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What will the sea look like in 2120?

Ecosystem services in the central Gulf of Bothnia

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Länsstyrelsen Västerbotten

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Foreword

Climate change is the greatest environmental crisis of our time. The changes due to climate change are already happening everywhere in the world both on land and in water and our actions today will determine our future. It is expected that the effects of climate change such as temperature increases will be greater in the Gulf of Bothnia than in any other part of the Baltic Sea. In the ECOnnect project we have studied what the sea in the central Gulf of Bothnia will look like in 2120. This was done by analysing present and future environmental conditions and species distribution, ecosystem services, and connectivity in the central Gulf of Bothnia. The results from the project indicate that climate change will make the sea warmer, the ice-cover thinner and the salinity slightly lower. Species will react differently to these changes depending on their living requirements. Lower salinity affects marine species such as the blue mussel which are already living at the limit of their tolerance for low salinity, while reduced ice-cover will benefit perennial algae, for instance. Changes in ecosystem services are in many parts expected to follow the changes in species distribution. Some areas might experience an increase in ecosystem services while others may undergo a decrease. A drastic change in ecosystem services is however not expected. Kvarken is an important route for species to spread between Sweden and Finland. Marine protected areas are undisturbed areas for marine life. The better placed the protected areas are the better habitat network they create for species, which increases the chances for species survival in the future.

Three reports presenting the results from each work package and a summary report highlighting the main outcome from each report were produced within the project (all can be found at econnect2120.com). In this report, we present the possible changes that ecosystem services will face in the future within the ECOnnect project area. The other two reports concentrate on the possible changes to future environmental parameters and species distribution, and on evaluating existing and future networks of protected areas from a connectivity perspective.

The project was financed through the Interreg Botnia-Atlantica cross-border cooperation programme. It started in June 2018 and ended in May 2022. The project was a continuation of long-term cross-border collaboration between Finland and Sweden in Kvarken aiming at strengthening the management of the joint sea area. The project partners were Metsähallitus Parks & Wildlife Finland, the South Ostrobothnia Centre for Economic Development, Transport and the Environment, the County Administrative Board of Västerbotten, and the County Administrative Board of Västernorrland. The project area was confined to Ostrobothnia and Central Ostrobothnia in Finland and Västerbotten and Västernorrland county in Sweden.

The ECOnnect project would like to thank Interreg Botnia-Atlantica, the Regional Council of Ostrobothnia, the Swedish Agency for Marine and Water Management, and the participating organizations for making this project possible. We would also like to give thanks to SMHI and FMI who produced the climate models and to everyone else who have helped us in one way or another.

Contents

Abbreviations and Acronyms

BSAP	The HELCOM Baltic Sea Action Plan
BALTEX	The Baltic Sea Experiment
CICES	The Common International Classification on Ecosystem Services
EMMA	Finnish ecologically significant marine underwater areas
ES	Ecosystem services
ESI	Ecosystem services index
FMI	Finnish Meteorological Institute
GHG	Greenhouse gas
HELCOM HUB	The HELCOM Underwater Biotope and Habitat Classification System
IPCC	Intergovernmental Panel on Climate Change
LuTU	Habitat classification system used in Finland, based on HUBs
MAI	Maximum allowable input of nutrients, indicating the maximum level of inputs of water and airborne nitrogen and phosphorus into the Baltic Sea sub-basins to achieve good environmental status of the Baltic Sea (in BSAP)
MESAT	Marine Ecosystem Services Assessment Tool
MPA	Marine protected area
OECD	The Organisation for Economic Co-operation and Development
RCP8.5	Representative concentration pathway 8.5, the worst-case climate scenario
SDMs	Species distribution models
SMHI	Swedish Meteorological and Hydrological Institute

1. Introduction

1.1. The Baltic Sea

The Baltic Sea is a shallow sea characterized by brackish water (Leppäranta & Myrberg 2009). There are nine countries surrounding the Baltic Sea with around 85 million people living in the drainage area. The drainage area is about four times larger than the sea, and this puts great pressure on the biodiversity and ecosystem functions of the sea (HELCOM 2017). Environmental problems from human activities affecting the Baltic Sea include eutrophication, pollution, maritime traffic, introduction of non-indigenous species, fishing and hunting, habitat loss and disturbance, climate change, marine litter, etc. (Leppäranta & Myrberg 2009; HELCOM 2017).

Due to the brackish water, species diversity in the Baltic Sea is low compared to marine or freshwater environments (Kautsky & Kautsky 2000; HELCOM 2009). Nevertheless, the biodiversity is higher than expected in a brackish system because of the high variability in types of habitats and the unique salinity gradient (HELCOM 2018a). Moreover, the Baltic Sea has been estimated to be a very productive ecosystem providing a variety of ecosystem services. These include e.g. fish, water and climate regulation, nutrient recycling, and recreational opportunities (HELCOM 2009).

Marine species like *Fucus* spp. and the blue mussel (*Mytilus trossulus x edulis*) are examples of key species throughout almost the entire Baltic Sea as they form habitats (HELCOM 2009) and provide a food source for many other species (Waldeck & Larsson 2013; Wikström & Kautsky 2007). Areas where a few key species have a large influence on the ecosystem (HELCOM 2009), or where there is low species diversity (Peterson et al. 1998), like in the Baltic Sea, can be defined by their low resilience to stress factors (HELCOM 2009). One stress factor that could have a large impact on the Baltic Sea is climate change.

1.2. Project background

The aim of the ECOnnect project was to study the possible effects of climate change on the aquatic environment in the central Gulf of Bothnia hundred years ahead. The project area (Fig. 1) is especially interesting when it comes to climate change as some marine species in the area of Kvarken are already living near their tolerance limit regarding salinity. The low mean salinity in the project area is optimal for neither the marine nor freshwater species living together in the area (Kautsky & Kautsky 2000). A possible decrease in salinity due to climate change could have a great effect on the species distribution in the area. Additionally, the temperature has a great impact on the environment and ecosystems due to the seasonality and duration of ice cover. The aim of the project was to generate information that could assist community planners in adapting to the effects of climate change. The goal was also to make the results accessible for the public. The goals of the project were achieved by producing models of possible future distributions of underwater species and species groups in the area as well as maps of possible changes to physical parameters, such as the temperature, salinity, and sea ice cover. The models were based on future climate scenarios from the Swedish Meteorological and Hydrological Institute (SMHI) and the Finnish Meteorological Institute (FMI). Furthermore, the project studied the possible future ecological connectivity between biotopes and keystone species and marine protected areas (MPAs) and investigated the impact of climate change on important marine ecosystem services in the project area.

The climate models used in this project are based on the climate scenario RCP8.5 and the nutrient reduction schemes according to the HELCOM Baltic Sea Action Plan (BSAP). The RCP8.5 is the worst-case climate scenario created by IPCC in the Fifth Assessment Report (AR5) (Collins et al. 2013). The

BSAP is a collection of actions and measures for the HELCOM contracting parties to achieve a healthy marine environment in the Baltic Sea with a special emphasis on eutrophication mitigation (HELCOM 2020). The results from the ECOnnect project are based on assumptions that concentrations of greenhouse gases in the atmosphere will continue to increase in the future following RCP8.5, but a good environmental status concerning eutrophication will exist in the Baltic Sea.

The decision to focus on RCP8.5 and BSAP was made based on present trends and trajectories. While there are ambitious goals for climate change mitigation such as the EU's policy to reach carbon neutrality by 2050, the measures may be too little and too late. Climate change has been acknowledged as a serious threat for decades, but this awareness of the problem and its solutions have unfortunately not turned into sufficient action. Moreover, we wanted to use the worst-case scenario to study what totally neglecting the climate crisis might cause for the sensitive Kvarken area and to draw attention to how climate change, eutrophication, the state of the marine ecosystems and human well-being are intertwined. In contrast, eutrophication of the Baltic Sea has been taken seriously for a while, and inputs of nitrogen and phosphorus to the sea decreased by 22 % and 24 % respectively in the 1995–2014 period (HELCOM 2018b). Therefore, it seems possible to achieve the goals of the BSAP in future decades. Nevertheless, much of the work against eutrophication and other environmental stressors remain. We also wanted to show how important it is to reduce the nutrient input to lessen the stress on the marine environment to avoid cumulative effects of eutrophication and climate change.

Further information about RCP8.5 and BSAP can be found in the ECOnnect report *Future climate and species distribution models for the central Gulf of Bothnia* where species distributions have been modelled in the reference period and in the future.

Communicating the purpose of the project and the results to both community planners and environmental and climate experts, as well as to the general public was an important part of the project from the start. Social media was the main channel for communication and an online workshop for community planners and environmental and climate experts was organized at the beginning of 2021. The project results are presented in different reports, on the SeaGIS2.0 map portal, the project's webpage and in a story map. The reports include detailed information about the project's methods and results, and the models can be studied more closely in the SeaGIS2.0 map portal. The produced data is open and free to be used further in other climate related projects. In order to make the results available and interesting to a broader public with different backgrounds, several videos and animations were created about the different topics of the project. A story map was created to display the communication material produced and the main results from the project in an inspiring way.

1.3. Project area including Kvarken

The project area extends from north of Skellefteå in Sweden and Kokkola (Karleby) in Finland to south of Sundsvall in Sweden and Kristiinankaupunki (Kristinestad) in Finland (Fig. 1).

Within this central part of the Gulf of Bothnia lies Kvarken. Kvarken is a shallow transitional area separating the Bothnian Sea (BS) from the Bothnian Bay (BB). The coastline and topography of Kvarken are constantly changing and are shaped by the ongoing land uplift, which makes the land rise at a rate of around 9 mm/year (Poutanen & Steffen 2014). Kvarken contains several marine protected areas, including Natura 2000 areas, and important bird and biodiversity areas (Kallio et al. 2019). Moreover, Kvarken is classified as an Ecologically or

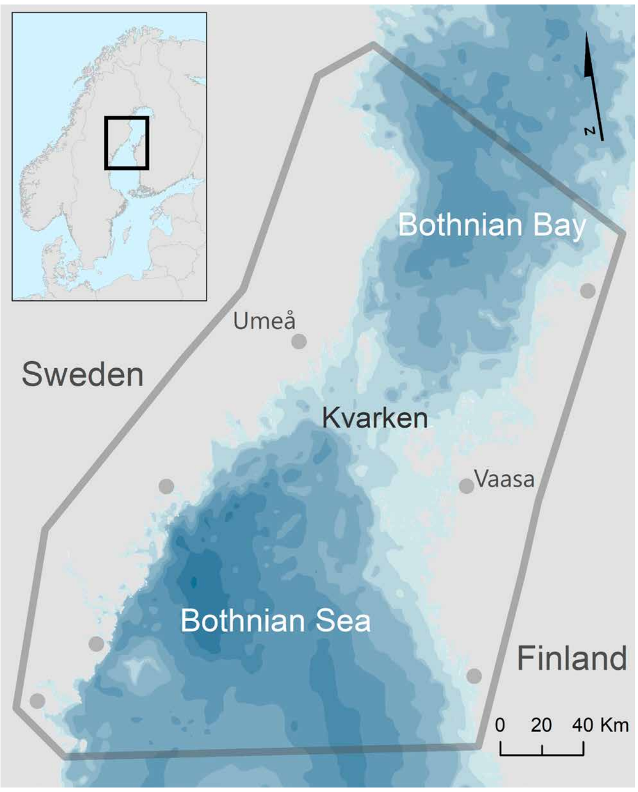


Figure 1. The ECOnnect project area is situated in the central Gulf of Bothnia in the northern Baltic Sea.

Biologically Significant Area (EBSA) (The Convention on Biological Diversity 2021).

The archipelago on the Finnish side of the project area is shallow and consists of thousands of small islands, whereas the landscape on the Swedish side is much steeper with fewer islands (Poutanen & Steffen 2014; Donadi et al. 2020). The UNESCO World Heritage Site High Coast / Kvarken Archipelago is located here (UNESCO 2021). On the Finnish side of the project area lies several EMMA areas (Finnish ecologically significant marine underwater areas): Revöfjärden, Rönnskäret, Mikkelinsaaret, and Kvimofjärden (Lappalainen et al. 2020).

There are variations in the salinity in the project area due to the shallow depth and strong currents in Kvarken. The salinity declines from 5 to 4 ‰ when moving only ca 10 kilometres northwards from Bergö, located south of Vaasa. The salinity is higher on the eastern side of the project area as the Coriolis effect steers the incoming saltwater from the south towards the Finnish west coast and the rivers on the Swedish east coast bring a lot of fresh water into the sea (Rinkineva & Bader 1998). The mean salinity in Kvarken is 3–4 ‰ which is lower than the mean salinity in the Baltic Sea (Kautsky & Kautsky 2000). The declining salinity from the Baltic proper to the Gulf of Bothnia affects the living conditions for species. Therefore, Kvarken is a border area for the distribution of several species (Rinkineva & Bader 1998), for example, for blue mussels and brown algae *Fucus* spp. (HELCOM 2017). The majority of the species within the project area are freshwater species that can tolerate brackish conditions, for example, fish species such as perch (*Perca fluviatilis*), bream (*Abramis brama*), and roach (*Rutilus rutilus*) and underwater vegetation such as pondweeds (*Potamogeton spp.*) and stoneworts (Charales) (Viitasalo et al. 2017). Since both marine and freshwater species are to some extent living outside of their optimal conditions regarding salinity, a lot of stress is put on the species. This stress can result in the smaller size of the species, for example, compared to areas where the species are not exposed to stress factors (Westerbom et al. 2002).

The mean and maximum depth in the project area is 64 m and 298 m, respectively (SeaGIS2.0). The shallow parts of the project area provide areas with warmer temperatures, especially in the spring, unlike the otherwise cold waters in the Gulf of Bothnia. These warmer areas are important for species reproduction, for example for several fish species. The ice that covers the project area during winter has a great impact on the sea, affecting for example the sedimentation process and scraping away underwater vegetation from shallow areas where land-fast ice has formed. The main currents in the Gulf of Bothnia travel northward along the eastern coast and southward along the western coast. There are also smaller and more local currents that affect local conditions, such as sedimentation. The currents are typically strong in Kvarken as it is the passage for water going between the Bothnian Sea and the Bothnian Bay (Rinkineva & Bader 1998).

1.4. Future effects of climate change

In the future, atmospheric changes due to climate change could include changes in air temperature and precipitation. In the oceans and seas, changes in water temperature, sea level, storm surges, and sea ice cover can be expected (HELCOM & Baltic Earth 2021; Meier et al. 2021). Increasing levels of carbon dioxide in the atmosphere are also causing ocean acidification, which leads to a decrease in the water pH (HELCOM 2017), but it is uncertain how much the pH might change in the Baltic Sea (HELCOM & Baltic Earth 2021). These changes, in turn, are expected to lead to changes in marine species and communities (Viitasalo & Bonsdorff 2021).

The greatest changes to water temperature in the Baltic Sea are predicted to occur in the Gulf of Bothnia in the summer (Meier et al. 2021). The surface layers will warm more than the deep waters, and mean summer surface water temperatures in the northern parts of the Baltic Sea could increase by over 3°C under the RCP8.5 scenario (Meier et al. 2021). Climate models have large uncertainties regarding the water balance, and because runoff is the greatest factor affecting salinity there are large uncertainties as to whether the salinity will decrease or increase. It is projected that precipitation will increase in the summer as well as in the winter in the northern part of the Baltic Sea, which could result in a salinity decline. However, with rising temperatures there could also be an increase in evaporation which would reduce the river-runoff and would not cause a decline in salinity. In addition, sea level rise affects salt inflows into the Baltic Sea, which could compensate the effect of increased runoff, further complicating the predictions of future salinity.

Rising sea levels are mainly caused by melting of glaciers and the thermal expansion of sea water as it gets warmer. In the Gulf of Bothnia, the potential sea level rise is expected to be compensated for by the ongoing land uplift (Meier et al. 2021). The sea level rise in the project area is further discussed in the ECOnnect report *Future climate and species distribution models for the central Gulf of Bothnia*. Future changes in storm surges will depend on the sea level rise and increased wind speed. At present, it is not well understood how winds may change in the future but increasing wind speed is considered possible by several recent studies, especially in the autumn (reviewed in HELCOM & Baltic Earth 2021; Meier et al. 2021). Sea level rise is the factor affecting changes to storm surges the most (von Storch et al. 2015), and one could assume that if the sea level rises, storm surge levels could also rise. This is, however, very uncertain.

Ice cover is highly dependent on the air temperature in the winter. The ice cover today is already smaller and thinner than the historical average, and the duration of the ice cover has shortened. In winter 2020, the annual maximum sea ice extent was at its lowest since 1720, when measurements began (Meier et al. 2021). Additionally, during the last 30 years the mean extent of the sea ice has been the lowest ever (Meier et al. 2021). The increasing temperature in the future is expected to accelerate these changes in the sea ice (HELCOM & Baltic Earth 2021; Meier et al. 2021).

How ocean acidification can affect species and ecosystems in the Baltic Sea is still highly uncertain (HELCOM & Baltic Earth 2021), but the available data implies that many species in the Baltic Sea are generally tolerant to a lower pH, but that some shell-building species, for example, may suffer (Navenhand 2012). It is also expected that brackish water communities will be less affected by ocean acidification as they are already adapted to variations in CO2 and pH (Bermudez et al. 2016). However, some studies have also found evidence that acidification in combination with warming waters will have more detrimental effect on Baltic Sea communities than acidity alone (Viitasalo & Bonsdorff 2021).

According to the future models produced for this project for the years 2070–2099, the mean bottom water temperatures in the summer will increase by 3°C, ice-thickness will decrease by more than 80% and salinity is on average projected to decline by 0.52‰, or -10%, compared to the reference period 1976–2005. These are the most important climate induced changes that the marine environment in the project area is expected to face in the future. In this report we do not go into detail for all the expected future environmental changes, but as these (and the species distribution models) are something that the results of this report also rely on, more information on them can be found in ECOnnect report *Future climate and species distribution models for the central Gulf of Bothnia*. It is expected that the effects of climate change such as an increase in sea surface temperature will be larger in the Gulf of Bothnia than in any other part of the Baltic Sea, partly because the albedo will decrease as the ice is lost, leading to even more warming (Meier et al. 2012). Climate change will affect the Baltic Sea ecosystems in different ways and together with other human pressures can also affect the resilience of the ecosystems making them even more vulnerable to future changes (HELCOM 2013; von Storch et al. 2015; HELCOM & Baltic Earth 2021).

2. Ecosystem services

Ecosystem services (ES) are natural conditions and processes through which ecosystems, and the species within them, enable and sustain human life (Daily 1997). Regarding marine ES these include explicit ecosystem goods such as the fish catch, aquaculture, and water for industrial use. Together, these form what are called 'provisioning services', something that the marine environment directly offers to humans. In addition to the production of goods, ES are the actual life-support functions such as recycling of materials and nutrients, mediation of toxins and maintenance of physical, chemical, and biological conditions, and further the intangible aesthetic and cultural benefits that seascapes offer. In the literature, ES have been divided and referred to in many different ways (e.g. Hattam et al. 2015). The Millennium Ecosystem Assessment (MA) 2005 divided the since then widely used division of ES into four service sections: provisioning services, regulating and maintenance services, cultural services, and supporting services. However, nowadays the supporting services are often omitted when talking about service outputs as they form the underlying processes and functions in ecosystems that maintain many other services. Hence in this work, we concentrate on the provisioning, regulating and maintenance, and cultural services (Fig. 2).

The ES concept first surfaced due to concerns of environmental degradation and biodiversity loss and the will to shed more light on the meaning of ecosystems as providers for human life (Daily 1997; MA 2005). The backbone of the concept of ES is to foster and legitimize biodiversity and nature conservation and promote the sustainable use of natural resources and support management policies (Daily 1997). In the past decades the concept has developed to become a formal body of information, classifications and policies, and the research on ES has grown extensively. The importance of ES for sustainable management is largely acknowledged and the European Union (EU) has been working to integrate the concept into its directives and management guidelines to ensure future maintenance and restoration of member states' ecosystems and services. For instance, the management goal in the Water Framework Directive (WFD; Directive 2000/60/EC) and Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC) is to achieve a better environmental and ecological status of marine and fresh waters so that the sustainable future use of ES can be secured. These directives are further incorporated into Finnish and Swedish legislation and into the marine strategies of both countries to guide marine and coastal management and spatial planning (YM 2016, 2020; HaV 2020a).

Incorporating ES into policy and management plans has required developing different ways and measures to value and estimate ES and the changes that happen within them in human impacted environments. The valuation of ES is inherently interdisciplinary and requires combining approaches of natural and social sciences to find linkages between ecosystem, the provision of ES and human well-being (Ahtiainen & Öhman 2014). The valuation of ES can be done on three levels: qualitative, quantitative, and monetary (White et al. 2011). On top of various means of valuing and estimating ES, also ES classification systems have been numerous in the academic field hampering efforts to compare ecosystems, used methods or the produced services (Fisher et al. 2009; Costanza et al. 1997; MA 2005; Hattam et al. 2015). Haines-Young & Potschin (2012) aimed to tackle these problems by providing a standardized ES classification system and coordinated the development of the Common International Classification on Ecosystem Services (CICES). This classification organizes ES hierarchically and promotes a thorough review of different services, and it has been welcomed by many operators such as the EU (European Commission 2011; Maes et al. 2015). Thus, also in this work we use the CICES classification.

Climate change will affect ecosystems and the services they produce in the Baltic Sea (e.g. HELCOM

Figure 2. Ecosystem services are often grouped into three main categories: provisioning services, regulating and maintenance services, and cultural services. Pictures: Anniina Saarinen/Länsstyrelsen Västerbotten, Juuso Haapaniemi/Metsähallitus, & Seger Marketing.

2007). Changes at the ecosystem level depend on how different species will be affected by the changing climate and due to various factors (e.g. uncertain future changes in environmental variables, ecosystem resilience and species interactions), the expected changes on a species level are highly uncertain (e.g. Viitasalo et al. 2015). Further, the magnitude of these changes is dependent on the choices we humans make in the coming decades regarding climate actions and tackling other Baltic Sea threats such as pollution and habitat degradation. However, regardless of the uncertainties under the changing climate, it is important to anticipate how the ES provision might change in the future and how that information can be used to determine sustainable future management plans. Additionally, within the ES research field, a lack of sufficient knowledge of future changes to ES in the Baltic Sea has been acknowledged and more information has been called for (Ahtiainen & Öhman 2014), and other projects (e.g. SmartSea) have been collecting information on the changes, in addition to this project.

Based on the future models used in this project (SMHI's climate models run with climate scenario RCP8.5, and nutrient reduction scheme from the BSAP, and species distribution models constructed in this project), as well as literature and various expert opinions, we have assessed the present ES provision and estimated the changes that the warming climate will impose on these services in 100 years by using a method called the Marine Ecosystem Services Assessment Tool (MESAT) (Inácio et al. 2018). This assessment was done for three separate pilot areas inside the ECOnnect project area to view potential future changes in different kinds of marine areas. Further, by using smaller and well-defined pilot areas, the evaluation of ES is more reliable. Additionally, broader changes in ES in the whole project area induced by climate change were assessed using an ecosystem services index (ESI) that was constructed in this project based on species distribution models. Read more on species distribution models in the ECOnnect report *Future climate and species distribution models for the central Gulf of Bothnia*.

2.1. Ecosystem services in the project area

From the deep waters of the High Coast in Sweden to the shallow archipelago in Finland, the project area includes a diversity of nature types, habitats, and species and therefore provides a great number of different ES. Probably the most well-known ES that nature provides in the area is fish. Small scale fisheries operate in the whole project area and the species fished are mainly herring (*Clupea harengus membras*), whitefish (*Coregonus lavaretus;* Luke 2021), and salmon (*Salmo salar;* Havet 2021). Recreational fishing is also common in the area. Fish farming on the Finnish side of the project area further contributes to this provisioning ES. In contrast, water-based aquaculture systems on the Swedish side of the project area have recently been shut down for environmental reasons.

The provisioning services can only exist if there are well-functioning supporting services and regulating and maintenance services (Daily 1997; MA 2005). Regulating and maintenance services include aspects such as maintaining nursery populations and habitats. There need to be specific types of habitats, substrates, and vegetation for different fish species to breed. Fish species in the project area such as whitefish, prefer shallow sandy bottoms (Veneranta et al. 2013), whereas perch and pike (*Esox lucius*) need sheltered areas with dense vegetation such as the common reed (*Phragmites australis*), and pondweeds (Snickars et al. 2009). Thanks to the fast land uplift process, lagoons are a typical and numerous nature type in the project area, especially in Kvarken. They provide not only reproduction and nursery areas for fish but are also hotspots for biodiversity of different species of vascular plants and macroalgae (Naturvårdsverket 2011). The oxygen that these underwater plants and algae produce together with phytoplankton also belongs to the regulating and maintenance ecosystem services. NASA has estimated that oxygen produced by phytoplankton through photosynthesis makes up between 50–90% of the oxygen we breath depending on the season (Hoppenrath et al. 2009). Both phytoplankton (Hutchins & Fu 2017) and macrovegetation (Marbà et al. 2015) have an important role in regulating the climate as they fix carbon dioxide through photosynthesis and sequestrate it into living tissue. The vegetation has also an important role for counteracting erosion at shorelines by binding the sediment effectively with roots and by mitigating the wave action (Madsen et al. 2001). At the sea bottom, fauna and bacteria living in the sediment take care of decomposing the organic material that is not utilized by other organisms and ends up on the sea floor (Carstensen et al. 2014). Biodiversity is the basis for all ecosystem services. The ecosystems in the Baltic Sea are already fragile due to the low number of species (Johanssen & André 2006) and low species richness, and genetic variation is needed for adapting to the changing environment. Additionally, a healthy, diverse ecosystem is also more resilient to other environmental stressors (Laikre et al. 2016), such as alien species that might try to settle in the area.

The project area is also rich in cultural ES and especially the Kvarken area has an interesting geological history. Around 20 000 years ago, Kvarken was covered with a 2500-3000-meter-thick ice sheet (Poutanen & Steffen 2014). When this glacial ice sheet melted, it left behind exciting geological formations that are still rising from the sea in a process of rapid glacio-isostatic uplift. Different moraine formations make up the 5600 islands in the Kvarken Archipelago (UNESCO 2021) that are full of birdlife as well as cultural heritage sites. There are hundreds of old buildings ranging from lighthouses to fishing huts both on the islands and mainland of Sweden and Finland (SeaGIS2.0). Today, many people either live or have their summer cottages close to the sea. The shores of Västerbotten for example are among the most exploited in the whole of Sweden. Over 37% of the mainland shores are occupied with buildings closer than 100 meters from the shore (Lundberg & Nilsson 2018).

3. Marine Ecosystem Services Assessment Tool

The Marine Ecosystem Services Assessment Tool (MESAT) is a methodological approach and tool developed by Inácio et al. (2018) to address changes in ES provision over time for transitional and coastal waters. The tool builds on the presumption that changes in ecosystem functions and formations may influence a system's ability to provide ecosystem services. Initially the tool was developed to compare changes in ES provision between the present and the past decades to see how services have changed to this day, but in this project the tool was modified to address changes between the present and the future for evaluations of the effects that climate change may impose on ecosystems. MESAT offers a practical tool for assessing the provisioning, regulating and maintenance, and cultural services in a specific confined area. The size of the ECOnnect project area covers about 40 000 km^2 (excluding land areas such as islands) and within this large area many different ecosystems occur, and habitats shift gradually, which challenges ES assessments. Concentrating on a smaller scale ES assessment offers opportunities to view changes in different kinds of marine areas. Additionally, it is difficult to find data on indicator values for such a large area and the possibility of errors increases when estimating large areas. Therefore, instead of evaluating the ES for the whole project area, three separate pilot areas within the project area were selected for the MESAT approach (Fig. 4), which made the ES assessment process easier and more reliable. The ES of the pilot areas do not directly describe or are comparable to the ES of the project area, but they give indications of wider changes in the area and describe the spatial differences well within the project area's different environments. We concentrated on the ES provided by the Baltic Sea and the coastal areas in the immediate vicinity (no more than 1 km from the shoreline). The effects of climate change and nutrient reductions on ES provision are difficult to isolate from other factors that may affect ecosystems in the future. Thus, it is important to note that on top of the effects of climate change and nutrient reductions, we also expect that the exploitation of sea areas will increase in the future in the project area and that this will have an effect on many ES. These anthropogenic factors are taken into account as much as possible due to their high impact on many services, but our main focus has been on the effects of climate change and eutrophication mitigation.

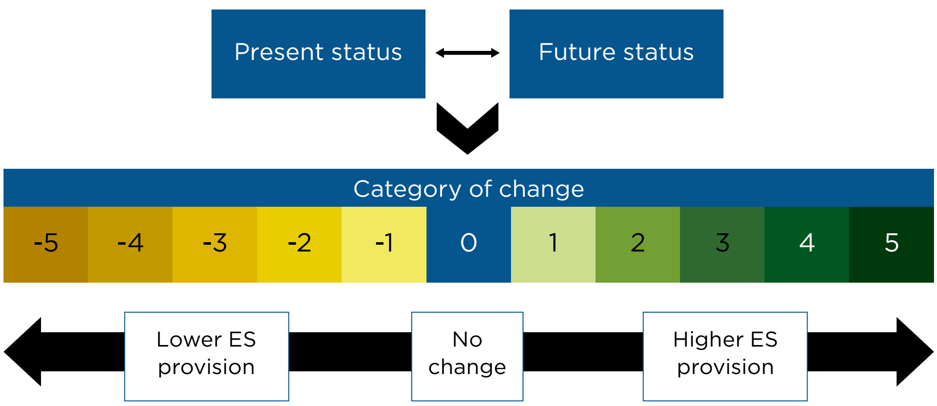


Figure 3. Modified from Inácio et al. (2018). The difference between indicator values (present/future) is allocated to a category of change which conveys the relative change to the ES provision and allows a comparison of different indicators.

In MESAT the ES are classified according to CICES version 4.3 and the relative change in ES provision has been assessed through a set of indicators that are proxies for the services (Inácio et al. 2018). Thus, for each ES a set of 1-6 indicators have been used to assess the change in each service (Table 1). For the different indicators the present and future values were assessed separately and then the total change (present vs. future) was converted to a Likert scale category of change to compare the magnitude of change between different indicators (Fig. 3). Hence the change in each indicator ranges within the Likert scale from -5 to +5. Minus values indicate a decrease in ES provision and plus values indicate an increase in ES provision. The change that occurs in the ES in 100 years was then calculated as the average of the Likert scale category of change values of the indicators describing each service. The future change in indicators has been assessed by using different sources of information including modelling, literature sources, expert opinions, and databases. The comprehensive list of data sources for each indicator can be found in Table A3 in the Appendix. In this MESAT assessment the present time period was set to the years 2010–2020 and the evaluated future time period comprised the years 2100–2120. **A thorough methodology of the MESAT assessment conducted in this project can be found in Section A1 in the Appendix.**

3.1. Pilot areas

The pilot areas used for the MESAT assessment were Utgrynnan-Molpehällorna on the Finnish side of the project area, and Yttre Täftefjärden and Husumbukten on the Swedish side of the project area (Fig. 4). Utgrynnan-Molpehällorna is a large sea area that extents far into the outer sea with multiple islands that create diverse environments. The area holds various nature types ranging from sheltered lagoons and soft bottom ecosystems to rocky reef habitats. In contrast, Yttre Täftefjärden and Husumbukten are smaller bay areas close to the mainland. The areas and coasts around both of the Swedish pilot areas are rather densely populated and used for human activities. Additionally, a paper factory is situated in the Husumbukten area. The vegetation in both Swedish pilot areas consists largely of soft bottom fauna and flora although hard bottom organisms also occur but to a lesser extent. There are ecologically important lagoons in Yttre Täftefjärden. **A more specific description of each of the pilot areas can be found in Section A2 in the Appendix.**

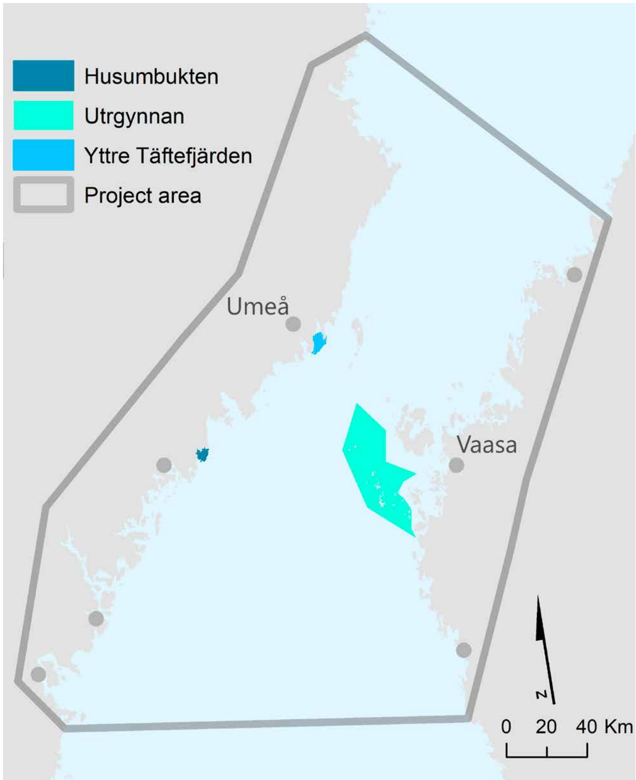
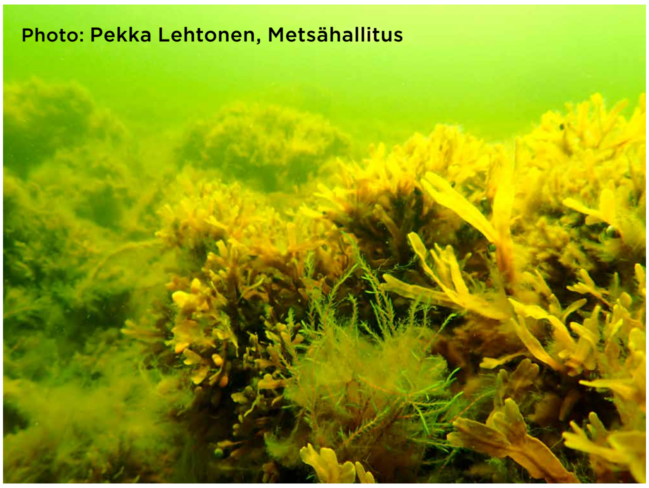
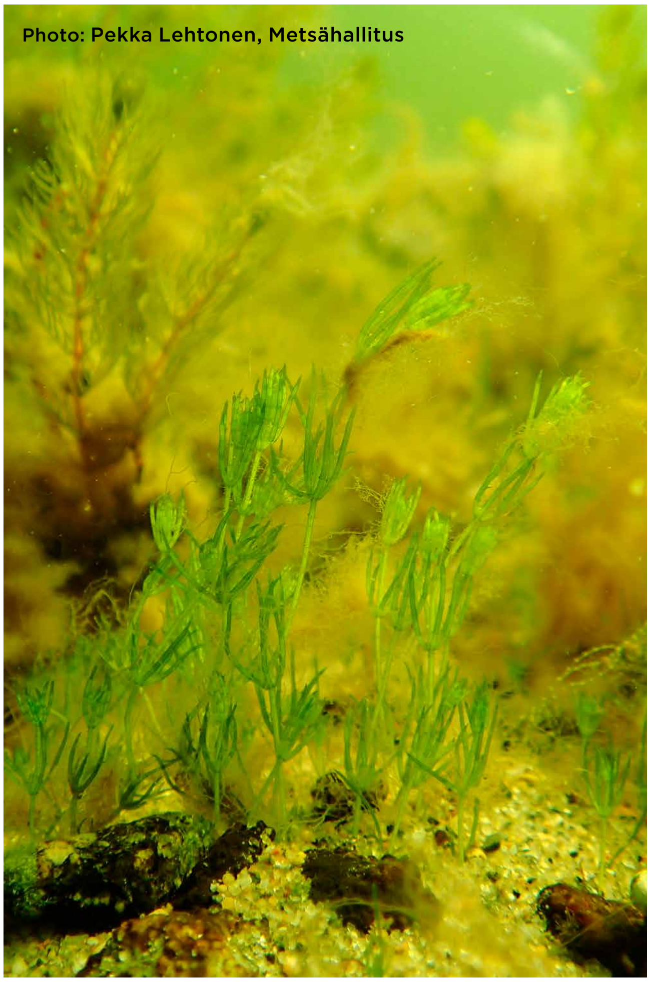


Figure 4. Pilot areas (Husumbukten, Utgrynnan-Molpehällorna and Yttre Täftefjärden) within the ECOnnect project area.





The Utgrynnan-Molpehällorna pilot area is a large sea area with a multitude of islands and the area extends far into the outer sea. Many different ecosystems occur in the area ranging from beautiful reef habitats to lush soft bottom vegetation. The cultural heritage in the area is rich.

Photo: Anniina Saarinen, County administrative board of Västerbotten

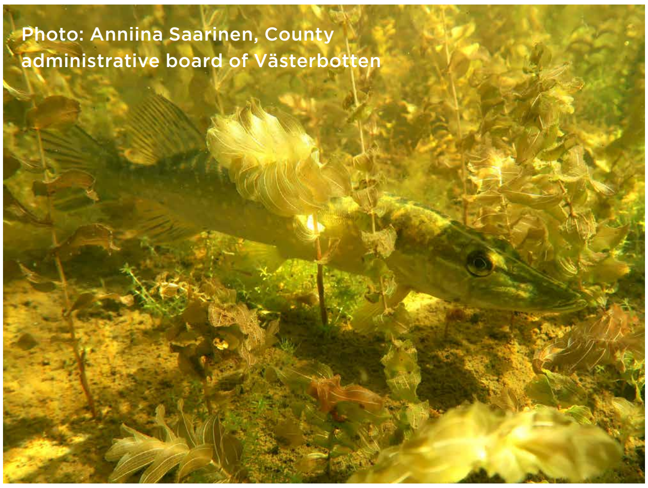


Photo: Anniina Saarinen, County administrative board of Västerbotten

Photo: Johnny Berglund, County administrative board of Västerbotten

Photo: Anniina Saarinen, County administrative board of Västerbotten

The Yttre Täftefjärden pilot area is a bay area close to the mainland and it includes coastal lagoons that are biological hot spots. In these sheltered bays you can find fish such as pike lurking in the lush vegetation.

Photo: Karin Jönsson, County administrative board of Västernorrland

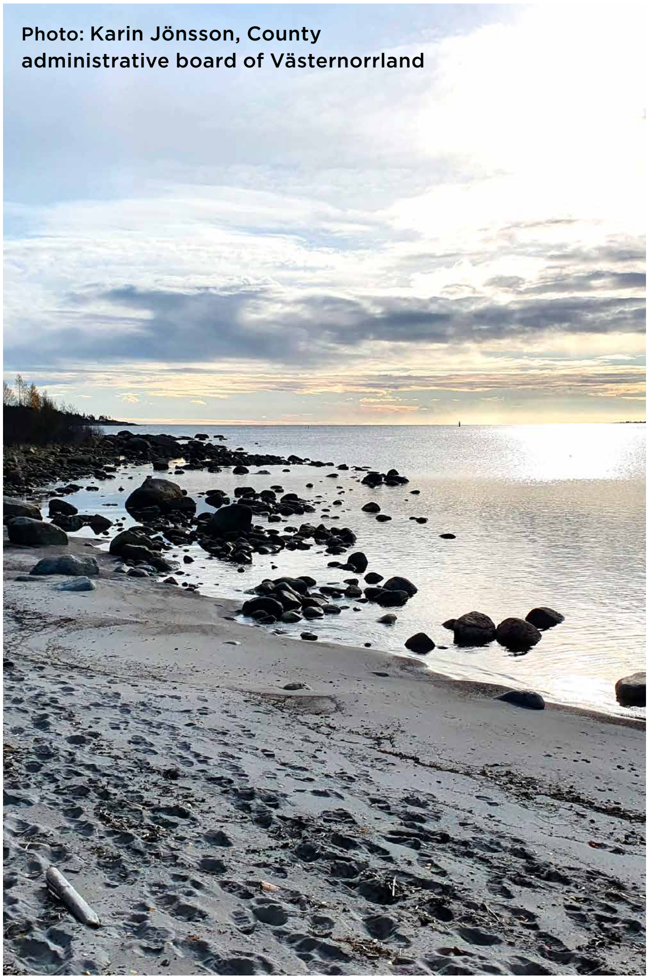


Photo: Karin Jönsson, County administrative board of Västernorrland

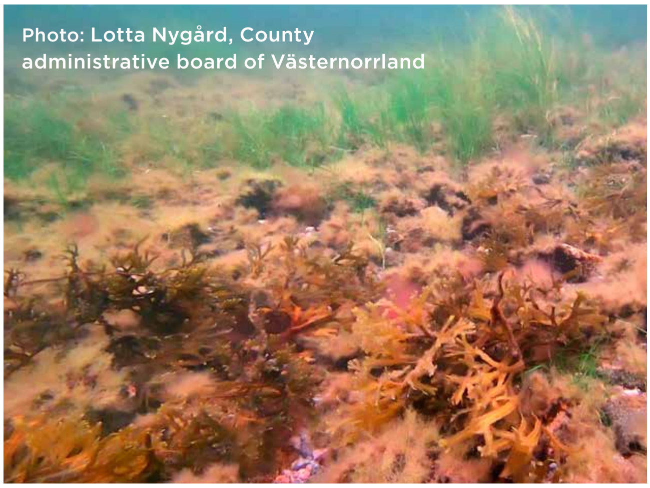


Photo: Lotta Nygård, County administrative board of Västernorrland

Photo: David Rocksén, County administrative board of Västernorrland

The Husumbukten pilot area is a small bay area close to the mainland. Habitats in the area consist mainly of soft bottom flora and fauna. The bay is also used for industrial activity.

3.2. Results

Ecosystem services now and in 100 years

In this section the general changes in ES in the area are explained first. Pilot-area-specific results are presented after the general results. In the section on general changes, the text is divided into chapters according to the evaluated ES and the service names are given as headers *in italics*. Further within the chapters, the different indicators that are used to evaluate the services are marked **in bold**.

3.2.1. General changes in provisioning services

Provisioning services are direct products such as fish, water, and raw materials that we get from nature. One of the most certain effects of climate change is that the water temperature is going to rise (HELCOM & Baltic Earth 2021; von Storch et al. 2015; ECOnnect report *Future climate and species distribution models for the central Gulf of Bothnia*). This will affect the provisioning services both directly and indirectly. All species have a specific tolerance range for different environmental parameters such as temperature. But even if a species is able to tolerate new temperatures, its prey or nursery areas might be negatively affected by climate change. Here we list the general changes in the provisioning ES that are expected to take place in all the pilot areas.

Wild animals and their outputs

It is clear that climate change will affect most fish species, and some effects can already be seen today (Pankhurst et al. 2011). In the project we have tried to foresee some of the effects of climate change on fish species that are commercially fished in the pilot areas. At the same time, we have tried to make qualified guesses based on expert opinions and literature sources of which species might be important for fisheries in the future. Today, the warm water adapted fish commercially fished in the pilot areas are pike, perch, cyprinids, and pikeperch (*Sander lucioperca*) (HaV 2020b; Luke 2021). Of these warm water species, only perch can be counted as a key market species as the catches of pike, cyprinids and pikeperch are marginal. The cold water adapted fish species make up most of the key market species in the pilot areas. These include salmon, whitefish, European smelt (*Osmerus eperlanus*), and herring, although there are big differences in the catch sizes between the pilot areas. Additionally, burbot (*Lota lota*) is fished commercially, but to a lesser extent, and trout (*Salmo trutta*) is caught as a by-catch and has a slight commercial value (HaV 2020b; Luke 2021).

It is important to notice that human activities apart from climate change will affect the future of fisheries. In 100 years, it is not known what species of fish will be caught and for what purposes. The fishery methods might be different and the demand for specific species might differ from today. Furthermore, the alteration and degradation of fish spawning and nursery habitats due to coastal construction, dredging, and physical barriers already negatively affect several fish species today (Sundblad et al. 2014; Sundblad & Bergström 2014). Luckily, the restoration of habitats, nature conservation, and marine spatial planning are recognized as ways to counteract the exploitation and other harmful human impacts on fish stocks (Geist & Hawkins 2016; Ehler 2018; HELCOM & Baltic Earth 2021). Furthermore, predator species have an impact on several fish species, and they will also affect the fish population dynamics in the future (Hansson et al. 2018).

Pike, perch, and cyprinids are examples of fish that are negatively affected by coastal exploitation (Sundblad & Bergström 2014) but could be positively affected by climate change as their early life stages develop faster in warmer water (Härmä et al. 2008; Engstedt et al. 2010; Kokkonen et al. 2019). In the future, the reproduction areas of these species, thanks to higher water temperatures and lower salinity, could also become larger (MacKenzie et al. 2007), which would further increase the populations of adult fish (Sundblad et al. 2014). Pikeperch populations are also likely to thrive in a warmer climate and this is expected to contribute significantly to the future catches (Pekcan-Hekim et al. 2011). Pikeperch is a predator for small perch (Lehtonen et al. 1996) and climate change could in this way have an indirect negative effect on perch in the Gulf of Bothnia due to an increase in the pikeperch population. Additionally, if three-spined stickleback (*Gasterosteus aculeatus*) populations, which also seem to be favoured by higher water temperatures, keep growing, as studies from the Swedish Baltic coast show

(Ljunggren et al. 2010; Eriksson et al. 2011; Bergström et al. 2015), then both perch and pike reproduction might be negatively affected by stickleback predation on their eggs and larvae (Byström et al. 2015; Nilsson et al. 2019; Eklöf et al. 2020).

The future of colder water species in warming water seems more problematic. In general, all salmonids, such as salmon and sea trout, which in their lifecycle live both in freshwater and the sea, are expected to be negatively affected by climate change due to warming waters. The most southern populations in the Baltic Sea and elsewhere in the world might even face extinction (Jonsson & Jonsson 2009). Baltic salmon stocks and sea trout stocks have been in bad shape historically because of the damming of rivers for electricity production, fishing, and habitat destruction. These problems have partly been addressed by fishing restrictions and habitat restoration, but still the physical barriers of dams pose serious threats to the natural populations (Ignatius & Haapasaari 2018). Furthermore, climate change adds to the stressors already affecting salmon populations making salmon more prone to infectious diseases (Miller et al. 2014). Due to the long-term harmful effects to the salmonid populations in the Baltic Sea and high monetary value of the species, fish stocking has played an important role in maintaining populations (MMM 2015). We expect salmonid stocking to continue in abundance also in the future which will counteract at least some of the negative future effects on the salmonid populations and thus expect only a slight decrease in salmonid landings in the pilot areas. There is also a growing hope that to some extent stocking could be replaced by better breeding area restorations and by improving migratory opportunities for the salmonids in the future.

The sea spawning whitefish is already showing signs of being negatively affected by warming temperatures, reduced ice cover, and eutrophication (Veneranta et al. 2013). Whitefish are therefore expected to decline in the pilot areas in the future. Burbot is red listed in Sweden and is also expected to decline in the future due to warming waters along with other stressors such as pollution and acidification (Stapanian et al. 2010). Herring populations are expected to increase slightly at first due to warming waters, but only if herring fisheries are at a sustainable level (Bartolino et al. 2014). Herring could also be negatively affected by the reduced salinity or reduced food availability (SmartSea 2018a; Engelhard & Heino 2006). The reproduction areas of vendace (*Coregonus albula*) are today restricted to the northernmost Gulf of Bothnia presumably due to the high salinity in the south (Veneranta et al. 2013). If climate change results in lower salinities, this could mean that vendace could reproduce in the project area in the future. Vendace stocks can also be expected to increase in the project area if the herring stock size declines (SmartSea 2018a). However, vendace also prefer cooler waters (Bergström et al. 2011), which may limit their occurrence in the more southern parts of the project area in the future, even if the salinity falls to more favourable levels for the species.

At least two introduced fish species are expected to become established in the pilot areas in the next 100 years. These species are round goby (*Neogobius melanostomus*) and Prussian carp (*Carassius gibelio*), which are already encountered especially in the Gulf of Finland and the Archipelago Sea. The number of introduced species that arrive in the pilot areas in the future will depend on which actions are taken today to prevent introduced species from arriving in the Baltic Sea for example in ship ballast waters. Even though it is feared that introduced species may affect the native ecosystem negatively through competition and predation, invasions by alien fish species have not yet resulted in the loss of native species, although they may cause changes in the population sizes of native species. Nevertheless, there is also potential for introduced species to be fished and used for commercial purposes such as for human consumption. Round goby is already fished both commercially and for recreation for example in Latvia and Russia (ICES 2019). Additionally, the invasive alien pink salmon species (*Oncorhynchus gorbuscha*) has been recently observed along the Swedish west coast as well as in Jutland in Denmark, and there is also a concern that the species will spread further into the Baltic Sea (Petersson et al. 2018). However, the species has been introduced to the Baltic Sea earlier by Russia, and so far, stockings in brackish water areas have not been very successful, which gives hope for the future.

In summary, the indicators **landings of cold water species**, as well as **landings of key market species**, which in the pilot areas mainly include colder water adapted fish species, are likely to decline in the future, whereas the indicator **landings of warm**

water species such as perch, pike, pikeperch, and cyprinids are expected to increase with the warming water. Therefore, it is possible that in the future, some warm water species could become key market species for fisheries whereas some of the cold water species would be fished to a lesser extent. Nevertheless, it is important to remember that ecological systems are complex and for example the prey species of warm water fish might be negatively affected by climate change and therefore lead indirectly to negative effects on some of the warm water fish as well. The alien species round goby and Prussian carp have been included in the landings of warm water species as there is no clear evidence of their invasive characteristics that would severely harm native species. Thus, from the perspective of fish landings, they could benefit humans. However, ecologically the spread of alien species into new areas should always be viewed as negative and thus their spread is evaluated negatively in the service 'maintaining nursery populations and habitat' under the indicator 'nursery areas for warm water fish species'.

Wild plants, algae, and their outputs

On the coasts of the project area, sea-buckthorn (*Hippophaë rhamnoides*) is the only financially valuable exploited plant species. It grows on land in barren and open coastal areas where it gets a lot of direct sunlight. The species naturally occurs also in warmer climate (GBIF 2021) so increasing the mean air temperature is not likely to pose a threat to the species in the future in the project area. Other direct or indirect climate change induced factors affecting the species harmfully are not clear, although ice might benefit the species as it withstands the ice scraping well, but the ice removes competing vegetation so decreasing ice cover in the future could harm the species. However, as this is not an entirely clear connection due to the warming climate and increasing length of the growing season (von Storch et al. 2015; Christidis et al. 2007) we expect that **the yield** of sea-buckthorn will increase slightly in the future (Expert group 2020). Of the pilot areas, the species is present in significant amounts only in Utgrynnan-Molpehällorna.

Animals from in situ aquaculture, and surface water for non-drinking purposes

According to both Swedish and Finnish marine strategy for the Baltic Sea, **fish farming** is expected to increase in the coming years (YM 2016, 2020; HaV 2020a). Worldwide, the demand for farmed fish is high as many wild fish populations are overfished (Hilborn et al. 2003) and at the same time the human population is growing (UN 2010). Already today, 40% of all fish in the world that are directly consumed by humans originate from fish farms (Goldburg & Naylor 2005). Unfortunately, farmed fish are often fed with feed produced from wild fish, which contributes to the decline of wild fish populations globally. Furthermore, fish farming is a source of several other environmental problems such as habitat destruction, pathogens, and eutrophication (Naylor et al. 1998). Nevertheless, we are expecting an increase in fish farming in our pilot areas due to the marine strategies of both countries. It is unclear what fish farming will look like in the future and whether it will happen on land or in open cages in water, but we expect that there will be more environmentally friendly ways of fish farming in 100 years through technological advances. If fish farming is going to take place on land in the future, then the **usage of sea water** in these systems will increase. We are also expecting that the **number of species in fish farms** will increase in the future because of higher demand for farmed fish products and warmer water which will allow the use of new species in fish farming. As water-based aquaculture has ceased to operate on the Swedish side of the project area in recent years due to environmental reasons, it is expected that there the increase in fish farming will be in closed land-based systems. In the Husumbukten pilot area, the usage of sea water could also increase in the future if there is an increase in factory operations.

Fibres and other materials from plants, algae and animals for direct use or processing

In the future it is possible that we will use materials from plants, algae, or animals in ways that we cannot imagine today. Marine organisms are being studied worldwide as a source of new pharmaceuticals, natural products, and compounds (Munro et al. 1999; Faulkner 2001; Mazur-Marzec et al. 2014). In Finland and Sweden reeds have historically been used as roofing material and as an abundant and common plant, reeds could be a potential material source also in the future (Dervishi & El-Zoubi 2012). Already reeds are being seen as a potential replacement for peat as seedbeds for gardening usage and the monetary value could increase in the future (John Nurminen Foundation 2021). Today, large potential within blue growth is also seen in fish and microalgae products (Ahvonen et al. 2019; Latokartano 2018). In a project called "Blue products", new possible ways have been widely mapped for using fish materials in future food and other products (Ahvonen et al. 2019). Today a large part of herring catches in Finland and Sweden are used as animal feed and future potential uses of fish material are seen in medical, cosmetic, and human nutrition fields where a higher degree of processing could lead to higher returns (Ahvonen et al. 2019). Extensive usage of wild fish as animal feed is not sustainable and therefore it is better that the future usage is concentrated for human consumption and higher quality processed products that are sustainably produced. We are expecting that the Baltic Sea, including the pilot areas, will likely be a source for more **blue products** in the future.

3.2.2. General changes in regulating and maintenance services

Primary production and nutrient recycling are examples of regulating and maintenance services (Inácio et al. 2018; Haines-Young & Potschin 2012). These services consist of ecosystem processes that maintain environmental conditions which are favourable to life. Below the general changes in the regulating and maintenance ES that are expected to take place in all the pilot areas are listed.

Filtration/sequestration/storage/accumulation by ecosystems

Substantial changes in environmental conditions will affect the ability of species and ecosystems to filtrate, sequestrate, store, and accumulate different substances such as nutrients and alter the flow of organic matter and functioning of food webs. Nutrient reduction schemes according to BSAP, if met in the future, will have an effect on the total nutrient budget of the project area, which will be broadly reflected in the functioning of ecosystems. According to the models used in this project, the total phytoplankton production is anticipated to decrease in the future. Similar modelled future changes were detected by Meier et al. (2012). The main decrease is expected to happen in diatom and dinoflagellate production. Phytoplankton production accounts for a major part of the annual primary production and supports pelagic and benthic secondary production (e.g. Hjerne et al. 2019; Zdun et al. 2021). This decrease in **primary production** is expected to have a positive effect on the ecosystem as lower pelagic primary production is naturally characteristic for the Gulf of Bothnia. **Nitrogen fixation** is also expected to decrease according to the models used in this study. This change is connected to a phenomenon, where a state of less eutrophication leads to higher N/P-ratios (i.e. nitrogen to phosphorus ratios) and because of that to a decreased nitrogen fixation (Friedland et al. 2012). Cyanobacterial species responsible for nitrogen fixation can also consume dissolved inorganic nitrogen (DIN) and switch to N-fixation only when the availability of DIN sources is reduced (e.g. Agawin et al. 2007). A decrease in nitrogen fixation is considered a positive effect on ecosystem level as it further reduces the accumulation of excess nutrients into the water.

The marine species blue mussel (*M. trossulus x edulis*) plays an important role in filtrating the water and in the process removing nutrients and harmful substances from the water very effectively (Viitasalo et al. 2017). As the sea water is expected to get less saline in the future due to climate change, the northernmost populations of blue mussels will most probably be lost due to the drop in salinity. Additionally, species distribution models used in this project predict a major decrease in areas suitable for blue mussels also in the southern parts of the project area due to the combined stress from low salinity and high temperatures. This would lead to a decrease in the **filtration capacity of blue mussels** in the project area in the future. The effect on the ecosystem is expected to be negative, not only because of the reduced filtration capacity but also because blue mussels make up an important habitat and food source for other species (e.g. Zander et al. 2015; Kautsky 1981).

Mass stabilization and control of erosion rates

The main drivers of change in coastal geomorphology are changes in sea level, long-shore currents, storm surges, structural resistance, and winter ice conditions (von Storch et al. 2015). These factors are responsible for both coastal erosion and accumulation. Identifying the contribution of climatic change to geomorphic changes can be difficult and will also vary regionally depending on aspects such as the exposure to the open sea. Wave action is expected to increase in the northern Baltic Sea in the future as the extent and duration of the sea ice will decrease due to the warmer climate (von Storch et al. 2015; Saraiva et al. 2019; SmartSea 2018b). This will increase the strain and stress that coastal areas will face and will affect the overall erosion. However, the formation of sea ice also influences the shores of the Baltic Sea as ice scrapes and modifies the shallow bottom areas and shorelines, eroding material in the process. As a consequence, the interaction of the shores with sea ice will become less important regarding erosion in the future, while the impact of wave energy will become more important. Thus, we are expecting that the driving force of erosion will change in the future, but it is difficult to assess how this will affect the overall magnitude of erosion (Łabuz 2015). In addition, in the northern Baltic Sea the land uplift is expected to exceed the sea level rise still in a hundred years, meaning that no erosion related to sea level rise is expected. The structural resistance of the shallow coastal areas also plays a very important role for species and ecosystems. Emerged and submerged habitats in the project area are dominated by rooted macrophytes such as perfoliate pondweed and common reeds. By stabilizing sediments, reducing sediment resuspension, erosion, and turbidity the vegetation improves water quality and controls the overall erosion in coastal areas (Madsen et al. 2001). According to species distribution models, the **extent of emerged and submerged habitats** is expected to increase moderately due to warmer waters, increased light availability, and less ice in the future and the effect on the ecosystem level is expected to be positive.

Buffering and attenuation of mass flows

This service describes the material flows in ecosystems. When phytoplankton are not consumed by other organisms in the free water column, they sink and accumulate on the sea bottom where zoobenthos and bacteria consume some of them. Excessive amounts of sedimentation can have a negative effect on the ecosystem, as the sea bottom might become anoxic in the microbial degradation process, thereby killing the living macro-organisms (Bianchi et al. 2000). Of the different phytoplankton groups, diatoms are often the dominating group in the water column (Carstensen et al. 2015) and a large part of the diatoms end up on the sea floor through sedimentation (Heiskanen & Kononen 1994). According to the climate models and nutrient reduction schemes used in this project, there will be fewer diatoms and dinoflagellates in the future, which could lead to a reduced sediment accumulation rate. The reduction in sediment accumulation rate is expected to have a slightly positive effect in our project area in the future as there will be a lower risk of anoxia at the sea bottom. There are of course other factors that might affect future sedimentation and the sediment loads from river runoff are also important. Precipitation in northern Europe is expected to increase due to climate change but it is contested as to how this will affect the total annual river runoff regime as evaporation will increase at the same time (von Storch et al. 2015). The models used in this project predict a small increase in annual runoff. However, the more important aspect is that the annual cycle of runoff is expected to change considerably in areas presently characterized by spring floods due to snow melt (von Storch et al. 2015; Sonnenborg 2015; Lotsari et al. 2010). In the future climate, the spring floods are likely to occur earlier in the year and their magnitude is likely to decrease owing to less snowfall and a shorter snow accumulation period. Therefore, the overall sediment transport is likely to decrease as the erosion power of peak flooding is decreased (von Storch et al. 2015; Lotsari et al. 2010). For these reasons, the overall annual **sediment accumulation rate** is expected to decrease in the future with positive effects on the ecosystem level.

Flood protection

The results of wind projections according to future changes in the wind speed diverge highly between studies (von Storch et al. 2015). A common feature of many model simulations, however, is an increase in wind speed over sea areas that are ice-covered in the present climate, but not in the future. The significant wave height, the average of the highest one-third (33 %) of waves, depends on regional wind fields and currents. As there are a lot of uncertainties in the future wind projections, the future wave conditions are also difficult to assess thoroughly. However, especially in the northern Baltic Sea, reduced ice cover is expected to increase the significant wave heights, increasing the probability of flooding events annually (von Storch et al. 2015; SmartSea 2018b; HELCOM & Baltic Earth 2021). Additionally, the Bothnian Bay is expected to face relatively greater changes in significant wave heights than the Bothnian Sea (SmartSea 2018b). Thus, **the significant wave height** in the project area is expected to increase on average and this will have a negative impact on the 'flood protection' ecosystem service. Buildings and other infrastructure in coastal areas are likely to be more affected by damage caused by flooding and waves in the future.

Maintaining nursery populations and habitats

To secure provisioning services such as landings of different fish species, the composition and distribution of nursery populations and habitats need to be in good condition. Water transparency measured as Secchi depth serves as an index for the trophic state of a water body. This measure reflects the amounts of nutrients, the chlorophyll-a concentration, and organic substances in the water. The primary environmental threats to fish recruitment arise from eutrophication and high levels of DOM (dissolved organic matter) and POM (particulate organic matter) in the water, which may directly or indirectly alter feeding conditions, relative oxygen concentrations and increase siltation rates, which can interfere with spawning or egg incubation (Winfield 2004; Leach et al. 1977). According to the models used in this project, the **Secchi depth** will slightly increase in the future in the Husumbukten and Utgrynnan-Molpehällorna pilot areas and remain the same at Yttre Täftefjärden. The changes between the areas are connected to the river runoff projections in the models that vary between watersheds. Generally, a decrease in the river runoff would lead to an increased Secchi depth as the water would transport less nutrients and humic substances to the sea which would lead to clearer waters (Paczkowska et al. 2020). However, in the models used in this project, the future runoff is expected to increase very slightly in the future. Thus, the expected increase in the future Secchi depth is a sum of several things: decreasing nutrient concentrations due to BSAP, less primary production and less chlorophyll-a in the water. All in all, increasing water transparency has a positive effect on the ecosystem level.

Biodiversity is declining worldwide. This trend is also going to continue unless rigorous actions are taken to prevent further degradation and reduce the human impact on nature (Worm et al. 2006; Kontula & Raunio 2018). In the Baltic Sea, which has naturally lower diversity compared to the oceans, the loss of species could have a major impact on the ecosystem (Dahl et al. 2013). Several species and habitat types that used to be common and considered as least-concern are declining (Eide et al. 2020; Hyvärinen et al. 2019; Kontula & Raunio 2018), and therefore we assume that there will be more threatened species in the pilot areas in the future. In other words, we expect that the **number of Red List and extinct species** is likely to increase in the future in ecosystems that are stressed by climate change and other human impacts. It is important to note that this change is due to a decline in previously common species and not due to new, rare species appearing in the area. Likewise, **submerged and emerged habitat diversity** is expected to decrease slightly according to the models used in this project due to warmer waters and the decline in salinity. The decrease in species and habitat diversity might result e.g. in changes in the food web dynamics and species interactions (Gray et al. 2014) and reduce the ecosystem's potential to support and maintain fish nursery and rearing areas. We are also expecting introduced species to arrive in our area in the future, which in the worst case will affect the living conditions of native species and further contribute to the loss of biodiversity.

We predict that climate change will have a moderately negative effect on **nursery areas of cold water fish species** due to warmer water temperatures. **Nursery areas for warm water fish species** on the other hand could instead increase as a result of warmer sea water (MacKenzie et al. 2007). To counteract and mitigate the changes to fish populations due to climate change, we expect a moderate increase in the protection of nursery areas for cold water fish and a slight increase in the protection of nursery areas for warm water fish (**% nursery areas which are protected**). Research shows that nursery habitat availability limits the adult stock of coastal predatory fish populations (Sundblad et al. 2014) and that there is a need for much larger protected areas with restrictions that actually protect the sea and the organisms living there (IUCN 2016).

Pest and disease control

Harmful algal blooms take place mainly in summertime and early autumn in the Baltic Sea and consist of cyanobacteria that can produce substances that are toxic to e.g. humans, other mammals, and fish (Karjalainen et al. 2007; Jonasson et al. 2010). Cyanobacteria in general benefit from higher water temperatures, thermal stratification, high nutrient levels, and a low N/P (nitrogen to phosphorus) ratio which gives them a competitive advantage (Wagner

& Adrian 2009). Climate models used in this project predict that there will be a slight increase in cyanobacteria production in the future due to warming waters even with nutrient reductions according to BSAP. Additionally, in the Bothnian Sea and the Bothnian Bay the spring cyanobacterial bloom will start about one month earlier at the end of the 21st century compared to the present because of the warmer springs and declining ice cover (Neumann 2010). Even though not all cyanobacteria produce toxins (Stal et al. 2003), the risk for **harmful algal blooms** will increase as there will be more cyanobacteria in the water. Additionally, toxin-producing cyanobacteria species have been shown to directly benefit from climate change induced shifts in the ecosystem over other phytoplankton species, such as alterations in seasonal and interannual weather patterns, temperature rise and enhanced vertical stratification (Paerl & Huisman 2009). From the harmful algal bloom point of view, the 'pest and disease control' service is expected to be negatively affected by climate change. In the future we are also expecting more alien species (**presence of alien species**) in our project area as the water temperatures will rise. Alien species are non-native to an ecosystem and have the potential to cause economic or environmental harm. They can threaten the biodiversity by competing with native species or by predation and transmission of pathogens (Leppäkoski et al. 2002; Occhipinti-Ambrogi 2007; Gollash et al. 2015). Alien species tolerate often variable environmental conditions and are presumed to be favoured by climate change (Dukes & Mooney 1999; Jones & Cheung 2015; Holopainen et al. 2016). Furthermore, hundreds of ships sail in and out of the Baltic Sea every day and most of the alien species find their way here via the ballast water and tank sediments of ships (Leppäkoski et al. 2002). We are therefore expecting an increase in the numbers of alien species in the future and thereby predict a negative effect on the ecosystem.

Decomposition and fixing processes

This service describes the biogeochemical processes of the water and sediment surface. The water residence time is the time a water mass spends in a specific area. In the Baltic Sea the water residence time is about 30–40 years. The water residence time affects the circulation of toxic compounds and nutrients. A long water residence time means that these compounds circulate within the sea for a long time (Snoejis & Andrén 2017). Many factors affect the water residence time, which makes the future evaluations for the indicator very uncertain. A warming climate and decrease in winter ice cover will result in an increased wind-induced surface flow of water during the winters, while in the summers warming is likely to increase stratification, which decreases the surface water flow and leads to a longer residence time (Expert group 2020). However, due to reduced ice-cover and a shorter sea ice period, we are expecting the overall effect to present as a slight decrease in the **water residence time** in the project area in the future (Expert group 2020), and this is expected to have a positive effect on the ecosystem as excess nutrients and toxic compounds will circulate out of the area a bit faster.

The knowledge of the impacts that future changes in climate and other anthropogenic drives will have on the sediment biogeochemical cycles of the Baltic Sea is still rather limited and estimates are uncertain (von Storch et al. 2015). However, future denitrification under BSAP nutrient schemes and the worst-case climate scenario have been modelled by Meier et al. 2012 for the Baltic Sea. Their models predicted that **denitrification efficiency** would slightly improve under BSAP nutrient loads by 2099 regardless of a warmer climate (see also Friedland et al. 2012 for similar results). Additionally, the biogeochemical model from SMHI/FMI used in this project predicts a slight increase in denitrification efficiency in the project area. This would mean that relative to the nutrient levels, denitrification will be efficient, reducing NO_3 to elemental N_2 and thus removing biologically available nitrogen from the system. Better denitrification efficiency is expected to have a positive impact on the ecosystem as with nutrient loads under BSAP, nutrient cycling is presumed to become closer to the natural nutrient cycling of the Gulf of Bothnia.

Chemical conditions of salt water

The nutrient reduction scheme according to BSAP will affect the nutrient balance of the water in the project area and change the concentration of nitrate (NO_3 in surface water), ammonium (NH_4 in surface water) and phosphate (PO_4 in surface water) during the growing season. According to the models, **ammonium** and **phosphate** will decrease compared to the reference period. Generally, we are expecting a positive effect on the ecosystem as a result of decreasing ammonium and phosphate concentrations. The **nitrate** concentration in the water on the other hand is expected to increase due to a stronger decline in phosphorus concentration, which means that phytoplankton growth will be limited by phosphorus, meaning that excess nitrogen will thus accumulate in the water. Nutrient levels have fluctuated in the Gulf of Bothnia in past decades but still the mean nutrient levels have not changed very drastically between the reference period of the models (1976-2005) and the current time (2010-2020), lending some reliability to the modelled outcome. The Bothnian Sea currently receives also nutrient rich waters from the Baltic Proper (Rolff & Elfwing 2015) and should the nutrient reductions according to BSAP be met in the future in the entire Baltic Sea, including the Baltic Proper, the beneficial effects of nutrient reductions will be reflected in large sea areas nearby.

The **salinity** is expected to decrease slightly in the project area according to the models, mostly due to increased precipitation and changes in the runoff cycle. We are therefore expecting a slightly negative effect on the ecosystem as marine species are already living at the limit of their tolerance due to the low salinity, thus even small changes can pose threats to the species. However, it is important to note that there is a lot of uncertainty in the salinity projections, and that this is a common phenomenon in future climate model scenarios which is due to the large uncertainties in the water balance projections (von Storch et al. 2015). The future **oxygen concentration** in the bottom water is expected to remain roughly at the same level in the project area compared to the reference period according to the models used in this project. There are however slight spatial differences, as the oxygen concentration in the deeper waters will slightly increase while in the shallow areas the oxygen concentration will slightly decrease due to much warmer waters. In any case, the expected change in oxygen concentration in all parts of the project area is so small that it is not expected to have significant ecological or biogeochemical effects. Higher temperatures will naturally reduce the solubility of oxygen in sea water as well as accelerate many biological and biogeochemical processes, and with heightened nutrient concentrations this combination could have very negative effects on the bottom fauna as well as biogeochemical cycles (von Storch et al. 2015; Viitasalo & Bonsdorff 2021; Neumann & Friedland 2011). However, if the nutrient reductions according to BSAP are met, the detrimental effect of the temperature rise on oxygen levels will remain minimal.

Climate regulation by reduction of greenhouse gas (GHG) concentrations

The seas and oceans around the world have absorbed a large part (30%) of the carbon dioxide that has been released by humans since the start of industrialization (Havenland 2012). As a small sea, the role of Baltic Sea in this is small but still important. As a result of increasing carbon dioxide levels in the atmosphere due to fossil-fuel burning and the following absorption of carbon dioxide into waters, the acidity of the sea water is rising (e.g. Omstedt et al. 2012). Acidity is measured as the **pH**. In the project area, we are expecting a slightly lower pH in the future according to the literature and expert opinions, meaning that the waters in the project area will become more acidic (e.g. HELCOM & Baltic Earth 2021). Despite the important role of oceans and seas in balancing the CO_2 levels in the atmosphere, a decreasing pH can threaten marine species and ecosystems. Thus, the total effect of the decreasing pH is interpreted to have a negative effect on ES. Acidification is likely to have severe implications especially for calcifying organisms such as bivalves (von Storch et al. 2015; Fitzer et al. 2018). Additionally, key physiological processes such as growth, metabolic rate and reproduction are likely to be affected, hence potentially affecting the abundance, diversity, and functioning of benthic communities (von Storch et al. 2015). There are also implications that acidification combined with warming will produce changes to microbial and zooplankton communities in the Baltic Sea (Viitasalo & Bonsdorff 2021).

The carbon stock (C-stock) is the carbon stored in the ecosystem. It comprises of all carbon that accumulates in organic components of the marine ecosystem by photosynthesizing, feeding and biomass accumulation. It also includes carbon that gets buried in the sediment at the sea bottom. All organisms consist of carbon, and hence contribute to the C-stock, but we have used pondweeds, the common reed, *Fucus* spp., blue mussels, amphipods *Monoporeia affinis* and Baltic clams (*Limecola balthica*) as examples. These species are abundant, and because they were included in the species distribution modelling of this project, it was possible to estimate the future C-stock based on them.

The carbon stored in organisms is highly dependent on the species and ecosystems occurring in each pilot area. Some species have a higher C-content than others and with species distribution modelling it could be assessed which species are the most probable to occur in a certain place in the future and thus influence the C-stock. Hence, the future **C-stock** varies between pilot areas: a slight increase is expected in Yttre Täftefjärden, no change in Husumbukten and a slight decrease in C-stock is expected in Utgrynnan-Molpehällorna. From an ecological perspective, an increase in C-stock would mean a positive change as more carbon would be incorporated into living organisms and sediments instead of the atmosphere.

3.2.3. General changes in cultural services

Cultural services are the non-material benefits that humans obtain from nature. For example, these include using nature for recreational purposes, aesthetic experiences, and cultural identity. Here we list the general changes in the cultural ES that we are expecting to take place in the area in the future.

Physical use of land-/seascapes in different environmental settings

People use and enjoy land and seascapes in many ways ranging from day trips to nature trails, and from boating and sailing to swimming and spending weekends at summer cottages. Many local people take advantage of the project area's and especially Kvarken's potential for leisure activities, but there still is a lot of unused potential in the region considering tourism. Tourism in Finland is far behind many other European countries and within the country it is concentrated in southern and northern Finland (Jänkälä 2019; Hiltunen 2019). This is partly due to poorer accessibility to some areas and national tourism development measures (Jänkälä 2019). In Sweden, more has been invested in the development of tourism in the past decades. However, also on the Swedish side of Kvarken growth potential can be detected. Observed changes in the market show that in the coming decades environmental awareness, nature, and well-being will determine the direction of tourism development more than now (Jänkälä 2019; OECD 2018). In addition, smaller and exclusive travel destinations and local food are becoming of more interest to travellers. Kvarken with its beautiful nature, archipelago and intriguing geology offers a favourable destination for tourism development and future travellers from this point of view. In addition, the cultural heritage of Europe has been one of the oldest and most important generators of tourism especially in the central and southern Europe (Richards 1996; Thorburn 1986). This potential has been largely undeployed in the Kvarken area which is rich in cultural heritage sites that could offer possibilities for tourism development. Predicting social and global trends linked to tourism for the next hundred years is challenging and highly uncertain. The OECD (2018) has defined global megatrends for tourism until the year 2040. These trends forecast that the number of tourists will increase worldwide in the future, demand for sustainable tourism (low carbon, resource efficient, socially sustainable) will grow, new technologies will make travelling more accessible, economical, and easy, and transportation will develop (transport innovations, routes etc.). These trends could to some extent be applicable also until the year 2120. Sustainable tourism can be expected to be a determinant factor also in the next century. Technological advantages and development in transportation solutions will be even more drastic in a hundred years making many inaccessible areas easier to travel to. These trends and aspects in future tourism indicate growth in tourism in the Kvarken area and in the whole project area. Furthermore, domestic tourism and tourism from nearby countries could also be more popular in a hundred years as people seek sustainable choices. Tourism always requires infrastructure, accommodation, and attractions (Jänkälä 2019), and developments in the coming decades would pave the way for tourism in the area for decades to come. 'Climate tourism', although controversial, could also affect the northern countries and the project area in the future and there have already been indications of tourism from southern countries to Finland and Sweden due to the cooler climate (HELCOM & Baltic Earth 2021).

Tourism as well as the increased use of the Kvarken area and the whole project area is expected to be focused on the summer months. Due to climate change, the wide utilization of the project area in winter is expected to decrease significantly. Mild winters and weak ice conditions will eliminate the opportunities to enjoy the ice and the archipelago by skiing, skating, or snowmobiling, and the winter use of the sea area is probably going to be reduced in the future.

In summary, tourism and **the number of tourists** is expected to increase in the future in the whole project area but especially in Kvarken. Growth in tourism requires improvements in the infrastructure, and services in marinas and **the number of boat berths in the marinas** are expected to increase, as well as the number of sailors and boaters (**the number of tourist boats**). With increasing number of tourists in the future and the tourism development measures to be taken in the region, **the number of outdoor life opportunities in the area** is expected to increase. Winter use, and thus **the number of people using ice for recreational activities** is expected to decrease in the project area in the future.

Cultural heritage

Cultural heritage is an important part of the cultural services in the project area and especially in Kvarken. On top of the tourism benefits that can contribute the area, cultural heritage both on land and in water have existence value, and social and historical value (Díaz-Andreu 2017). Seafaring and fishing have a strong history in the project area, which has resulted in multiple wrecks found in the project area, and the various cultural heritage sites on islands and the mainland. Of the pilot areas, especially the Utgrynnan-Molpehällorna area has several culturally and historically valuable sites. The unique brackish-water conditions in the Baltic Sea have supported the survival of wooden wrecks and other heritage sites (Fors & Björdal 2013; Björdal et al. 2012). It is expected that in the future with technological advances, more old wrecks and possible other underwater cultural heritage sites could be found in the area, increasing the underwater cultural heritage value of the project area. However, climate change is expected to have negative impacts on underwater cultural heritage, although some of the final consequences of the changes remain uncertain (Kaslegard 2011; Fors & Björdal 2013; Harkin et al. 2020). Higher temperatures, acidification, possible increased erosion on land, wave action, and changes in the chemical composition of the water could negatively affect the underwater cultural heritage (Perez-Alvaro 2016; Kaslegard 2011). When the expected increase in exploitation of marine areas and other anthropogenic factors such as boating, coastal construction and pressures from wreck diving are all added, the overall effect on **wrecks and other underwater cultural heritage sites** is expected to be negative in the future. Climate change will also have various deteriorating effects on cultural heritage sites on the land and islands in the future (Sabbioni et al. 2008), because they are exposed to the weather. The future vulnerability of cultural heritage sites on land is associated with e.g. the elevated risk of wave action, increased precipitation, soil wetness and changes in the soil chemistry, changes in humidity cycles and pH, and extreme weather conditions. In addition, expected increases in tourism may pose threats to cultural heritage sites in the project area especially on the mainland and on islands closest to the mainland, while the most remote areas and islands may avoid the pressures of tourism. For these reasons, **cultural heritage sites on land** in the pilot areas are expected to deteriorate at least to some extent in the future.

Aesthetic, symbolic & bequest

The aesthetic value of the pilot areas were evaluated using the indicator **the area of pristine environment in the future**. A pristine-looking environment is and will most probably be appreciated in the future, but is expected to be slightly less common in some places in the project area in a hundred years. The high demand for more sustainable energy sources predicts more offshore wind farms in the future (European Commission 2020; IRENA 2019; HELCOM & Baltic Earth 2021), which will reduce the aesthetic value of the marine environment in the project area and in some pilot areas. The expected increase in aquaculture (European Commission 2021a) will also reduce the aesthetic value of the marine area and shorelines. The symbolic value of cultural services were evaluated by **the number of iconic species** in the pilot areas. Iconic species are thought to characterize the project area and give symbolic meaning to the area. The future status was evaluated for ca. 20 different species (e.g. *Fucus* spp.; white-tailed eagle *Haliaeetus albicilla*; Baltic ringed seal *Pusa hispida botnica*; whitefish; and salmon), which were assessed to be the most notable, well-known, and appreciated in the area (a full list of the species can be found in Appendix in Table A4). Biodiversity in general is expected to decline in the future and the same decline was estimated to happen in the populations of many iconic species in the project area based on the literature, red-list status, and future threats (e.g. Kontula & Raunio 2018; SLU 2020; Lehtiniemi et al. 2021). Bequest values, i.e., other heritage outputs than cultural heritage, which is reflected in aspects such as the willingness to preserve plants, animals, ecosystems, land, and seascapes for the experience and use of future generations, were evaluated by **the number/extent of marine protected areas**. The EU Biodiversity strategy for 2030 retains a goal for establishing protected areas for at least 30% of sea areas in Europe (European Commission 2021b). This increase is expected for this decade, but the protection goals for the next hundred years are difficult to evaluate. It could be possible that while the use of marine areas may increase in the future, the whole sea area would be managed more holistically, and more areas would also be assigned for marine protection in the future. However, the new protected areas would be established in the project area in places where there would be the most need for them, but for the pilot areas a huge potential increase was not detected. Additionally, the ecological connectivity of marine protected areas is starting to gain more attention in decision making and the protection measures concentrating on this issue could mean new criteria for establishing protected areas in the future.

3.2.4. Pilot area specific changes

In this section the specific changes in ecosystem services in each pilot area is explained.

Table 1: A, B, C. MESAT results for the Utgrynnan-Molpehällorna (A), Yttre Täftefjärden (B), and Husumbukten (C) pilot areas. Likert-scale values for the expected future changes for each ecosystem service are calculated as a mean value from the expected future changes in indicators' values. Specifications for the changes are given in the table, and the materials and data used for the assessment are presented in Table A3 in the Appendix. Sections 3.2.1, 3.2.2, and 3.2.3 in the results provide more background data for the expected changes. Explanations for the Likert-scale for ecosystem services and indicators are as follows: 0 = no change, +1/-1 = slight positive/negative change, +2/-2 = moderate positive/negative change, +3/-3 = considerable positive/negative change, +4/-4 = extensive positive/negative change, +5/-5 extreme positive/negative change.

A.	Ecosystem service		Indicator		Specification
Provisioning services	Wild animals and their outputs	0	Landings of warm water sp.	2	Sp. evaluated: perch, pike, cyprinids, pikeperch and alien species round goby and Prussian carp.
			Landings of cold water sp.	-1	Sp. evaluated: salmon, white fish, herring, burbot, trout, European smelt.
			Landings of key market sp.	-1	Sp. evaluated: salmon, white fish, herring, perch, European smelt.
	Wild plants, algae and their outputs	1	Harvest	1	Increase in the yield of sea-buckthorn due to warmer climate.
			No. of species	0	No expected change.
	Animals from in situ aquaculture	3	Harvest	2	Moderate increase. Due to MPAs and EMMA areas more pressure of aquaculture is expected outside of Utgrynnan.
			No. of species	3	Due to technological advantages, higher demand, and warmer water; No. of species being farmed is anticipated to increase.
	Fibres etc. from organisms for direct use or processing	2	Harvest	2	Moderate increase expected (especially herring products) due to political emphasis on blue products/growth.
	Surface water for non-drinking purposes	0	Use of water	0	No large-scale usage of sea water at present and no change expected due to the location of Utgrynnan far from mainland.
Regulating and maintenance services	Filtration/sequestration/ storage/accumulation by ecosystems	-1	N-fixation	1	Decrease due to BSAP with positive effect on ecosystems.
			Primary production	1	Decrease due to BSAP with positive effect on ecosystems.
			Filtration capacity (Mytilus)	-4	Modelled decline in suitable areas for blue mussel.
	Mass stabilisation and control of erosion rates	2	Extent of emerged, submerged habitats	2	Increase in the sediment binding vascular plants according to the models with a positive effect on ecosystems.
	Buffering and attenuation of mass flows	1	Sediment accumulation rate	1	A decrease in sediment accumulation rate is expected to have a slight positive effect on ES.
	Flood protection	-1	Significant wave height	-1	An increase expected due to reduced ice cover.
	Maintaining nursery populations and habitats	0	Habitat diversity	-1	Decline in biodiversity due to various human pressures.
			Secchi depth	2	Secchi is expected to increase (climate change vs. BSAP)
			No. of Red List and extinct species	-2	Decline in biodiversity is expected to raise the number of Red List species and have negative impact on ES.
			Nursery areas (cold water)	-2	Less suitable reproduction areas due to warming.
			Nursery areas (warm water)	1	More suitable reproduction areas due to warming.
			% of protected nursery areas	1	A slight increase in protected nursery areas is expected.
	Pest and disease control	-1	Harmful algal blooms	-1	A slight increase expected with a negative impact on ES.
			Presence of alien species	-1	A slight increase in presence and abundance expected.
	Decomposition and fixing processes	1	Denitrification efficiency	1	Due to BSAP denitrification efficiency is expected to increase.
			Water residence time	1	A slight decrease is expected with a positive effect on ES.
	Chemical condition of salt water	1	NO3 surface water	-1	NO3 accumulates in water instead of biomass as primary production decreases due to phosphorus limitation.
			NH4 surface water	3	A decrease in N inputs from the drainage basin is expected.
			PO4 surface water	4	A decrease in P inputs is expected.
			Salinity	-1	A slight decline in salinity with negative effects on species.
			Oxygen conc.	0	No change expected (eutrophication mitigation vs. temp.)
	Climate regulation by reduction of GHG conc.	-1	C-stock	-1	A slight decrease in C-stock expected.
			pH	-1	More acidic water has a negative impact on ES.
Cultural services	Physical use of land-/seascapes	0	No. of tourists	2	Tourism and investing in tourism are expected to increase.
			No. of ship berths	1	Tourism related infrastructure is presumed to expand slightly.
			No. of tourists' boat	2	Boating is expected to increase as tourism increases.
			Use of ice for recreation	-4	Climate models predict over 80% thinner ice cover in 100 years.
			No. of outdoor opportunities	1	Investing in tourism is expected to increase opportunities.
	Cultural heritage (CH)	-1	CH sites underwater	-1	E.g. higher temperatures & acidification have a negative impact.
			CH sites on land	-1	E.g. precipitation, higher temp, tourism have a negative impact.
	Aesthetic	-1	Pristine environment	-1	Offshore wind farms and aquaculture in nearby areas expected to reduce the aesthetics of the area in the future.
	Symbolic	-2	No. of iconic species	-2	Due to biodiversity loss, a decline in the area's number of iconic species is expected.
	Bequest	0	Extent of MPAs	0	There are i.e. Natura 2000 area, UNESCO World Heritage Site and EMMA sites in Utgrynnan covering ca. 39% of the area.

B.	Ecosystem service		Indicator		Specification
Provision services	Wild animals and their outputs	0	Landings of warm water sp.	2	Sp. evaluated: perch, pike, cyprinids, pikeperch and alien species round goby and Prussian carp.
			Landings of cold water sp.	-1	Sp. evaluated: salmon, white fish, herring, and trout.
			Landings of key market sp.	-1	Sp. evaluated: salmon, white fish, herring, and perch.
	Animals from in situ aquaculture	3	Harvest	2	No fish farming at present but a moderate increase in the future is expected. More likely in land-based systems.
			No. of species	3	Due to technological advantages, higher demand, and warmer water; No. of species being farmed is anticipated to increase.
	Fibres etc. from organisms for direct use or processing	1	Harvest	1	No large-scale use now, but increase expected due to political emphasis on blue products/growth.
	Surface water for non-drinking purposes	1	Use of water	1	No large-scale usage of sea water at present, but an increase in fish farming in the future could mean increased usage of water.
Regulating and maintenance services	Filtration/sequestration/ storage/accumulation by ecosystems	1	N-fixation	1	Decrease due to BSAP with positive effect on ecosystems.
			Primary production	1	Decrease due to BSAP with positive effect on ecosystems.
	Mass stabilisation and control of erosion rates	2	Extent of emerged, submerged habitats	2	Increase in the sediment binding vascular plants according to the models with a positive effect on ecosystems.
	Buffering and attenuation of mass flows	1	Sediment accumulation rate	1	A decrease in sediment accumulation rate is expected to have a slight positive effect on ES.
	Flood protection	-1	Significant wave height	-1	An increase expected due to reduced ice cover.
	Maintaining nursery populations and habitats	-1	Habitat diversity	-1	Decline in biodiversity due to various human pressures.
			Secchi depth	0	No change expected.
			No. of Red List and extinct species	-3	Decline in biodiversity is expected to raise the number of Red List species and have negative impact on ES.
			Nursery areas (cold water)	-2	Less suitable reproduction areas due to warming.
			Nursery areas (warm water)	2	More suitable reproduction areas due to warming.
			% of protected nursery areas	1	An increase in nursery area protection is expected in the future.
	Pest and disease control	-1	Harmful algal blooms	-1	A slight increase expected with a negative impact on ES.
			Presence of alien species	-1	Some new alien species are expected to arrive in the Yttre Täftefjärden in the next 100 years with a negative impact on ES.
	Decomposition and fixing processes	1	Denitrification efficiency	1	Due to BSAP denitrification efficiency is expected to increase.
			Water residence time	1	A slight decrease is expected with a positive effect on ES.
	Chemical condition of salt water	1	NO3 surface water	-1	NO3 accumulates in water instead off biomass as primary production decreases due to phosphorus limitation.
			NH4 surface water	3	A decrease in N inputs from drainage basin is expected.
			PO4 surface water	4	A decrease in P inputs is expected.
			Salinity	-1	A slight decline in salinity with negative effects on species.
			Oxygen conc.	0	No change expected (eutrophication mitigation vs. temp.)
	Climate regulation by reduction of GHG conc.	0	C-stock	1	A slight increase in C-stock expected.
			pH	-1	More acidic water has a negative impact on ES.
Cultural services	Physical use of land-/seascapes	1	No. of tourists	3	Tourism and investing in tourism are expected to increase.
			No. of ship berths	2	Tourism related infrastructure is presumed to expand slightly.
			No. of tourists' boat	2	Boating is expected to increase as tourism increases.
			Use of ice for recreation	-4	Climate models predict over 80% thinner ice cover in 100 years.
			No. of outdoor opportunities	2	Investing in tourism is expected to moderately increase opportunities.
	Cultural heritage (CH)	-2	CH sites underwater	-1	E.g. higher temperatures & acidification have negative impact.
			CH sites on land	-2	E.g. precipitation, higher temp, tourism have negative impact.
	Aesthetic	0	Pristine environment	0	No heavy anthropogenic use of the area is expected and thus the area of pristine environment is not expected to change.
	Symbolic	-2	No. of iconic species	-2	Due to biodiversity loss, a decline in the area's number of iconic species is expected.
	Bequest	0	Extent of MPAs	0	One MPA at present, and no additional nature conservation areas are expected.

C.	Ecosystem service		Indicator		Specification
Provision services	Wild animals and their outputs	0	Landings of warm water sp.	2	Sp. evaluated: perch, pike, cyprinids, pikeperch and alien species round goby and Prussian carp.
			Landings of cold water sp.	-1	Sp. evaluated: salmon, white fish, herring, burbot and trout.
			Landings of key market sp.	-1	Sp. evaluated: salmon, white fish, herring, and perch.
	Animals from in situ aquaculture	3	Harvest	2	No fish farming at present but a moderate increase in the future is expected. More likely in land-based systems.
			No. of species	3	Due to technological advantages, higher demand, and warmer water; No. of species being farmed is anticipated to increase.
	Fibres etc. from organisms for direct use or processing	1	Harvest	1	No large-scale use now, but increase expected due to political emphasis on blue products/growth.
	Surface water for non-drinking purposes	2	Use of water	2	Usage of sea water at the factory at present. Possible increase in factory operation and in fish farming in the future could mean increased usage of water.
Regulating and maintenance services	Filtration/sequestration/ storage/accumulation by ecosystems	1	N-fixation	1	Decrease due to BSAP with positive effect on ecosystems.
			Primary production	1	Decrease due to BSAP with positive effect on ecosystems.
	Mass stabilisation and control of erosion rates	2	Extent of emerged, submerged habitats	2	Increase in the sediment binding vascular plants according to the models with a positive effect on ecosystems.
	Buffering and attenuation of mass flows	1	Sediment accumulation rate	1	A decrease in sediment accumulation rate is expected to have a slight positive effect on ES.
	Flood protection	-1	Significant wave height	-1	An increase expected due to reduced ice cover.
	Maintaining nursery populations and habitats	-1	Habitat diversity	-1	Decline in biodiversity due to various human pressures.
			Secchi depth	1	Secchi depth is expected to increase (climate change vs. BSAP).
			No. of Red List and extinct species	-3	Decline in biodiversity is expected to raise the number of Red List species and have negative impact on ES.
			Nursery areas (cold water)	-3	Less suitable reproduction areas due to warming.
			Nursery areas (warm water)	2	More suitable reproduction areas due to warming.
			% of protected nursery areas	1	A slight increase in protected nursery areas is expected.
	Pest and disease control	-2	Harmful algal blooms	-1	A slight increase expected with a negative impact on ES.
			Presence of alien species	-2	Some new alien species are expected to arrive in the Husum bay.
	Decomposition and fixing processes	1	Denitrification efficiency	1	Due to BSAP denitrification efficiency is expected to increase.
			Water residence time	1	A slight decrease is expected with a positive effect on ES.
	Chemical condition of salt water	1	NO3 surface water	-1	NO3 accumulates in water instead off biomass as primary production decreases due to phosphorus limitation.
			NH4 surface water	2	A decrease in N inputs from drainage basin is expected.
			PO4 surface water	3	A decrease in P inputs is expected.
			Salinity	-1	A slight decline in salinity with negative effects on species.
			Oxygen conc.	0	No change expected (eutrophication mitigation vs. temp.)
	Climate regulation by reduction of GHG conc.	-1	C-stock	0	No change expected.
			pH	-1	More acidic water has a negative impact on ES.
Cultural services	Physical use of land-/seascapes	0	No. of tourists	1	Tourism and investing in tourism are expected to increase slightly.
			No. of ship berths	1	Tourism related infrastructure is presumed to expand slightly.
			No. of tourists' boat	1	Boating is expected to increase slightly as tourism increases.
			Use of ice for recreation	-4	Climate models predict over 80% thinner ice cover in 100 years.
			No. of outdoor opportunities	1	Investing in tourism is expected to slightly increase opportunities.
	Cultural heritage (CH)	-2	CH sites underwater	-1	E.g. higher temperatures & acidification have negative impact.
			CH sites on land	-2	E.g. precipitation, higher temp, tourism have negative impact.
	Aesthetic	-1	Pristine environment	-1	Industrial use of the area is expected to decrease the aesthetics of the area in the future.
	Symbolic	-2	No. of iconic species	-2	Due to biodiversity loss, a decline in the area's number of iconic species is expected.
	Bequest	1	Extent of MPAs	1	No MPA right now. Local recruitment area for whitefish exists close to Husum, which might be a reason to establish an MPA.

Utgrynnan-Molpehällorna

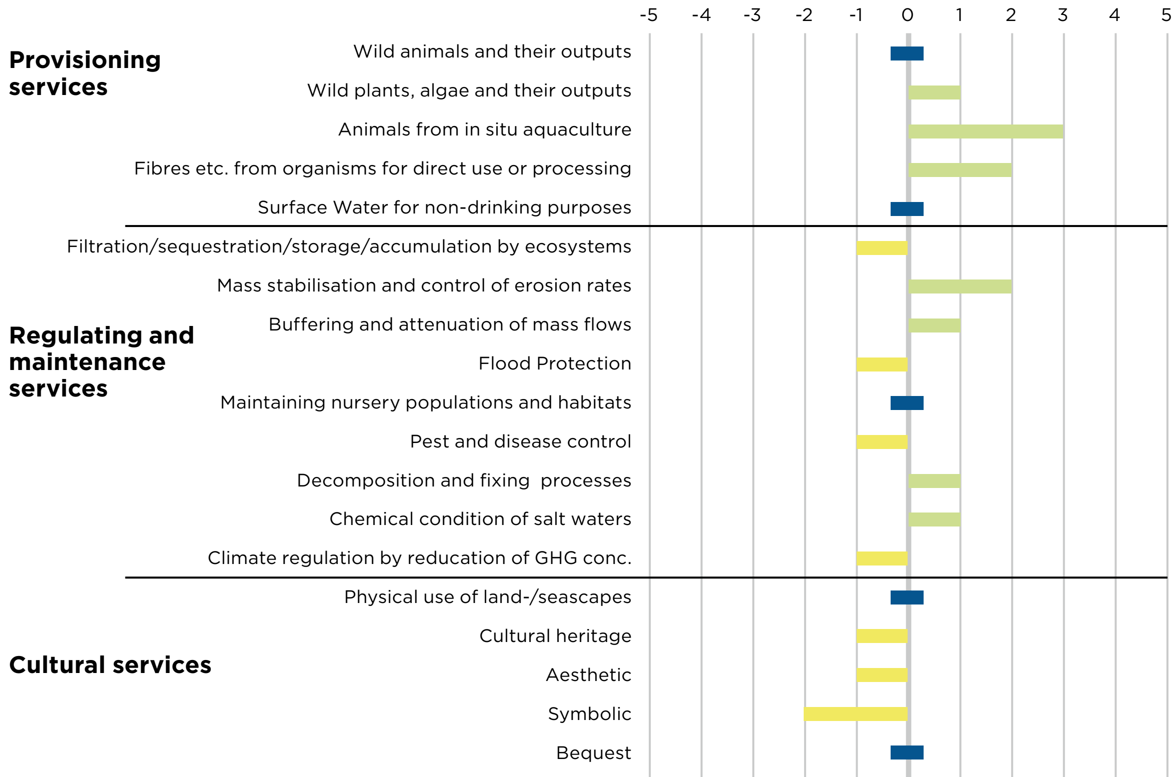


Figure 5. The expected future changes of ecosystem services (CICES class level services) for the Utgrynnan-Molpehällorna pilot area. The indicators representing different services can be found in Table 1. The expected future change is calculated from the mean values of the indicators. Explanations for the Likert-scale for ES provision are as follows: 0 = no change, +1/-1 = slight positive/negative change, +2/-2 = moderate positive/negative change, +3/-3 = considerable positive/negative change, +4/-4 = extensive positive/negative change, +5/-5 extreme positive/negative change.

The specific results for the Utgrynnan-Molpehällorna pilot area on changes in the CICES class level services can be found in Fig. 5 and indicator-specific expected future changes can be found in Table 1. Based on the indicators used in this project, the provisioning services in general are expected to increase in the future. This is mostly due to increased human utilization of sea areas and resources. The combined effects of climate change and nutrient reductions according to BSAP will manifest themselves in regulating and maintenance services. Climate change will negatively affect services such as ‘pest and disease control’, ‘climate regulation’ and ‘flood protection’, while the implementation of BSAP is expected to have a positive effect on aspects such as ‘chemical conditions of salt water’, ‘buffering and attenuation of mass flows’ (sediment accumulation rate) and ‘decomposition and fixing processes’. Cultural services in Utgrynnan-Molpehällorna reflect the expected increase in the use of marine areas (e.g. tourism in the summer) and the effects of climate change can be seen in the future heritage and symbolic values, as well as in reduced cultural potential in winters due to expected decrease in ice cover. Utgrynnan-Molpehällorna is a large marine area where human actions in the future might increase, which could also affect the aesthetic value of the area.

Yttre Täftefjärden

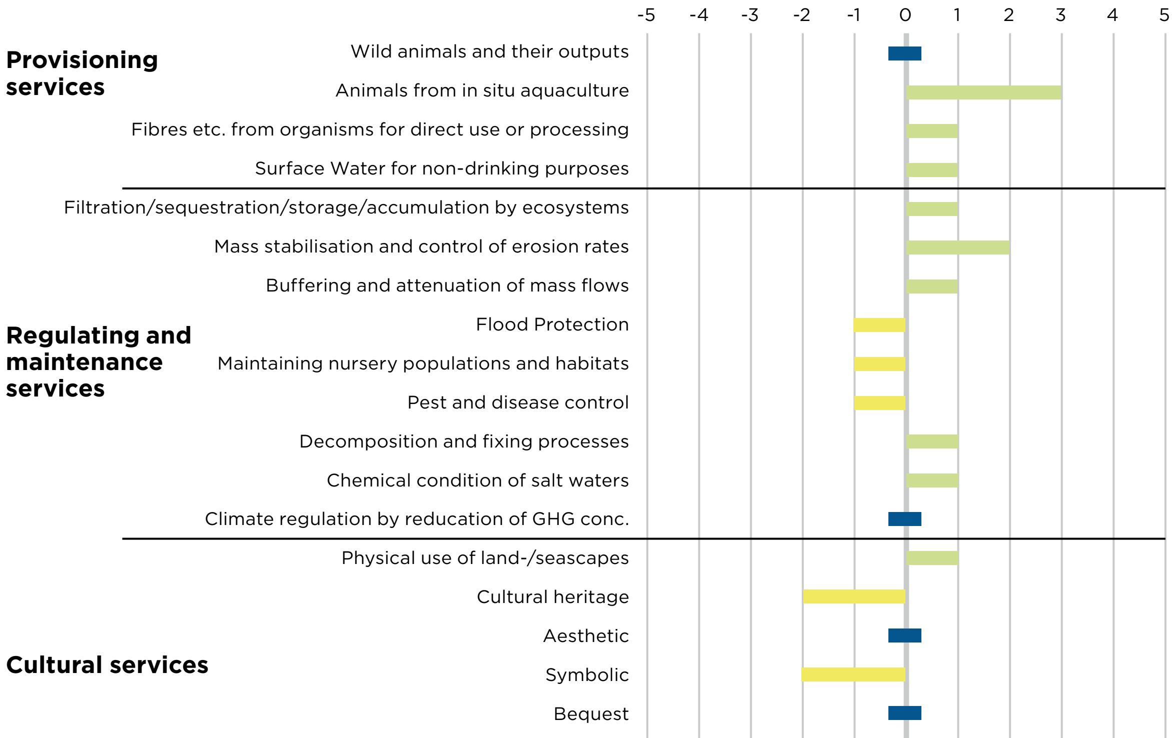


Figure 6. The expected future changes in the ecosystem services (CICES class level services) for the Yttre Täftefjärden pilot area. The indicators representing different services can be found in Table 1. The expected future change is calculated from the mean values of the indicators. Explanations for the Likert-scale for ES provision are as follows: 0 = no change, +1/-1 = slight positive/negative change, +2/-2 = moderate positive/negative change, +3/-3 = considerable positive/negative change, +4/-4 = extensive positive/negative change, +5/-5 extreme positive/negative change.

The specific results for the Yttre Täftefjärden pilot area on changes in the CICES class level services can be found in Fig. 6 and the indicator-specific expected future changes are shown in Table 1. Based on the indicators used in this project, the provisioning services in general are expected to increase in the future. This is mostly due to the increased human utilization of sea areas and resources. The combined effects of climate change and nutrient reductions according to BSAP will manifest themselves in the regulating and maintenance services also in Yttre Täftefjärden. Climate change will negatively affect services such 'pest and disease control' and 'maintaining nursery populations and habitats', while the implementation of BSAP is expected to have a positive effect on aspects such as the 'chemical conditions of salt water' and 'decomposition and fixing processes'. Cultural services in Yttre Täftejärden reflect the expected increase in the use of marine areas (e.g. tourism) and the effects of climate change can be seen in the future heritage and symbolic values.

Husumbukten

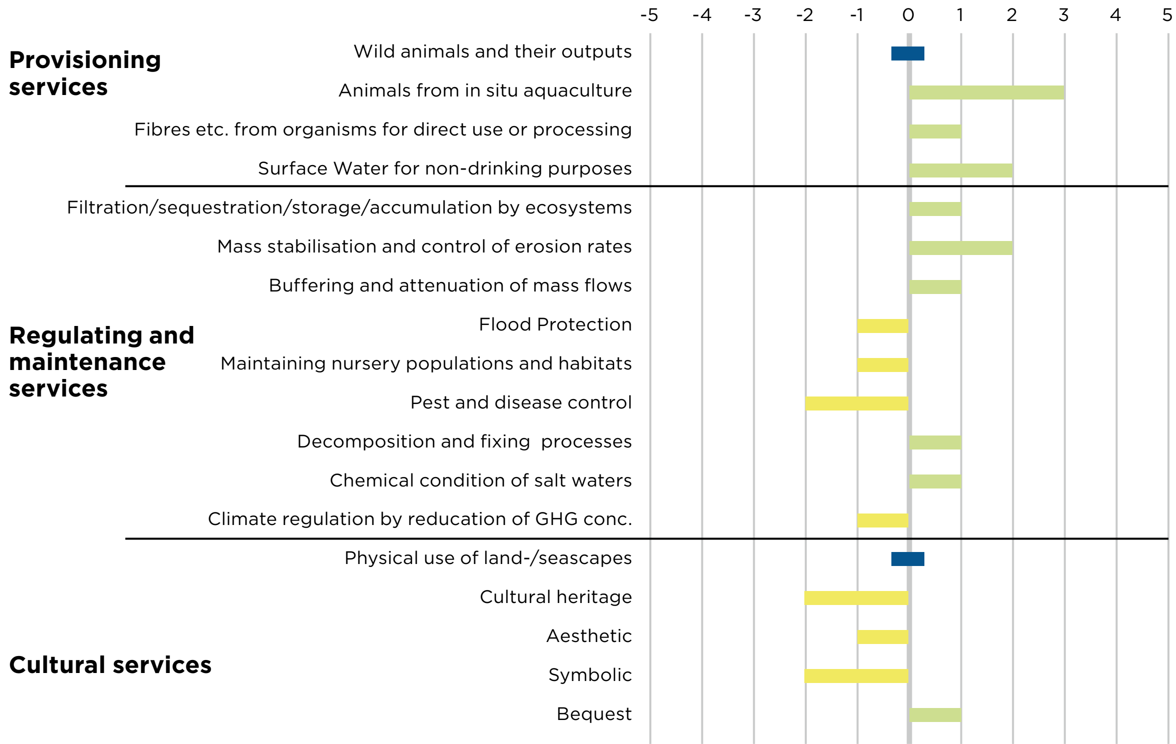


Figure 7. The expected future changes in the ecosystem services (CICES class level services) for the Husumbukten pilot area. The indicators representing different services can be found in Table 1. The expected future change is calculated from the mean values of the indicators. Explanations for the Likert-scale for ES provision are as follows: 0 = no change, +1/-1 = slight positive/negative change, +2/-2 = moderate positive/negative change, +3/-3 = considerable positive/negative change, +4/-4 = extensive positive/negative change, +5/-5 extreme positive/negative change.

The specific results for Husumbukten pilot area concerning changes in the CICES class level services can be found in Fig. 7 and the expected indicator-specific future changes are shown in Table 1. Many of the changes in the Husumbukten pilot area are similar to the changes in the Utgrynnan-Molpehällorna and Yttre Täftefjärden pilot areas, and, for example, the provisioning services in general are expected to increase in the future. The effects of climate change and the nutrient reduction scheme according to BSAP could also produce very similar results in Husumbukten as in the other pilot areas. The biggest difference in Husumbukten is that the area has industrial activities which could affect the provisioning services the coastal area may provide (i.e. surface water for industrial purposes). Should the industrial activities increase in the future, the effect on the cultural services of the area will be negative.

3.3. Discussion

3.3.1. The future of ecosystem services

Future ES under worst-case climate scenario (RCP8.5) and nutrient reduction scheme (BSAP) were evaluated for three pilot areas with differences in their environments, level of human impact, and species compositions, among other factors. Despite these differences, several similarities in the future ES provision in the pilot areas were recognized. The main trends were that provisioning services as a whole are expected to increase while cultural services are expected to decrease. The response in different services especially concerning regulating and maintenance services was variable, producing positive effects on about half of the services and negative effects on about the other half. The largest increase in provisioning services is related to the expected increase in the utilization of sea areas and their resources in the future. The EU's strategy for future blue growth is being taken forward in Finland and in Sweden and the governments of both countries support relevant projects (YM 2016, 2020; HaV 2020a; Ahvonen et al. 2019) and therefore we can expect that usage of sea-based resources will increase in 100 years. Especially various fish-based products, material for medical and cosmetic use, as well as aquaculture that will have better yields in a warmer climate, are expected to increase (Ahvonen et al. 2019). The largest direct effect of climate change on provisioning services will be seen in the future fish catch, as we expect the catches of colder water adapted fish species (e.g. salmon and whitefish) will decrease in the future, while the potential catch of warmer water adapted fish (e.g. perch, pike and cyprinids) will increase. This is also expected to change the key market species in the future. The salmonid species are expected to suffer from climate change, although fish stocking and better life cycle management (spawning area restorations and improved migratory opportunities) will probably counteract the most harmful effects of this for the monetary value of the fishing industry, but still, it is possible that the local value of fisheries will decrease slightly in the future. On the other hand, these future changes may put pressure on the industry to develop and further process products for consumers also from less valuable fish such as cyprinids. It is also important to note that even though we anticipate an overall increase in the provisioning services in the MESAT assessment, the increase is not related to what the sea can offer but to the expected increase in our demand for the services in the future. This increase in resource utilization is possible but if it is not done sustainably it will negatively affect the regulating and maintenance services as well as cultural services. We are expecting a sustainable increase in provisioning services and have not estimated major harmful effects on the regulating and maintenance services and cultural services related to the increase in provisioning services.

In regulating and maintenance services the positive changes concerning certain services (e.g. the chemical conditions of salt water and decompositions and fixing processes; Table 1) are solely related to the positive effects of eutrophication mitigation by BSAP, which strengthens the known concept that eutrophication has a greater effect on species and ecosystems than climate change might have in the next 100 years (Viitasalo & Bonsdorff 2021; Olsson et al. 2015). This applies especially to the southern parts of the project area, which currently receive nutrient rich waters from the Baltic Proper (Rolff & Elfwing 2015). Nutrient reductions due to BSAP are expected to positively affect many biogeochemical processes in the project area and improve living conditions for several species (HELCOM 2021). We expect that the negative effects of climate change will in the future be seen within the regulating and maintenance services especially in the services 'pest and disease control' and 'maintaining nursery populations and habitat'. These expected changes are connected especially to the negative effects of warming waters and declining salinity. The warming is anticipated to increase the probability of harmful algae blooms, improve the living conditions for alien species, and to degrade the nursery and rearing areas of fish species adapted to colder water (Wagner & Adrian 2009; Paerl & Huisman 2009; Dukes & Mooney 1999; Jones & Cheung 2015). The increasing abundance of alien species in the project area may lead to changes on the ecosystem level and alter species interactions in the future, while increasing occurrences of harmful algae blooms can sporadically degrade the water quality and cause local hypoxic or anoxic bottom conditions. Additionally, in the project area land uplift is expected to mitigate the harmful effects of climate change related to sea level rise such as heavy flooding and coastal erosion, adverse effects that are expected further south in the Baltic Sea where land uplift is weaker (e.g. von Storch et al. 2015).

For cultural services the harmful effects of climate change are expected to be related to negative effects on cultural heritage sites that may suffer from acidification, storms and higher temperatures (Perez-Alvaro 2016; Kaslegard 2011; Sabbioni et al. 2008), and to the cultural services related to ice (e.g. ice fishing, skiing, and skating) that will most probably be compromised in the future as the climate gets warmer. One positive consequence of climate change was also seen in the summer tourism of the pilot areas as climate change is expected to increase local tourism. Warmer summer temperatures may increase the attractiveness of the area, and in general the northern regions may become more appealing travel destinations for people living in areas that are heating up due to climate change

(Jänkälä 2019; OECD 2018). On the other hand, the increase in the utilization of the sea areas by human actions (e.g. aquaculture, increase in off-shore wind farms) will negatively affect the aesthetic cultural value of some areas in the project area in the future (Firestone & Kempton 2007).

Major differences in the magnitude of change in ES provision in the future were not detected between the different pilot areas. The pilot areas are located relatively close to each other, so most of the hydrological, chemical, and physical forces affecting the areas are the same, producing rather similar responses in the pilot areas. The main differences between the pilot areas in their service provision were connected to differences in the human utilization of the areas: the current and presumed future use of the different pilot areas for aquaculture, industry, fishing, tourism, renewable energy resources, restoration, and protection. Additionally, it is important to note that the exact changes in one specific service cannot be compared between the pilot areas directly as the evaluations are tied to the present state of each pilot area and the present states may differ between the different pilot areas.

Predicting future ES is not straightforward. One hundred years is a very long time and when we are estimating changes so far in the future the uncertainties in our estimations grow larger with each decade. With models we can make informed predictions of certain environmental variables, although these predictions also contain a high amount of uncertainty. When moving from modelled results further to the functioning of ecosystems, including interactions between variables and species, and even further to ES provisioning, the uncertainty increases in every step. Therefore, the results are highly uncertain even at their best. Additionally, it is important to note that not all factors that will affect species, ecosystems and ES provision in the future were possible to take into consideration when producing the MESAT assessment. There are relatively many drivers of change, not only climate change and nutrient mitigation processes, but also atmospheric and aquatic pollution, overfishing, species interactions, changes in land cover, and marine litter, among other things, that affect the functioning of ecosystems (von Storch et al. 2015). Yet, as there is a lot of speculation on how these will change in the future, we sought to consider only the drivers of change for which we have a valid hypothesis on how they will change, for example, the utilization of marine areas and increase in human activities at sea.

3.3.2. Methodological aspects

MESAT offers a convenient tool for assessing the various ES holistically in a certain area, but there are some aspects to take into consideration in terms of the methodological approach. Regarding any method for ES valuation, it is crucially important to bear in mind that the method is only as good as the set of indicators used. Indicators, for their part, are far from perfect, as they are essentially only proxies for complex phenomena (Hattam et al. 2015). Many ES are extremely hard to measure. Some of the underlying mechanisms for instance concerning regulating and maintenance services in less studied systems remain poorly understood, as do the relative impacts of different factors on ES such as nutrient cycling and decomposition processes (e.g. Ahtiainen & Öhman 2014; Daily 1997). Thus, some of the used indicators may describe the ES slightly insufficiently. Furthermore, data unavailability limits the performance of the used indicators. There is little openly available material, data, or literature for many of the ES indicators and that reduced the number of indicators possible to use in this project. Evaluating the future changes in the indicators due to climate change produced additional difficulties. Some indicators with distinct knowledge on the present status had to be left out of the evaluation process as it was not clear how climate change would affect them. Precise quality standards for the used indicators are important, yet they pose a dilemma by reducing the number of indicators and thus making the assessment of the ES more unreliable. Data unavailability is a common problem in ES assessments in the Baltic Sea and therefore research has focused on only a very small fraction of different ecosystem services (Ahtiainen & Öhman 2014).

Likert categories of change have both benefits and disadvantages in MESAT. Converting all absolute indicator values between the present and future status into categories of change enables direct comparisons between indicators and services as well as data types and study areas, which is the main advantage of the MESAT tool. However, in this project the future evaluations lead to problems using the category of change as it is based originally (Inácio et al. 2018) on absolute initial and present values. In this project, because the indicators' future values are of course not known, we had to estimate the future values for the category of change calculations. Additionally, absolute future value estimations were not possible for all indicators and in these situations the category of change was decided directly by the ECOnnect project group based on the literature and expert opinion. In this way, the method is highly sensitive to subjective judgments. Nonetheless, this source of error was kept in mind by the ECOnnect project group when making the evaluations, and literature, expert opinions, and other available data was sought and assessed comprehensively.

Ecosystem services are numerous and diverse, and some have a greater impact on human welfare than others (Daily 1997). Albeit extremely important, weighing some services over others is a very difficult task that has been addressed in various ways in the literature (e.g. Armoškaitė et al. 2020; Daily 1997) with no solid or generally accepted method to be found. The downside to giving more weight to some services than others is that if the knowledge behind the weighting process is not sufficient, there is a possibility that the method is less accurate than without weighting. Often, not enough reliable information can be found for weighting, and also in MESAT the weighting process is absent. Hence all the different services are treated equal to each other even though they are not equal in the sense of the benefits provided. One example of this concerns biodiversity. Biodiversity provides healthy ecosystems, and healthy and resilient ecosystems produce stable ES that benefit the human population (e.g. Palumbi et al. 2009; Elmqvist et al. 2003). It is important to note that biodiversity is one of the key players in ES provisioning (e.g. Cardinale et al. 2012; Peterson et al. 1998). The expected loss of biodiversity affects the MESAT evaluation of some indicators, but still it is essential to emphasize that climate change and other human-induced threats are expected to weaken biodiversity in the decades to come (e.g. Bellard et al. 2012; Ojaveer et al. 2010; Worm et al. 2006) and MESAT is unable to give biodiversity the full value in ES provisioning it should have.

4. Ecosystem services index (ESI)

Comprehensibly capturing nature's production of goods and services is difficult because ecosystems are complex units with a nearly uncountable number of components interacting non-linearly. Accounting systems and indices do not convey the entire truth about any system, but they can be looked at for important signals of welfare and progress or decline (Banzhaf & Boyd 2012). An ecosystem services index (ESI) is a measure of quantity that relates to, but does not directly measure, the value of nature to humans (Boyd & Banzhaf 2007). Such a stand-alone index of ecosystem services can act as a yardstick of gains and losses to environment-related well-being, and it can be used to compare ES in space and time. There are many ways to construct an ESI, but mostly the ESI's architecture requires both economic and ecological content and analysis (Banzhaf & Boyd 2012). One often used method is to quantify and weigh services by using the measure of WTP (willingness to pay). In this project, we decided to construct an ESI based on the services different habitats and species provide in the Gulf of Bothnia and avoid giving weights to separate services as the weighing process is challenging and subjective and contains many possibilities for errors. The index proposed here provides a tool for evaluating and comparing ES in the whole project area and numerically assessing the changes that may happen to them in the future. The index aggregates a broad range of services into a simple measure, referring both to the types of service and their spatial and temporal distribution. This can help to answer the question of how climate change might affect ES on a broader scale.

4.1. Methods for service rating

A total of 10 species or species groups occurring in the project area were chosen for the ESI calculation. The species were selected based on their ecological importance and ability to provide ecosystem services. The selected species and species groups are commonly found in the project area and have particular importance in service provisioning in the area, and many of them also play a key role in ecosystem functioning. Additionally, considering climate change, the estimated sensitivity of the species to changes in salinity and temperature were contemplated when selecting the species. The species and species groups included in the index construction were *Fucus* spp., pondweeds (*Potamogeton perfoliatus, Stuckenia pectinata*), aquatic mosses (i.a. *Fontinalis* spp., *Drepanocladus* spp.), the red alga *Furcellaria lumbricalis*, the common reed (*Phragmites australis*), stoneworts (i.a. *Chara* spp., *Nitella* spp.), the blue mussel (*Mytilus trossulus x edulis*), the Baltic clam (*Limecola balthica*), Chironomid larvae (i.a. *Chironomus* spp., *Tanytarsus* spp.) and the amphipod *Monoporeia affinis*. The complete list of species included and more information on their ecological role can be found in the ECOnnect report *Future climate and species distribution models for the central Gulf of Bothnia*, where species distributions have been modelled in the reference period and in the future.

The assessment of service provision for the species and species groups in this study was based on the extensive work done in the MERIAVAIN project on the linkages between Baltic Sea habitats and ecosystem services using the CICES ES classification system (Haines-Young & Potschin 2012; see also Sections 2.0 and 3.0 in this report for more information). In the MERIAVAIN project an extensive literature review and expert assessment were performed to gather and combine information on how many and what kinds of ES different Baltic Sea habitats provide. The assessment was done for LuTU habitat types (the habitat classification used in the 'Assessment of threatened habitat types in Finland' and constructed based on the HELCOM HUB) and as the same species used in this project are also included in LuTU habitats, the use of the material was straightforward. The MERIAVAIN project utilized CICES class level services as a base for the assessment, yet they selected only the services most applicable for the Baltic Sea environment. In this project we used the same service package as in the MERIAVAIN project (Fig. 8). As the ES assessment for the different Baltic Sea habitats was made in the MERIAVAIN project for all Finnish sea areas combined, we only used their assessment as a basis for our own more precise assessment for the project area. We assessed each service for each of the species and species groups in the project area by using literature sources and expert evaluations and for each species and species group we obtained a number of the services they produce (Fig. 8). *Fucus* spp. and the common reed were found to provide the highest number of different ES in the project area of the species evaluated. After that the species were categorized or ranked for ESI calculation according to the number of ES they produce: 5 or less services = category 1; 6–8 services = category 2; 9–11 services = category 3; and 12 or more services = category 4. Ranking was carried out to give more value to the species and species groups that produce more services and thus have more value to humans. Additionally, when there are many species in a certain ecosystem and all produce a high number of different ES, it is more probable that they provide the same services as well which gives resilience to the ecosystem and is valuable for that reason (Peterson et al. 1998). Further, we did not detect any species from the ones that produced a small number of services to be solely responsible for producing a certain service and thus being extremely valuable in the ecological sense. Thus, there was no need to give special emphasis or assign a special ranking to any of those species in the lower categories.

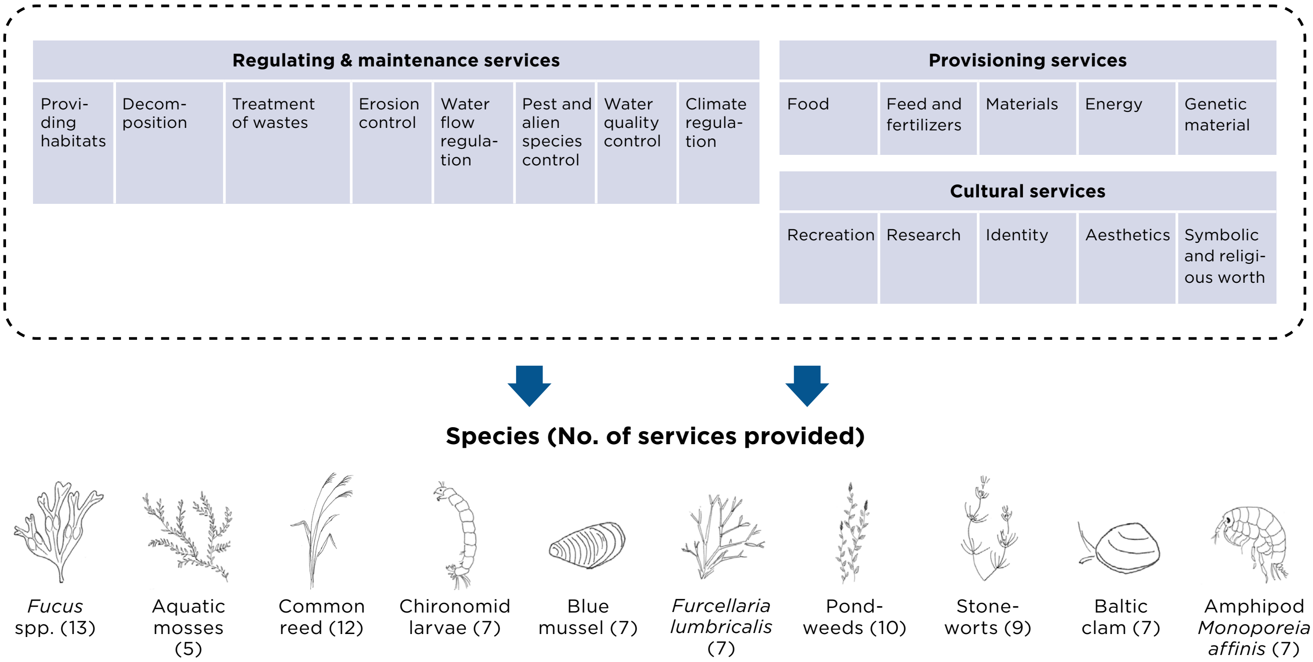


Figure 8. Evaluated ecosystem services for different species and species groups used in the ESI calculation. The number of different services produced by species and species groups were evaluated based on the literature and expert opinions, and the number of different services produced are given in parenthesis. The names of the ecosystem services are not official CICES names but abbreviated versions.

4.2. Modelling & index construction

The distributions of different species and species groups in the reference period and in the future were based on species distribution models (SDM) made for these time periods. Species distribution modelling is essentially a technique for creating maps over large areas from sparse species observation data. SDMs take species observations and environmental conditions in those observation sites as input data, infer the response of a species to environmental conditions, and generalize the habitat requirements of a species over a study area using maps of environmental variables. The result is a map of modelled occurrence probability.

For future SDM, the process is repeated using modelled future environmental conditions. This way, it is possible to predict where the areas suitable for the species might be located in the future. Here, we used modelled future environmental conditions based on an ocean circulation model run by SMHI assuming that in the future GHG concentrations will increase following RCP8.5 and nutrient levels in the sea will develop following the BSAP. For further details on SDM and future modelling, see the ECOnnect report *Future climate and species distribution models for the central Gulf of Bothnia*.

The SDMs were run as probability models, meaning that the resulting map displays values that can be interpreted as the predicted probability of a species to occur in that area. To focus on the most likely (and therefore, most suitable) areas, a species-specific threshold was applied to each SDM. In practice, the models were shown to biologists with expertise on the species and the area, and they evaluated the model to find a threshold for the modelled probability that optimally includes the known occurrences of the species but leaves out areas where the species is rare or does not occur. The models were then cut with these thresholds, and the remaining modelled areas were considered as possible occurrence sites.

The occurrence sites of each species were given a species-specific value that describes their ability to provide ES, as outlined previously in Section 4.1. The models were resampled to a 2 km x 2 km grid, and the resampled models were summed according to the species ranking. For example, if a 2 km x 2 km grid cell within it had modelled occurrences of *Fucus* spp., blue mussels, Baltic clams, annual algae, and the common reed in the reference period, it got a total index value of 4+2+2+1+4 =13, as based on each species' ranking. If, in the future, the blue mussels and *Fucus* spp. disappeared from the grid cell according to the future SDM, then the index would drop to 2+1+4, or 7, declining by 46%, (((13-7)/13)*100).

The total ESI within the project area was calculated as the sum of all grid cells values. To study the change in ES within the project area in 100 years, the reference period ESI and the future ESI were compared. Because there could be differences in how the ESI will change between different parts of the study area, also a map was produced where these spatial patterns can be seen.

4.3. Results

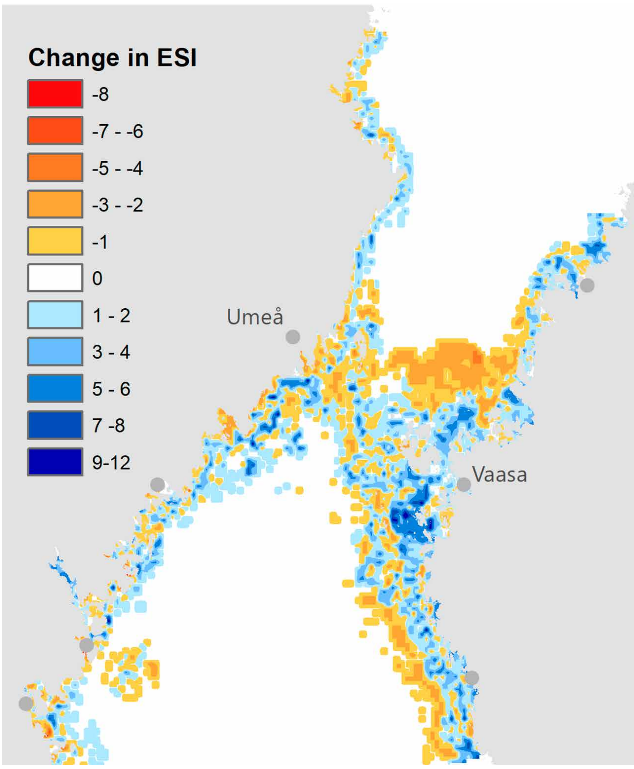


Figure 9. Ecosystem services index (ESI) increases in most shallow areas of the Finnish coast and decreases in the deeper areas. On the Swedish coast a clear decline in the index towards the deeper areas was not detected but the index changes more regionally. The mean change in ESI in the whole project area is slightly positive, increasing by 3%.

Based on the category values given for the species according to the number of ES produced, and their modelled distribution in the reference period and in the future, the ESI will on average slightly increase in the project area, by 3 %. However, this change is so minor that practically it does not have any significant effects on the expected overall services on the scale of the whole project area. Interestingly, there are remarkable spatial differences in how the index will change (Fig. 9). The clearest pattern can be seen in Kvarken and on the Finnish coast of the project area, as ES in shallow coastal areas are positively affected while the ES in the deeper parts of the coast are negatively affected in the future compared to the reference period. The negative change in the index and thus ES in the deeper regions of the Finnish coast and in Kvarken in particular reflect the decline in blue mussels, Baltic clams and in *Monoporeia affinis*, all providing a relatively good number of services. Blue mussels will be negatively affected by the combined stress of the slight salinity decline and increase in temperature, while Baltic clams will suffer from declining salinity and nutrient levels, and *M. affinis* will suffer from the increasing temperature. Additionally, the largest uniform area with a negative impact on ES just north of Kvarken is due to the decline in *M. affinis*. Amphipod *M. affinis* has an important ecological role in deep soft bottoms as it consumes organic matter, and in the process bioturbates and oxygenizes the sediment. However, the decline in ES in the deep soft bottoms is not entirely straightforward as a species group occupying a similar niche to *M. affinis* was omitted from the ESI calculation: species of *Marenzelleria*. The reason *Marenzelleria* spp. were left out is that the species in the group are alien to the Baltic Sea and their occurrence in an area is sometimes problematic. They do oxygenize the bottom sediments and provide ES, but their effective burrowing can also release toxins from the bottom sediments, and they can possibly compete with native species.

The relatively large increase in ES along the shallow Finnish coast and also on the Swedish coast and shallow parts of Kvarken reflects the fact that many shallow-water species will benefit from future warmer waters, the longer growing season, decreasing ice cover and increasing water transparency (BSAP). These species include pondweeds, aquatic mosses and stoneworts. In addition, decreasing ice-cover will benefit *Fucus* spp., which provides a high number of ES and, according to models, may begin to occur in shallower waters in the future. The reason that a similar decline is not seen in the ESI on the Swedish coast as on the Finnish coast when moving into deeper waters could be due to the topography of the Swedish coast. The coastline of Sweden is steep, leaving a relatively narrow area for brackish water organisms to inhabit. Most probably the factors affecting the future species distribution and ES are largely the same on both sides of the project area, but because the depth drops so fast in Sweden, the resolution on which the index was calculated might be too coarse to detect a clear change in the ES. Additionally, blue mussels occur in a narrow coastal strip on the deep coast of Sweden and the occurrences and abundance of the species on the Finnish side of the coast is much higher, so the decline of the species is also relatively larger on the Finnish coast and this change is reflected in the index.

The ESI in general terms is further positively affected by the eutrophication mitigation actions in the BSAP. Eutrophication mitigation measures improve the living condition of several species, for example by improving the water transparency, bottom oxygen conditions and decreasing sedimentation. Especially the occurrence probability of *Fucus* spp. and *Furcellaria lumbricalis* is improved in the project area due to the BSAP.

4.4. Discussion

The ESI offers an interesting insight into the possible changes in ES in a large project area in the future. The index reflects both the negative effects of climate change, and the positive effects of eutrophication mitigation of the BSAP on the species and services produced. Additionally, climate change can benefit some species (e.g. ice-scour effect on *Fucus* spp.) and the BSAP can limit the success of some species (e.g. the effect of less phosphorus, through food availability, on Baltic clam). The index describes that when the environmental conditions in the sea change, the suitability of bottom areas to the species changes as well. This means that species shift to occur in new more suitable areas and the ES they produce shift as well. Thus, on some areas the ES will decline and on others they will increase, and the change is most probably mosaic-like. The index also tells another important story. As we see that the ES and species distribution will change spatially, it would be important on a wider scale to make sure that the species will have the possibility to move and shift to more suitable areas and that human actions (e.g. on-shore and off-shore constructions, dredging, wind-power) won't stand in the way of species. Additionally, the ESI indicates that the services produced by the important deeper and hard bottom habitat adapted species are going to decline especially off the Finnish coast and in Kvarken. This emphasizes that those areas where the decline is expected to happen should be taken into account in marine spatial planning to ensure that no further degradation to the species by human activities occurs.

The shallow Kvarken area is an ecologically important area bringing the coasts of Finland and Sweden closer together and acting as a corridor for species to move and spread between the coasts of the two countries. The shallow Kvarken area has widely been considered an area where the effects of climate change on brackish water species and ecosystems will be seen the first because originally marine species live close to their tolerance limits regarding the salinity, and also as the area is so shallow that the warming will probably have higher impacts there. The ESI produced in this project reflects this change in ES in the Kvarken as the services there overall are expected to decline, and in contrast a more general increase in ESI can be seen both north and south of Kvarken.

The drawback of the ESI is that it does not widely take into account the services provided by all species occurring in the area but only concentrates on certain organisms. For example, fish species and phytoplankton and zooplankton are important components in the Baltic Sea ecosystem directly and indirectly producing services to humans and are disregarded in the ESI. The reason for this is that through modelling we were limited by the availability and usability of the data in the ESI construction. The sessile macrophytes and benthos have been mapped widely in the Baltic Sea making future distribution modelling possible for these species. On the other hand, it is also interesting to concentrate on certain important species and gain information on the services produced by vascular plants, macroalgae and benthic invertebrates. Furthermore, the methods used in this project to assess future ES, the MESAT tool and the ESI, complement each other: MESAT describes changes on a smaller scale but for a wider selection of species and ecosystems, and the ESI describes changes to the ES on a wider scale produced by the most interesting species.

5. Conclusions

The goal of the project was to produce new material on how climate change might affect the project area in the next 100 years. There are no previous predictions on the effects of climate change on species distributions, ecosystem services or connectivity for the whole area. The produced material is meant to be used in climate adaptation and societal planning as well as by the public. Predictions of the effects of climate change on the sea can help in planning how to adapt to the possible changes and to help understand which areas might be especially important for species and ecosystems in the future, also from a conservation perspective.

Climate models used in this project indicate that the most drastic environmental changes will happen in water temperature and winter ice-cover and thus they will have the greatest effect on species and ecosystems. The salinity, which strongly affects the distribution of species, is not expected to change dramatically within 100 years, although future predictions of the salinity are highly uncertain. If the salinity were to decrease more than the models predict, then the changes in species occurrences could be more pronounced and in turn affect the ecosystem services they produce. In general, the models show a similar flora and fauna in the future compared to the reference period in the project area. The most notable future changes in species distribution are expected due to warmer and clearer waters, decreasing ice-cover and slightly lower salinity. The marine species that are already living at the limit of their tolerance for low salinity (e.g. the blue mussel) might decline in the future as well as the species which prefer cool waters (e.g. *Monoporeia affinis*). Then again, the declining ice-cover will especially benefit perennial algae and vegetation as the ice will not scrape them off each year. The nutrient reductions according to the BSAP will result in clearer waters which will benefit most species that are originally adapted to lower nutrient levels. More on the expected changes in species distribution can be read in the ECOnnect report *Future climate and species distribution models for the central Gulf of Bothnia*.

Changes in the connectivity and provisioning of ecosystem services in the future are expected and follow the changes in species distribution and abundance. Within ecosystem services it is expected that the provisioning services in general will increase in the future, while the effect of climate change and the BSAP on regulating and maintenance services will be variable, benefiting some services and harming others. For cultural services the summertime use of the project area will increase, while the winter cultural services will decrease. Additionally, the cultural heritage of the area could be negatively affected by climate change in the future. Furthermore, the ecosystem services tied to the modelled species (ESI) are not expected to change in the amount of services produced, but since the species distribution areas are expected to change, the areas where certain services are produced will shift to different areas.

Results from connectivity analyses suggest that Kvarken is an important route for species to move between Sweden and Finland. The Finnish side of the Gulf of Bothnia promotes the movement of species because the coastline is shallow and thus fosters lush ecosystems for many species to occur. On the Swedish coast, the movement of species is restricted in many places due to the deep coastline, which limits the occurrence of many species to a rather narrow zone and weakens the possibilities for dispersal between habitat patches. The Swedish coastline in the central Gulf of Bothnia can thus be considered naturally fragmented and sensitive. Further results from the connectivity analyses can be read in the ECOnnect report *Ecological connectivity and the resilience of marine protected areas in the central Gulf of Bothnia*. Species and ecosystems adapt to changes in their environment if the changes are gradual and happen over a long period of time (Jansen et al. 2007; Viitasalo et al. 2015). However, human induced climate change is not gradual but rapid in nature (Jansen et al. 2007; Viitasalo et al. 2015) and poses major challenges to the ability of species to adapt (Viitasalo et al. 2015; Urban 2015).

The changes in environmental variables according to the project's models are in line with current predictions from other sources concerning the future in the Baltic Sea and Gulf of Bothnia, most notably HELCOM & Baltic Earth 2021 and Meier et al. 2021. It should be kept in mind that the project's results are specific to certain scenarios, species, ecosystem services, and connectivity analyses in the project area. The results provide an insight into how the studied species may react to climate change and how different ecosystem services and the connectivity linked to those species could be affected. However, if the future follows another climate scenario or if the BSAP is not successfully implemented, the future can look different from how it is presented here. Moreover, as previously discussed there is great uncertainty regarding future projections of the effects of climate change in the sea.

The ECOnnect project has focused on the effects of climate change on the central Gulf of Bothnia. However, as mentioned throughout the report, there are additional pressures with a profound impact on the sea area. One of these pressures is biodiversity loss which is closely connected to climate change. A balanced and functional ecosystem is the foundation for human well-being and failing to address the joint challenges can jeopardize a good quality of life for people (IPBES-IPCC 2021). It is crucial not to separate actions to fight biodiversity loss and climate change, but to take actions that simultaneously tackle both problems (Pörtner et al. 2021). The same can be said for other environmental problems such as eutrophication, pollution, marine litter, and other increased human activities affecting the Baltic Sea and the Gulf of Bothnia. The functions in our sea are interlinked and tackling eutrophication, for example, helps to simultaneously reduce the effects of climate change. This realization will get us closer to achieving a healthy sea than focusing on each problem separately.

Appendix

A1 MESAT methodology

The custom-built and computer-aided MESAT tool has been constructed to work in MS Excel format. It assesses relative changes in ES provision through a set of indicators (Inácio et al. 2018). Within the tool, ES are classified according to the CICES version 4.3 classification system developed by Haines-Young & Potschin (2012) (the newest CICES version 5.1 was not used as version 4.3 was the most MESAT compatible and better served the needs of the project). CICES separates all ES on a base level into provisioning, regulating and maintenance, and cultural services. Within these main sections, services are further divided hierarchically into divisions, groups and classes moving towards more distinct services on each level. In this work, we concentrated only on the most distinct services on the CICES class level. Finally, in the MESAT tool, the services are assessed by a set of indicators. Indicators are used as proxies for services, because most services cannot be directly quantified (Egoh et al. 2012). MESAT uses the EU project MAES's (Maes et al. 2016) indicator set as it has a direct correspondence with CICES, and marine environments are well covered by the indicators. Inácio et al. (2018) additionally defined new indicators for situations where the MAES indicator set did not provide suitable indicators for specific services. The same was done in this project as some regionally important indicators were identified but correspondence lacked from the MAES indicator set and from the indicators defined by Inácio et al. (2018). New indicators were selected based on data availability, expert knowledge, and modelled data. The final indicator set for this project was composed of 39 indicators, although not all indicators were evaluated for all pilot areas (Table 1) due to lack of regional data. These 39 indicators represented 19 services (5 provisioning services, 9 regulating and maintenance services, and 5 cultural services) that were possible to assess in the pilot areas.

A1.1 Assessment process

The MESAT evaluation process starts with a careful definition of pilot areas and then proceeds to the determination of the time periods when the ES provision is to be compared. In this project the present time period for the MESAT evaluation was set to the years 2010–2020 and the evaluated future time period comprised of the years 2100–2120. In the used climate models by SMHI and FMI and in the species distribution models, the reference time period and the future time period differed from the present and future time periods used in MESAT. In the models, the reference time period was based on the years 1976–2005 and the future time period was comprised of the years 2070–2099. The reason for this mismatch in time periods between the MESAT and the used models was that in the models the time periods are fixed due to underlying climate forcing data and cannot be changed (more information on this and the used models is found in the ECOnnect report *Future climate and species distribution models for the central Gulf of Bothnia*) and in the MESAT the aim was to compare present services to services 100 years ahead. Thus, for the MESAT evaluation, data extracted from the models was used as a basis for thorough expert evaluations that draw the changes from the models towards the years of MESAT present and future time periods. Literature sources and historical and present day environmental variable data were used to aid in the assessment process of modelled data.

After defining the time periods, the indicators' present and future values were assessed for all pilot areas. Semi-quantitative and qualitative assessment processes were combined in this project. For indicators using modelled data, both present and future values were received from the models. Indicators for which modelled data were not available were evaluated by using measured present values (e.g. the present fish catch) with expert evaluations and/or a literature review for the most probable future changes for the indicator. The modelled data included environmental variables (e.g. salinity, temperature, Secchi depth, oxygen concentration, nutrient levels, sea ice cover) and species distribution models that were used to calculate aspects such as the water filtration capacity of blue mussels, the extent of selected emerged and submerged habitats, and the carbon stock. Table A3 in the Appendix combines all the information and background data used for evaluating different indicators. The literature and separate databases were used as sources for the measured present indicator values for the pilot areas. For a few indicators, both modelled and measured indicator values were lacking. These indicators were still accepted in the evaluation process if there was a strong expert conception of the magnitude of change for these indicators in the future under the climate scenario (RCP8.5) and nutrient scenario (BSAP) reviewed in this project.

In order to view changes in indicator values relative to each other and to get comparable outcomes, the changes in present and future indicator values were transformed into a Likert scale category of change (Fig. 3). The Likert scale category of change varies from -5 to +5 with minus values indicating a decrease in ES provision and plus values indicating an increase in ES provision, while the value 0 indicated no change in ES provision between the present and the future. The allocation into categories of change was done in MESAT with a customized function where the category was calculated based on the indicator's present, future, and certain boundary values (see more in Inácio et al. 2018). The categories of change for indicators with modelled present and future values were received straight from the MESAT customized function (albeit the present values for 2010–2020 were drawn from the model reference period values for 1976-2005 by expert evaluations as mentioned above). For the indicators with measured present values, an expert opinion-based estimation was made for the future values in order to calculate the category of change with the MESAT customized function. In situations where category of change calculations were not possible, i.e. no measured present values were available for the indicators or the exact estimation for future values were not applicable, an expert group was set up to assess the category of change for the indicators. For these indicators an extensive literature search for future changes was performed and relevant experts were consulted. After this, the combined information was evaluated in separate workshops by the expert group which consisted of 8–11 ECOnnect project group members with diverse knowledge of the Baltic Sea environment and the category of change was given based on the gathered knowledge. Importantly, the MESAT customized function reads an increase in indicator value automatically as a positive change and vice versa, although an increase in some indicator values may reflect a negative change in the ecosystem (e.g. the indicator 'number of harmful algal blooms'). For these indicators the category of change was modified accordingly (i.e. change +2 was modified to -2 if the effect on ecosystem level was negative).

Finally, the MESAT tool generates an aggregated combination of results for ES provision. The aggregation is done by averaging the categories of change values of each hierarchical level of CICES. As we concentrated on CICES class level services in this work, the aggregation is done only on class level. This means that for each service the category of change is calculated by averaging the category of change values of all the indicators used to describe the service.

A2 Pilot areas

Utgrynnan-Molpehällorna

Utgrynnan-Molpehällorna is a large, 1103 km2 sea area in the Kvarken archipelago on the Finnish side of the project area, southwest from the largest island in the area called Raippaluoto. The area is a coastal water body assigned for the purposes of the river basin planning and management required under the EU Water Framework Directive (WFD). Parts of the area of Utgrynnan-Molpehällorna are included in the UNESCO World Heritage Site of the High Coast and Kvarken Archipelago and large areas are also included in the Natura 2000 network of nature protection areas (e.g. Ollqvist & Överholm 2010). The area extends far out into the sea and a multitude of islands create a mosaic in the landscape forming different kinds of habitats from open weather-beaten shores to more sheltered and wind protected shores and lagoons. The shorelines are very shallow which is typical on the Finnish side of the Kvarken area, and the maximum depth extends down to 65 meters in the area while the mean depth is 15 meters. The salinity is around 4.8‰ and many marine species occur in the area (VELMU 2020).

The Utgrynnan-Molpehällorna area offers a wide range of environments for many different species to prosper. In open areas with stony bottoms the brown algae *Fucus vesiculosus* and *Fucus radicans* create habitats for other species and below *Fucus* spp. red algae *Furcellaria lumbricalis* and blue mussels *Mytilus trossulus x edulis* occupy the hard bottoms (VELMU 2020; Natura 2000 Data Form 2018). Vascular plants such as *Potamogeton* spp., *Zannichellia* spp., *Myriophyllum* spp. and many species of stoneworts grow on soft bottom sediments creating underwater meadows where invertebrates and fish species find food and shelter. The vast region offers nursery areas and breeding grounds for fish species that lay their eggs on vegetated open shores, such as Baltic herring (*Clupea harengus membras*), and in sheltered vegetated bays, such as pike (*Esox lucius*) and perch (*Perca fluviatilis*). Deeper soft bottom areas are occupied by invertebrates i.a. chironomid larvae, Baltic clams *Limecola balthica*, polychaetes *Marenzelleria* spp. and amphipods *Monoporeia affinis*. Many species of seabirds nest on the islands (e.g. common eider *Somateria mollissima*, black guillemot *Cepphus grylle*) and an important bird migration route intersects the area offering resting places for moving birds. Additionally, Baltic ringed seals (*Pusa hispida botnica*) and grey seals (*Halichoerus grypus*) live in the area. Parts of the area's outer archipelago are included in the Finnish ecologically significant marine underwater areas (EMMA) on the basis of the rich macroalgae occurrence and the area's important role for fish nurseries and reproduction (Lappalainen et al. 2020).

Because the vast area extends far out to the sea, the long distance from the mainland coast has resulted in rather little human activity on most of the islands. However, islands closer to the mainland nowadays have more human activity and summer cottages. Islands in the Utgrynnan-Molpehällorna area are rich in cultural-historical features that recall the area's importance in traditional fishing and seafaring (Claudino-Sales 2019). Many old fishing villages and huts as well as lighthouses stand on the multitude of islands (SeaGIS2.0). Wrecks and ancient monuments serve as reminders of the old days. Many sailors and boaters visit the islands during the summer and some organized excursions are also available but to a smaller extent. The Utgrynnan-Molpehällorna is in a good ecological condition, but there are signs of deterioration (SYKE 2020). Chlorophyll and phosphorus levels are occasionally elevated, and the status of the area is affected by nutrient rich water currents from nearby sea areas.

Yttre Täftefjärden

Yttre Täftefjärden is a36 km^2 coastal waterbody close to Umeå on the Swedish side of the project area. It is the outer and most exposed part of the Täftefjärden area that receives discharge from the river Täfteån. The pilot area includes different nature types ranging from lagoons to small islands and from shallow depths down to depths of 18 m in the offshore area. Salinity is around 3.4 ‰. Yttre Täfteåfjärden is a relatively densely populated area. There are many summer cottages and houses on the eastern and western shores, but also some less exploited islands and islets.

Yttre Täftefjärden's shallow coastal area is characterized by the land uplift process that can be up to 10 mm per year (Poutanen & Steffen 2014). In the area you can find shallow enclosed bays (lagoons) with a soft bottom and dense vegetation, perfect nursery areas for species such as perch and pike (Snickars et al. 2009; Berglund et al. 2013; Donadi et al. 2020). The diversity of vegetation is high in the lagoons (Naturvårdsverket 2011; Mikkola et al. 2019), however, some of the lagoons in the area have been dredged which negatively affects the vegetation and fish production in the area (Sundbland & Bergström 2014; Sundblad et al. 2014). Shallow shores are dominated by stoneworts *Chara aspera* and higher plants such as pondweeds *Potamogeton perfoliatus* and *Stuckenia pectinata*. Filamentous algae *Cladophora glomerata*, *Ceramium tenuicorne* and *Battersia arctica* can be found growing on the bedrock and stones (County Administrative Board of Västerbotten 2021c). The most exposed shores with little vegetation and a coarser substrate can function as reproduction areas for whitefish (SeaGIS2.0). Herring also reproduce in the more exposed parts of the pilot area (SeaGIS2.0). Deep softbottom areas are filled with invertebrates such as benthic amphipods *Monoporeia affinis*, Baltic clams and isopod crustaceans *Saduria entomon*. An alien species, Polychaete *Marenzelleria* spp., can also be found in the deep soft sediments (County Administrative Board of Västerbotten 2021c). The biggest colony of greater scaup (*Aythya marila*) in the whole of Sweden breeds on the small islands and islets of Yttre Täftefjärden. Other bird species that can be seen here are common gulls (*Sterna hirundo*) and little gulls (*Hydrocoloeus minutus*). The number of breeding birds and species is generally high in the area (Sundström & Olsson 2005).

The area is popular among locals as well as among visitors and many have been to the restaurant, lodge, and the small visitor harbour called Kvarken Fisk, located on the tip of the Täfteå peninsula at the old fishing harbour. Today there are only a few local fishers who use the harbour regularly. All the fish is used for human consumption and most of it is sold locally (local fishermen, personal communication 2020). Smaller amounts are sold to Finland and Norrbotten county. On the eastern side of Yttre Täftefjärden starts a nature reserve called Tavasten-Skeppviksskärgården which continues to the eastern side of the peninsula where the coastal areas are much less exploited. Yttre Täftefjärden has also several cultural heritage sites, wrecks and old shipping routes and harbours as there is a long history of seafaring in the area (SeaGIS2.0). There are no industries in the area and the ecological status according to the Water Framework Directive is good (County Administrative Board 2021a).

Husumbukten

The bay of Husum is a coastal area of around 21 km2 located in the northern part of Västernorrland region in Sweden. The area receives water from the Gide River and the smaller Fanby bay and a few small islands are located in the area. Husum city is a densely populated area close to the coast with several big industries, for example a paper pulp factory.

The pilot area extends over a mix of marine habitats, from 3 m in depth at the coastline down to 50 m in the offshore area. The ecosystems are mainly soft bottom habitats and include benthic species such as isopod crustaceans *Saduria entomon, Monoporeia affinis*, the invasive mud snail *Potamopyrgus antipodarum*, and soft bottom macrophytes such as stoneworts, pondweeds and water-starwort (*Callitriche stagnalis*). Additionally, in a few locations in the outer parts of the area the hard bottom *Fucus* spp. can be found (Kautsky et al. 2009; Guiry & Guiry 2021; SMHI 2021b). Furthermore, the red-listed species *Limosella aquatica* can be found in shallow areas in the bay, and there are several important locations for birds in the area.

Unfortunately, species in the area have been negatively affected by the residual wood fibres and industrial discharges for a long time. Therefore, an extensive part of the soft bottom is uninhabited and species abundances in the whole Husum bay are reduced compared to surrounding coastal areas (Kautsky et al. 2009). Despite improvements in reducing and controlling the discharges, the marine environment is still negatively affected by industrial activities, for example noise disturbances, release of concentrated nutrients and chemicals, accumulation of old discharges, and dredging (Korpinen et al. 2012; HaV 2015). An extension of the paper factory is planned in the next 10 years and an increase in other industries in the area is also expected in the next 100 years, which may further worsen the ecosystems in Husum bay.

Commercial fishing in Husum is scarce and according to a local fisherman, the local catches are mostly for human consumption and mainly sold locally, but some of the fish is sold to Finland and other parts of Sweden (local fisherman, personal communication, 2020). Recreational fishing is more common, and Gide River is a recognized fishing site. Some small harbours such as Husums båthamn, Malnviken and Trollön also receive tourists for fishing (Wedin & Röschmann 2014).

Some recreational and touristic areas are present, such as Sandviken beach close to the city and Aggösundet beach south of the bay. Many recreational boats operate during the summer period visiting the nearby islands. There are no popular hiking routes along the coast close to the bay (HaV 2019), however some unofficial walking trails are found around Fanby bay and attractive places for coastal viewpoints are located at Själön, in the north of Husum bay (Hav 2019). The ecological status of Husum bay is moderate according to the Water Framework Directive (County Administrative Board 2021b).

A3 Data sources

Table A3. Units and data sources of indicator values for each pilot area. A=ECOnnect models, B= database/dataset, C=literature D=Expert opinion, E=ECOnnect project group evaluation.

	Ecosystem services on the CICES class level	Indicators (from MAES, Inacio et al. 2018 and this project)	Unit	Source		
				Ut-grynnan	Yttre Täftef.	Husum
Provisioning services	Wild animals and their outputs	Landings of warm water species	Ton/yr/km^2	B, D, E	B, D, E	B, D, E
		Landings of cold water species	Ton/yr/km^2	B, D, E	B, D, E	B, D, E
		Landing of key market species	Ton/yr/km^2	B, D, E	B, D, E	B, D, E
	Wild plants, algae, and their outputs	Harvest	Ton/yr/km^2	C, D, E	-	-
		No. of species	No./km^2	C, D, E	-	-
	Animals from in situ aquaculture	Harvest	Ton/yr/km^2	C, D, E	C, D, E	C, D, E
		No. of species	No./km^2	C, D, E	C, D, E	C, D, E
	Fibres etc. from plants, algae and animals for use or processing	Harvest	Ton/yr/km^2	C, D, E	C, D, E	C, D, E
	Surface water for non-drinking purposes	Use of water	m^3/km^2	D, E	D, E	D, E
Regulating & maintenance services	Filtration/sequestration/storage/ accumulation by ecosystems	N-fixation	kg/yr/km^2	A, C, E	A, C, E	A, C, E
		Primary production	tonC/yr/km^2	A, E	A, E	A, E
		Filtration capacity (Mytilus)	km^2/km^2	A, E	-	-
	Mass stabilisation and control of erosion rates	Extent of emerged, submerged habitats	km^2/km^2	A, E	A, E	A, E
	Buffering and attenuation of mass flows	Sediment accumulation rate	cm/yr	C, D, E	C, D, E	C, D, E
	Flood protection	Significant wave height	m	C, D, E	C, D, E	C, D, E
	Maintaining nursery populations and habitats	Habitat diversity	No./km^2	A, E	A, E	A, E
		Secchi depth	m	A, E	A, E	A, E
		No. of Red List and extinct species	No./km^2	C, E	C, E	C, E
		Nursery areas (cold water species)	km^2/km^2	C, D, E	C, D, E	C, D, E
		Nursery areas (warm water species)	km^2/km^2	C, D, E	C, D, E	C, D, E
		% of nursery areas which are protected	km^2/km^2	E	E	E
	Pest and disease control	Harmful algal blooms	No./yr/km^2	A, D, E	A, D, E	A, D, E
		Presence of alien species	No./km^2	C, E	C, E	C, E
	Decomposition and fixing processes	Nitrogen removal	%	C, E	C, E	C, E
		Water residence time	Months	C, D, E	C, D, E	C, D, E
	Chemical condition of salt water	NO3 surface water, mean of growing season	mmole-N/m^3	A, E	A, E	A, E
		NH4 surface water, mean of growing season	mmole-N/m^3	A, E	A, E	A, E
		PO4 surface water, mean of growing season	mmole-P/m3	A, E	A, E	A, E
		Salinity	PSU	A, E	A, E	A, E
		Oxygen concentration	mg/L	A, E	A, E	A, E
	Climate regulation by reduction of GHG concentrations	C-stock	tonC/km2	A, E	A, E	A, E
		pH	pH	B, E	B, E	B, E
Cultural services	Physical use of land-/seascapes	No. of tourists (within 1 km of coastal zone)	No./yr/km^2	C, D, E	C, D, E	C, D, E
		No. of ship berths in the marinas	No./km^2	D, E	D, E	D, E
		No. of tourists' boat	No. *cap/km^2	D, E	D, E	D, E
		No. of people using ice for recreational activities	No./km^2	E	E	E
		No. of outdoor life opportunities in area	No./km^2	B, E	B, E	B, E
	Heritage, cultural	No. of cultural and heritage sites (underwater)	No./km^2	B, C, E	B, C, E	B, C, E
		No. of cultural and heritage sites on land (adjacent coastal areas)	No./km^2	B, C, E	B, C, E	B, C, E
	Aesthetic	Area of pristine environment	km^2/km^2	C, E	C, E	C, E
	Symbolic	No. of iconic species	No./km^2	E	E	E
	Bequest	Extent of marine protected areas (MPA)	km^2/km^2	C, E	C, E	C, E

Table A4. List of iconic species evaluated for different pilot areas.

Iconic species in the project area	Utgrynnan	Yttre Täftefjärden	Husumbukten
Haliaeetus albicilla/Havsörn/merikotka	X	X	X
Fucus spp.	X	X	X
Ringed seal (Pusa hispida botnica)	X	X	X
White fish/migratory/merialueen vaellussiika	X	X	X
White fish/marine spawning/merikutuinen siika	X	X	X
Salmon (Salmo salar)	X	X	X
Perch (Perca fluviatilis)	X	X	X
Pike (Esox lucius)	X	X	X
Sea-buckthorn/Hippophaë rhamnoides/havtorn	X	X	X
Larus marinus/Havstrut/merilokki	X	X	X
Cygnus cygnus/Sångsvan/Laulujoutsen	X	X	X
Cepphus grylle/Tobisgrissla/Riskilä	X		
Alca torda/Tordmule/Ruokki	X		
Somateria mollissima/Ejder/Haahka	X		
Otter (Lutra lutra)	X	X	X
Chara tomentosa	X	X	X
Sand ryegrass/Leymus arenarius/rantavehnä	X	X	X
Sea sandwort/Honckenya peploides/suola-arho	X	X	X
Herring (Clupea harengus membras)	X	X	X
Trout (Salmo trutta)	X	X	X

References

Agawin, N. S. Rabouille, S. Veldhuis, M. J., Servatius, L., Hol, S., van Overzee, H. M. & Huisman, J. 2007. Competition and facilitation between unicellular nitrogen-fixing cyanobacteria and non-nitrogen-fixing phytoplankton species. Limnology and Oceanography, 52(5), 2233-2248.

Ahtiainen, H., Liski, E., Pouta, E., Soini, K., Bertram, C., Rehdanz, K. & Meyerhof, J. 2019. Cultural ecosystem services provided by the Baltic Sea marine environment. Ambio, 48(11), 1350-1361.

Ahtiainen, H. & Öhman, M. C. 2014. Ecosystem services in the Baltic Sea: valuation of marine and coastal ecosystem services in the Baltic Sea. Nordic Council of Ministers.

Ahtiainen, H., Artell, J., Czajkowski, M., Hasler, B., Hasselström, L., Huhtala, A. & Semeniene, D. 2014. Benefits of meeting nutrient reduction targets for the Baltic Sea –a contingent valuation study in the nine coastal states. Journal of Environmental Economics and Policy, 3(3), 278-305.

Ahvonen, A., Hiidenhovi, J., Mattila, P., Mäkinen, S., Niva, T., Setälä, J., Välimaa, A.-L., Alakomi, H.-L., Honkapää, K., Lantto, R., Nisov, A., Suomalainen M., Hopia, A., Ihanus, S., Kakko, T., Marttunen, K., Sandell, M., Tuomasjukka, S., Yang, B. & Svanbäck, G. 2019. Blue Products – Kalatalouden innovaatio-ohjelma, väliraportti vuosilta 2017-2019. European maritime and fisheries fund.

Armoškaitė, A., Purina, I., Aigars, J., Strãke, S., Pakalniete, K., Frederiksen, P., Schroder, L. & Hansen, H. S. 2020. Establishing the links between marine ecosystem components, functions and services: An ecosystem service assessment tool. Ocean & Coastal Management, 193, 105229.

Banzhaf, H. S. & Boyd, J. 2012. The architecture and measurement of an ecosystem services index. Sustainability, 4(4), 430-461.

Bartolino, V., Margonski, P., Lindegren, M., Linderholm, H. W., Cardinale, M., Rayner, D. & Casini, M. 2014. Forecasting fish stock dynamics under climate change: Baltic herring (Clupea harengus) as a case study. Fisheries Oceanography, 23(3), 258-269.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. & Courchamp, F. 2012. Impacts of climate change on the future of biodiversity. Ecology letters, 15(4), 365-377.

Berglund, J., Stenroth, P., Larsson, S. & Larsson, S. 2013. Fiskrekrytering längs Västerbottenskusten. Länsstyrelsen i Västerbotten meddelande 2.

Bergström, U., Olsson, J., Casini, M., Eriksson, B. K., Fredriksson, R., Wennhage, H. & Appelberg, M. 2015. Stickleback increase in the Baltic Sea - a thorny issue for coastal predatory fish. Estuarine and Coastal Shelf Science 163: 134-142.

Bermudez, R., Winder, M., Stuhr, A., Almén, A-K., Engström-Öst, J. & Riebesell, U. 2016. Effect of ocean acidification on the structure and fatty acid composition of a natural plankton community in the Baltic Sea. Biogeosciences. 13. 6625-6635.

Bianchi, T. S., Johansson, B. & Elmgren, R. 2000. Breakdown of phytoplankton pigments in Baltic sediments: effects of anoxia and loss of deposit-feeding macrofauna. Journal of experimental marine biology and ecology, 251(2), 161-183.

Björdal, C. G., Gregory, D., Manders, M., Al-Hamdani, Z., Appelqvist, C., Haverhand, J., & Dencker, J. 2012. Strategies for protection of wooden underwater cultural heritage in the Baltic Sea against marine borers. The EU Project 'WreckProtect'. Conservation and management of archaeological sites, 14(1-4), 201-214.

Boyd, J. & Banzhaf, H.S. 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecol. Econ. 63, 616–626.

Byström, P., Bergström, U., Hjältén, A., Ståhl, S., Jonsson, D. & Olsson, J. 2015. Declining coastal piscivore populations in the Baltic Sea - where and when do sticklebacks matter? Ambio 44(3): 462-471.

Bergström, I., Mattsson, T., Niemelä, E., Vuorenmaa, J. & Forsius, M. 2011. Ekosysteemipalvelut ja elinkeinot-haavoittuvuus ja sopeutuminen muuttuvaan ilmastoon. VACCIA-hankkeen yhteenvetoraportti.

Cardinale, B. J., Duffy, E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., Mace, G.M, Tilman, D., Wardle, D.A., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D. & Naeem, S. 2012. Biodiversity loss and its impact on humanity. Nature. Volume: 486, Number: 7401, 59-67.

Carstensen, J., Klais, R. & Cloern, J. E. 2015. Phytoplankton blooms in estuarine and coastal waters: Seasonal patterns and key species. Estuarine, Coastal and Shelf Science, 162, 98-109.

Carstensen, J., Conley, D. J., Bonsdorff, E., Gustafsson, B. G., Hietanen, S., Janas, U. & Voss, M. 2014. Hypoxia in the Baltic Sea: Biogeochemical cycles, benthic fauna, and management. Ambio, 43(1), 26-36.

Christidis, N., Stott, P. A., Brown, S., Karoly, D. J. & Caesar, J. 2007. Human contribution to the lengthening of the growing season during 1950–99. Journal of Climate, 20(21), 5441-5454.

Claudino-Sales, V. 2019. High Coast and Kvarken Archipelago, Finland and Sweden. Coastal World Heritage Sites, 81-86. Springer, Dordrecht.

Climate Change in the Baltic Sea. 2021 Fact Sheet. Baltic Sea Environment Proceedings n°180. HELCOM/Baltic Earth 2021.

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver & M. Wehner, 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B. & Van Den Belt, M. 1997. The value of the world's ecosystem services and natural capital. Nature, 387 (6630), 253-260.

County administrative board. 2021a. Viss Vatteninformationssystem Sverige. Yttre Täftefjärden. Retrieved 17.06.2021 from https://viss.lansstyrelsen.se/Waters.aspx?waterEUID=SE634350-202900

County administrative board. 2021b. Viss Vatteninformationssystem Sverige. Husumbukten. Retrieved 06.07.2021 from https://viss.lansstyrelsen.se/Waters.aspx?waterMSCD=WA15887752

County administrative board. 2021c. Vegetation data from years 2000-2020 and Zoobenthos data from 2018.

Dahl, K., Josefson, A. B., Göke, C., Christensen, J. P. A., Hansen, J. L., Markager, S. & Bonsdorff, E. 2013. Climate Change Impacts on Marine Biodiversity and Habitats in the Baltic Sea –and Possible Human Adaptations. Coastline Reports, 1.

Daily, G. C. 1997. Introduction: what are ecosystem services. Nature's services: Societal dependence on natural ecosystems, 1(1).

Depellegrin, D. & Blažauskas, N. 2013. Integrating ecosystem service values into oil spill impact assessment. Journal of Coastal Research, 29(4), 836-846.

Dervishi, A. & El-Zoubi, S. 2012. Vass- och tegeltak – En studie om användningen av vass och tegel då, idag och i framtiden. Lund Universitet.

Díaz-Andreu, M. 2017. Heritage values and the public. Journal of Community Archaeology & Heritage vol. 4, 1.

Donadi, S., Bergström, L., Berglund, J. M. B., Bäck, A., Mikkola, R., Saarinen, A. & Bergström, U. 2020. Perch and pike recruitment in coastal bays limited by stickleback predation and environmental forcing. Estuarine, Coastal and Shelf Science, 246.

Donnelly, C., Yang, W. & Dahné, J. 2014. River discharge to the Baltic Sea in a future climate. Climatic Change, 122(1), 157-170.

Dutheil, C., Meier, H. E. M., Gröger, M. & Börgel, F. 2021. Understanding past and future sea surface temperature trends in the Baltic Sea. Climate Dynamics, 1-19.

Egoh, B., Drakou, E. G., Dunbar, M. B., Maes, J. & Willemen, L. 2012. Indicators for mapping ecosystem services: a review. European Commission, Joint Research Centre (JRC), p. 111.

Ehler, C. N. 2018. Marine spatial planning: An idea whose time has come. Routledge, 6-17.

Eide, W., Ahrné, K., Bjelke, U., Nordström, S., Ottosson, E., Sandström, J., & Sundberg, S. 2020. Tillstånd och trender för arter och deras livsmiljöer: rödlistade arter i Sverige 2020.

Eklöf, J. S., Sundblad, G., Erlandsson, M., Donadi, S., Hansen, J. P., Eriksson, B. K. & Bergström, U. 2020. A spatial regime shift from predator to prey dominance in a large coastal ecosystem. Communications biology, 3(1), 1-9.

Elmqvist, T., Folke, C., Nyström, M., Peterson, G., Bengtsson, J., Walker, B. & Norberg, J. 2003. Response diversity, ecosystem change, and resilience. Frontiers in Ecology and the Environment, 1(9), 488-494.

Engelhard, G. H., & Heino, M. 2006. Climate change and condition of herring (Clupea harengus) explain long-term trends in extent of skipped reproduction. Oecologia, 149(4), 593-603.

Engstedt, O., Stenroth, P., Larsson, P., Ljunggren, L. & Elfman, M. 2010. Assessment of natal origin of pike (Esox lucius) in the Baltic Sea using Sr: Ca in otoliths. Environmental Biology of Fishes, 89(3), 547-555.

Eriksson, B. K., Sieben, K., Eklöf, J., Ljunggren, L., Olsson, J., Casini, M. & Bergström, U. 2011. Effects of altered offshore food webs on coastal ecosystems emphasizes the need for cross-ecosystem management. Ambio 40:786–797.

European Commission. 2021a. Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030. Brussels. Retrieved 24.5.2021 from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0236&from=EN

European Commission. 2021b. EU Biodiversity strategy for 2030. Luxembourg, publication office of the European Union. Retrieved 29.6.2021 from https://op.europa.eu/en/publication-detail/-/publication/31e4609f-b91e-11eb-8aca-01aa75ed71a1

European Commission. 2020. EU:n strategia avomerellä tuotettavan uusiutuvan energian potentiaalin valjastamiseksi ilmastoneutraalin tulevaisuuden tarpeisiin. Brussels. Retrieved 24.5.2021 from https://eur-lex.europa.eu/legal-content/FI/TXT/HTML/?uri=CELEX:52020DC0741&from=EN

European Commission. 2011. European Commission: our life insurance, our natural capital: an EU biodiversity strategy to 2020. European Commission, Brussels.

Expert group. 2020. The ECOnnect project members group to set up evaluate ES provision. Evaluations were based on professional opinions within the group, literature reviews, and on the opinions and comments from several scientists and experts outside the project.

Faulkner, D. J. 2001. Marine natural products. Natural product reports, 18(1).

Firestone, J. & Kempton, W. 2007. Public opinion about large offshore wind power: underlying factors. Energy policy, 35(3), 1584-1598.

Fisher, B., Turner, R. K. & Morling, P. 2009. Defining and classifying ecosystem services for decision making. Ecological economics, 68(3), 643-653.

Fors, Y. & Björdal, C. G. 2013. Well-preserved shipwrecks in the Baltic Sea from a natural science perspective. Interpreting Shipwrecks. Maritime Archaeological Approaches, 36-45.

Friedland, R., Neumann, T. & Schernewski, G. 2012. Climate change and the Baltic Sea action plan: model simulations on the future of the western Baltic Sea. Journal of Marine Systems, 105, 175-186.

GBIF Secretariat. 2021. Hippophae rhamnoides L. Global Biodiversity Information Facility. Retrieved 8.7.2021 from https://www.gbif.org/species/3039285

Geist, J. & Hawkins, S. J. 2016. Habitat recovery and restoration in aquatic ecosystems: current progress and future challenges. Aquatic Conservation: Marine and Freshwater Ecosystems, 26(5), 942-962.

Goldburg, R. & Naylor, R. 2005. Future seascapes, fishing, and fish farming. Frontiers in Ecology and the Environment, 3(1), 21-28.

Gollasch, S., Minchin, D. & David, M. 2015. The transfer of harmful aquatic organisms and pathogens with ballast water and their impacts. Global maritime transport and ballast water management. Springer, Dordrecht, 35-58.

Gray, C., Baird, D. J., Baumgartner, S., Jacob, U., Jenkins, G. B., O'Gorman, E. J. & Woodward, G. 2014. Ecological networks: the missing links in biomonitoring science. Journal of Applied Ecology, 51(5), 1444-1449.

Guiry, M.D. & Guiry, G.M. 2021. AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. https://www.algaebase.org; searched on 06 July 2021.

HaV. 2020a. Havs- och vattenmyndigheten rapport. Marin strategi för Nordsjön och Östersjön. Samråd om uppdaterat åtgärdsprogram för havsmiljön i Nordsjön och Östersjön 2022-2027 enligt havsmiljöförordningen, 254.

HaV. 2020b. Swedish fisheries data between years 2014-2018.

HaV. 2019. Havs- och vattenmyndigheten. Havsplaner för Bottniska viken, Östersjön och Västerhavet. Statlig planering i territorialhav och ekonomisk zon. Diarienummer 3628-2019

HaV. 2015. Havs- och vattenmyndigheten. God havsmiljö 2020: Marin strategi för Nordsjön och Östersjön – Del 4: Åtgärdsprogram för havsmiljön. Rapport ID: 2015:30

Havenhand, J. N. 2012. How will ocean acidification affect Baltic Sea ecosystems? An assessment of plausible impacts on key functional groups. Ambio, 41(6), 637-644.

Havet. 2021. Web porta about the sea. Stockholm university, Umeå university, Göteborg university, Swedish University of Agricultural Sciences and Swedish Institute for the Marine Environment. Retrieved 11.8.2021 from: Havet.nu

Haines-Young, R. & Potschin, M. 2012. Common International Classification of Ecosystem Services (CICES, Version 4.1). European Environment Agency, 33, 107.

Harkin, D., Davies, M., Hyslop, E., Fluck, H., Wiggins, M., Merritt, O. & Westley, K. 2020. Impacts of climate change on cultural heritage. MCCIP Sci. Rev, 16, 24-39.

Hattam, C., Atkins, J. P., Beaumont, N., Börger, T., Böhnke-Henrichs, A., Burdon, D. & Austen, M. C. 2015. Marine ecosystem services: linking indicators to their classification. Ecological Indicators, 49, 61-75.

Heckwolf, M. J., Peterson, A., Jänes, H., Horne, P., Künne, J., Liversage, K. & Kotta, J. 2020. From ecosystems to socio-economic benefits: A systematic review of coastal ecosystem services in the Baltic Sea. Science of the Total Environment, 142565.

Heiskanen, A. & Kononen, K. 1994. Sedimentation of vernal and late summer phytoplankton communities in the coastal Baltic Sea. Archiv Fur Hydrobiologie, 131, 175-175.

HELCOM & Baltic Earth. 2021. Climate Change in the Baltic Sea. 2021 Fact Sheet. Baltic Sea Environment Proceedings n°180.

HELCOM. 2021. Baltic Marine Environment Protection Commission. Baltic Sea Action Plan 2021 update.

HELCOM. 2020. Baltic Marine Environment Protection Commission. First draft of the updated BSAP: https://helcom.fi/baltic-sea-action-plan/bsap-update-2021/

HELCOM. 2018a. HELCOM Thematic assessment of biodiversity 2011-2016. Baltic Sea Environment Proceedings No. 158.

Retrieved 21.4.2021 from: http://stateofthebalticsea.helcom.fi/wp-content/uploads/2019/09/BSEP158-Biodiversity.pHELCOM. 2018b. Implementation of the Baltic Sea Action Plan 2018: Three years left to reach good environmental status. Retrieved 5.3.2021 from: https://helcom.fi/wp-content/uploads/2019/06/Implementation-of-the-BSAP-2018.pdf

HELCOM. 2017. First version of the 'State of the Baltic Sea' report - June 2017 - to be updated in 2018. Retrieved 5.3.2021 from: http://stateofthebalticsea.helcom.fi/wp-content/uploads/2017/07/HELCOM_State-of-the-Baltic-Sea_First-version-2017.pdf HELCOM. 2013e. Climate change in the Baltic Sea area: HELCOM thematic assessment in 2013. Balt. Sea Environ. Proc. No. 137

HELCOM. 2013. Climate change in the Baltic Sea area: HELCOM thematic assessment in 2013. Balt. Sea Environ. Proc. No. 137.

HELCOM. 2009. Biodiversity in the Baltic Sea – An integrated thematic assessment on biodiversity and nature conservation in the Baltic Sea. Balt. Sea Environ. Proc. No. 116B. Retrieved 2.3.2021 from: https://helcom.fi/wp-content/uploads/2019/08/BSEP116B.pdf

HELCOM. 2007. Climate Change in the Baltic Sea Area. HELCOM Thematic Assessment in 2007. Baltic Sea Environment Proceedings No. 111.

Hense, I., Meier, H. M. & Sonntag, S. 2013. Projected climate change impact on Baltic Sea cyanobacteria. Climatic Change, 119(2), 391-406.

Highcoastkvarken. 2021. Joint web portal of the World Heritage Site High Coast / Kvarken Archipelago. Länsstyrelsen Västernorrland & Metsähallitus Parks and Wildlife Finland. Retrieved 31.5.2021 from: https://highcoastkvarken.org/

Hilborn, R., Branch, T. A., Ernst, B., Magnusson, A., Minte-Vera, C. V., Scheuerell, M. D. & Valero, J. L. 2003. State of the world's fisheries. Annual review of Environment and Resources, 28(1), 359-399.

Hiltunen, E. 2019. Matkailun tulevaisuus -raportti. Helsingin Matkailusäätiö.

Hjerne, O., Hajdu, S., Larsson, U., Downing, A. S. & Winder, M. 2019. Climate driven changes in timing, composition and magnitude of the Baltic Sea phytoplankton spring bloom. Frontiers in Marine Science, 6, 482.

Holopainen, R., Lehtiniemi, M., Meier, H. M., Albertsson, J., Gorokhova, E., Kotta, J. & Viitasalo, M. 2016. Impacts of changing climate on the non-indigenous invertebrates in the northern Baltic Sea by end of the twenty-first century. Biological Invasions, 18(10), 3015-3032.

Hoppenrath, M., Elbrächter, M. & Drebes, G. 2009. Marine Phytoplankton: Selected microphytoplankton species from the North Sea around Helgoland and Sylt.

Hutchins, D. A. & Fu, F. 2017. Microorganisms and ocean global change. Nature microbiology, 2(6), 1-11.

Hyvärinen, E., Juslén, A., Kemppainen, E., Uddström, A. & Liukko, U.-M. 2019. The 2019 Red List of Finnish Species. Ympäristöministeriö & Suomen ympäristökeskus. Helsinki. 704 p.

Hyytiäinen, K., Ahlvik, L., Ahtiainen, H., Artell, J., Dahlbo, K. & Huhtala, A. 2013. Spatially explicit bio-economic modelling for the Baltic Sea: Do the benefits of nutrient abatement outweigh the costs?

Härmä, M., Lappalainen, A. & Urho, L. 2008. Reproduction areas of roach (Rutilus rutilus) in the northern Baltic Sea: potential effects of climate change. Canadian Journal of Fisheries and Aquatic Sciences, 65(12), 2678-2688.

ICES. 2019. Baltic Sea Ecosystem – Fisheries Overview. In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, section 4.2. https://doi.org/10.17895/ices.advice.5566

Ignatius, S. & Haapasaari, P. 2018. Justification theory for the analysis of the socio-cultural value of fish and fisheries: The case of Baltic salmon. Marine Policy, 88, 167-173.

Inácio, M., Schernewski, G., Nazemtseva, Y., Baltranaitė, E., Friedland, R. & Benz, J. 2018. Ecosystem services provision today and in the past: a comparative study in two Baltic lagoons. Ecological research, 33(6), 1255-1274.

IPBES-IPCC. 2021. Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change. From: https://ipbes.net/sites/default/files/2021-06/2021_IPCC-IPBES_scientific_outcome_20210612.pdf

IRENA. 2019. Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects. A Global Energy Transformation paper, International Renewable Energy Agency, Abu Dhabi.

IUCN. 2016. Increasing marine protected area coverage for effective marine biodiversity conservation. World Conservation Congress, Hawai ‘i, United States of America.

Jansen, E., J. Overpeck, K.R. Briffa, J.-C. Duplessy, F. Joos, V. Masson-Delmotte, D. Olago, B. Otto-Bliesner, W.R. Peltier, S. Rahmstorf, R. Ramesh, D. Raynaud, D. Rind, O. Solomina, R. Villalba and D. Zhang, 2007: Palaeoclimate. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jaatinen, K., Westerbom, M., Norkko, A., Mustonen, O., Koons, D. N. 2020. Detrimental impacts of climate change may be exacerbated by density-dependent population regulation in blue mussels. Journal of Animal Ecology, 00:1-12. DOI: 10.1111/1365-2656.13377

Jakobsson, M., Stranne, C., O'Regan, M., Greenwood S.L., Gustafsson, B., Humborg, C. & Weidner, E. 2019. Bathymetric properties of the Baltic Sea. Ocean Science. 15. 905-924

Johannesson, K. & Andre, C. 2006. Invited Review: Life on the margin: genetic isolation and diversity loss in a peripheral marine ecosystem, the Baltic Sea. Molecular Ecology, 15(8), 2013-2029.

John Nurminen Foundation. 2020. Rannikkoruokohanke käynnistyi Kirkkonummella – niitolla positiivinen vaikutus Itämereen, ilmastoon ja perinnemaisemiin. Retrieved 22.11.2021 from https://johnnurmisensaatio.fi/rannikkoruokohanke-kaynnistyi-kirkkonummella-niitolla-positiivinen-vaikutus-itamereen-ilmastoon-ja-perinnemaisemiin/

Jonasson, S., Eriksson, J., Berntzon, L., Spáčil, Z., Ilag, L. L., Ronnevi, L. O. & Bergman, B. 2010. Transfer of a cyanobacterial neurotoxin within a temperate aquatic ecosystem suggests pathways for human exposure. Proceedings of the National Academy of Sciences, 107(20), 9252-9257.

Jones, M. C. & Cheung, W. W. 2015. Multi-model ensemble projections of climate change effects on global marine biodiversity. ICES Journal of Marine Science, 72(3), 741-752.

Jonsson, B. & Jonsson, N. 2009. A review of the likely effects of climate change on anadromous Atlantic salmon Salmo salar and brown trout Salmo trutta, with particular reference to water temperature and flow. Journal of fish biology, 75(10), 2381-2447.

Jänkälä, S. 2019. Matkailun toimialaraportti - Tourism sector report. Työ- ja elinkeinoministeriö - Ministry of Economic Affairs and Employment. Työ- ja elinkeinoministeriön julkaisuja 2019:3.

Karjalainen, M., Engström-Öst, J., Korpinen, S., Peltonen, H., Pääkkönen, J. P., Rönkkönen, S. & Viitasalo, M. 2007. Ecosystem consequences of cyanobacteria in the northern Baltic Sea. AMBIO: A Journal of the Human Environment, 36(2), 195-202.

Kaslegard, A. S. 2011. Climate change and cultural heritage in the Nordic countries. Nordic Council of Ministers.

Kautsky, L. & Kautsky, N. 2000. The Baltic Sea, including Bothnian Sea and Bothnian Bay. Chapter 8. In: Sheppar, C. Seas at the millennium: an environmental evaluation. Elsevier Science Amsterdam,1-3, 121-133.

Kautsky, H., Qvarfordt, S. & Wallin, A. 2009. Marina skyddsvärda områden i Västernorrlands län - Kompletterande undersökningar av utvalda områden. Länsstyrelsen Västernorrland, avdelningen för Miljö och Natur 2009:3

Kautsky, N. 1981. On the trophic role of the blue mussel (Mytilus edulis L.) in a Baltic coastal ecosystem and the fate of the organic matter produced by the mussels. Kieler Meeresforschungen Sonderheft, 5, 454-461.

Kokkonen, E., Heikinheimo, O., Pekcan-Hekim, Z. & Vainikka, A. 2019. Effects of water temperature and pikeperch (Sander lucioperca) abundance on the stock–recruitment relationship of Eurasian perch (Perca fluviatilis) in the northern Baltic Sea. Hydrobiologia, 841(1), 79-94.

Kontula, T. & Raunio, A. 2018. Suomen luontotyyppien uhanalaisuus 2018. Luontotyyppien punainen kirja – Osa 1: Tulokset ja arvioinnin perusteet & Osa 2: luontotyyppien kuvaukset. Suomen ympäristökeskus ja ympäristöministeriö, Helsinki. Suomen ympäristö 5/2018. 388 s. & 925 s.

Korpinen, S., Meski, L., Andersen, J. H., & Laamanen, M. 2012. Human pressures and their potential impact on the Baltic Sea ecosystem. Ecological Indicators, 15(1), 105-114.

Kulmala, S., Haapasaari, P., Karjalainen, T. P., Kuikka, S., Pakarinen, T., Parkkila, K., Romakkaniemi, A. & Vuorinen, P. J. 2012. Ecosystem services provided by Baltic salmon –a regional perspective to the socio-economic benefits associated with a keystone migratory species. The Ecomomics of Ecosystems and Biodiversity.

Laikre, L., Lundmark, C., Jansson, E., Wennerström, L., Edman, M. & Sandström, A. 2016. Lack of recognition of genetic biodiversity: International policy and its implementation in Baltic Sea marine protected areas. Ambio, 45(6), 661-680.

Lappalainen, J., Kurvinen, L. & Kuismanen, L. 2020. Suomen ekologisesti merkittävät vedenalaiset meriluontoalueet (EMMA) – Finlands ekologiskt betydelsefulla marina undervattensmiljöer (EMMA). Suomen ympäristökeskuksen raportteja 8, Suomen ympäristökeskus, Merikeskus.

Łabuz, T. A. 2015. Environmental Impacts-Coastal Erosion and Coastline Changes. In the BACC II Author Team, Second Assessment of Climate Change for the Baltic Sea Basin, Regional Climate Studies, 381–396.

Latokartano, M. 2018. Otetaan kala käyttöön vihoviimeistä suomua myöten. Luonnonvarakeskus, Natural Resources Institute Finland. Retrieved 12.7.2021 from www.luke.fi/mt-otetaan-kala-kayttoon-vihoviimeista-suomua-myoten/

Leach, J. H., Johnson, M. G., Kelso, J. R. M., Hartmann, J., Nümann, W. & Entz, B. 1977. Responses of percid fishes and their habitats to eutrophication. Journal of the Fisheries Board of Canada, 34(10), 1964-1971.

Lehtiniemi, T., Toivanen, T. & Södersved, J. 2021. Linnuston tila Suomessa. Birdlife Finland, Helsinki.

Lehtonen, H., Hansson, S. & Winkler, H. 1996. Biology and exploitation of pikeperch, Stizostedion lucioperca (L.), in the Baltic Sea area. Annales Zoologici Fennici. Finnish Zoological and Botanical Publishing Board, 525-535.

Leppäranta, M. & Myrberg, K. 2009. Physical Ocenaography of the Baltic Sea. Chapter 1. Springer-Praxis books in geophysical sciences, Springer, Berlin.

Leppäkoski, E., Gollasch, S., Gruszka, P., Ojaveer, H., Olenin, S. & Panov, V. 2002. The Baltic a sea of invaders. Canadian Journal of Fisheries and Aquatic Sciences, 59(7), 1175-1188.

Ljunggren, L., Sandström, A., Bergström, U., Mattila, J., Lappalainen, A., Johansson, G., Sundblad, G., Casini, M., Kaljuste, O. & Eriksson, B. K. 2010. Recruitment failure of coastal predatory fish in the Baltic Sea is coincident with an offshore system shift. ICES Journal of Marine Science 67, 1587-1595.

Lotsari, E., Veijalainen, N., Alho, P. & Käyhkö, J. 2010. Impact of climate change on future discharges and flow characteristics of the Tana River, sub-Arctic northern Fennoscandia. Geografiska Annaler A, 92:263-284.

Luke. 2021. Statistics database. Fishery and game statistics: commercial marine fishery. Database of Natural Resources Institute Finland. Retrieved 8.8.2021 from https://statdb.luke.fi/PXWeb/pxweb/en/LUKE/LUKE__06%20Kala%20ja%20riista__02%20Rakenne%20ja%20tuotanto__02%20Kaupallinen%20kalastus%20merella/

Lundberg, C. & Nilsson, T. 2018. Exploatering av stränder 2013 – 2018. Jämförande statistik på läns- och kommunnivå. Länsstyrelsens rapportserie nr. 15/2018.

Länsstyrelsen Västernorrland. 2019. Underlag för kust- och havsplanering, Örnsköldsviks kommun och Kramfors kommun, p. 95.

MA. 2005. Millennium Ecosystem Assessment. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC.

MacKenzie, B. R., Gislason, H., Möllmann, C. & Köster, F. W. 2007. Impact of 21st century climate change on the Baltic Sea fish community and fisheries. Global Change Biology, 13(7), 1348-1367.

Madsen, J. D., Chambers, P. A., James, W. F., Koch, E. W. & Westlake, D. F. 2001. The interaction between water movement, sediment dynamics and submersed macrophytes. Hydrobiologia, 444(1), 71-84.

Maes, J., Liquete, C., Teller, A., Erhard, M., Paracchini, M. L., Barredo, J. I., Grizzetti, B., Gardoso, A., Somma, F., Petersen, J-E., Meiner, A., Gelabert, E. R., Zal, N., Kristensen, P., Bastrup-Birk, A., Biala, K., Piroddi, C., Egoh, B. & Lavalle, C. 2016. An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020. Ecosystem services, 17, 14-23.

Maes, J., Fabrega, N., Zulian, G. et al. 2015. Mapping and assessment of ecosystems and their services: trends in ecosystems and ecosystem services in the European Union between 2000 and 2010. Publications Office of the European Union, Luxembourg.

Marbà, N., Arias-Ortiz, A., Masqué, P., Kendrick, G. A., Mazarrasa, I., Bastyan, G. R. & Duarte, C. M. 2015. Impact of seagrass loss and subsequent revegetation on carbon sequestration and stocks. Journal of ecology, 103(2), 296-302.

Mazur-Marzec, H., Błaszczyk, A., Felczykowska, A., Hohlfeld, N., Kobos, J., Toruńska-Sitarz, A. & Węgrzyn, G. 2015. Baltic cyanobacteria –a source of biologically active compounds. European Journal of Phycology, 50(3), 343-360.

Meier, H. M., Müller-Karulis, B., Andersson, H. C., Dieterich, C., Eilola, K., Gustafsson, B. G. & Schimanke, S. 2012. Impact of climate change on ecological quality indicators and biogeochemical fluxes in the Baltic Sea: a multi-model ensemble study. Ambio, 41(6), 558-573.

Meier, H. E. M., Hordoir, R., Andersson, H.C., Dieterich, C., Eilola, K., Gustafsson, B.G., Höglund, A & Schimanke, S. 2012. Modeling the combined impact of changing climate and changing nutrient loads on the Baltic Sea environment in an ensemble of transient simulations for 1961–2099. Climate Dynamics 39, 2421–2441.

Merino, G., Barange, M., Blanchard, J. L., Harle, J., Holmes, R., Allen, I. & Rodwell, L. D. 2012. Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate? Global Environmental Change, 22(4), 795-806.

Mikkola, R., Bäck, A., Saarinen, A., Haapamäki, J. & Berglund J. 2019. Kvarkens flador och deras tillstånd. Analys av mänsklig påverkan utifrån flygbilder och resultat av vegetationskarteringar i 74 flador. Kvarken Flada, Interreg Botnia-Atlantica.

Miller, K. M., Teffer, A., Tucker, S., Li, S., Schulze, A. D., Trudel, M. & Hinch, S. G. 2014. Infectious disease, shifting climates, and opportunistic predators: cumulative factors potentially impacting wild salmon declines. Evolutionary Applications, 7(7), 812-855.

MMM. 2015. Kansallinen lohi- ja meritaimenstrategia 2020 Itämeren alueelle. Maa- ja metsätalousministeriö, Ministry of Agriculture and Forestry of Finland.

Munro, M. H., Blunt, J. W., Dumdei, E. J., Hickford, S. J., Lill, R. E., Li, S. & Duckworth, A. R. 1999. The discovery and development of marine compounds with pharmaceutical potential. Progress in Industrial Microbiology, 35, 15-25.

Natura 2000 Data Form. 2018. Natura 2000 tietolomake - data form. Merenkurkun saaristo - Kvarken archipelago, area code FI0800130.

Naturvårdsverket. 2011. Vägledning för 1150 laguner. Beskrivning av naturtypen.

Navenhand, J.N. 2012. How will ocean acidification affect Baltic Sea evosystems? An assessment of plausible impacts on key functional groups. AMBIO. 41. 637-644.

Naylor, R. L., Goldburg, R. J., Mooney, H., Beveridge, M., Clay, J., Folke, C. & Williams, M. 1998. Nature's subsidies to shrimp and salmon farming. Science, Vol. 282, Issue 5390: 883-884.

Neumann, T. & Friedland, R. 2011. Climate change impacts on the Baltic Sea. Global change and Baltic coastal zones. Springer, Dordrecht, 23-32.

Neumann, T. 2010. Climate-change effects on the Baltic Sea ecosystem: A model study. Journal of Marine Systems, 81(3), 213-224.

Nilsson, J., Flink, H. & Tibblin, P. 2019. Predator–prey role reversal may impair the recovery of declining pike populations. Journal of Animal Ecology, 88(6), 927-939.

Occhipinti-Ambrogi, A. 2007. Global change and marine communities: alien species and climate change. Marine pollution bulletin, 55(7-9), 342-352.

OECD. 2018. OECD Tourism Trends and Policies 2018. OECD Publishing, Paris.

Ojaveer, H., Jaanus, A., MacKenzie, B. R., Martin, G., Olenin, S., Radziejewska, T., Telesh, I., Zettler, M. & Zaiko, A. 2010. Status of biodiversity in the Baltic Sea. PLoS one, 5(9).

Ollqvist, S. & Överholm, N. 2010. Yhteinen maailmanperintömme - Vårt gemensamma världsarv. Metsähallitus, Vantaa.

Olsson, J., Tomczak, M. T., Ojaveer, H., Gårdmark, A., Pollumäe, A., Müller-Karulis, B. & Bergström, L. 2015. Temporal development of coastal ecosystems in the Baltic Sea over the past two decades. ICES Journal of Marine Science, 72(9), 2539-2548.

Paczkowska, J., Brugel, S., Rowe, O., Lefébure, R., Brutemark, A. & Andersson, A. 2020. Response of coastal phytoplankton to high inflows of terrestrial matter. Frontiers in Marine Science, 7, 80.

Palumbi, S., Sandifer, P., Allan, J., Beck, M., Fautin, D., Fogarty, M., Halpern, B., Incze, L., Leong, J-A., Norse, E., Stachowicz, J. & Wall, D. 2009. Managing for ocean biodiversity to sustain marine ecosystem services. Frontiers in Ecology and the Environment, 7(4), 204-211.

Pankhurst, N. W. & Munday, P. L. 2011. Effects of climate change on fish reproduction and early life history stages. Marine and Freshwater Research, 62(9), 1015-1026.

Paerl, H. W. & Huisman, J. 2009. Climate change: a catalyst for global expansion of harmful cyanobacterial blooms. Environmental microbiology reports, 1(1), 27-37.

Pekcan-Hekim, Z., Urho, L., Auvinen, H., Heikinheimo, O., Lappalainen, J., Raitaniemi, J. & Söderkultalahti, P. 2011. Climate warming and pikeperch year-class catches in the Baltic Sea. Ambio, 40(5), 447-456.

Perez-Alvaro, E. 2016. Climate change and underwater cultural heritage: Impacts and challenges. Journal of Cultural Heritage, 21, 842-848.

Peterson, G., Allen, C. R., & Holling, C. S. 1998. Ecological resilience, biodiversity, and scale. Ecosystems, 1(1), 6-18.

Petersson, E., Degerman, E. & Axén, C. 2018. Översikt, riskbedömning och förslag på åtgärder för puckellax (Oncorhynchus gorbuscha). Aqua Reports 2018:17. SLU.

Poutanen, M. & Steffen, H. 2014. Land uplift at Kvarken Archipelago /High Coast UNESCO world heritage area. Geophysica. 50(2). 49-64

Pörtner, H.O., Scholes, R.J., Agard, J., Archer, E., Arneth, A., Bai, X., Barnes, D., Burrows, M., Chan, L., Cheung, W.L., Diamond, S., Donatti, C., Duarte, C., Eisenhauer, N., Foden, W., Gasalla, M. A., Handa, C., Hickler, T., Hoegh-Guldberg, O., Ichii, K., Jacob, U., Insarov, G., Kiessling, W., Leadley, P., Leemans, R., Levin, L., Lim, M., Maharaj, S., Managi, S., Marquet, P. A., McElwee, P., Midgley, G., Oberdorff, T., Obura, D., Osman, E., Pandit, R., Pascual, U., Pires, A. P. F., Popp, A., ReyesGarcía, V., Sankaran, M., Settele, J., Shin, Y. J., Sintayehu, D. W., Smith, P., Steiner, N., Strassburg, B., Sukumar, R., Trisos, C., Val, A.L., Wu, J., Aldrian, E., Parmesan, C., Pichs-Madruga, R., Roberts, D.C., Rogers, A.D., Díaz, S., Fischer, M., Hashimoto, S., Lavorel, S., Wu, N., Ngo, H.T. 2021. IPBES-IPCC co-sponsored workshop report on biodiversity and climate change; IPBES and IPCC.

Richards, G. 1996. Cultural tourism in Europe. Cab International.

Rinkineva, L. & Bader, P. 1998. Chapter 2.3 Den marina miljön in Kvarkens natur. Kvarkenrådets publikationer 10.

Rolff, C. & Elfwing, T. 2015. Increasing nitrogen limitation in the Bothnian Sea, potentially caused by inflow of phosphate-rich water from the Baltic Proper. Ambio, 44(7), 601-611.

Rugiu, L., Manninen, I., Rothäusler, E. & Jormalainen V. 2018. Tolerance to climate change of the clonally reproducing endemic Baltic seaweed Fucus radicans: is phenotypic plasticity enough?. Journal of Phycology. 54(6).888-898

Ruosteenoja, K., Jylhä, K. & Kämäräinen M. 2016. Climate projections for Finland under the RCP forcing scenarios. Geophysica. 51(1). 17-50

Sabbioni, C., Cassar, M., Brimblecombe, P. & Lefevre, R. A. 2008. Vulnerability of cultural heritage to climate change. EUR-OPA major hazards agreement, Council of Europe November.

Saraiva, S., Meier, H. M., Andersson, H., Höglund, A., Dieterich, C., Gröger, M. & Eilola, K. 2019. Baltic Sea ecosystem response to various nutrient load scenarios in present and future climates. Climate Dynamics, 52(5), 3369-3387.

SeaGIS2.0. Map portal. SeaGIS 2.0 -project, Interreg Botnia-Atlantica. Retrieved year 2021 from https://seagis.org/internt/.

SLU. 2020. Artdatabanken, Rödlistade arter i Sverige 2020. SLU, Uppsala.

SmartSea. 2018a. Tietolaatikot: Tulevaisuuden Pohjanlahti; Silakan kalastus. Information box: herring fishing. Retrieved 10.12.2021 from http://smartsea.fmi.fi/app/uploads/2018/09/tietoiskut-SilakanKalastus.pdf.

SmartSea. 2018b. Tietolaatikot: Tulevaisuuden Pohjanlahti; Aallokko. Information box: Future Gulf of Bothnia; Wave action. Retrieved 14.10.2021 from http://smartsea.fmi.fi/tulevaisuuden-pohjanlahti/

SMHI. 2021a. Klimatscenarier. Retrieved 10.6.2021 from: https://www.smhi.se/klimat/framtidens-klimat/klimatscenarier/sweden/nation/rcp85/year/temperature

SMHI. 2021b. SHARKweb data. Datavärdskap oceanografi och marinbiologi. Retrieved 6.7.2021 from https://www.smhi.se/data/oceanografi/datavardskap-oceanografi-och-marinbiologi/sharkweb

Snickars, M., Sundblad, G., Sandström, A., Ljunggren, L., Bergström, U., Johansson, G. & Mattila, J. 2010. Habitat selectivity of substrate-spawning fish: modelling requirements for the Eurasian perch Perca fluviatilis. Marine Ecology Progress Series, 398, 235-243.

Snoeijs-Leijonmalm, P. & Andrén, E. 2017. Why is the Baltic Sea so special to live in? In Biological oceanography of the Baltic Sea (pp. 23-84). Springer, Dordrecht.

Sonnenborg, T. O. 2015. Projected change—hydrology. Second assessment of climate change for the Baltic Sea Basin, 235-241.

Stal, L. J., Albertano, P., Bergman, B., von Bröckel, K., Gallon, J. R., Hayes, P. K. & Walsby, A. E. 2003. BASIC: Baltic Sea cyanobacteria. An investigation of the structure and dynamics of water blooms of cyanobacteria in the Baltic Sea—responses to a changing environment. Continental Shelf Research, 23(17-19), 1695-1714.

Stapanian, M. A., Paragamian, V. L., Madenjian, C. P., Jackson, J. R., Lappalainen, J., Evenson, M. J. & Neufeld, M. D. 2010. Worldwide status of burbot and conservation measures. Fish and fisheries, 11(1), 34-56.

Sundblad, G. & Bergström, U. 2014. Shoreline development and degradation of coastal fish reproduction habitats. Ambio, 43(8), 1020-1028.

Sundblad, G., Bergström, U., Sandström, A. & Eklöv, P. 2014. Nursery habitat availability limits adult stock sizes of predatory coastal fish. ICES Journal of Marine Science, 71(3), 672-680.

Sundström, T. & Olsson, C. 2005. Västerbottens kustfågelfauna - Inventering av kustfågelbestånden 2001/2002. Meddelande 4, 2005. Länsstyrelsen Västerbotten.

SYKE. 2020. Vesikartta, vesientila - watermap, water body status. Data portal. Retrieved 20.5.2021 from http://paikkatieto.ymparisto.fi/vesikarttaviewers/Html5Viewer_2_5_2/Index.html?configBase=http://paikkatieto.ymparisto.fi/Geocortex/Essentials/REST/sites/Vesikartta/viewers/VesikarttaHTML525/virtualdirectory/Resources/Config/Default

Söderqvist, T., Hasselström, L., Soutukorva, Å., Cole, S. & Malmaeus, M. 2012. An ecosystem service approach for analyzing marine human activities in Sweden: A synthesis for the Economic and Social Analysis of the Initial Assessment of the Marine Strategy Framework Directive.

Tegeback, A. & Hasselström, L. 2012. Costs associated with a major oil spill in the Baltic Sea. Report of Baltic Master II–project.

Thorburn, A. 1986. Marketing cultural heritage. Does it work within Europe? Travel & Tourism Analyst, 39-48.

UN. 2010. World Population Prospects: The 2010 Revision. Department of Economic and Social Affairs. Population Division, New York.

UNESCO. 2021. United Nations Educational, Scientific and Cultural Organization. World Heritage Convention. High Coast / Kvarken Archipelago. Retrieved 31.5.2021 from: https://whc.unesco.org/en/list/898/

Urban, M. C. 2015. Accelerating extinction risk from climate change. Science 348, 571–573.

VELMU. 2020. The Finnish Inventory Programme for the Underwater Marine Environment (VELMU). VELMU-data, Finnish Environment Institute SYKE, Marine center.

Veneranta, L., Hudd, R. & Vanhatalo, J. 2013. Reproduction areas of sea-spawning coregonids reflect the environment in shallow coastal waters. Marine Ecology Progress Series, 477, 231-250.

Viitasalo, M. & Bonsdorff, E. 2021. Global climate change and the Baltic Sea ecosystem: direct and indirect effects on species, communities and ecosystem functioning. Earth System Dynamics Discussions, 1-38.

Viitasalo, M., Kostamo, K., Hallanaro, E. L., Viljanmaa, W., Kiviluoto, S., Ekebom, J. & Blankett, P. 2017. Meren aarteet: löytöretki Suomen vedenalaiseen meriluontoon. Gaudeamus, 518.

Viitasalo, M., Blenckner, T., Gårdmark, A., Kaartokallio, H., Kautsky, L., Kuosa, H., Lindegren, M., Norkko, A., Olli, K. & Wikner, J. 2015. Environmental Impacts - Marine Ecosystems. In: The BACC II Author Team (eds) Second Assessment of Climate Change for the Baltic Sea Basin. Regional Climate Studies. Springer, Cham.

von Storch, H., Omstedt, A., Pawlak, J. & Reckermann, M. 2015. Introduction and Summary. Chapter 1. In: Second assessment of climate change for the Baltic Sea basin. The BACC II Author Team. Springer International Publishing, 1-22.

Wagner, C. & Adrian, R. 2009. Cyanobacteria dominance: quantifying the effects of climate change. Limnology and Oceanography, 54(6part2), 2460-2468.

Webb, C. T. 2007. What is the role of ecology in understanding ecosystem resilience? BioScience, 57(6), 470-471.

Wedin, M. & Röschmann, G. 2014. Skärgårdsguide Höga Kusten. Örnsköldsviks kommun. Ednas Print

White, S., Ten Brink, P., Hayashi, K., Liekens, I., Ninan, K., Meire, P. & Wielgus, J. 2011. Recognizing the value of biodiversity: new approaches to policy assessment. The Economics of Ecosystems and Biodiversity (TEEB) in National and International Policy Making. Earthscan, London.

Winfield, I. J. 2004. Fish in the littoral zone: ecology, threats and management. Limnologica, 34(1-2), 124-131.

Worm, B., Barbier, E. B., Beaumont, N., Duffy, J. E., Folke, C., Halpern, B. S. & Watson, R. 2006. Impacts of biodiversity loss on ocean ecosystem services. science, 314(5800), 787-790.

YM. 2016. Ympäristöministeriö, Ministry of the Environment (Finland). Suomen merenhoitosuunnitelman toimenpideohjelma 2016–2021. Ympäristöministeriön raportteja, 5.

YM. 2020. Ympäristöministeriö, Ministry of the Environment (Finland). Suomen merenhoitosuunnitelman seurantaohjelma vuosille 2020–2026.

Zander, C. D., Rupp, K., Böhme, K., Brix, S., Detloff, K. C., Melander, J, Nordhaus, I. & Schiro, C. 2015. The phytal fauna of the SW Baltic Sea and its importance as reservoir for fish prey - Die Phytalfauna der SW-Ostsee und ihre Bedeutung als Reservoir von Fischnahrung. Bulletin of Fish Biology, 15(1/2), 33-51.

Zdun, A., Stoń-Egiert, J., Ficek, D. & Ostrowska, M. 2021. Seasonal and Spatial Changes of Primary Production in the Baltic Sea (Europe) Based on in situ Measurements in the Period of 1993–2018. Frontiers in Marine Science.

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