmental Code aim to secure landscape conservation to protect specific nature, landscape and scenic values; to preserve biodiversity by protecting rare flora and bird life; and to ensure public availability for recreation (Naturvårdsverket 2005).

The nature values of the project site were made nature reserves to increase protection from activities that endanger the values in the area.

Fishing industry of national interest
Provisions in the Swedish Environmental Code aim to secure fishing areas and the accessibility for the fishing industry (HaV 2015).

The Bunkeflo beach meadow and Klagshamnsudden peninsula were made nature reserves with regards to preserving and reconstructing wetlands and shallow water ecosystems of national interest.

Coastal zones of national interest
Provisions in the Swedish Environmental Code aim to protect natural and cultural areas that provide recreation for inhabitants and visitors from being exploited and potentially lost (Malmö stad n.d.).

The CAB has identified Bunkeflo beach meadows and the Klagshamnsudden peninsula as having 'specific core values'.

The city of Malmö expresses that no exploitation that endanger specific core values will be approved - also a reason for making the areas nature reserves (Malmö stad 2018b). Malmö stad also state that new constructions in the area may not obstruct the visual connection to the ocean.

Swedish Planning and Building Act

Climate adaptation for the Bunkeflostrand and Klagshamn coastline may concern several detailed development plans simultaneously.

Natura 2000

The adjacent coastl area south of Klagshamnsudden is identified as a particularly important area. Consideration to the Natura 2000 area must be taken.

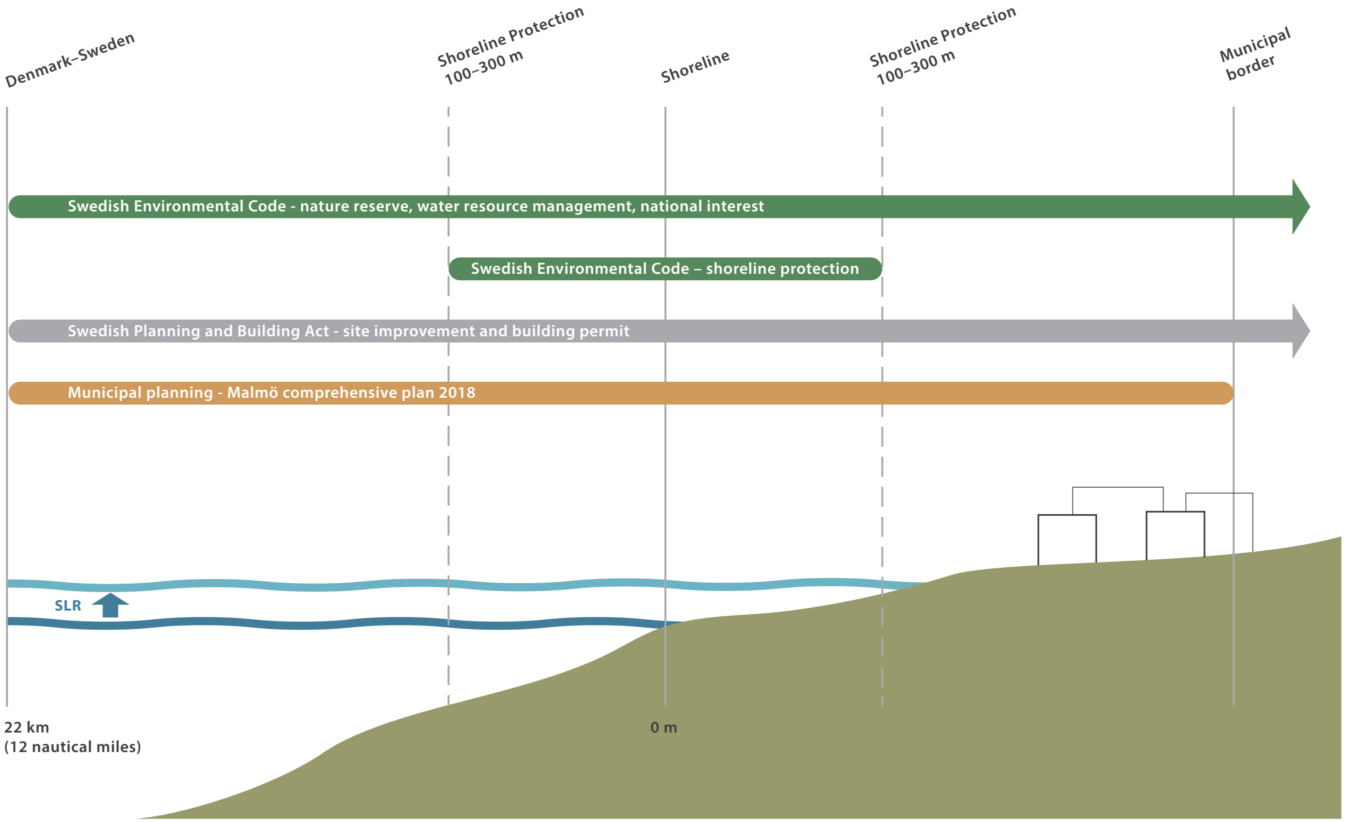

Figure 49: Laws to take into consideration when planning coastal zones (Borner 2020).

Examples

7

In this section and according to the formerly described core principles; hard structures, soft, and hybrid methods will be tested. This allows the selected structures and methods to be evaluated in isolation. Subsequently they can be compared, gaining an understanding on the possible outcomes before implementing them. Again, this means that the given examples are not an attempt to demonstrate the better solution/s for Bunkeflostrand and Klagshamn but to evaluate and assess selected approaches separately. The selected structures and methods are also related to and based on the statement by Denton et al. (2014) that, in the climate adaptation discourse, innovation is advocated as nature-based features are gaining popularity and conventional methods are being questioned.

Each example starts with a plan map/s showing where the present shoreline runs, and where the 1,1 m SLR shoreline will be. They also show the selected structures and methods, followed with a brief explanation of each and their eventual relation to the previously described international reference projects (section 4). This is then followed by bullet point/s displaying to what/which measure/s they correlate with according to section 2.3.3 (summarized in Table 1).

The following simplified and principled viewpoint visualizations illustrate the estimated 1,1 meter SLR, visual impacts, storm surge water levels, and suggested actions to some extent. The illustrations are simplified in the sense that details, such as vegetation, is excluded. By doing so, the coastal protection suggestion focus will be made clearer. The illustrations are then described, presenting positive and negative effects.

Lastly, each structure or method is evaluated through a pros and cons bullet list, to which its correspondence to the selected Sustainable Development Goals (SDGs) will be incorporated (see section 3). Though, not all actions directly relate to the SDGs and will in those cases not be evaluated. N.B. the SDGs have been placed according to the pros and cons list or placed in the middle indicating both positive and negative effects.

Worth mentioning is that the solutions may not necessarily be implemented all together or simultaneously.

7.1 HARD STRUCTURES

According to the current and existing coastal protection plan for Bunkeflostrand (section 6.2.1), an earthen embankment with vegetation may be constructed to protect the settlements in the future (Malmö stad 2018b). Based on this information, an earthen embankment like the existing one around Strandhem (see Photo 1-3) will be tested and evaluated in this example – considered a commonly used and conventional embankment.

Correlating adaptation measures (see Table 1):

Defend/Protection/Hold the line

Figure 50: Testing hard structures.

Embankments (a.k.a. sea-dike, levee, floodbank):

Here, embankments run along the nature reserve border to protect the existing settlements from floods and simultaneously minimize land take from the nature reserve (see. Figure 44)

Depending on the expected water level, the embankments may vary in height, from 3 m in parts closer to the shoreline, to 1 m in parts more distant to the shoreline.

In terms of minimizing land take, the width of the embankment depends on its height. For example, a 3 m tall embankment with a 1:2 slope and a 2 m bicycle and pedestrian pathway on top, implies a total width of 14 meters.

Detached breakwaters:

Sufficient quantities on strategic locations may reduce wave energy on the embankments and facilitate sediment build-up.

The current situation

The open nature reserve (yellowish-green), located between the ocean and the settlements with public lawns and private gardens (dark green), serves as a recreational area with both natural and culture and historical values. The unique flora and fauna have developed along with temporary salt water inundations and grazing animals.

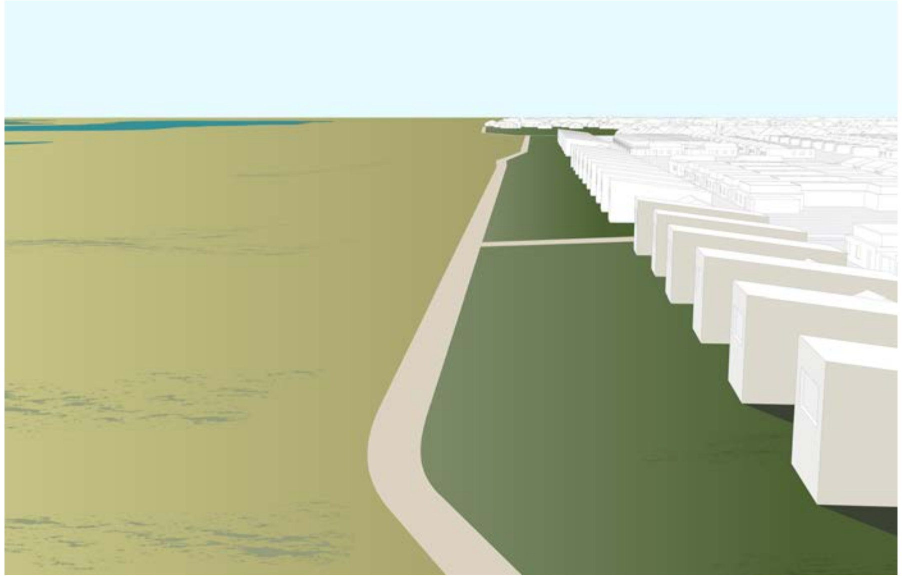

Figure 51: The curent situation (Borner 2020).

Figure 52: Sea Level Rise 1,1 meter (Borner 2020).

Sea Level Rise 1,1 meter

Much of the nature reserve is lost and only fragments remain. The water table is close to the pathway and settlements; during a storm event the settlements are in great risk of being flooded.

Embankment SLR 1,1

The embankment obstructs the openness and connection to the ocean. It implies land take from the nature reserve, public space, and private gardens. The embankment also hinders natural hydrology and sedimentation dynamics, requiring pumps to handle stormwater within the settlements.

A 3 meters tall embankment will protect the settlements and inhabitants from high water levels during a storm event. The former pathway is placed on top of the embankment, facilitating connection to the water, and serving as a recreational path.

Figure 53: Embankment SLR 1,1 (Borner 2020).

Figure 54: Embankment with high water level (Borner 2020).

Embankment with high water level

The illustration shows a water level reaching 1,5 meter up on the embankment; resembling living beside a dam, making it easy to imagine the impact if the water would overtop the embankment.

To cope with higher water levels in the future, the embankment will eventually require adjustments and reinforcements.

Street view – no embankment

The settlements and inhabitants are capable to "see, hear, and smell the water", although aware of possible floods in a storm event.

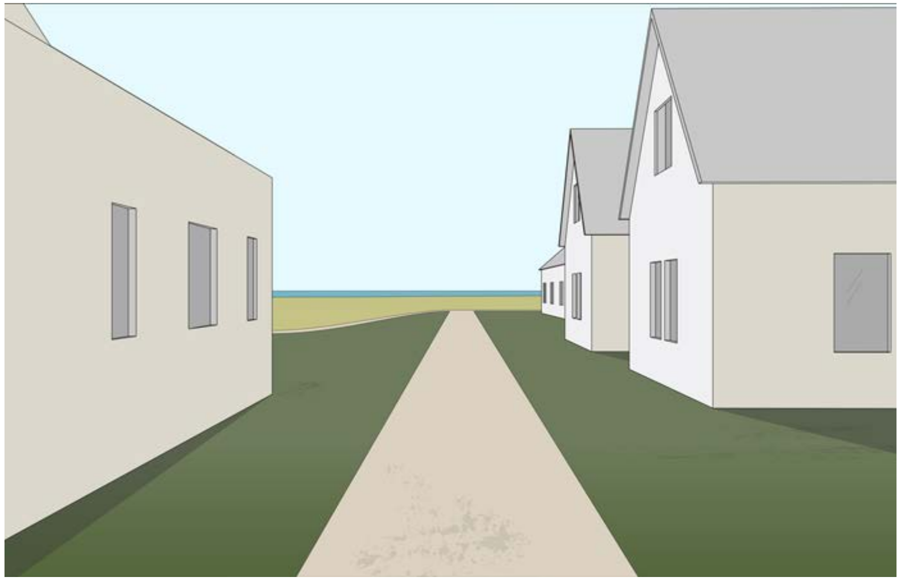

Figure 55: Street view – no embankment (Borner 2020).

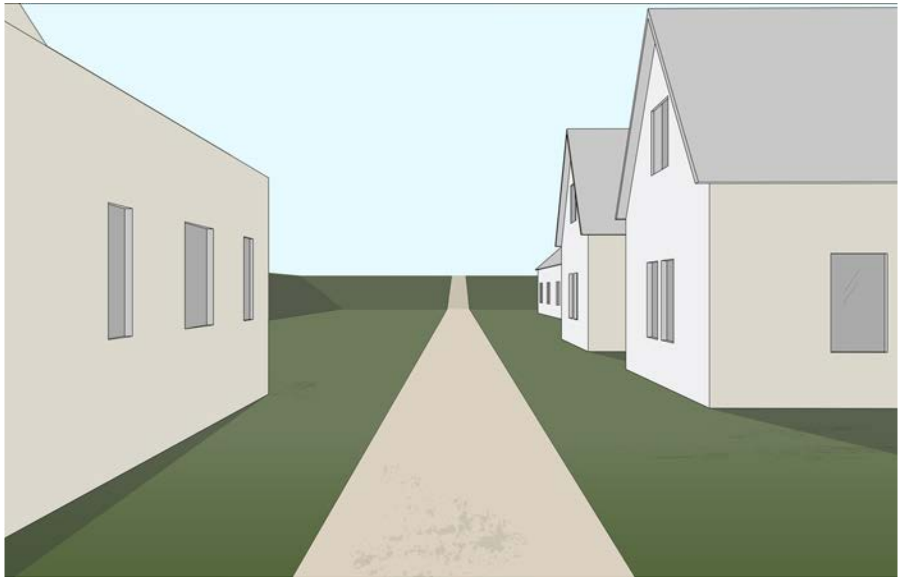

Figure 56: Street view – 3 m embankment (Borner 2020).

Street view – 3 m embankment

The visual connection to the water is disrupted by the embankment. The embankment serves as a recreational pathway and protects the settlement from high water levels, though in risk of providing a 'false sense of security'.

(Approximately 180 meters from the lookout to the embankment.)

7.1.1 Evaluations

Embankments

+

- Immediate protection.
- Provide sense of security to inhabitants.
- Bicycle and pedestrian path on top of embankments provide recreational use (multifunctionality).

–

- Land take from private gardens and nature reserve required in many cases.
- Obstructing inland ecological migration.
- Much ecosystems connected to temporary inundation will be permanently inundated and lost.
- Visual impact and disconnection from the water.
- Need reinforcements as SLR continues, and also if storm events will become more frequent.
- Extensive amount of fill materials required – costly.
- Natural hydrology disrupted – pumps needed.

Detached breakwaters

+

- Facilitates sediment trapping.
- Attenuate weave energy.

–

- Construction might impact on the nature reserve's shallow water ecosystems, such as eelgrass meadows and hatching environments for marine fauna.
- Land build-up obstructed if sedimentation possibilities reduced.

SDGs correspondence:

Embankments:

- 3 GOOD HEALTH AND WELL-BEING: *Will protect settlements and people. Although, eventually much of the terrestrial nature values will be lost.*
- 6 CLEAN WATER AND SANITATION: *May obstruct storm water run-off and natural dynamics.*
- 11 SUSTAINABLE CITIES AND COMMUNITIES: *Not resilient nor sustainable as reinforcements and require extensive landfill volumes.*
- 15 LIFE ON LAND: *An embankment implies much loss of the intertidal ecosystems as sea levels rise.*

Detached breakwaters:

- 3 GOOD HEALTH AND WELL-BEING: *Might have both positive and negative effects to the marine and terrestrial ecosystems in the area.*
- 14 LIFE BELOW WATER: *Might have both positive and negative effects to the marine and terrestrial ecosystems in the area.*
- 11 SUSTAINABLE CITIES AND COMMUNITIES: *Possibly facilitating resilience*
- 15 LIFE ON LAND: *Ecosystems may benefit from land build-up facilitated by breakwaters.*

7.2 SOFT METHODS

In this section, the tests and evaluations of soft methods are related to nature-based or natural features in terms of flood protection in coastal zones. The embankment is in line with the existing coastal protection plan for the area (section 6.2.1). Although, the embankment is of a 'softer' nature compared to the previous 'hard structure' embankment.

Two plan maps are presented below. The major differences are the inlets for the 'Make room for the water' principle (further described below), and how the concerned settlements will be handled.

Correlating adaptation measures (see Table 1):

Accommodation
Attack
Attenuation
Defend/Protection/Hold the line
EbA / NbS
Limited intervention
Planning
Retreat

Figure 57: Soft methods applied to the project site. Here the southern settlements are protected by embankments, allowing floods through two inlets.

Figure 58: Soft methods applied to the project site. Southern settlements evacuated allowing water through one inlet.

Gently sloping vegetated embankments:

The embankments protect the settlements from flooding. They run along the nature reserve border and are gently sloping towards the ocean. They are vegetated with trees, shrubs and herbaceous vegetation.

Constructing gently sloping and vegetated embankments implies land elevation to some extent.

Sand replenishment:

The slopes of the vegetated embankments are replenished with sand, again inspired by the LIFE Coast Adapt (4.2) and the Zandmotor project in the Netherlands (4.3.1).

'Make room for the water':

This implies designating a pathway for the sea water and ecological values. In order to protect existing settlements, embankments or evacuation is suggested. This action is inspired by the Dutch 'Room for the river' project (4.3.4).

Barrier islands:

This action can reduce wave energy to the gently sloping embakment. It is also inspired by the Dutch Zandmotor project (4.3.1).

Natural barriers:

Establishing marine vegetation (e.g. eelgrass meadows), or wetlands inspired by the ecosystem-based measures applied in the Swedish LIFE Coast Adapt (4.2).

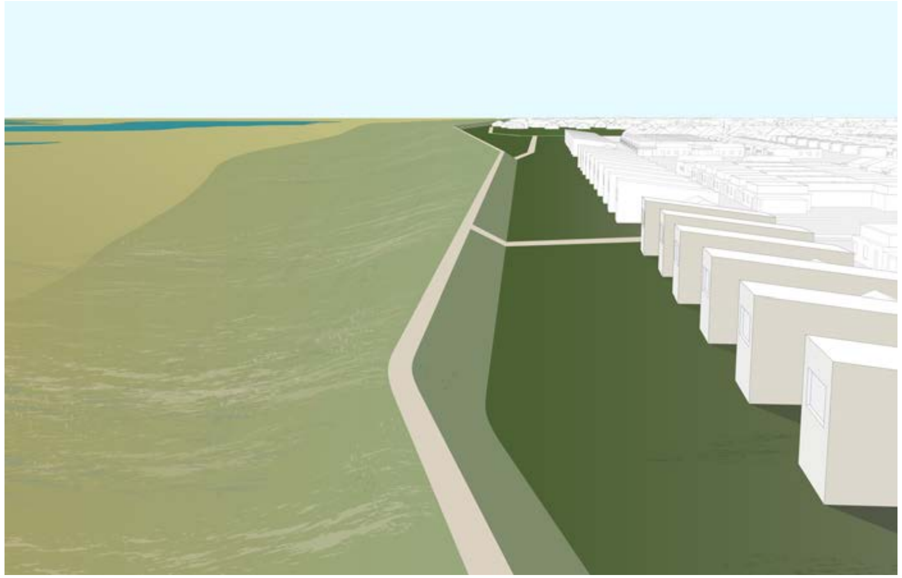

Figure 59: Gently sloping vegetated embankment and sand replenishment (Borner 2020).

Gently sloping vegetated embankments and sand replenishment

The image illustrates a gently sloping embankment towards the ocean. It runs along the nature reserve border.

Vegetation (trees, shrubs and herbaceous vegetation) enable organic build-up, trap sediment, and reduce wave energy to the coastline.

Sand replenishment imitates and facilitates sand migration and dynamics, adding to the land build-up in itself but also as waves carry sand with them out in the water. The land build-up aims to reduce the predicted SLR level for year 2100 (1,1 m).

By building up the land, the 1,1 m SLR shoreline decrease may be reduced and, to some extent, preserve the intertidal coastal areas - saving the ecological values connected to them, and simultaneously provide protection to the existing settlements.

Make room for the water – two inlets

The illustration shows the current ocean (dark blue), SLR (1,1 m) (medium dark blue), and finally the approximate level of a storm surge event (light blue).

Here, the existing settlements and inhabitants are protected by vegetated and sand replenished embankments. The embankments can be constructed with a lower height (compared to other places in the area) due to lower anticipated water levels. Though, they might have to be reinforced or readjusted as sea levels rise or if recurrence intervals of storm events will be more frequent or severe.

By constructing bridges between the settlements, water is allowed to move further to the hinterland. This allows natural hydrology and sediment dynamics, and enables ecological migration.

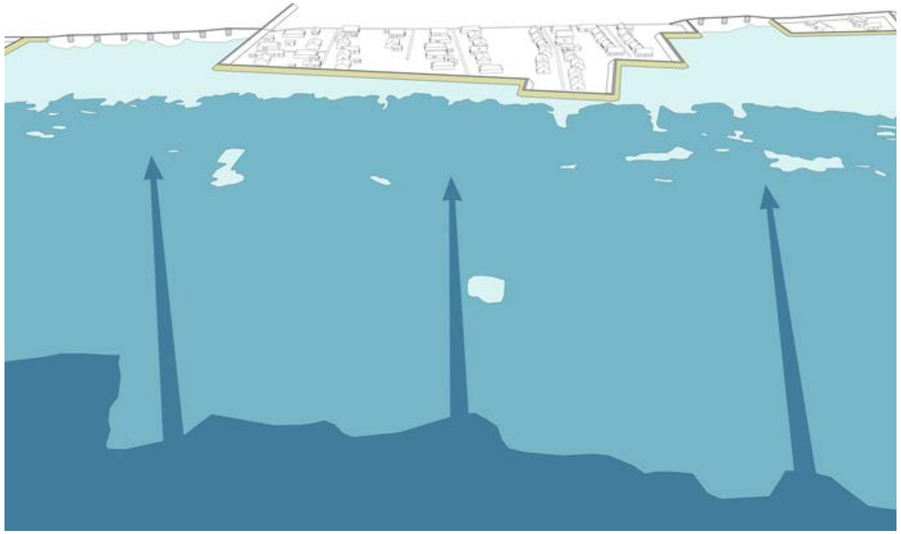

Figure 60: Make room for the water - two inlets (Borner 2020).

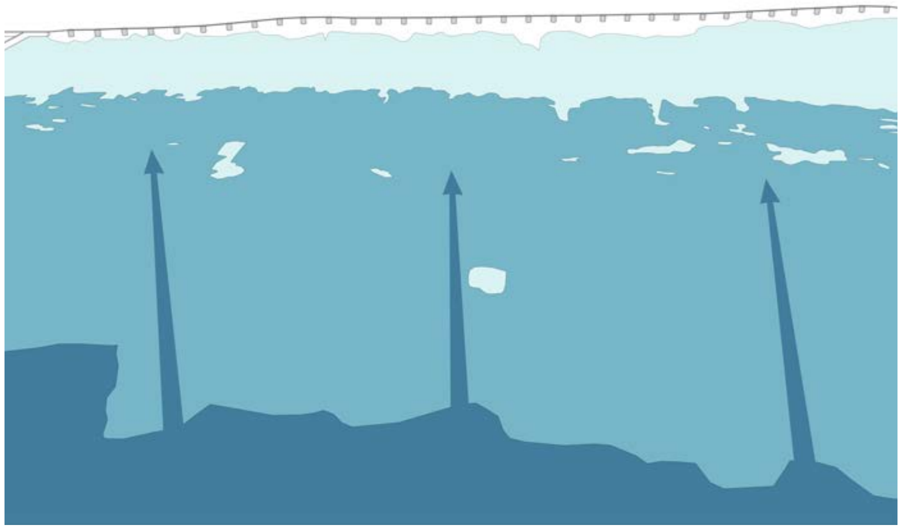

Figure 61: Make room for the water - big inlet (Borner 2020).

Make room for the water – big inlet

The illustration shows the current ocean (dark blue), SLR (1,1 m) (medium dark blue), and finally the approximate level of a storm surge event (light blue).

The existing settlements have been evacuated. The bridge allows natural hydrology and sediment dynamics, and enables ecological migration.

7.2.1 Evaluations

Gently sloping vegetated embankments

+

- Immediate protection.
- Provides sense of security to inhabitants.
- Enhances recreational possibilities and values.
- Vegetation enable organic build-up, bind soils, and trap sediment.
- Vegetation sequestrate carbon.

-

- Might interfere and/or disrupt with the identified and valuable flora and fauna.
- Gentle slopes imply more land take.
- Require landfill masses.
- Natural hydrology disrupted – pumps required.
- Disconnection from the water.
- Herbaceous vegetation not as effective to trap sediment during winter.

Sand replenishment

+

- Facilitates land build-up, sand migration and dynamics.
- Facilitates natural dune build-up.

-

- Requires sand excavation.
- Frequent replenishment required.
- Will impact on ecosystems.

Make room for the water

+

- Allows natural dynamics.
- Provide an ecological pathway for the nature reserve.
- An innovative statement of coastal planning.
- Provide recreational area.

-

- Affects the adjacent agricultural lands.
- Social impact if evacuation is implemented.
- Reconstruction of Klagshamnsvägen (bridge) required.

SDGs correspondence:

Gently sloping vegetated embankments

3 Good health and well-being: *May have both positive and negative impacts to the ecosystems.*

13 Climate action: *Vegetation may help sequestrate carbon.*

6 Clean water and sanitation: *May facilitate creating ecosystems functioning as natural filters.*

14 Life below water: *Allowing natural coastal dynamics may benefit marine ecosystems.*

11 Sustainable cities and communities: *Multifunctional embankments bring several co-benefits. Although, landfill may not be sustainable.*

15 Life on land: *Construction may impact on existing values, but vegetation may be beneficial.*

Sand replenishment

3 Good health and well-being: *May preserve or create new ecosystems.*

14 Life below water: *Sand excavation might impact on marine ecosystems.*

11 Sustainable cities and communities: *Sand excavation and frequent replenishment might not be considered sustainable.*

15 Life on land: *May impact terrestrial ecosystems when implemented, but provide new habitats as well.*

Make room for the water

3 Good health and well-being: *Make room for the water allows ecological migration, natural dynamics, and recreational possibilities.*

13 Climate action: *Planning to make room for the water may raise awareness about climate adaptation in coastal zones.*

6 Clean water and sanitation: *Natural coastal dynamics may contribute to the sustainable management of water.*

14 Life below water: *Allowing ecological migration benefits marine ecosystems.. The bridge may impact the marine ecosystems negatively.*

15 Life on land: *Implies allowing salt water intrusion. May enhance terrestrial ecosystems.*

Barrier islands

+

- Reduce wave energy to the coastline.
- Provide environments for flora and fauna.
- Possibility to integrate recreational values.
- Facilitates sediment trapping.

–

- Might change water currents.
- Will impact the sea bed and the ecosystems connected to it.
- Might impact adjacent Natura 2000 area to the south.
- Requires sand excavation and extensive volumes.

Natural barriers

+

- Trap sediment.
- Reduce wave energy.
- Improve habitats.

–

- Eelgrass can be hard to establish.

SDGs correspondence:

Barrier islands

3 GOOD HEALTH AND WELL-BEING — *Recreational values promote healthy lives.*

14 LIFE BELOW WATER — *Marine ecosystems will be affected.*

11 SUSTAINABLE CITIES AND COMMUNITIES — *May contribute to coastal resilience and safety.*

15 LIFE ON LAND — *Can provide space for terrestrial flora and fauna.*

Natural barriers

3 GOOD HEALTH AND WELL-BEING — *Enhance marine ecosystems promoting healthy lives.*

13 CLIMATE ACTION — *May contribute to carbon sequestration.*

6 CLEAN WATER AND SANITATION — *Marine vegetation may help purifying the water.*

14 LIFE BELOW WATER — *Marine ecosystems benefit from habitat enhancements.*

11 SUSTAINABLE CITIES AND COMMUNITIES — *May reduce wave energy and contribute to safer settlements along the coastline.*

15 LIFE ON LAND — *Reduced wave energy may reduce coastal erosion and loss of intertidal habitats.*

7.3 HYBRID METHODS

In this section, the selected methods are of a more radical nature compared to the two previously described examples. The suggested methods are connected to and anchored in the described adaptation concepts (section 2.3.3), and address the identified threats in the area, although being radical in the sense that they suggest drastic change to the project site and the inhabitants.

The artificial reefs in the plan map are not suggestions on where to place them. Further evaluations would be needed in order to select proper locations, sizes and numbers.

The hinterland retreat area is not evaluated to any extent. Currently, the area is used for agricultural purposes.

Correlating adaptation measures (see Table 1):

Accommodation
Attack/Advance/Move seaward
Attenuation
Defend/protection/hold the line
EbA/NbS
Planning
Retreat

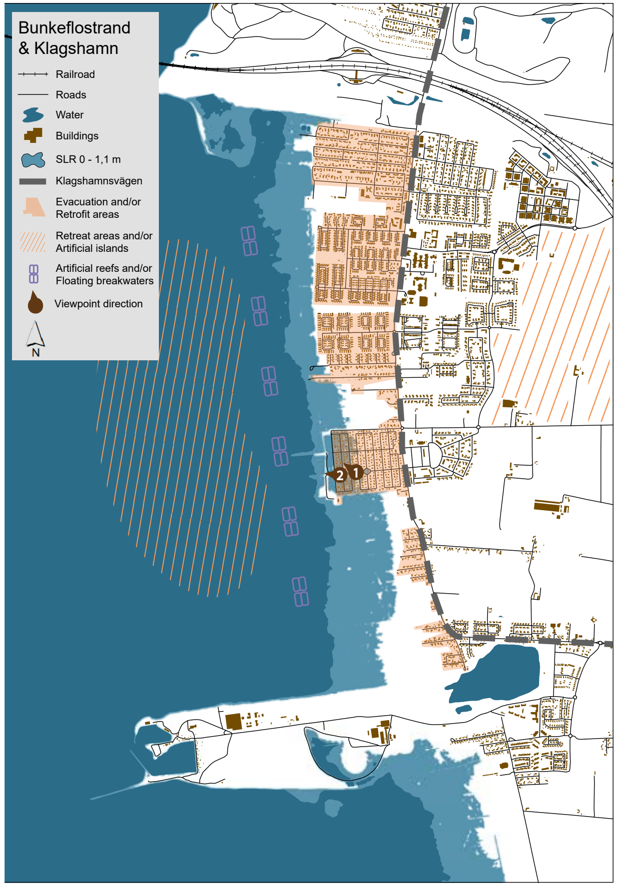

Figure 62: Hybrid methods.

Retreat (inland):
Evacuate settlements to designated areas.

Artificial islands (Retreat + Attack):
Construct islands to which settlements are relocated – inspired by Sluseholmen (4.1.2), HafenCity (4.1.3).

Elevated, floating or dry floodproofed architecture:
Accommodate buildings to water by retrofitting existing buildings or implement on new constructions - inspired by Chelsea Heights (4.1.1) and Maasbommel (4.3.2).

Artificial reefs:
To reduce wave energy on the hinterland inspired by LIFE Coast Adapt methods (see section 4.2).

Floating breakwaters:
Reduce wave energy on the hinterland.

Perspective – elevated buildings + water

In Strandhem the existing embankment may be removed allowing water to enter the neighborhood. Removing the embankment can be considered a soft method, though it is suggested as a combination to the proposed elevation of buildings.

The current shoreline is the border between the two blue colours, the medium blue illustrates the water level at a 1,1 meter SLR.

As elevated buildings require access, the roads are incorporated with embankments or other wave energy attenuating structures with openings in order to allow the water to both enter and exit.

The settlements up in the corner have been evacuated or retrofitted to withstand high water levels.

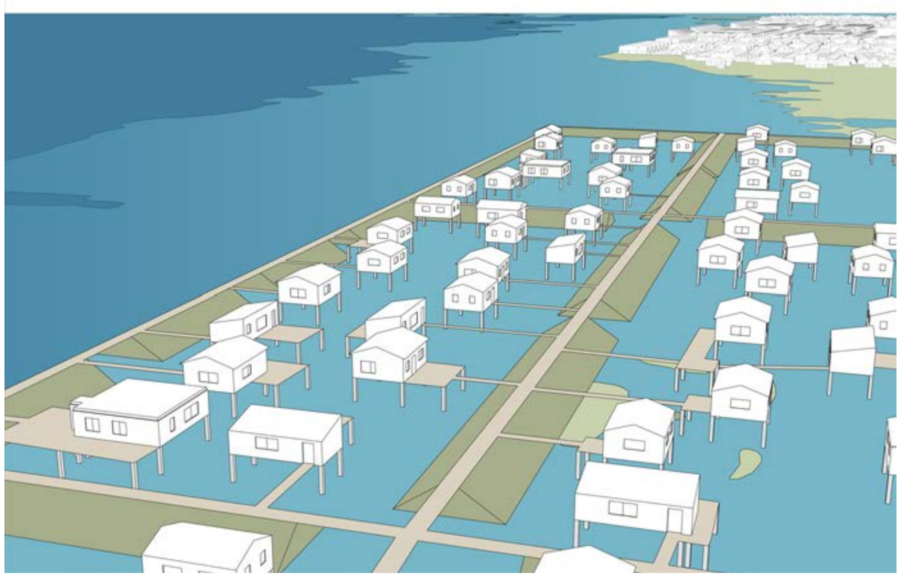

Figure 63: Perspective - elevated buildings + water (Borner 2020).

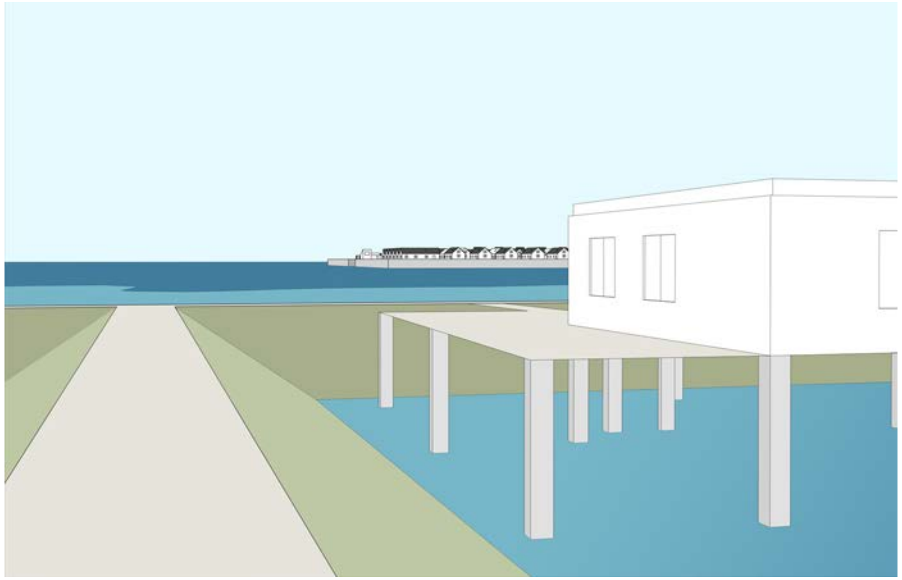

Figure 64: Visual impact (Borner 2020).

Visual impact

The illustration is from a human perspective from above an embankment looking towards an artificial island approximately 600 meters away. In the 3D model the artificial islands were placed on 5 m elevations.

Elevated buildings would completely change the spatiality of a neighborhood. Initially the ground level space could be utilized at lower water levels.

7.3.1 Evaluations

Elevated, floating or dry floodproofed architecture will be handled separately since an evaluation will vary depending on the chosen method.

Elevated architecture

+

- Reduced flood risk to settlements.
- Ecological migration not completely obstructed.
- Allows natural hydrology.

–

- Infeasible for larger buildings in terms of retrofitting.
- Elevation, in terms of retrofitting, is sometimes more expensive than the value of the building.
- New accesses to buildings required.
- Visual impact.
- If elevation is implemented as a retrofitting measure, temporary relocation of the inhabitants is required.
- Potential loss of cellar floors.
- Will need further adaptation as sea level rise.

Floating architecture

+

- Reduced flood risk to settlements.
- Novel and innovative method.
- Ecological migration not completely obstructed.
- Allows natural hydrology.

–

- Infeasible for larger buildings in terms of retrofitting.
- Permanently floating in the future.
- Potential loss of cellar floors.

Dry floodproofed architecture

+

- Reduced risk to damage.

–

- Not suitable for high water levels.
- Ecological migration obstructed.
- Potential loss of cellar floors.

SDGs correspondence:

Elevated architecture:

- 3 Good health and well-being: *Properly designed settlements allowing natural features promote healthy lives and well-being.*
- 6 Clean water and sanitation: *Allowing natural hydrology and water dynamics may contribute to the sustainable management of water.*
- 14 Life below water: *Allowing natural hydrology and water dynamics may contribute to the sustainable management of water.§*
- 11 Sustainable cities and communities: *May both increase and decrease safety.*
- 15 Life on land: *Natural hydrology and water dynamics may benefit the terrestrial ecosystems connected to the shoreline.*

Floating architecture:

- 3 Good health and well-being: *Properly designed settlements allowing natural features promote healthy lives and well-being.*
- 13 Climate action: *May raise awareness of sustainable development in coastal zones, although it may signal and enable mass exploitation.*
- 14 Life below water: *Integrating settlements to natural environments may cause disturbance to marine environments.*
- 11 Sustainable cities and communities: *May both increase and decrease safety.*

Dry floodproofed architecture:

- 11 Sustainable cities and communities: *May not be safe, resilient or sustainable as SLR continues.*

Artificial reefs

+

- Attenuate wave energy to the hinterland.
- Facilitates sediment trapping.
- Possibility for a circular system in terms of harvesting oysters/ mussels.
- Possibility to grow with SLR.
- Possibility to integrate social and educational purposes and benefits.

–

- Construction might impact the sea bed and the ecosystems connected to it.

Retreat (inland)

+

- Eliminates risk to inhabitants.
- Facilitates ecological migration if evacuated areas will be deconstructed and restored.
- Possibility to reuse materials if evacuated areas will be deconstructed.
- Research possibilities regarding ecological migration and soil restoration on previously developed land.

–

- Social impact for evacuated inhabitants.
- Designated retrest areas must be identified – risk to contribute to urban sprawl effect and exploitation of agricultural land.
- Costly.

Artificial islands

+

- Attenuate wave energy to the hinterland.
- Provide space for a growing population.

–

- Ocean sprawl – land reclamation will impact on the sea bed, natural flows and currents, and the ecosystems connected to it.
- Requires land fill masses – costly.
- Possible impact on the Natura 2000 area to the south.
- Visual impact.
- Need further adaptation if sea levels continue to rise.

SDGs correspondence:

Artificial reefs

- 3 Good Health and Well-Being: *May be multifunctional if social and educational aspects are integrated.*
- 13 Climate Action: *Possibility to raise awareness about climate change and adaptation.*
- 6 Clean Water and Sanitation: *Possibility to contribute to water purification.*
- 14 Life Below Water: *May provide healthy habitats for marine life but also impact on the existing ecosystems when implemented.*
- 11 Sustainable Cities and Communities: *Can help achieving inclusive, safe, resilient and sustainable human settlements.*
- 15 Life on Land: *Reducing negative impacts to the coastal zones are beneficial for life around the shoreline.*

Retreat (inland)

- 3 Good Health and Well-Being: *Evacuation eliminates risk to people but may cause social impact.*
- 6 Clean Water and Sanitation: *Naturalization of previously developed areas facilitates natural hydrology.*
- 14 Life Below Water: *Marine ecosystems benefit from the possibility to migrate.*
- 15 Life on Land: *Naturalization of previously developed areas may benefit terrestrial flora and fauna.*

Artificial islands

- 6 Clean Water and Sanitation: *Artificial may impair sustainable water management.*
- 14 Life Below Water: *May have both positive and negative impacts on marine ecosystems.*
- 11 Sustainable Cities and Communities: *May reduce agricultural land take and urban sprawl, although may facilitate ocean sprawl.*

Floating breakwaters

+	–
• Attenuate wave energy to the hinterland.	• Reduced wave energy can reduce erosion and land loss to life on land. It can also facilitate land build-up.

SDGs correspondence:

May contribute to resilient coastal protection infrastructure.

May provide marine habitats.

Reduced erosion and land loss benefits terrestrial life. May also facilitate land build-up.

Results & discussion

8

RESULTS AND DISCUSSION

The GMSL is rising between 0,61–1,10 meter in the RCP8,5 scenario for year 2100. Selecting the higher value (1,1 meter) in this thesis could be viewed as illustrating a worst-case scenario, although it is important to realize that the lower and higher values differs with approximately 50 centimeters. At first, 50 centimeters sea level difference appears to form a whole other outlook for coastal zone management and planning, but maybe it is not - the ocean is never a static surface.

For the project area and in terms of socio-economic values, the 1,1 meter SLR pose risk to flood some parts of the Strandhem neighborhood, apart from that, not much of the built environment are endangered. Though, the ecological values connected to the coastal dynamics are severely endangered by a 1,1 m SLR as much of it will be permanently flooded. The project site of Bunkeflostrand and Klagshamn is a clear example of a coastal squeeze situation as much ecological values and the nature reserves are located shoulder to shoulder to the built environment to the west of Klagshamnsvägen.

In the U.S., a paradigm shift to incorporate natural and nature-based features in floodplain management was a result from acknowledging that the neglected and mismanaged natural systems likely could have decreased the severe impacts from Hurricane Katrina in 2005. Simultaneously, embankments and pumps to handle stormwater run-off are the current and existing proposals for Bunkeflostrand and Klagshamn in terms of coastal protection.

From the threat maps we know that large areas in Bunkeflostrand and Klagshamn will be flooded during a storm event. The 'extreme event' threat map is equivalent to a 10 000-year event and might yet again be viewed as a worst-case scenario, with a 68 centimeters difference between the highest values for the 100-year and the extreme event scenarios. Though remember, the IPCC (2019a) referred to a study indicating that a 100-year event will become common by 2100. Also, the Dutch municipality planned Scheveningen to cope with a 10 000-year event.

In this thesis the first research question was:

A. What are the benefits and tradeoffs from different coastal protection solutions, and from the Sustainable Development Goals standpoint?

Benefits and tradeoffs

As conventional methods are being questioned and nature-based features are gaining attention, benefits and tradeoffs have been simpler to identify by testing various solutions in isolation (hard structures, soft, and hybrid methods), regardless of being considered a conventional, nature-based, or a not commonly used method (e.g. elevating buildings).

Bunkeflostrand and Klagshamn consist of several dimensions of values: social, economic, ecological and cultural. From the evaluations we see that *solutions many times benefit at the cost of another* – often between the socio-economic and the ecological values. A conventional embankment seen in the 'hard structures' example could affect natural values greatly by obstructing natural hydrology and sedimentation, create erosion to adjacent areas, and hinder ecological migration etc. Although, by incorporating natural features as in the 'soft method' example, it could become multifunctional in terms of improving natural values, provide recreational space, and protect from high water levels.

In the shift to work with nature instead of controlling it, it is important to *not make a direct parallel between nature-based features and ecological benefits*. In the 'soft method' example (section 7.2), the long-term vision of the vegetated and sand replenished embankment is to enable organic build-up, to trap sediment and hopefully facilitate land build-up in order to provide both protection to the settlements as well as preserving and enhancing the natural values in the future. Though, the nature-based feature 'sand replenishment' might have a negative impact on the marine ecosystems when excavating the sand, and even on the area that is being replenished – an ecological tradeoff for a socio-economic benefit with an ecologic long-term improvement. Is that truly sustainable? Also, continuous sand replenishment could be considered as a 'structural reinforcement', something that has been identified a problem with hard structures.

To evaluate benefits and tradeoffs between coastal protection solutions is complex. In a real-life situation, thorough investigations and assessments of e.g. geological conditions and cost-benefit analyses need to be carried out. An embankment may protect an area, but ground water can potentially emerge from below and inside the protected area as sea levels rise, depending on the geological conditions of the very site. A costly solution might be less costly than implementing another solution, or to do nothing.

The SDGs

Evaluating various coastal protection solutions from an SDG standpoint is another complex task as the SDGs do not correlate seamlessly to the three core values of sustainability (Figure 2).

The 'Make room for the water' example (section 7.2.1) with aims to preserve natural dynamics and allow ecological migration is at odds with the reconstruction of Klagshamnsvägen (made a bridge). Constructing a bridge implies CO_2 emissions, and evacuation of the existing settlements along the road will have a social impact. Furthermore, it brings even more light to the agricultural land take and urban sprawl discourse as the Make room for the water implies agricultural land loss and probably soil salinisation as well.

Terrestrial ecosystems could benefit from land build-up facilitated by for example detached breakwaters (in section 7.1.1), but as they attenuate wave energy the existing terrestrial ecosystems might as well disbenefit from a lessened land surface being temporarily inundated – both ecological values with conflicting benefits and tradeoffs.

Floating architecture – not commonly used in Sweden – is yet another example of *conflicting benefits and tradeoffs in relation to the SDGs*. Yes, a floating house could possibly protect inhabitants and reduce damage to property by adapting to sea level rise and temporary high water levels, though, a sustainably constructed structure/building could inspire to ocean sprawl and thereby still impact the near shore ecosystems negatively.

Applying the Attack/Advance/Move seaward measure (Table 1) and construct artificial islands (see 7.3.1) would provide retreat areas for evacuated settlements, and they could be a response to handle urban sprawl and simultaneously reduce wave energy to the shoreline etc. Although, such development would also entail multiple disbenefits that span over all three core values of sustainability. First of all, constructing artificial islands would probably be costly, it would impact the on-site ecosystems and likely affect the surrounding environments as well, evacuating existing settlements and changing the ocean horizon from an open sea to a sea with a built-up skyline would have a social impact.

Resilience

The second research question was:

B. How can different coastal protection solutions be applied to achieve coastal resilience?

Stated earlier, the term has historically been utilized in engineering, psychology and ecology contexts, from which the latter the principle was described.

Assessing resilience of adaptation and protection measures and/or methods could be done in isolation, although preferably as a whole as real-life situations might constitute an array of interlinked solutions; probably constituting a mixture of hard, soft and hybrid structures and methods.

Previously, when evaluating the benefits and tradeoffs, and from a sustainability standpoint it showed that benefits potentially were at cost of other values, and that the sustainability principle could conflict with the SDGs. This is also the case within the resilience sphere as resilient climate adaptation and protection solutions conflict depending on the focus. An example could be an embankment that provides protection to a settlement but obstruct ecological migration, which is equal to creating a *non-resilient ecosystem* for the area. Also, it was argued that *urban resilience to floods is the capability to handle and absorb flood impacts and later be reorganized*, which implies that truly resilient coastal zones should allow water to enter the areas and then 'bounce back' and adapt to a new state.

Method discussion

Much information can be acquired from reviewing and analyzing up-to-date literature, reports, publications and so forth. Although and in the end, profound investigations are required for each and every specific case. For the project site, further and multiple investigations would need to be carried out in order to be able to assess and evaluate various solutions adequately.

It is also important that the required data is accurate. For the GIS bathtub analysis, the Digital Elevation Model (DEM) must be accurate. Despite the existing embankment around Strandhem, the bathtub model showed that some parts of the neighborhood would be permanently flooded at a 1,1 meter SLR indicating either a shortcoming in the data or a flaw in the existing and surrounding embankment.

Building the 3D model in SketchUp was time consuming as it meant getting to know the program. Though, it was useful to understand the site spatiality which can be even more useful if it would integrate topography data etc. As t was vnot included in the 3D SketchUp model, the views and visualizations are flat. Since the area is sloping towards the ocean, visual impacts can be even greater from a distance than seen in the model. Another aspect to this is that vegetation, which was excluded in the visualizations, also play a significant role in spatiality and function. For example, an embankment implies less of a visual obstruction if it is blocked by shrubs and trees.

Additional reflections

- Nature-based features and concepts such as Nature-based Solutions and Ecosystem-based Adaptation are sometimes defined identically, and sometimes separated by a fine line. This creates nuisance in both the studies of and dialogues about climate adaptation in coastal zones. It is important to develop a common language and standardized terminology.

- The terms 'conventional, 'traditional', and 'innovative' are complicated to use in the coastal protection discourse. 'Conventional' and 'traditional' tend to be used together with negative side effect from commonly used hard structures. 'Innovative' on the other hand is a vague term since it can be applied to commonly used structures and methods, although in a novel thinking manner

REFLECTIONS

Among the tested structures and methods the more appealing solutions are the ones that promote multifunctionality, though not multifunctionality from an anthropocentric angle only. We can see that a combination of structures and methods may create such co-benefits in order to achieve the better solution, as sustainable as possible. The 'soft methods' suggest land build up through combinations of marine vegetation, sand replenishment and new vegetation on the sloping embankment – will this help preserving the marine and terrestrial nature values, protect the settlements, and simultaneously provide recreational values? Is this sustainable even if it was at the cost of another value? Ecological compensation is enforced to all exploitation according to the Malmö comprehensive plan: How do we compensate loss of shoreline ecosystems?

Applying the hybrid methods, or the more drastic solutions, is interesting as the retreat measure may have to be applied more in the future. If an amphibious approach to future settlements may be the case, we also need to investigate how it will or may affect the marine ecosystems.

For areas susceptible to both temporary and permanent floods and additional problems (e.g. erosion), a focus from socio-economic aspects towards a holistic approach that incorporate all values of sustainability is advocated. Cost-benefit analyses produce tangible and measurable data, which maybe one of the reason to the socio-economic focus. Although, little is known about long-term effects from loss of biodiversity and ecosystems.

Knowledge about various coastal protection solutions together with thorough and profound evaluations seems to always result in benefits and tradeoffs between different values, generating questions such as:

- What value/s should be protected and preserved?
- What value/s can we accept to lose?
- Which climate scenarios do we plan for?
- Is it possible to develop biodiversity loss assessments?

It is also shown that evaluations from a SDG standpoint is difficult and problematic as they possibly conflict with the core values of sustainability. Assessments on benefits and tradeoffs may identify a range of solutions with tradeoffs in every case, from which the 'best of the worst' might have to be chosen or else nothing will be done – an impossible solution for the Bunkeflostrand and Klagshamn situation as it endangers much property damage and the well-being of the inhabitants, and also a great loss of ecosystems and cultural values.

The term resilience must also be utilized in a way that underlines what aspects of coastal climate adaptation intended to achieve resilience. Also as a reminder, resilience may not only be applied to physical matters but also to nonstructural measures such as regulatory policies in order to be able to develop a reactive system. This requires long-term, strategic and circular and strategic planning.

Multidisciplinary inputs and collaborations are required in order to assess the best possible solution for a specific location when addressing issues connected to SLR and floods in coastal zones. Climate adaptation for coastal zones will most likely become more common in the future; let's work together and make the best of it.

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