Baltic Sea Coast - Conservation of coastal seaweeds, seagrasses, invertebrates and fish in the north-east Baltic Sea

Storyline 7

NBS 2 EFFECTIVE CONSERVATION

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Introduction

The EU Horizon project FutureMARES (2020-2024) was designed to develop science-based advice on socially and economically viable actions and strategies to safeguard biodiversity and ecosystem functions to maximise natural capital and its delivery of services from marine and transitional ecosystems in a future climate. The program investigates effective habitat restoration, conservation strategies and sustainable harvesting at locations across a broad range of European and other marine and transitional systems. The restoration of habitat-forming species (plants or animals) and habitat conservation (e.g. marine protected areas, MPAs) represent two nature-based solutions (NBS) defined by the EU as "resource efficient actions inspired or supported by nature to simultaneously provide environmental, social and economic benefits that help to build resilience to change". A third action that will interact with these two NBS and have positive effects on marine biodiversity is nature-inclusive harvesting (NIH) such as the sustainable farming of plants and animals at the base of marine food webs and ecosystem-based management practices for traditional (artisanal) and commercial fisheries. FutureMARES will advance the state-of-the-art forecasting capability for species of high conservation value, explore new and less carbon intensive aquaculture production methods, perform modelling analyses geared towards informing the development of climate-smart marine spatial planning approaches, and provide an assessment of ecosystem services based on scenarios of climate change and the implementation of NBS and NIH.

This document provides a multi-disciplinary summary of activities conducted in FutureMARES in a specific area on specific NBS and/or NIH. The activities include work across various disciplines including marine ecology (analyses of historical time series and experiments performed in the field and laboratory), climate change projection modelling (future physical, biogeochemical and ecological changes), economic analyses, social-ecological risk assessments. Many of these components and analyses, including NBS / NIH scenarios tested, were co-developed with local and regional stakeholders through regular engagement activities. The work presented in these Storylines represent activities conducted by a large number of FutureMARES project partners. Broader comparisons and syntheses (across regions and/or topics) are provided in the FutureMARES deliverable reports (www.futuremares.eu) submitted to the European Commission.

Introduction & NBS regional context

The north-east Baltic Sea (NEBS) is a brackish water sea area surrounded by Finland, Sweden, Estonia and Russia. The area is dense in human activities, including maritime traffic, fisheries, aquaculture, coastal construction, and active leisure usage. The NEBS is also heavily burdened by loading of both harmful substances from the industry and nutrient loading from agriculture and forestry and also via air.

The current ecological status of the NEBS varies with area but is usually considered poor or mediocre (HELCOM 2018). The Gulf of Bothnia is generally in a better condition than the Gulf of Finland or the Archipelago Sea, where the inner archipelago areas are most eutrophicated, with murky waters and large cyanobacteria blooms. The reasons are internal nutrient loading and transported nutrient loads from the main Baltic Sea basins. Consequently, hypoxia has been increasing in the past decades (Conley et al. 2011), inducing internal loading of nutrients from sediments and causing “a vicious circle of eutrophication” (Vahtera et al. 2007). Major changes have also taken place in the structure of offshore ecosystems, suggesting a “regime shift", potentially caused by long-term decline in salinity and increase in temperature, and by anthropogenic eutrophication (Casini et al. 2008, Möllmann et al. 2009).

The status of the coastal sublittoral habitats has long been deteriorating, with poor water clarity and slimy filamentous algae covering most surfaces, causing declines in key habitat forming species, such as the brown alga bladderwrack (*Fucus vesiculosus*) and eelgrass (*Zostera marina*) (Olsson et al. 2015, Sahla et al. 2020). There are also areas where the communities are in good condition and do, at present, support high primary and secondary productivity (Fig. 1). Not much is known of the long-term trends of invertebrate and fish fauna associated with these algae, but as they are hotspots for diversity (Wikström & Kautsky 2007; Norling & Kautsky 2008), it can be assumed that a decline of key reproductive and feeding habitat may cause declines in these species as well (Kotta et al. 2019). On the other hand, the environmental changes have favoured certain coastal fish species, such as pikeperch and cyprinids, that seem to thrive in eutrophic conditions (Pekcan-Hekim et al. 2011, Bergstrom et al. 2016).

Storylines (5 & 7) are using the Finnish sea area (ca. 83.000 km^2) to exemplify effects of climate change on marine nature in NEBS. Finland is well positioned to do so, because of the existing spatially explicit data on species and habitats (ca. 170.000 observations on species and habitats collected by VELMU - the Finnish Inventory Programme for Underwater Marine Diversity), the long-term monitoring data, and extensive information on human pressures. Scenarios on future environmental conditions are also available through published research using coupled oceanographic – biogeochemical models. The research in storylines 5 and 7 focus on shallow water communities, formed by key habitat forming algae, seagrasses, vascular plants, and the invertebrates and fish these are inhabited by.

The success of all nature-based solutions (NBS), such as restoration (NBS #1) and conservation (NBS #2) are strongly dependent and need to take into account the current status and trends of key habitat-forming species. Also, sustainable harvesting (NBS #3) is only possible in a situation where the target populations can withstand the planned harvesting, and when harvesting has positive effects on other populations.

Figure 1. Healthy algal communities provide food, shelter and reproduction area for a large number of other species, including invertebrates and fish. A functional ecosystem provides various provisioning, supporting, regulating and cultural ecosystem services for humans. Photo: Mats Westerbom.

Projected impacts of climate change

Observations made across recent decades indicate that the Baltic Sea has warmed significantly more rapidly than the world ocean, and especially the winter temperatures and ice conditions have become milder than 50 years ago. Salinity has fluctuated with long-term variations in fresh water runoff from the watershed of the NEBS (Lehmann et al. 2021). Climate change will induce changes in basic characteristics of the Baltic Sea: temperature and nutrients will increase, salinity will probably decline, and hypoxia may become more frequent (Viitasalo & Bonsdorff 2021).

The basic oceanographic conditions of the NEBS respond to long-term changes in climatological parameters, especially the North Atlantic Oscillation (NAO) and the Baltic Sea Index (BSI), with low index values resulting in high precipitation and mild winters, and high values with larger contrasts between summer and winter (Meier et al. 2021). It is projected that warming will be strongest in the NEBS, and that conditions that resemble those of high NAO, i.e., mild winters with high freshwater runoff will become more common in the NEBS (Lehmann et al. 2021). Also, with increasing dissolving of CO_2 in water, the seawater has gradually become more acidic, which may have consequences on species sensitive to low pH. These high NAO conditions have been projected to induce more nutrient inputs into the sea (Räike et al. 2019), with potential consequences in the eutrophication status of the Baltic Sea, including NEBS. More cyanobacteria blooms have commonly been projected, at least for the southern parts of NEBS (Meier et al. 2011, Funkey et al. 2014), while increased flow of DOC may decline primary production in the Gulf of Bothnia (Wikner and Andersson 2012). Signs of eutrophication have however recently been detected in the Gulf of Bothnia, apparently caused by flow of deep-water nutrients from the central Baltic reaching the Bothnian Sea through the Åland Sea (Ahlgren et al. 2017).

Climate change has also been projected to alter conditions for algae, seagrasses, invertebrates and fish in the region. Range shifts of marine species have been predicted for bladderwrack and certain red algae, eelgrass and blue mussel, and up to 50 other accompanying species (Vuorinen et al. 2015, Torn et al. 2020). Species distribution modelling studies have suggested that the decrease of bladderwrack may cause large effects on the biodiversity and functioning of the shallow water communities of the northern Baltic Sea (Jonsson et al. 2018, Kotta et al. 2019). Furthermore, ocean acidification (OA) has various effects on benthic invertebrates. For instance, OA has been predicted to induce a developmental delay in the bivalve species dominating the coastal soft sediments, Baltic clam (Jansson et al. 2016).

The processes also vary spatially. In areas previously burdened by hypoxia, benthic biomass has been projected to increase (until 2100) by up to 200% after re-oxygenating bottom waters, whereas in permanently oxygenated areas macrofauna will decrease by 35% due to lowered food supply to the benthic ecosystem (Timmermann et al. 2012). It can also be expected that the shallow lagoons and bays will be most rapidly altered due to increasing temperature. Moreover, inner archipelago areas with reduced water exchange are the most prone to hypoxia (Virtanen et al. 2018a), and hence may be burdened by increasing internal loading.

There are a number of uncertainties in projections. In particular, there are still uncertainties in projecting the future salinity level as well as stratification under different climate forcing. One of the reasons is the complex interplay between salinity pulses and river runoff, and another one the lack of small-scale projections in fragmented seascapes. This weakens our ability to project the resultant changes in species, including algae, seagrasses, invertebrates and coastal fish. While the climate induced changes in oceanography and biogeochemistry directly affect the algae, seagrasses, invertebrates and fish in NEBS, the biological responses also depend on human intervention, i.e. success of nutrient reduction schemes, and nature-based solutions, especially changes in fishing pressure (Hyytiäinen et al. 2019, Ehrnsten et al. 2020) as well as level of conservation (Virtanen et al. 2018b).

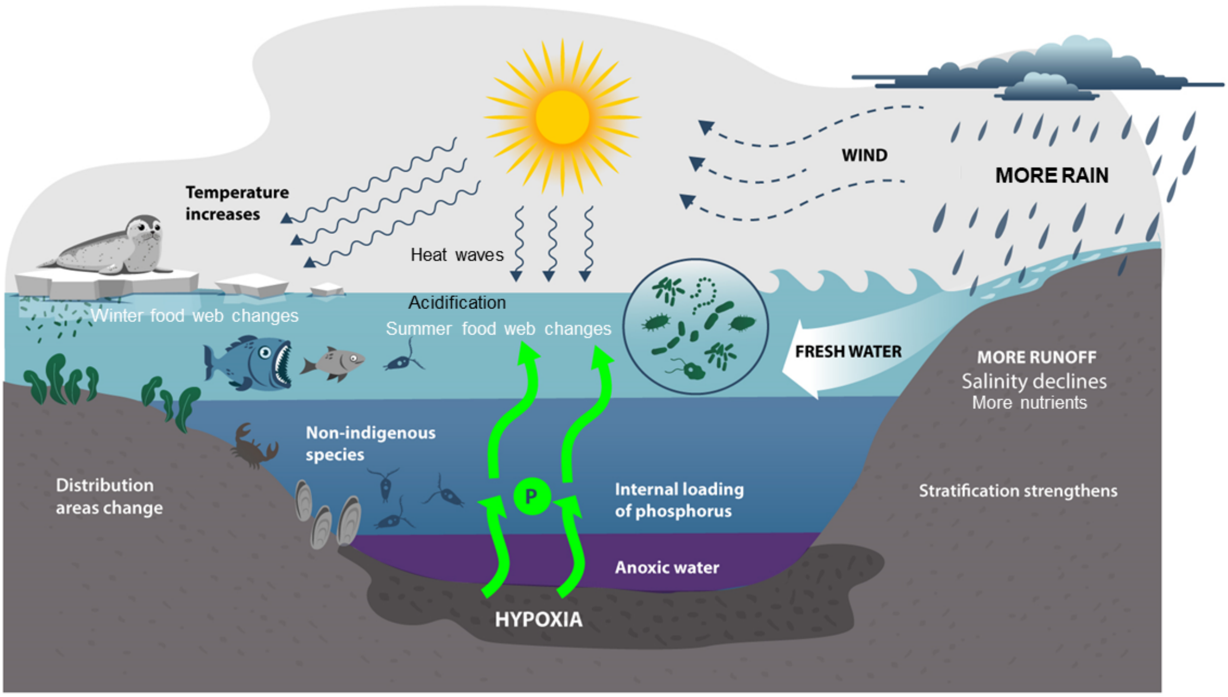


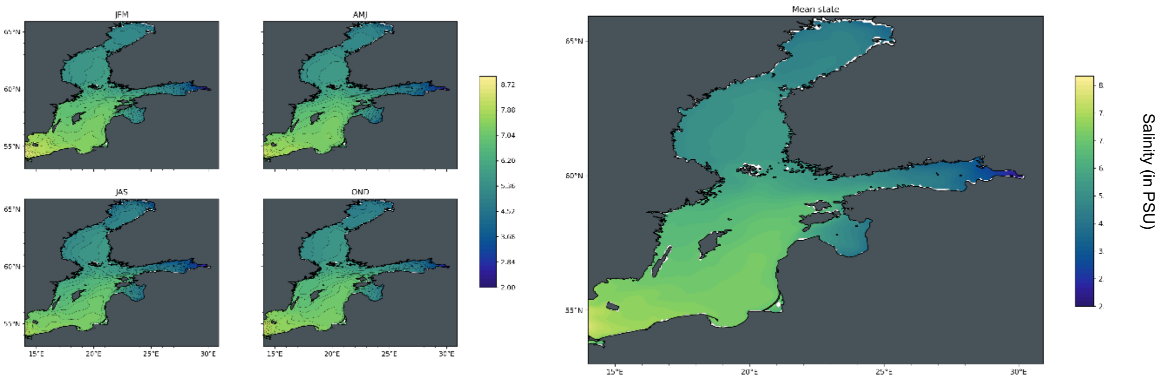
Figure 2. A schematic presentation of the effects of climate change on the Baltic Sea ecosystem. Illustration: Markku Viitasalo & Marianna Korpi, SYKE

The figures were produced using trend preserving statistical downscaling (Lange, 2019) of a multi-model ensemble Earth System Model historical simulations and future projections from the CMIP6 archive trained on reanalysis datasets from the Copernicus Marine Environment Monitoring Service.

Geographical Maps were extracted from the full dataset by averaging over the following periods, consistent with the periods considered in the IPCC AR6 WG1 report:

- present day: 1995-2014
- near future: 2021-2040
- mid future: 2041-2060
- far future: 2080-2099

Time-series plots were produced averaging over the area of interest for each storyline and show the ensemble mean in the full lines and the range of model responses in the shaded areas as represented by the 2.5 and 97.5 percentiles of the ensemble. Credit: Momme Butenschön, Euro-Mediterranean Center on Climate Change.



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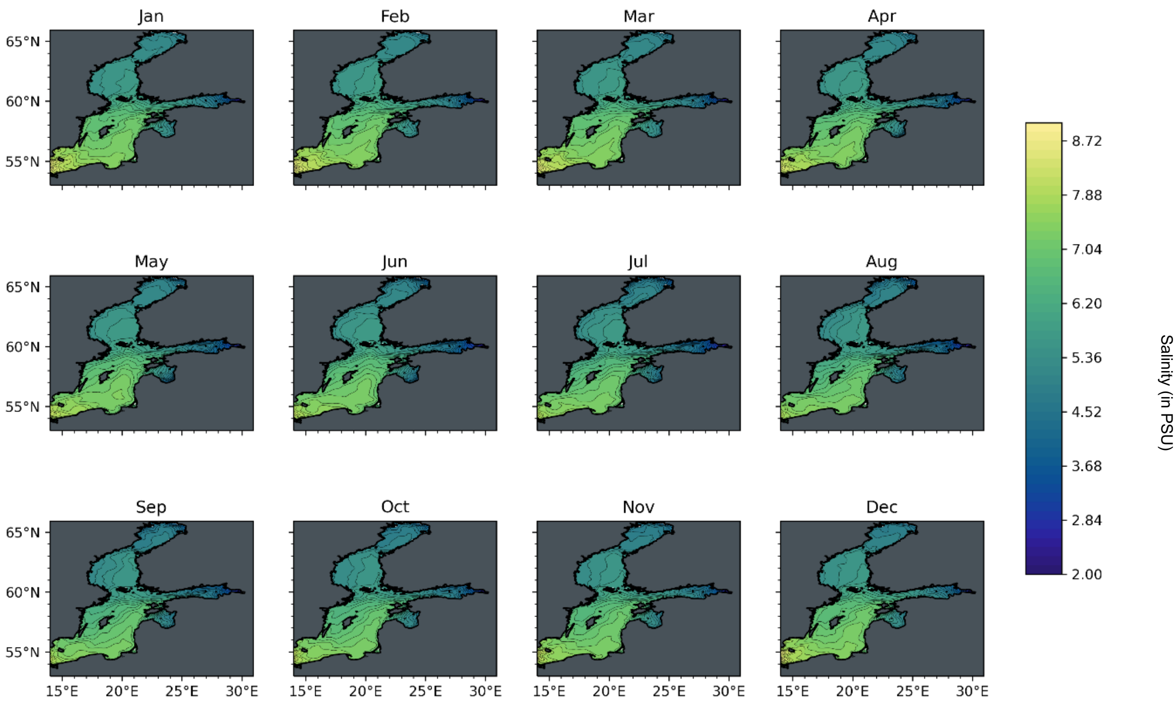

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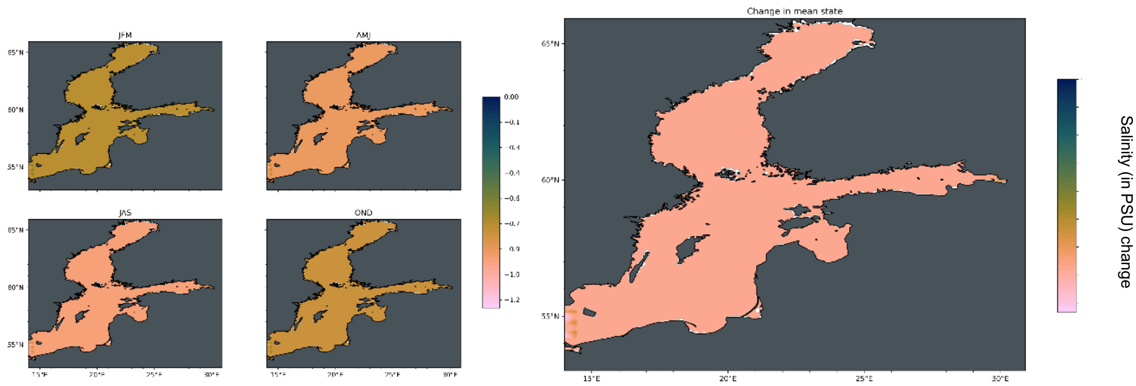

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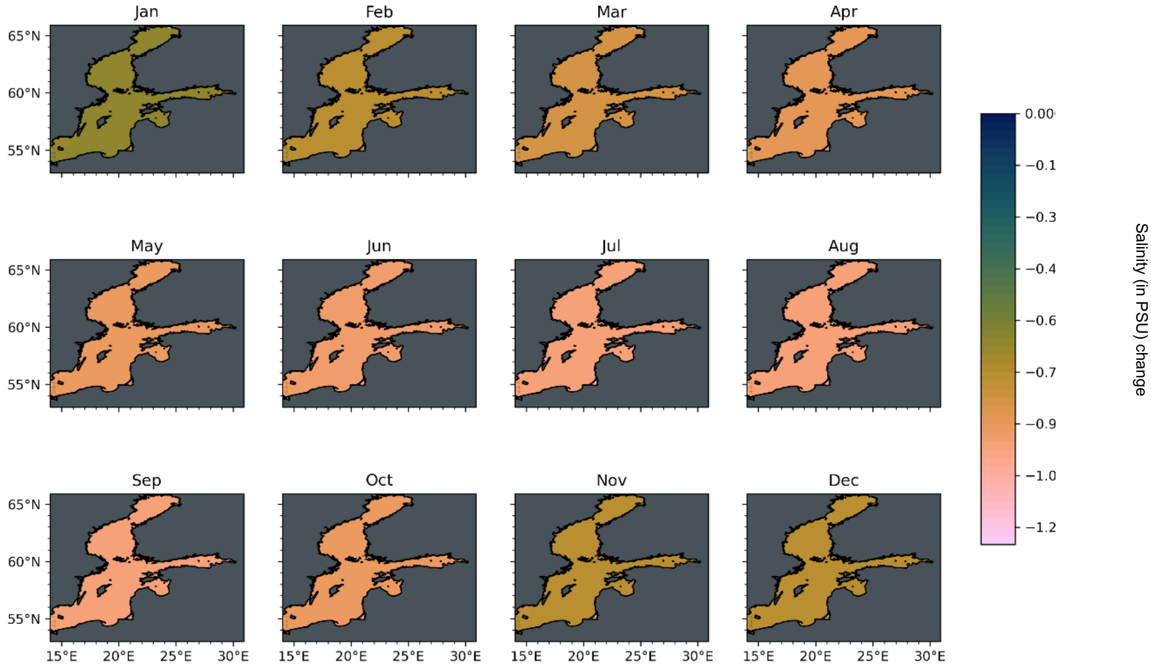

Figure 3: Top: Salinity (in PSU) at 5m depth under present day conditions **Bottom:** Salinity (in PSU) changes in the far future at 5m depth (under scenario SSP5-8.5). Credit: Momme Butenschön, Euro-Mediterranean Center on Climate Change

Scenarios describing future society and economy

FutureMARES will develop policy-relevant scenarios based on commonly used IPCC frameworks including SSPs and RCPs (Fig. 3). These broad scenarios are regionalised based on stakeholder perspectives to guide activities such as model simulations in specific Storylines. Each of these scenarios has implications for the three NBS examined in this program (effective restoration, effective conservation, sustainable seafood harvesting):

Global Sustainability (SSP126) - Low challenges to mitigation and adaptation

The world shifts gradually but pervasively to a more sustainable path, emphasising inclusive development that respects perceived environmental boundaries. Management of the global commons slowly improves, investments in educational and health accelerate lower birth and death rates, and the emphasis on economic growth shifts to an emphasis on human well-being. Societies increasingly commit to achieving development goals and this reduces inequality across and within countries. Consumption is oriented toward lower material growth, resource and energy intensity.

National Enterprise (SSP385) - High challenges to mitigation and adaptation

A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to focus on domestic or regional issues. Policies shift over time to be oriented more on national and regional security. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialised countries and high in developing ones. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions.

World Markets (SSP585) - High challenges to mitigation, low challenges to adaptation

The world increasingly believes in competitive markets, innovation and participatory societies to produce rapid technological progress and train and educate people for sustainable development. Global markets become more integrated and strong investments in health, education, and institutions are made to enhance human and social capital. The push for economic and social development is coupled with exploiting abundant fossil fuel resources and adopting resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy, while global population peaks and declines in the 21st century. Local environmental problems like air pollution are successfully managed. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary.

Figure 4: Representation of three, broad scenarios to be regionalised to guide activities such as model simulations in FutureMARES project. © FutureMARES

FutureMARES research needs

Research is needed to understand how future changes in temperature, salinity and nutrients impact the abundance and geographic distribution of key species, including algae, seagrasses, vascular plants, invertebrates and coastal fish. Such species, and habitats they form, provide a large array of ecosystem services for humans. Research is needed to better understand ecological gaps in the MPA design, and complement the geographical extent of MPAs in a way which considers climate change hotspots and refugia rich in biodiversity.

Research is needed to identify the ecosystem services that are under threat due to climate change in these shallow coastal waters in the NEBS that are rich in biodiversity as well as practical measures alongside MPAs needed to improve ecosystem health such as mitigation of eutrophication and sustainable use of the resources.

FutureMARES research (T = Task – see program structure at futuremares.eu)

- **T1.2** Functional traits of species in the NEBS will be collected and used to make more robust species distribution models and to analyse the risks of climate change to habitats and their ecosystem services.
- **T1.3** Indicators of ecosystem services for the NEBS will be chosen from a list of biodiversity, social and economic indicators that are responsive to climate change and related NBSs.
- **T2.1 & 2.3** Climate change hotspots and refugia will be identified based on projected changes in temperature, salinity and light availability using available downscaled (one to two nautical mile resolution) projections of coupled oceanographic-biogeochemical models for two time slices (2029-59 and 2069-99) combined with local trend analysis of changes in situ measurements from water monitoring stations in the NEBS;

- **T4.1** Following methods of Virtanen et al. (2018), the potential range shifts of species will be analysed based on species distribution models (SDMs) produced for various categories of species (most common and widespread, habitat-formers, threatened, rare, and non-indigenous invasive) (Fig. 4).
- **T 4.4** Projections of changes in food webs in the NEBS will be made based on Ecopath with Ecosim and Ecospace model in the Archipelago Sea. The model outputs will illustrate how the biomass of food web components (including fisheries catches) will change due to changes in eutrophication status and climate-related parameters.
- **T5.1, 5.2, 5.3** Relevant ecosystem service providers will be identified in the area (T 1.2 & T 1.3) and based on the modelled responses of species to climate change, risk to (i) areas, (ii) habitats and, also, (iii) ecosystem services will be assessed.
- **T6.1** Based on the projected range shifts of species, the functioning of the current MPA network will be re-assessed and a new proposal for climate-smart expansion of the existing MPA network ("Climate-smart blue parks") will be created based on quantitative conservation planning programme Zonation 5 (Moilanen et al. 2021);
- **T7.1** FutureMARES results will be discussed with relevant authorities and stakeholders, especially the ministry of the Environment of Finland, regional centres for Employment, transport and the Environment, and NGOs will be informed of results and engaged during the project.
- **T8.1** Engage local and regional stakeholders to co-create aspects of the FutureMARES program including regionalising NBS scenarios for NEBS MPAs to be tested and other knowledge gaps to be filled.

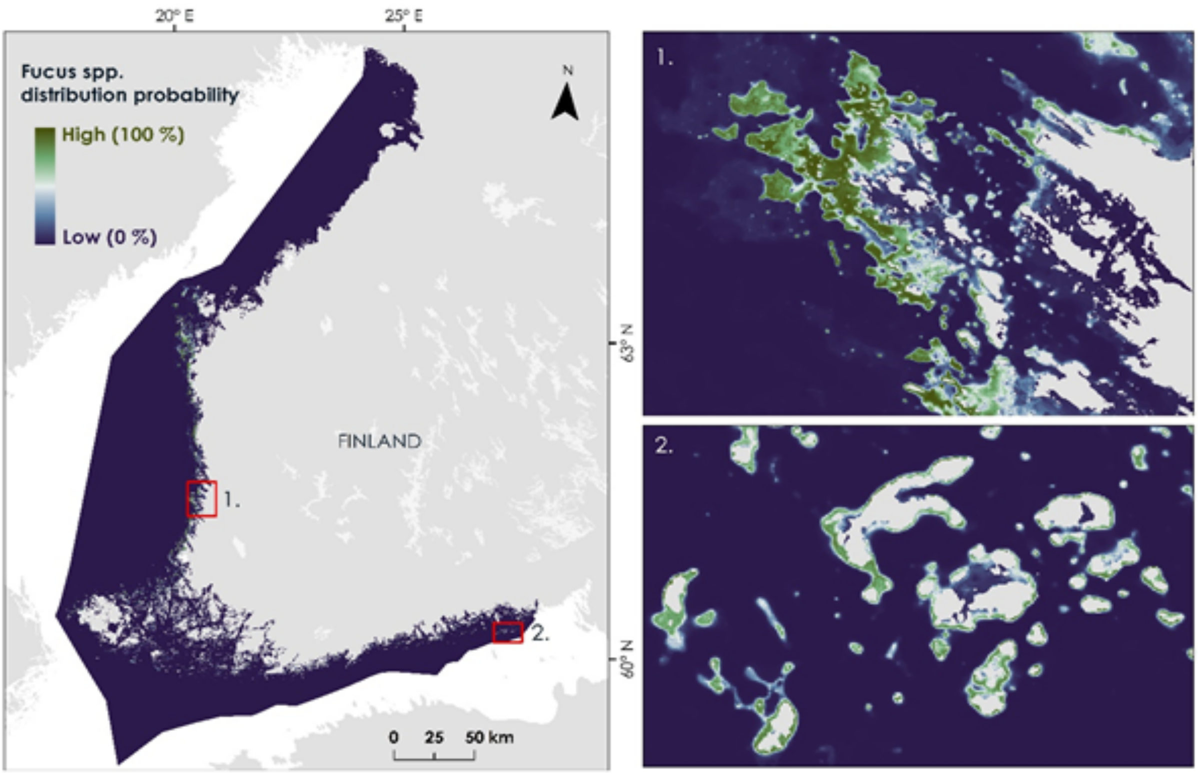

Figure 5. The distribution probability of a brown macroalgae, Fucus spp. for the whole coast of Finland. The distribution probability of Fucus spp. can be projected to future with changed environmental conditions, obtained either from relevant oceanographic-biogeochemical models, or from statistical trend analyses. Credit: Elina Virtanen, SYKE

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