D.T1.1.1. High-resolution maps on the intensity and extent of ecosystem services supply in the transnational pilot area

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Introduction

The benefits provided by ecosystems and biodiversity play an important role in ensuring the well-being of human societies. Thus, it is important to understand the ecosystems and their services in order to make informed decisions and guarantee the benefits for future generations. The Common International Classification of Ecosystem Services (CICES Classification, https://cices.eu/) divides ecosystem services into three broad categories: (1) provisioning services, which include, for example, food, drinking water, materials, energy; (2) regulating and maintenance services, which include, for example, climate regulation, water regulation and purification, air quality regulation, waste decomposition, habitat maintenance; and (3) cultural services, which include, for example, cultural diversity, aesthetic and spiritual values, recreation and education.

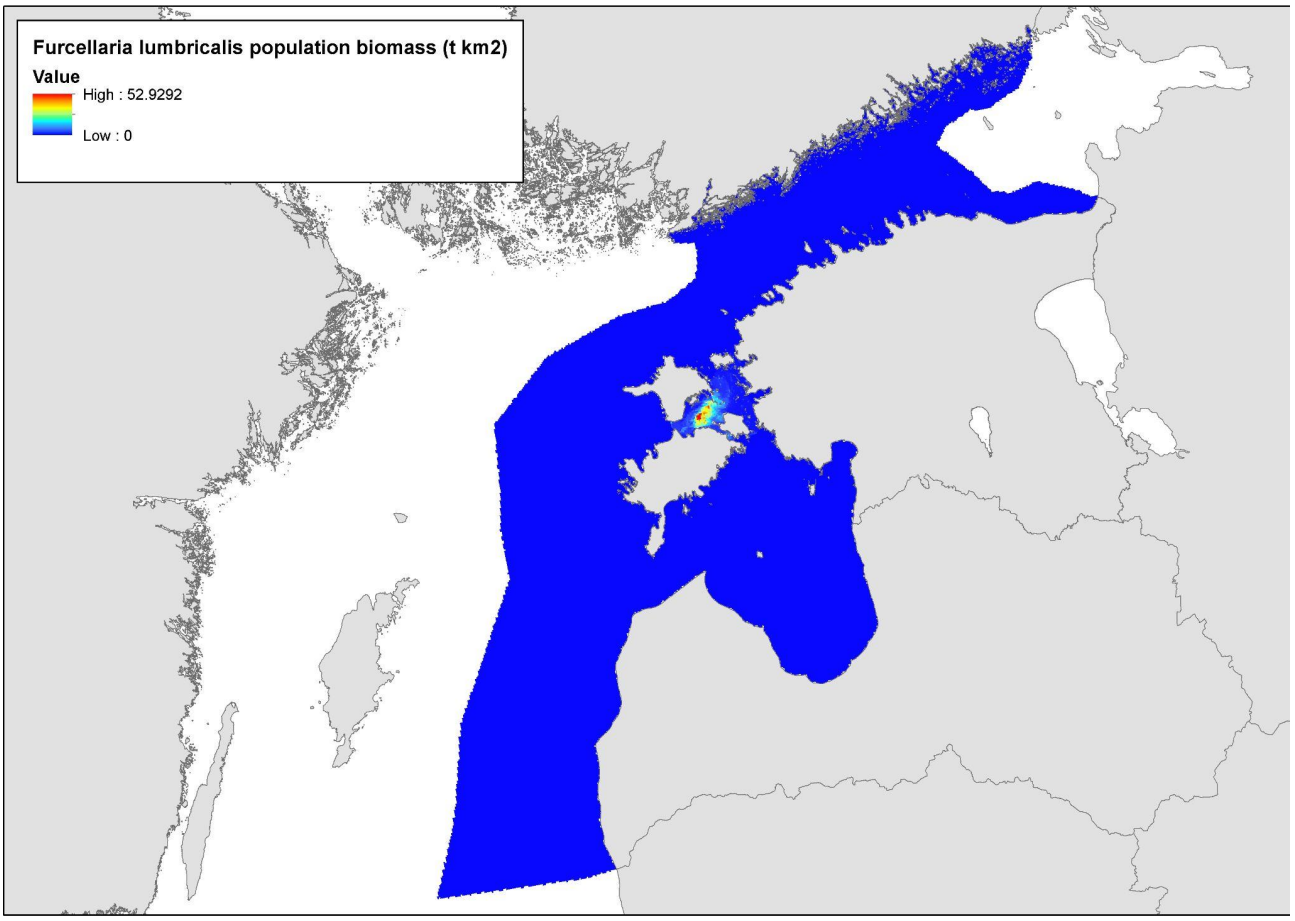
Mapping ecosystem services is essential if we want to allocate the use of different parts of the sea space and analyse conflicts between different human uses and the marine environment. We can also use such maps to assess the synergies and trade-offs between different ecosystem services and analyse potential impacts of different human use scenarios on these ecosystem services. The maps can be used to illustrate the spatial location of different natural assets and to explain to stakeholders the importance of ecosystem services for a sustainable development.

There are a wide variety of approaches to assessing the spatial distribution of ecosystem services. In this work, the main focus is on the development of spatial modelling techniques and indicators that directly assess the amount of natural values in the marine space that underlie ecosystem services and/or the intensities of the processes that define these services. Such an approach will result in maps that are a basis of the analysis that link natural processes, ecosystem services and anthropogenic pressures and, through these linkages, the prediction of the extent to which ecosystem services are realised in the marine space under different environmental settings and human use scenarios. The presented maps of ecosystem services will be published in the MAREA web portal (http://www.sea.ee/marea).

Provisioning services

Macroalgal harvesting

The red alga *Furcellaria lumbricalis* is one of the most common red algal species of the Baltic Sea region, and the species is found along almost the entire MAREA area. In the Baltic Sea, this algal species occurs in two forms - the attached and the detached or drifting form. The attached form is more common in the Baltic Sea. Currently, the drifting *F. lumbricalis* is found in the Estonian coastal waters only and its highest stocks are found in Kassari Bay. In this bay the species forms a distinct association with another red algal species *Coccotylus truncatus* and this two-species community is an important commercially exploited macroalgal species in the Baltic Sea region. Boosted Regression Trees (Elith et al., 2008) were used to model the relationship between macroalgal standing stock and different environmental variables and then this model was used to predict the spatial pattern of the drifting *F. lumbricalis* biomass.



Low trophic aquaculture: Macroalgal and mussel farming

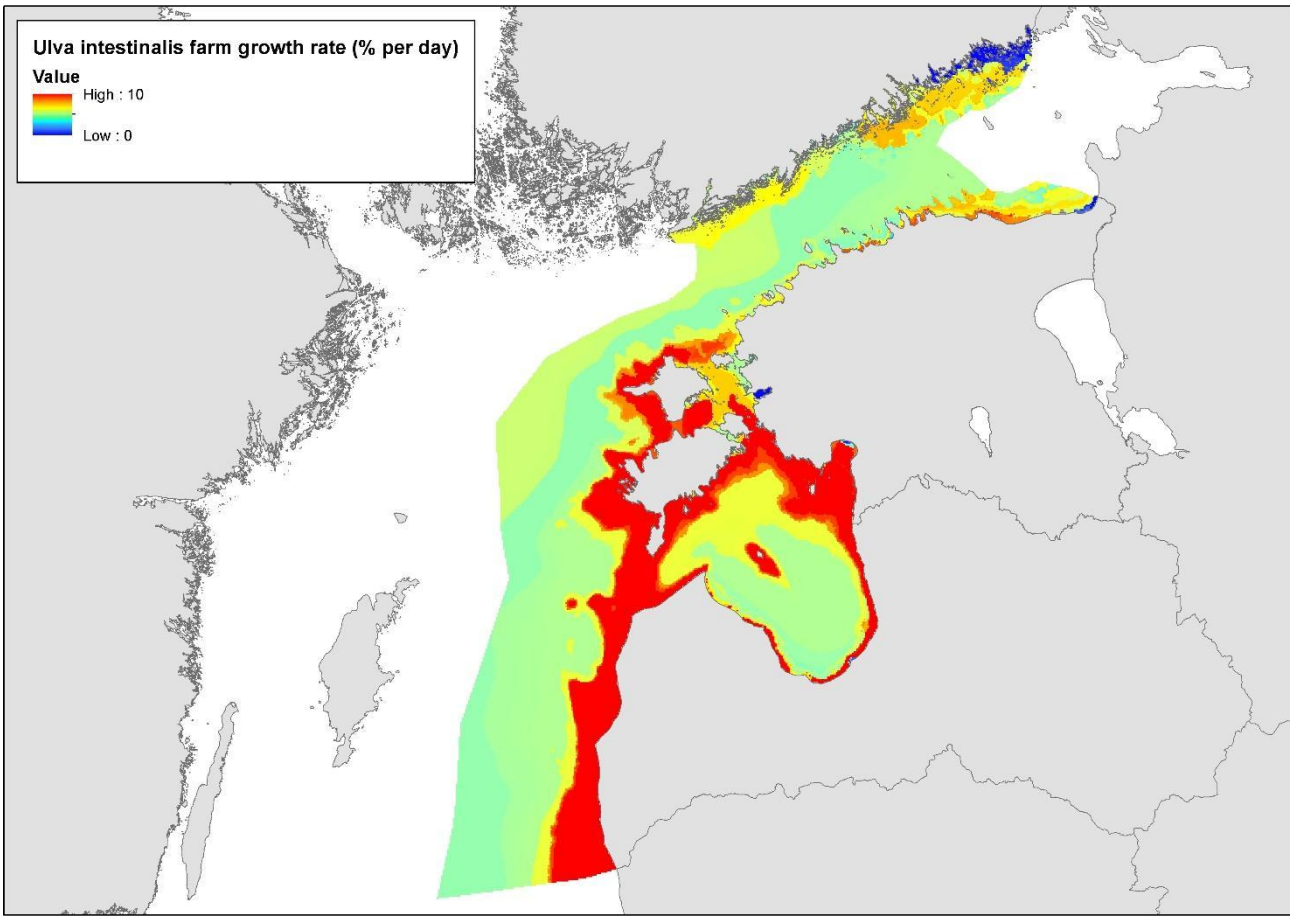
The cultivation of marine macroalgae and mussels is a promising enterprise within the aquaculture sector, consistent with the long-term vision of Blue Growth initiative (FAO, 2018) in that it competes for neither arable land nor freshwater resources and, importantly, provides low-impact eutrophication remediation in coastal water bodies currently degraded by excessive accumulation of nutrients. This is especially true for the Baltic Sea region where eutrophication continues to be among the most important environmental concerns despite of 40 years of international efforts to reduce external nutrient inputs (Helin, 2013; Fleming-Lehtinen et al., 2015; Andersen et al., 2017).

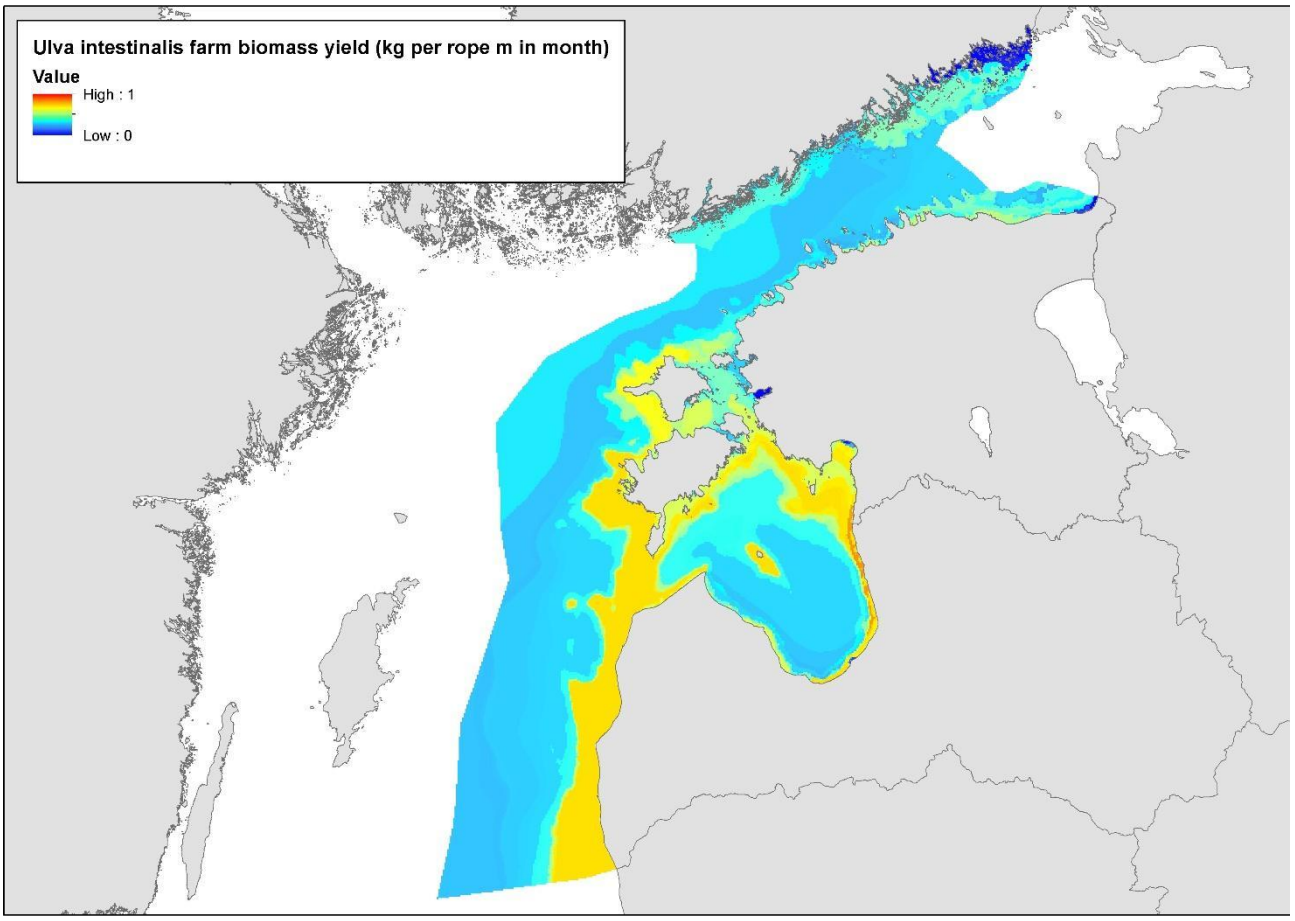
***Ulva intestinalis* farm.** In this model, a standard *U. intestinalis* cultivation farm covers 5 ha of sea area (200 × 250 m). The farm contains 65 horizontal parallel ropes, each 200 m long, placed within 1 m depth. The average distance between ropes is 4 m. This provides a total of 12 km of longline upon which *U. intestinalis* can grow. A typical deployment season for *U. intestinalis* in the Baltic Sea region would be from May to September. One harvest cycle is 1 month and the species can be harvested 5 times in a growing season. The initial biomass of *U. intestinalis* in the farm is 20 g ww per 1 m long-line.

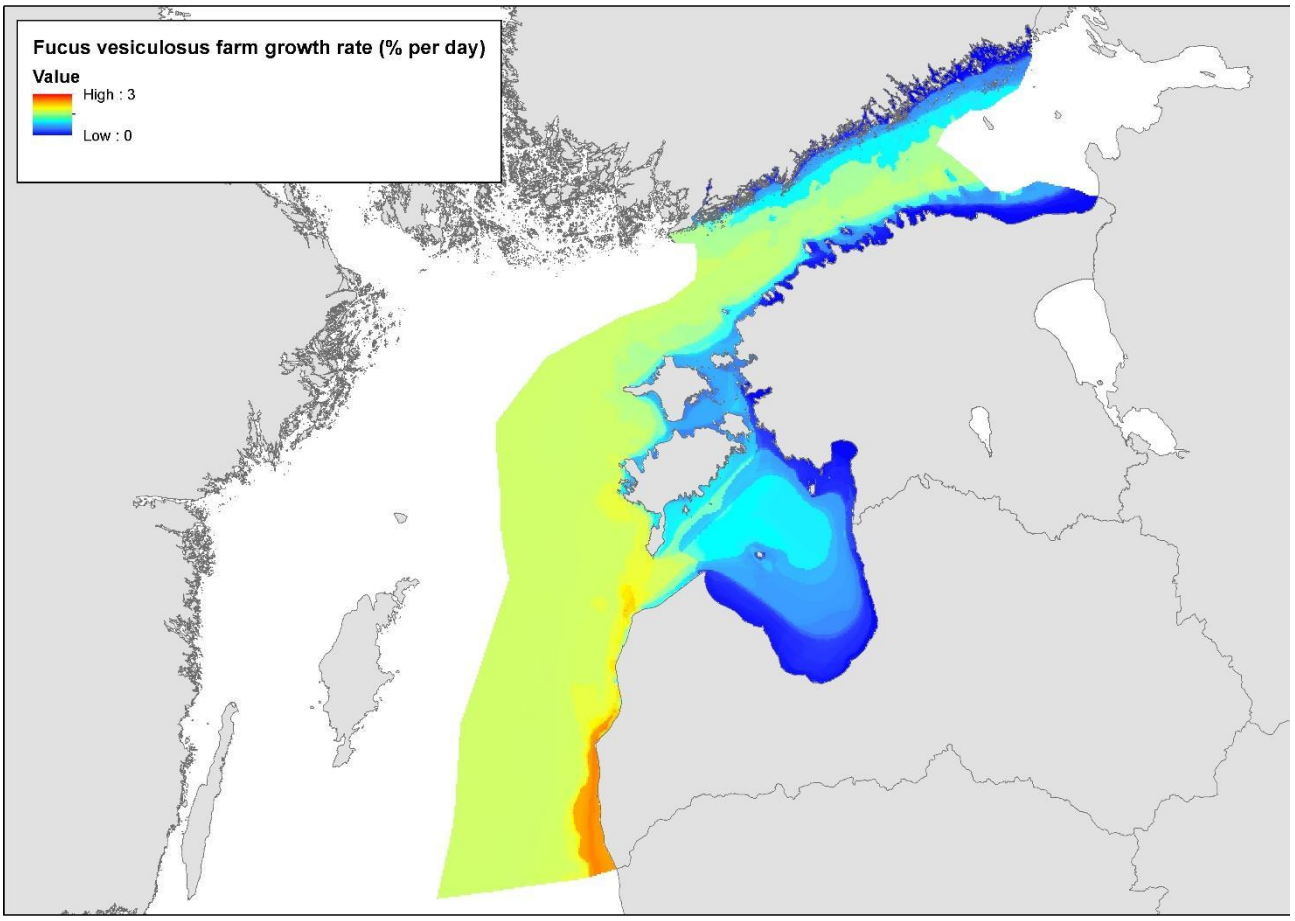
***Fucus vesiculosus* farm.** In the model, a standard *F. vesiculosus* cultivation system covers 5 ha sea area (200 × 250 m). The farm contains 65 lines of adjacently placed 1 m^3 cages at 1 m depth. The cages are placed parallel to one another and separated by 4 m access corridors. This provides a total of 13000 cages within which *F. vesiculosus* can grow. A typical deployment period for *F. vesiculosus* in the Baltic Sea region would be from May to September. The initial biomass of *F. vesiculosus* in the farm is 900 g ww per 1 m^3 cage (Fucosan, 2020). This farm is harvested once at the end of the deployment period in September.

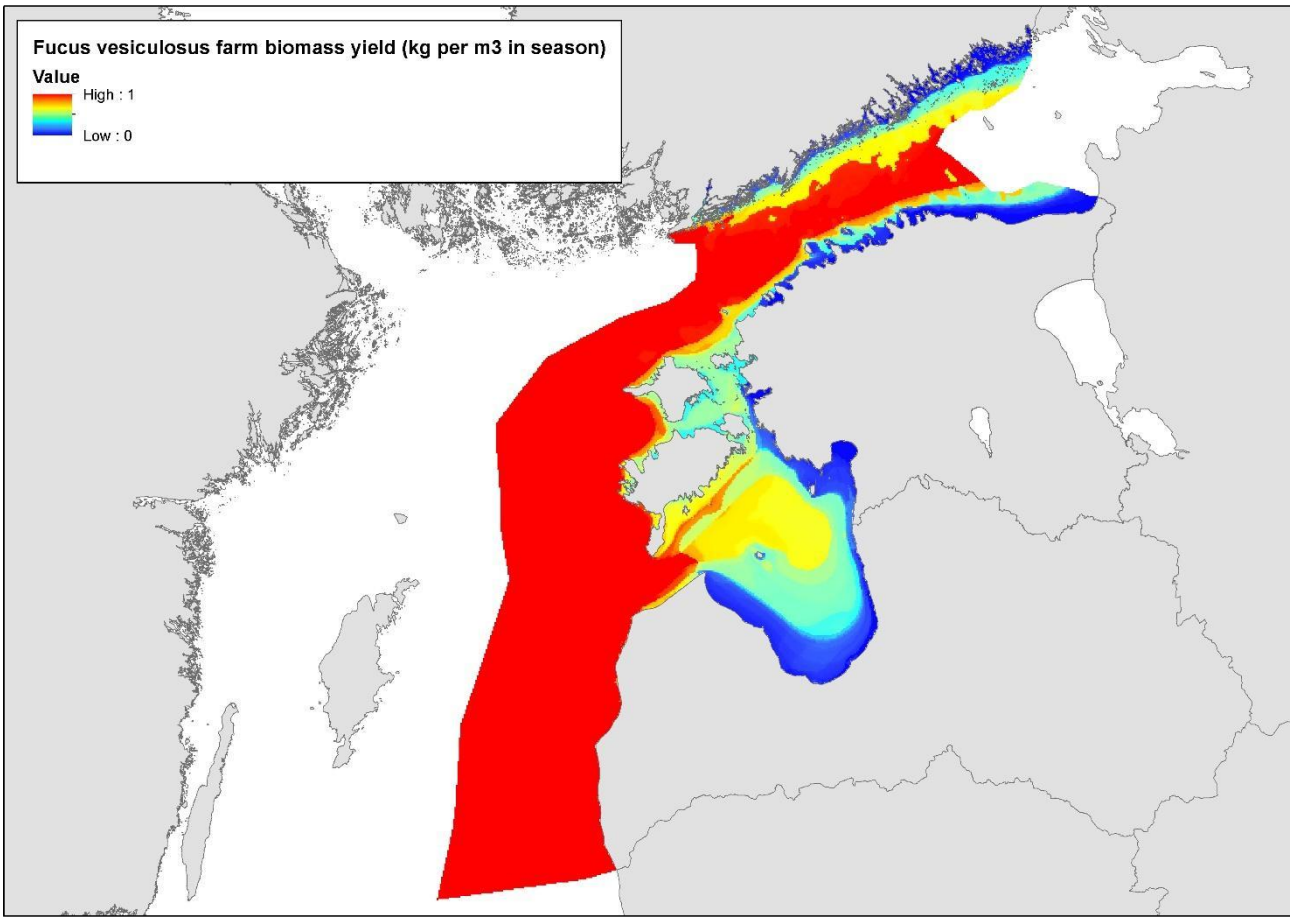
Macroalgal growth models are based on algal dry weight yields estimated experimentally across the MAREA study area. This approach allows the calculation of negative growth estimates during periods of resource limitation. Yields were normalized with the total incubation time (to produce

data for daily yield). Boosted Regression Trees (Elith et al., 2008) were used to model the relationship between macroalgal growth yields and different environmental variables. The established relationships were used to predict the macroalgal production potential for *U. intestinalis* and *F. vesiculosus* at the MAREA study area.




Ulva intestinalis farm biomass yield (kg per rope m in month)
Value
High : 1
Low : 0

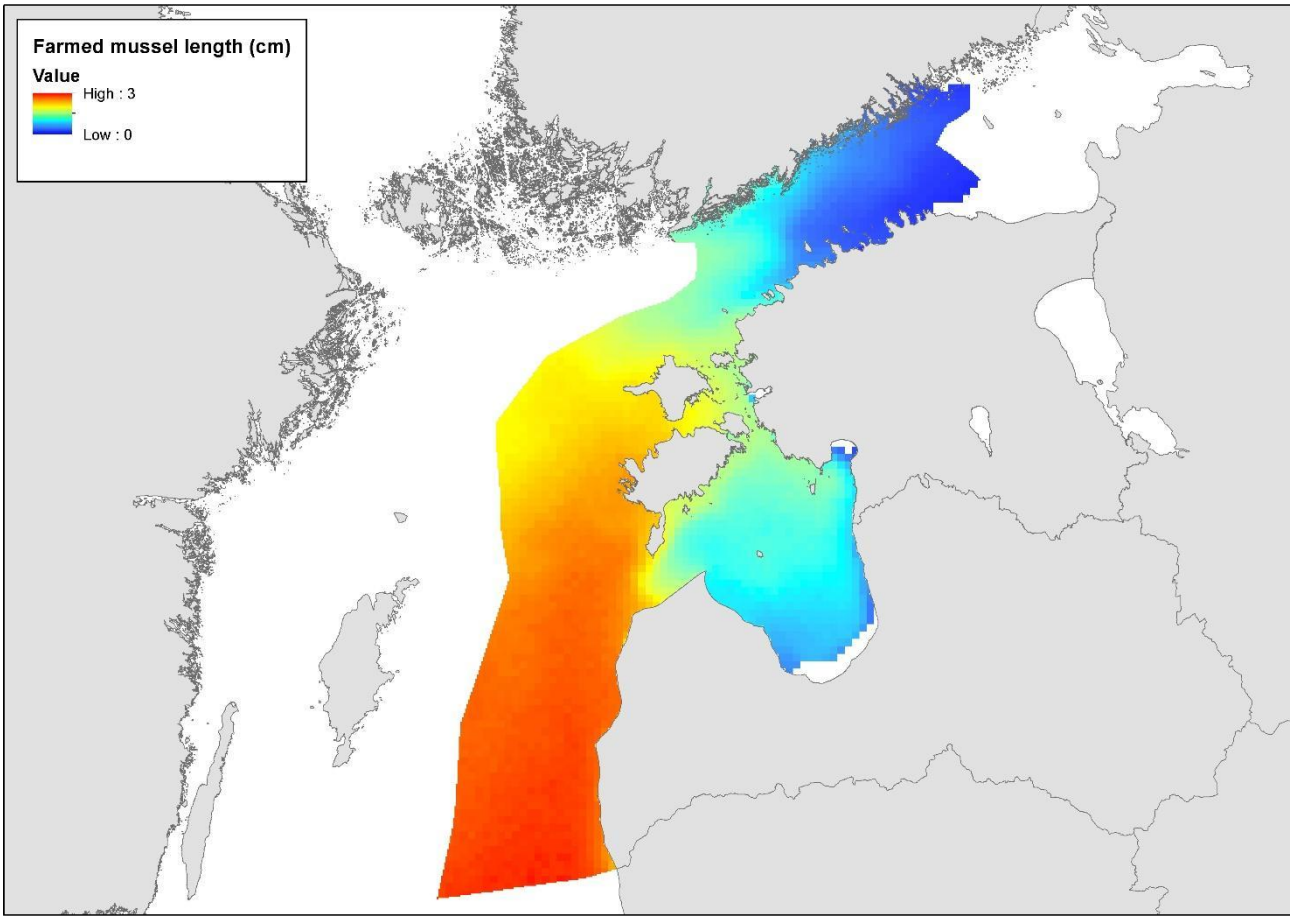


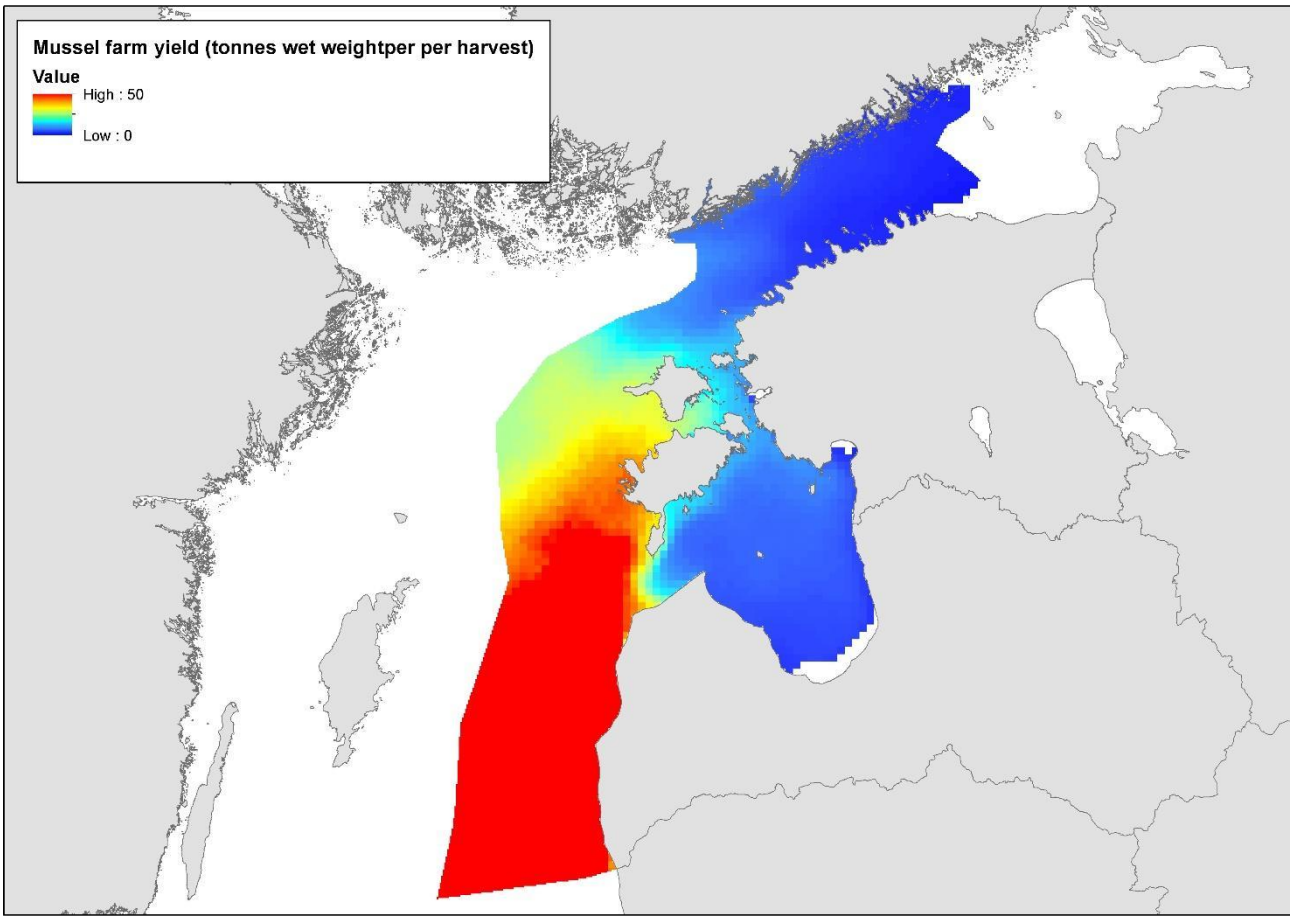


***Mytilus trossulus* farm**. Our test farm uses ropes with high surface area per unit length, i.e. “fuzzy ropes” that promote higher rates of larval settlement. The mussel farm has an area of 5 hectares

and consists of trawlnet suspended at 3−6 m depth. Such farm would host approximately 39,500,000 mussel individuals. The cultivation period is from the 1st of June to the 31th of October next year i.e. the biomass is harvested 1.5 years after the establishment of the farms.

When modelling mussel growth and the flows of nutrients in mussel farm the Dynamic Energy Budget (DEB) models were used based on the DEB theory established by Kooijman (2010). The DEB theory is a generic theory that is applicable to different species through species-specific DEB parameters. DEB describes the energy dynamics of an individual organism based on four state variables: energy reserve, E (*J*), body structural length, L (*cm*), the reproduction buffer, E_R (*J*) and the cumulative investment into development, called maturity, E_H (*J*) in DEB terminology.





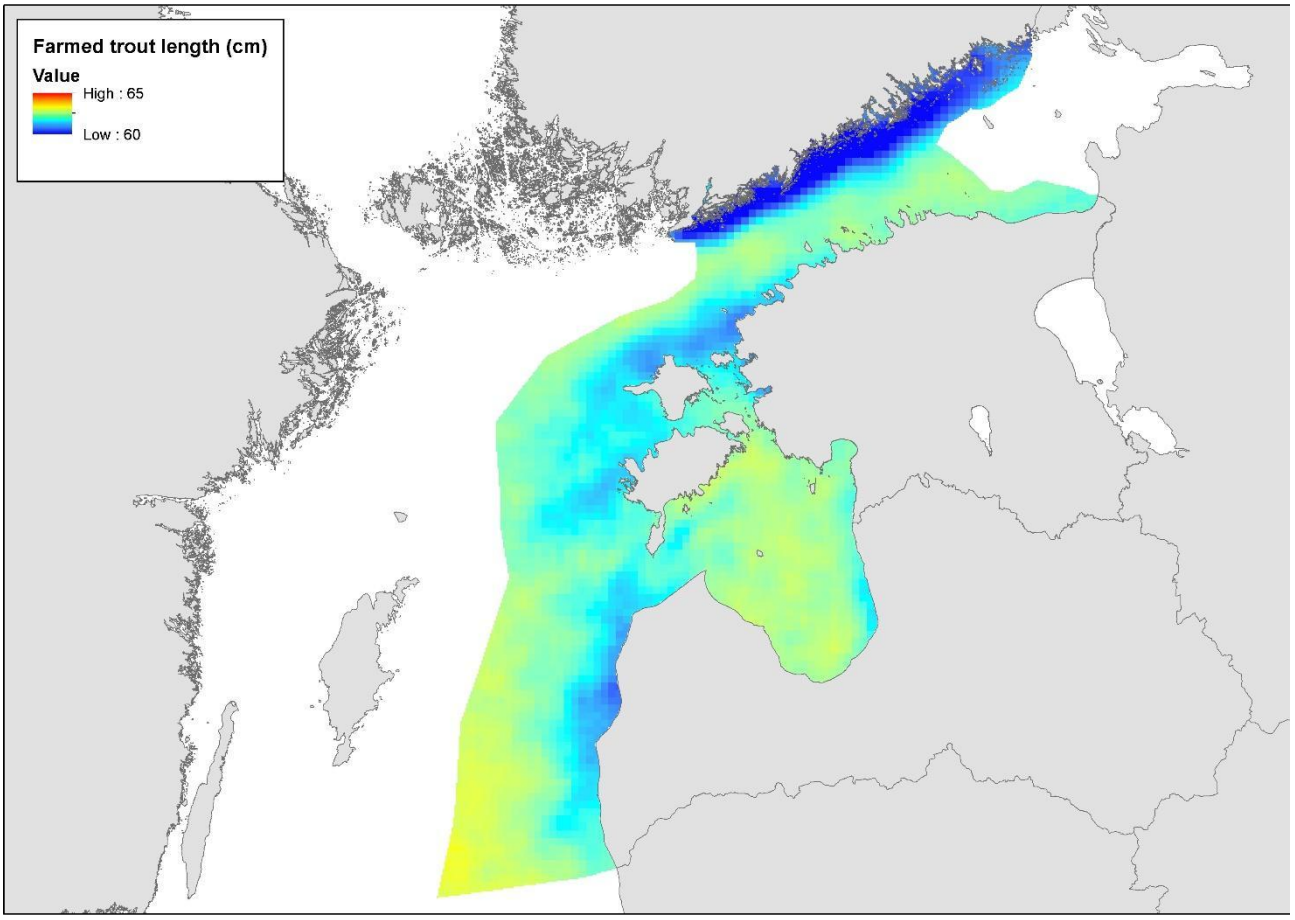
Fish aquaculture

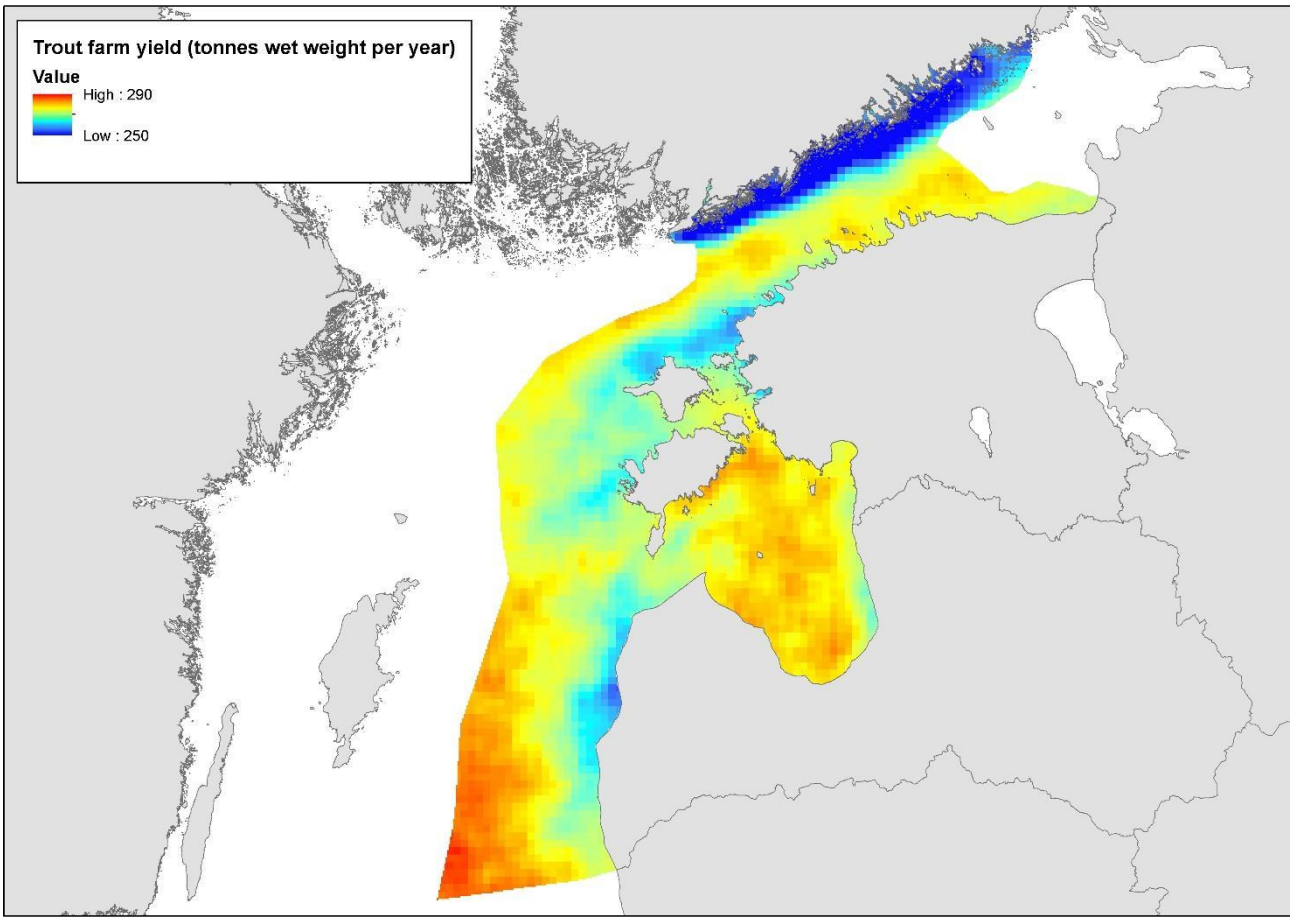
Fish for human consumption has been tremendously increased in past decades globally and this consumption is projected to further increase by 16.3% in the coming 10 years (OECD/FAO, 2020). Due to such rising demand, overfishing has become one of the most serious conservation concerns in marine ecosystems as the depletion of fish stocks has strong and often irreversible ecosystem-wide impacts, even if it involves small, low trophic-level fishes (Pinsky et al., 2011). Aquaculture is seen as a possible solution to revert the trend but only if the sector acts responsibly and reduces its environmental impacts (Naylor et al., 2000). During the last 20 years pressure on the aquaculture industry to adopt comprehensive sustainability measures has resulted in improved governance, technology, siting, and management including significant gains in aquaculture feed efficiency and reliance on terrestrial ingredients (Naylor et al., 2021).

To date fish farming is not considered sustainable in the Baltic Sea region due to the presence of many adverse symptoms of eutrophication compounded by significant internal release of legacy nutrients (Vahtera et al., 2007; Conley et al., 2009). Therefore, traditional finfish aquaculture is forced to embrace comprehensive environmental measures to minimise nutrient emissions from fish farms. Farming and harvesting of the native blue mussel species are increasingly recognized as a promising internal measure to compensate for nutrient loading of fish farms in the brackish Baltic Sea.

Fish farm. The rainbow trout farm deploys robust and flexible plastic rings and net cages. One farm consists of seven net cages, each consisting of 10,000 fish individuals. The initial weight of fish is 1 kg wet weight. The feed is loaded onto boats in the harbour and delivered to the cages. The cultivation period is six months from the 1st of May to the 31st of October.

The growth of rainbow trout in fish farm was modelled using the Dynamic Energy Budget (DEB) models based on the DEB theory established by Kooijman (2010).


Farmed trout length (cm)
Value
High : 65
Low : 60


Trout farm yield (tonnes wet weight per year)
Value
High : 290
Low : 250

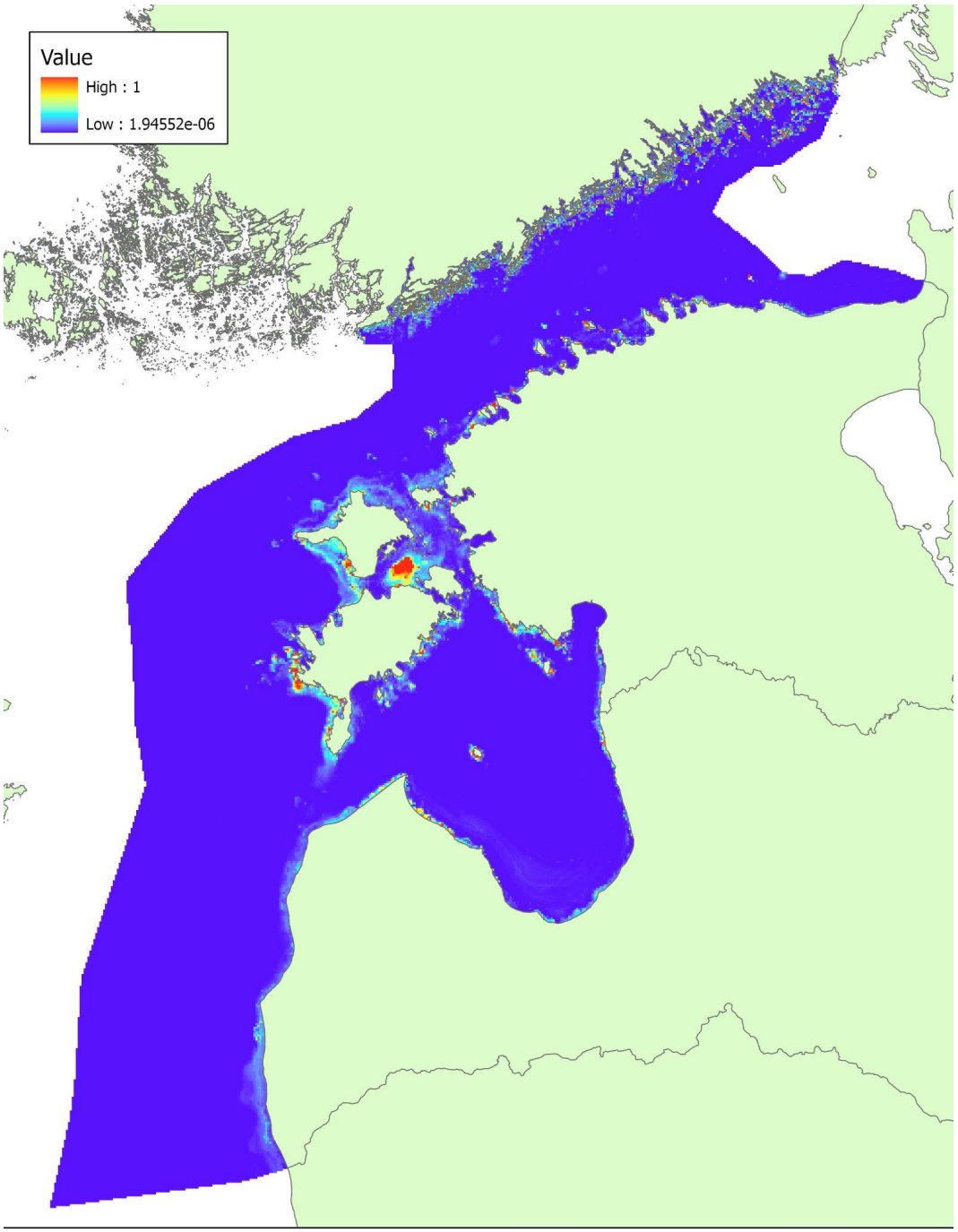
Materials

The use of algae and vegetation as materials has been quite small scale during the past decades. Traditionally, common reed *Phragmites australis* has been utilised, for instance, as a construction material. It was used as feed for cattle but its use decreased fast after 1950. The distribution of common reed has extended after that and its exploitation as material for energy source and for example as cattle feed has raised interest again (Hagelberg et al., 2008). Also, some algae species living on hard bottom habitats such as *Fucus vesiculosus* and red algae have some traditional small scale household use. This considers mostly loose lying algae and harvesting of algae from the sea bottom is rare. In Finland, some of the alga living on hard bottoms are threatened species, so harvesting is not a realistic option (Kontula and Raunio 2018). However, the algae habitats contribute to the stock of loose lying algae and thus indicate the capacity of this service.

To produce aggregated maps on the potential supply provided by aquatic vegetation on soft and hard substrates, distribution models were aggregated and adjusted using information on median percentage cover and, the median height of the species. The species data used for modelling the distribution of species in Finnish marine areas have mainly been gathered within the Finnish Inventory Programme for Underwater Marine Diversity, VELMU, which to date has gathered over 170 000 underwater observations. These data have been supplemented by observations of macrobenthic fauna from the Hertta database. The species distribution models for the Finnish marine area were fitted using Boosted Regression Trees (Elith et al. 2008), and follow the same procedure as described in Virtanen et al. (2018). For reed belts we used a satellite based presence absence layer instead of BRT (Koponen et al. 2022). Individual models considered to contribute to service supply were first adjusted by multiplying the continuous probability layers for occurrence by the median observed species cover in the raw data. Models were further adjusted by the median observed plant height to produce volume estimates.

To produce maps that cover the entire MAREA study area, the approach used in Finnish marine areas was also applied for Estonian and Latvian waters. In these waters biomass prediction was used instead of cover data and in order to reproduce similar distribution properties to species cover, the biomasses were limited to a certain threshold. Ultimately, all these models were compiled to produce joint map layers.

To produce the aggregated maps on the supply potential of the service for materials (CICES: 1.1.5.2) provided by aquatic vegetation, species were summed based on the expected contribution to respective service supply (Jernberg et al. submitted manuscript) and the resulting map layers were scaled to 0-1 for comparison of intensity between maps.

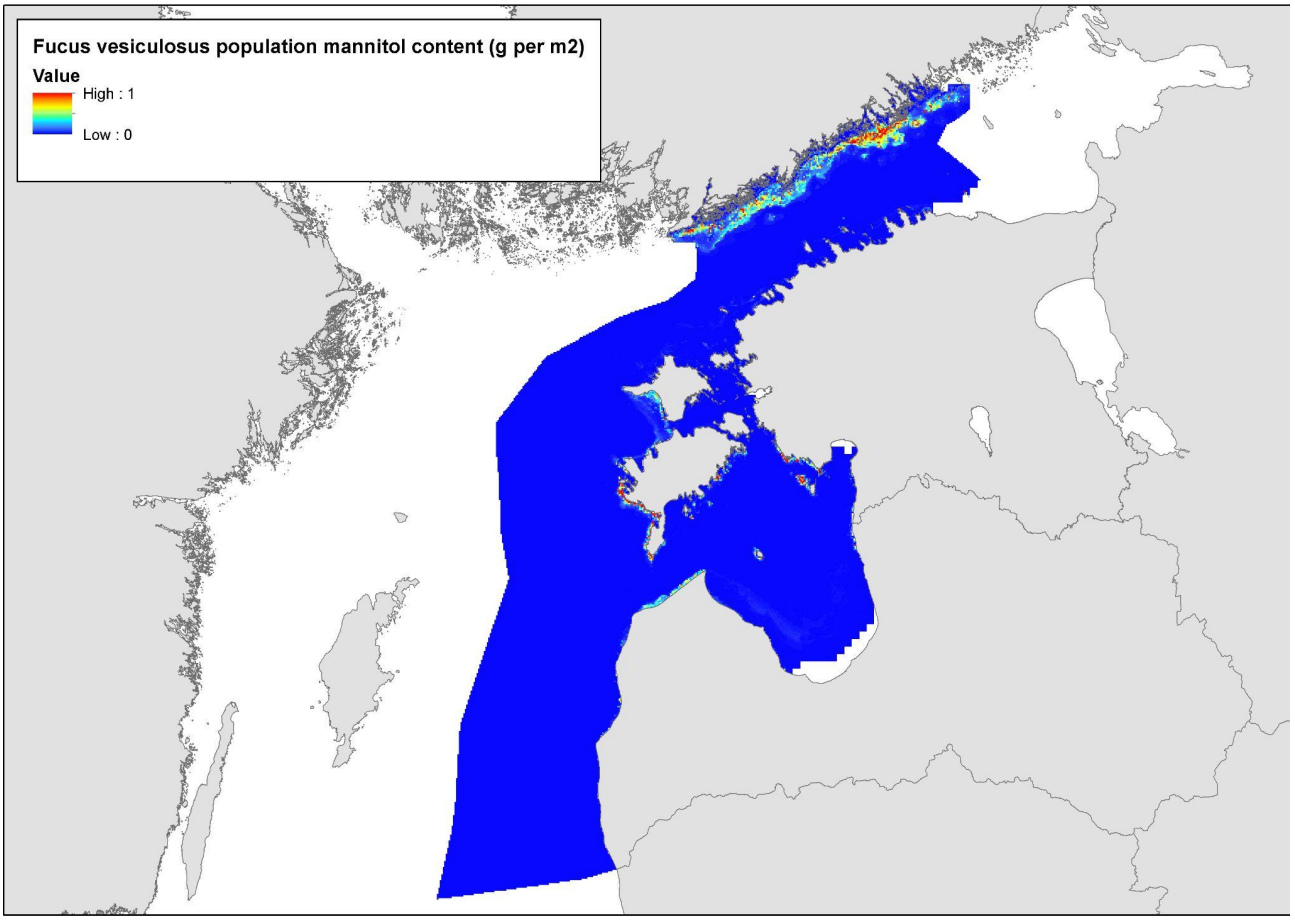


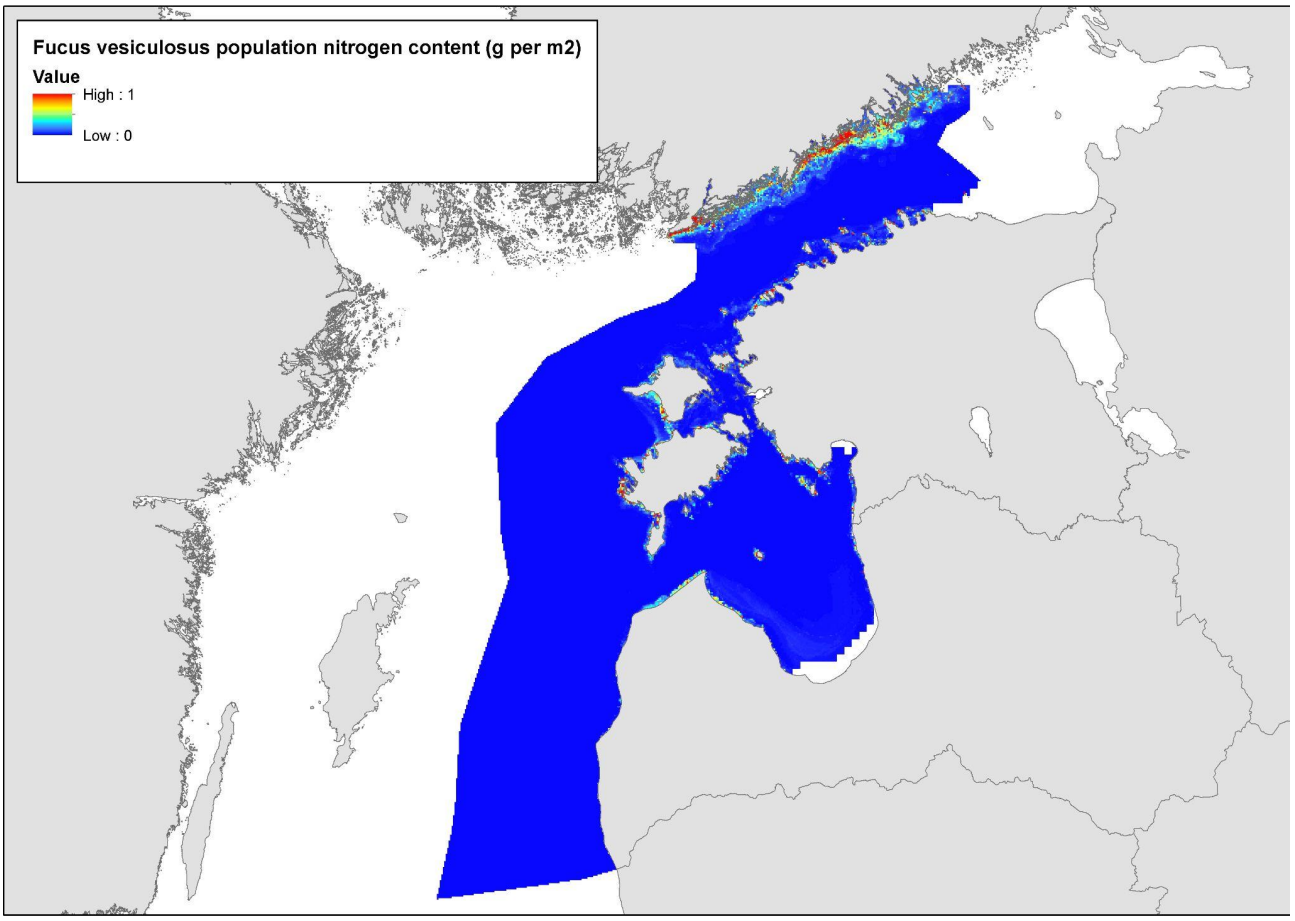
Materials contributed by aquatic vegetation on soft substrates

Nitrogen and mannitol production/sequestration of the *Fucus vesiculosus* populations

Fucus vesiculosus actively assimilates inorganic carbon and nutrients from the marine systems where it occurs during the process of photosynthesis, growth and hence the production of biomass. In this and other brown algae, the carbohydrate mannitol represents a major product of photosynthesis used for carbon and energy storage (Groisillier et al., 2014). In addition, mannitol represents a key nutritious compound that defines the palatability of *Fucus vesiculosus* and, therefore, its capacity to provide food to the associated community of invertebrates and support local biodiversity (Weinberger et al., 2011). Most of the nitrogen incorporated by macroalga is essential for the production of proteins, which also positively contribute to the palatability of *F. vesiculosus* and food provision to grazers, or stored and later used for growth (Lehvo et al., 2001; Angell et al. 2016).

The mannitol and nitrogen concentrations used to calculate stocks in *F. vesiculosus* are the result of an extensive and simultaneous sampling in summer of populations of the species along the salinity gradient of the Baltic Sea. Mannitol and nitrogen concentration were determined through standard analytical procedures as described in Barboza et al. (2019). Boosted Regression Trees (Elith et al., 2008) were used to model the change in mannitol and nitrogen concentrations in response to different environmental variables. Baltic-wide concentration models were combined with *F. vesiculosus* biomass predictions for the MAREA study area to produce the provided nitrogen and mannitol stock maps.




Fucus vesiculosus population nitrogen content (g per m2)
Value
High : 1
Low : 0

Regulating services

Blue carbon

Zostera marina

Eelgrass communities are very important in the context of carbon sequestration in the Baltic Sea. To assess the potential of seagrass meadows to sequester carbon over time, it is necessary to estimate the production potential of seagrass and to determine what fraction of the total production is deposited as a carbon pool. There is very little information in the scientific literature on the production of different marine organisms in the Baltic Sea, including seaweeds and seagrasses. A recent study published in the northern Baltic Sea (Finland) showed that there is relatively little variation in the growth of seagrass in different areas of the coastal sea (Röhr et al., 2016). Extrapolating the results of this study to the entire MAREA study area, the expected annual eelgrass production would be 5 times the values of eelgrass biomass, and of the order of 500 g dry weight per square metre per year. There are also no studies for the MAREA study area that describe the rate of organic carbon deposition in seaweed meadows. However, based on data published in the scientific literature (Duarte et al., 2013, Serrano et al., 2014, Miyajima et al., 2015), it is possible to indirectly estimate the intensity of the organic carbon accumulation process in our marine areas. For example, a seagrass meadow of 1 km^2 with an average biomass of 100 g m^{-2} is capable of sequestering 66−1082 tonnes of carbon per year when constants of the above publications are applied.

In order to integrate the data collected from marine monitoring and mapping into the assessments of the carbon sequestration supply of marine areas, the following formula can be used:

$CSC_i = B_i \times P_i \times L_i \times C_i \times S_i$, where

CSC_i is the carbon sequestration supply (tonnes of carbon per year) of the study species in the study area.

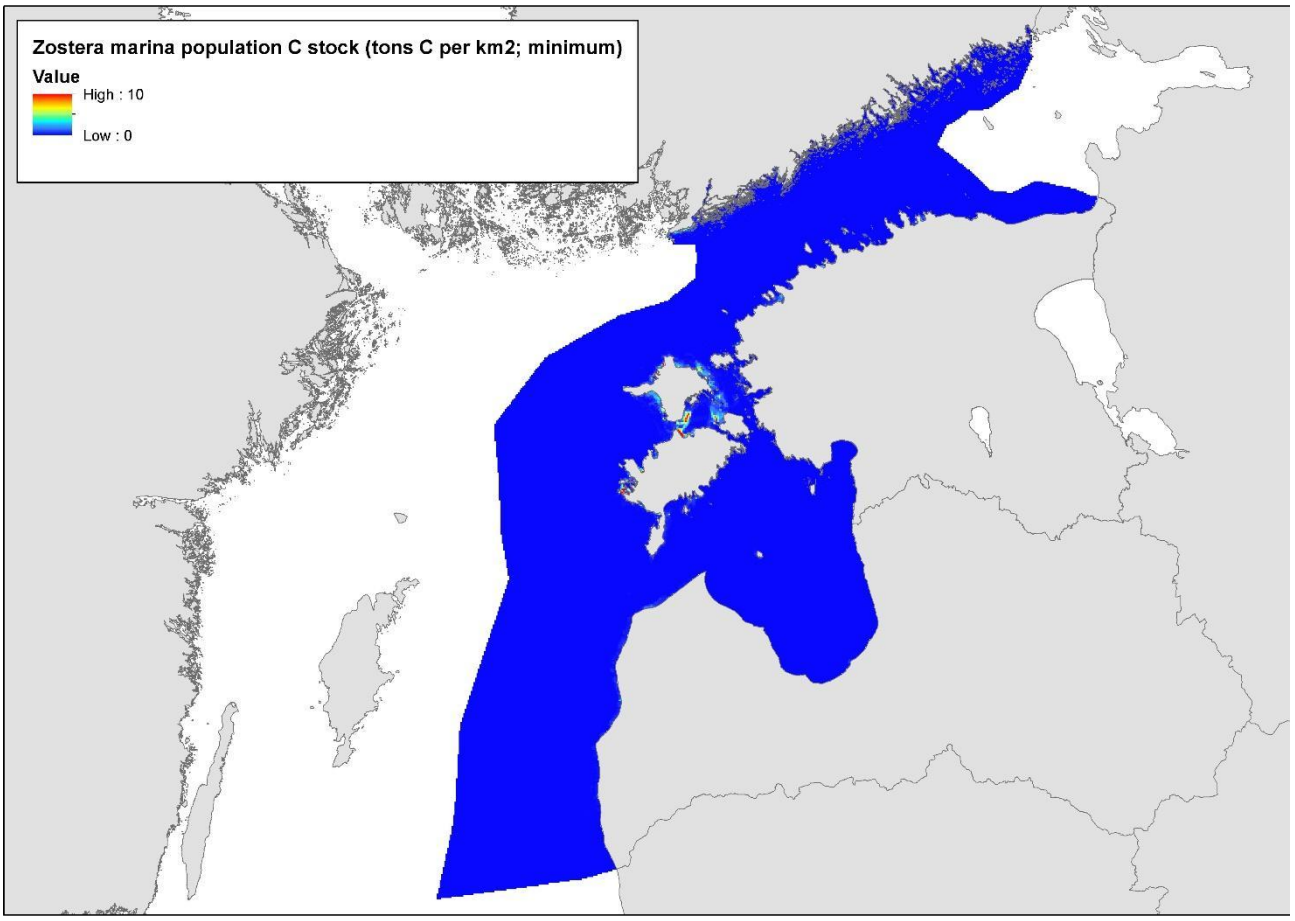
B_i is the average biomass of the species in the study area (g dry weight per square metre).

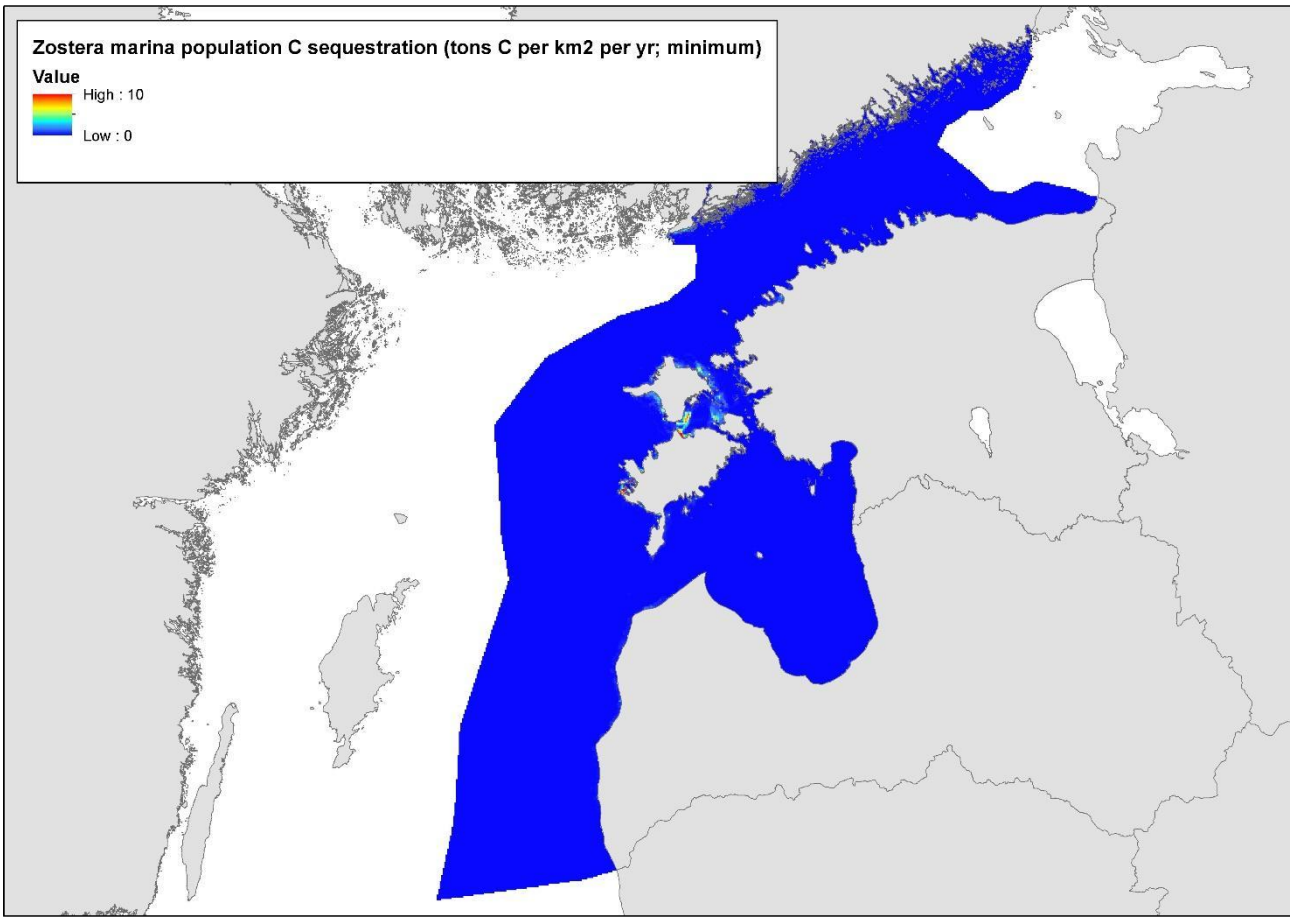
P_i is the average annual production of the species in the study area (g dry weight per g/m2/year of species i)

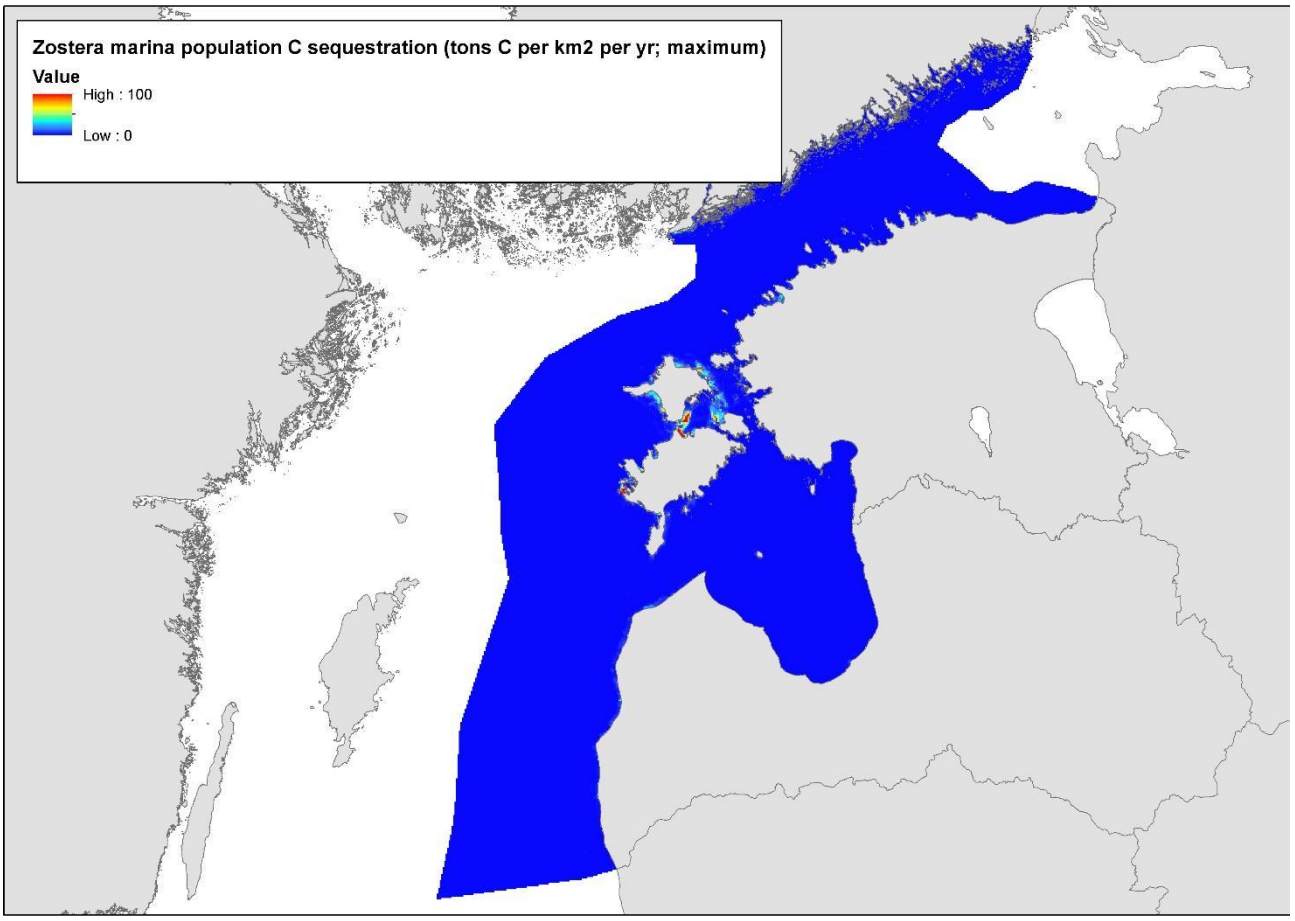
L_i is the ratio of the fraction of the annual production produced by the species that is deposited in the marine area (varies between 0 and ....1).

C_i is the ratio of the fraction of the deposited production that contains carbon (varies between 0....1).

Si is the area km^2 of the marine area under study.

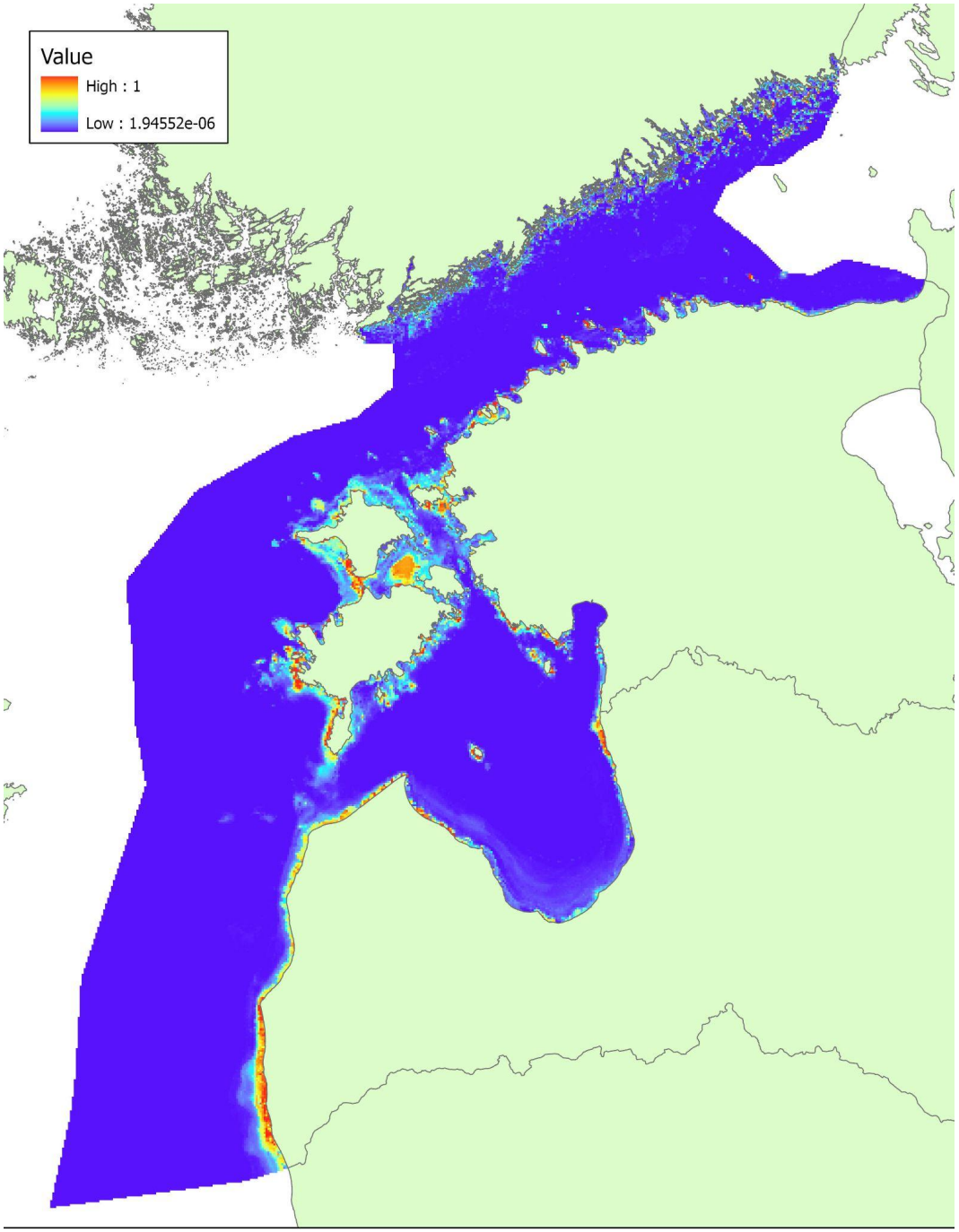

Zostera marina population C stock (tons C per km2; minimum)
Value
High : 10
Low : 0


Zostera marina population C sequestration (tons C per km2 per yr; minimum)
Value
High : 10
Low : 0

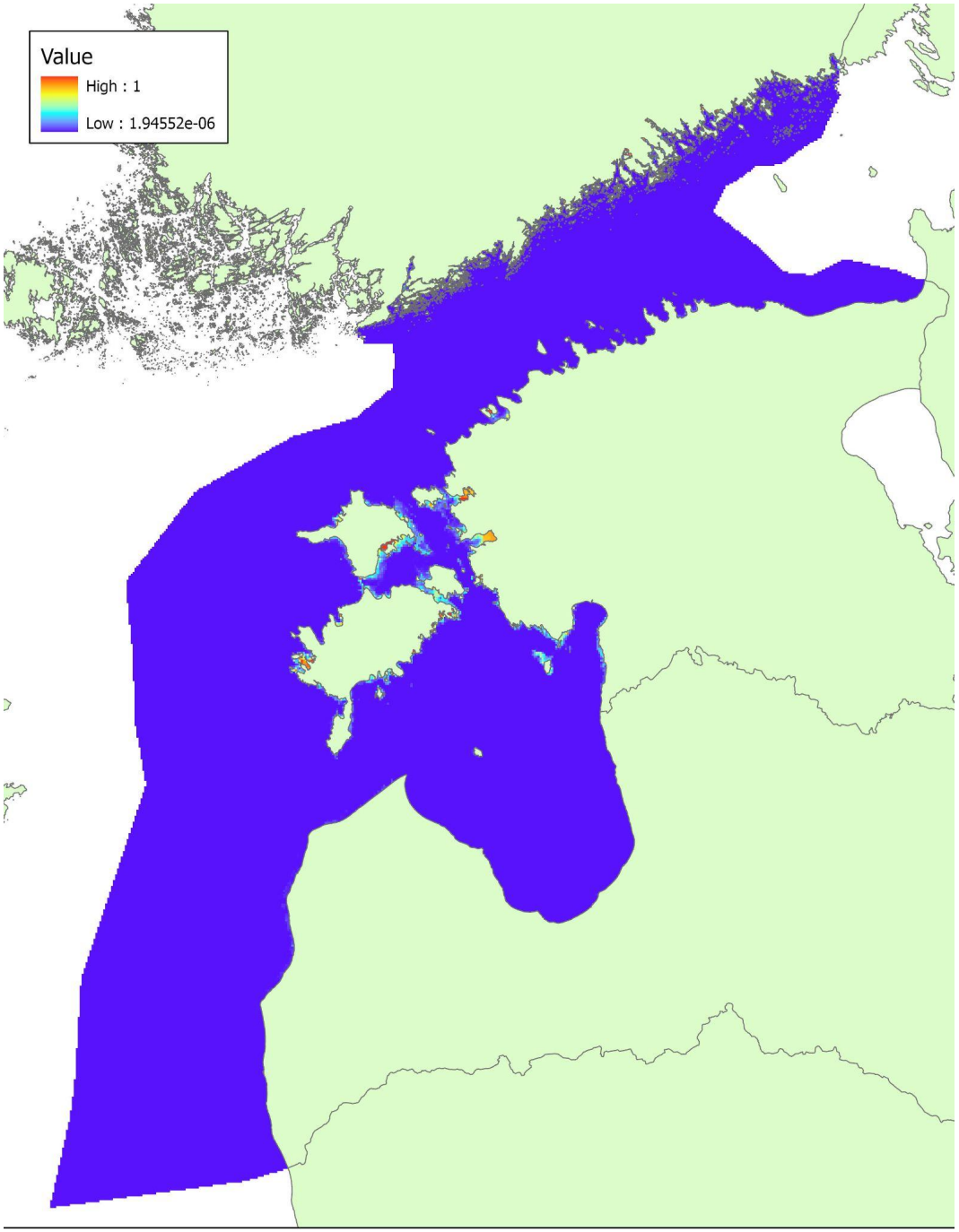


Aquatic vegetation

To produce aggregated maps on the carbon storage capacity in living tissue provided by aquatic vegetation on soft and hard substrates, species distribution models on occurrence in the Finnish area and biomass in Estonian and Latvian areas were adjusted, aggregated and normalised. Species were summed based on expected contribution to the potential service supply (CICES: 2.2.6.1) and the resulting map layers were scaled to 0-1 for comparison of intensity between maps. Please see the section on Materials and feed for methodology.



Carbon storage by aquatic vegetation on hard substrates



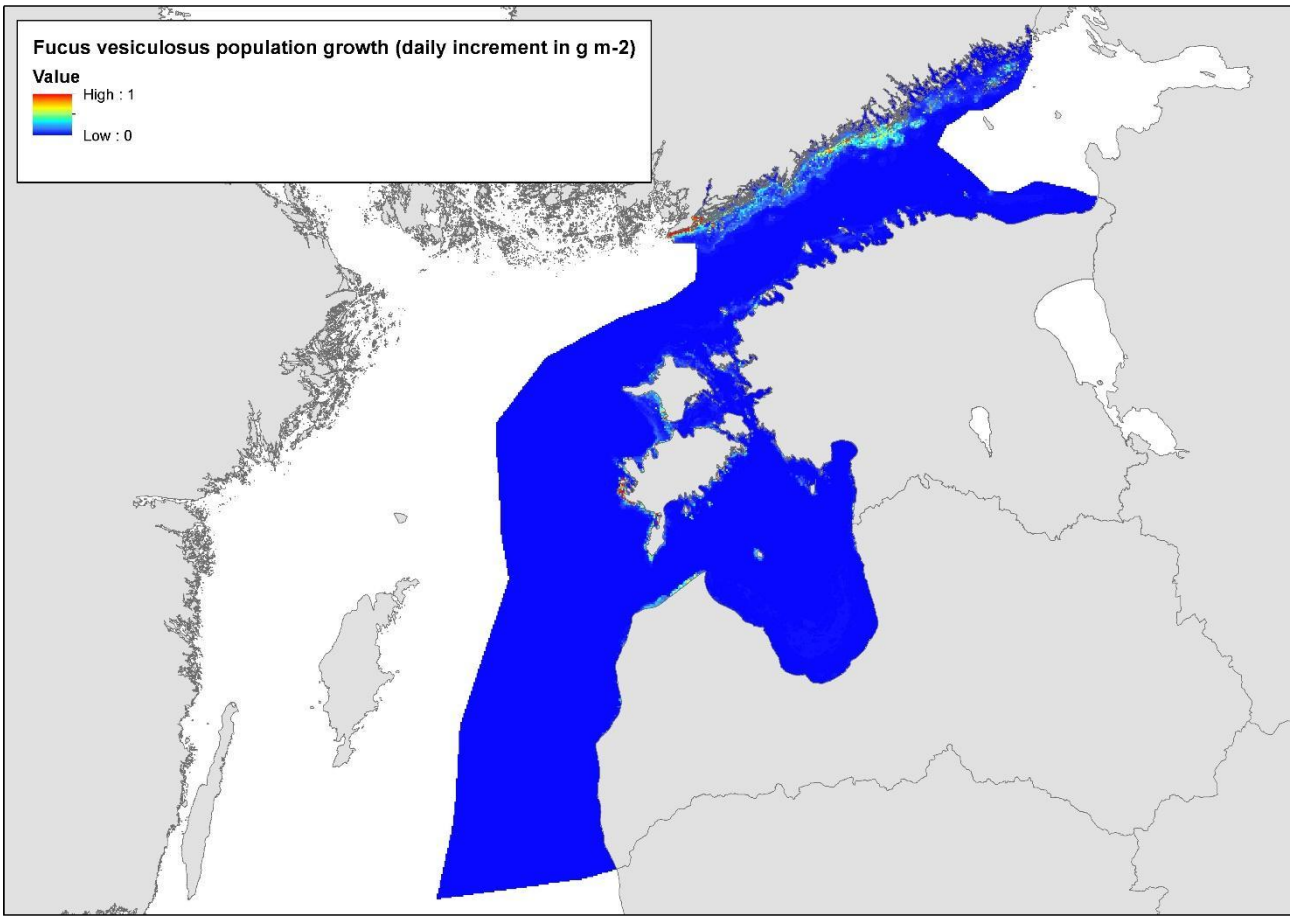
Carbon storage by aquatic vegetation on soft substrates

Macroalgal population growth

Primary production in the sea is the major process that supplies energy and matter to marine organisms. In coastal ecosystems, macroalgae constitute the most productive habitats and virtually all primary production is performed by them (Field et al., 1998; Mann, 2000, Steneck et al., 2002). In the Baltic Sea *Fucus vesiculosus* is one of the most important macroalgal species and hosts a large number of plant, invertebrate and fish species (Martin et al., 2013).

Fucus vesiculosus growth models were based on algal dry weight yields estimated experimentally at the community level across the MAREA study area. Boosted Regression Trees (Elith et al., 2008) were used to model the relationship between macroalgal growth yields and different environmental variables. The established relationships were used to predict the macroalgal production potential for *F. vesiculosus* populations at the MAREA study area. As *F. vesiculosus* is one of the most important habitat forming species in the coastal regions of the Baltic Sea, the

production of *F. vesiculosus* population defines the rates of matter and energy flows in coastal areas and directly regulates plant, invertebrate and fish species associated to this habitat forming species.



Filtration, sequestration and storage of nutrients and harmful substances

Coastal filter by mussels

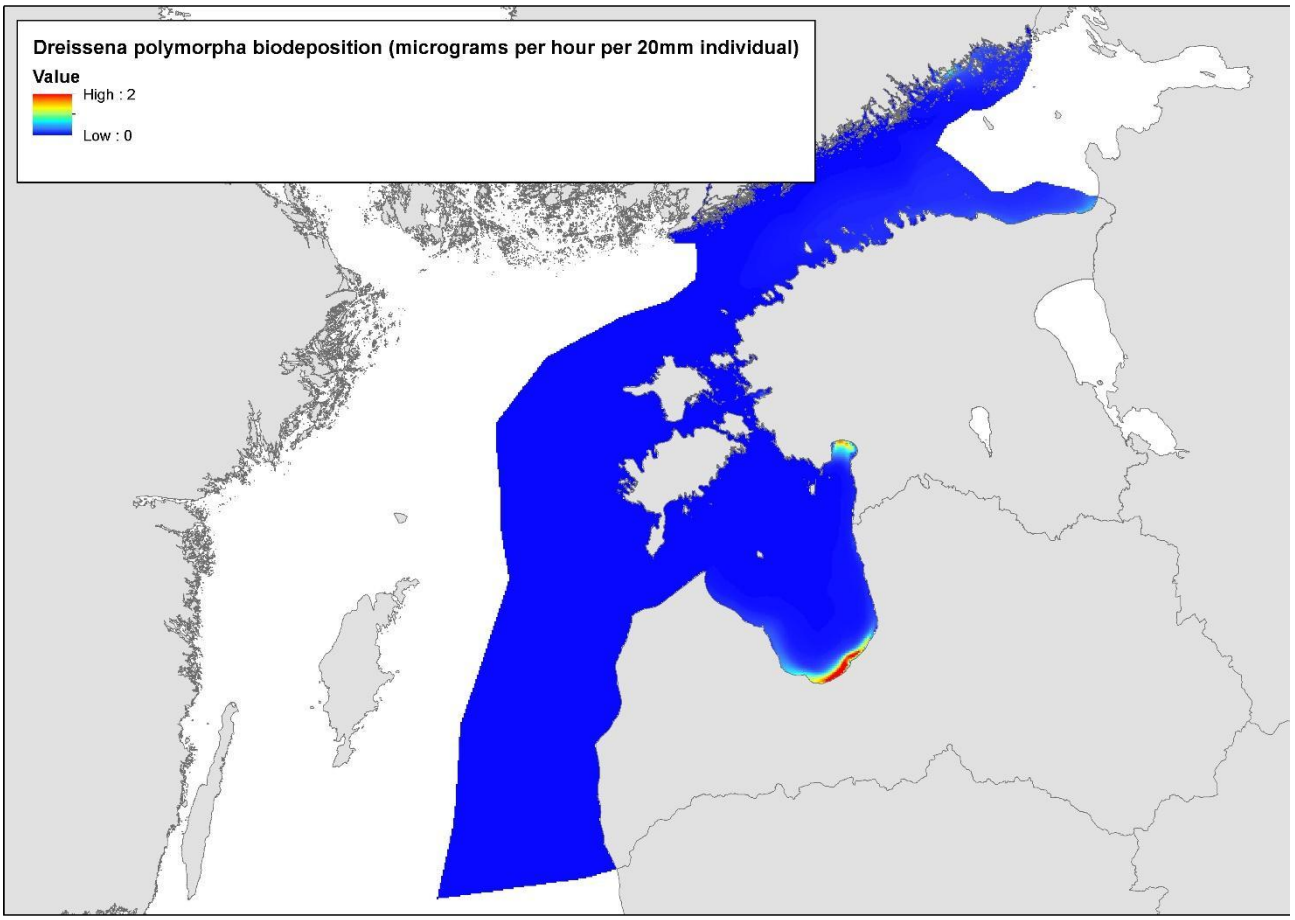
Rocky shores have roughly similar distribution patterns of organisms around the world (Suchanek, 1986, Little and Kitching, 1996, Schiel, 2004). Species diversity and community structure differs among regions; nevertheless, macroalgae and mussels are the most common inhabitants of temperate intertidal rocky shores.

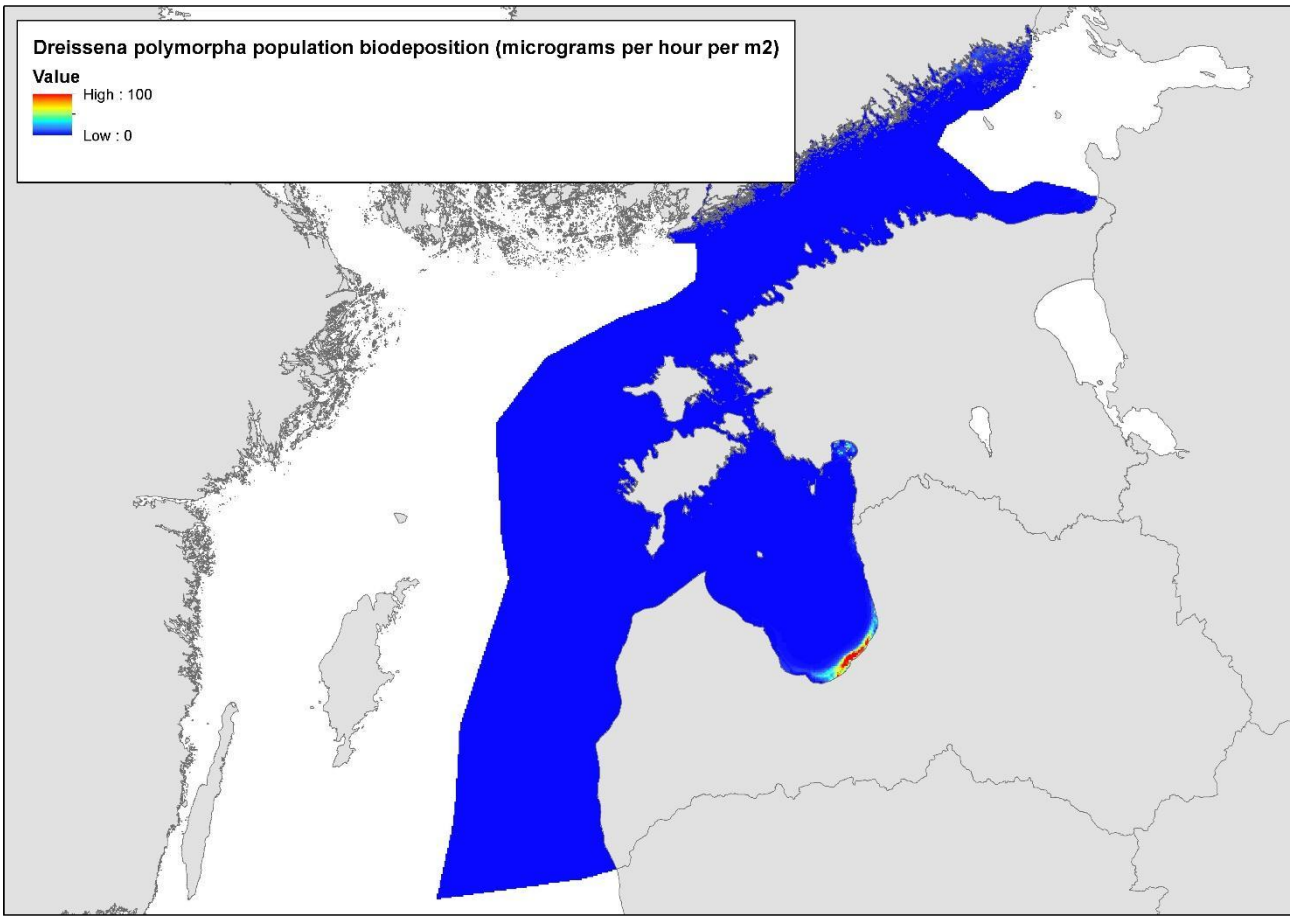
Mussels are suspension-feeders that derive their food by filtering the water column and retaining particulate matter on their gills. Clearance rate refers to an amount of water that is cleared per time unit by animal or biomass. Biodeposition is defined as the production of faeces and pseudofeces. At high densities the suspension-feeders are capable to deplete phytoplankton (Cloern, 1982; Fréchette and Bourget, 1985) and therefore control the standing stock and production of primary producers and limit via competition the growth of pelagic herbivores and fish (e.g. Officer et al., 1982; Møhlenberg, 1995). Consequently, suspension-feeders are considered to play a key role in the stability of coastal ecosystems (Herman and Scholten, 1990).

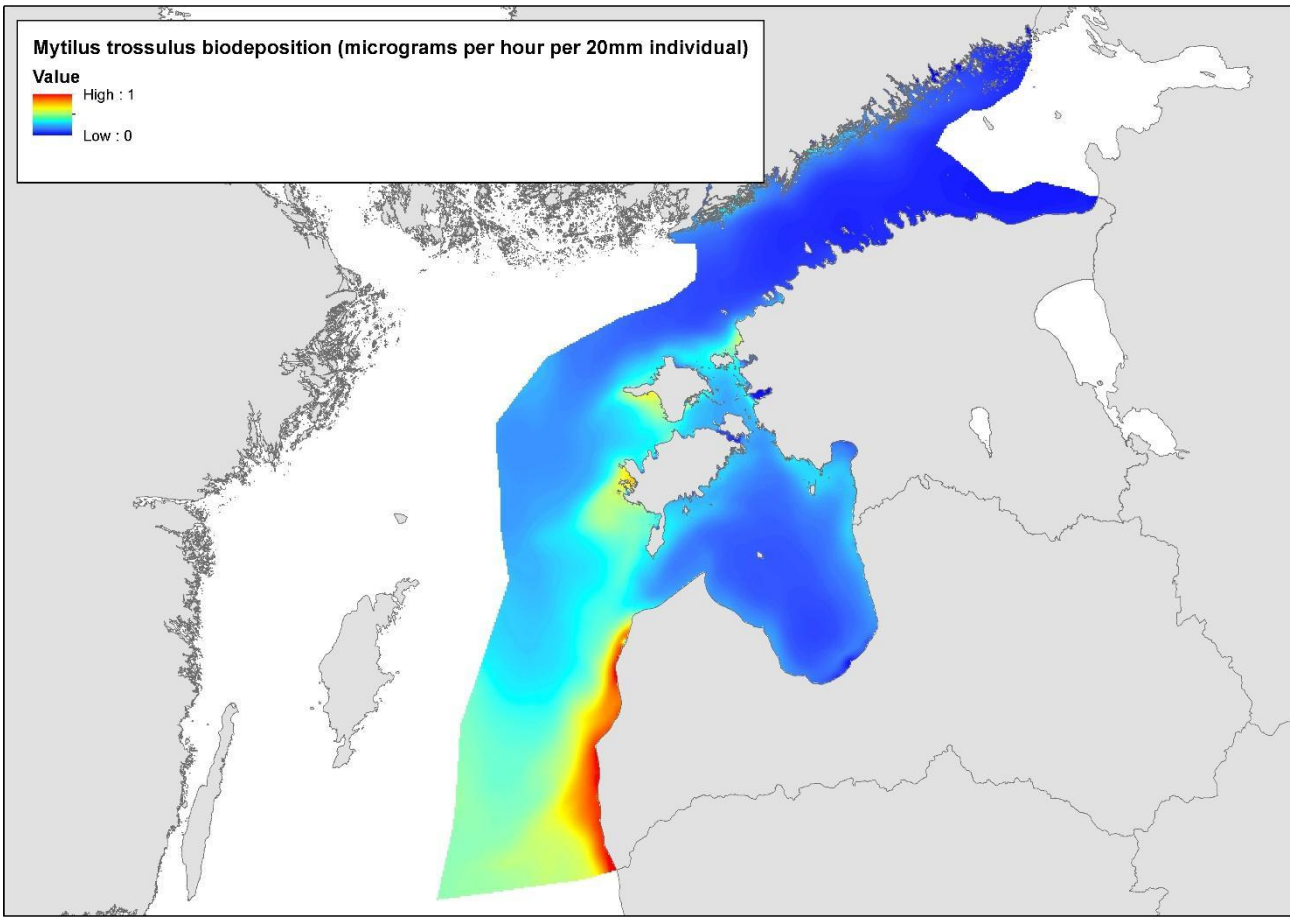
In situ grazing rates of *Mytilus trossulus* and *Dreissena polymorpha* were estimated by quantifying the defecation of Chl a by the mussels in the entire MAREA study area during different seasons (Kotta et al., 1998; Orav-Kotta, 2004; Kotta et al., 2005; Lauringson et al., 2007; Lauringson et al., 2009; Lauringson et al., 2014). Boosted Regression Trees (Elith et al., 2008) were used to model the relationship between mussel biodeposition and different environmental variables. The established

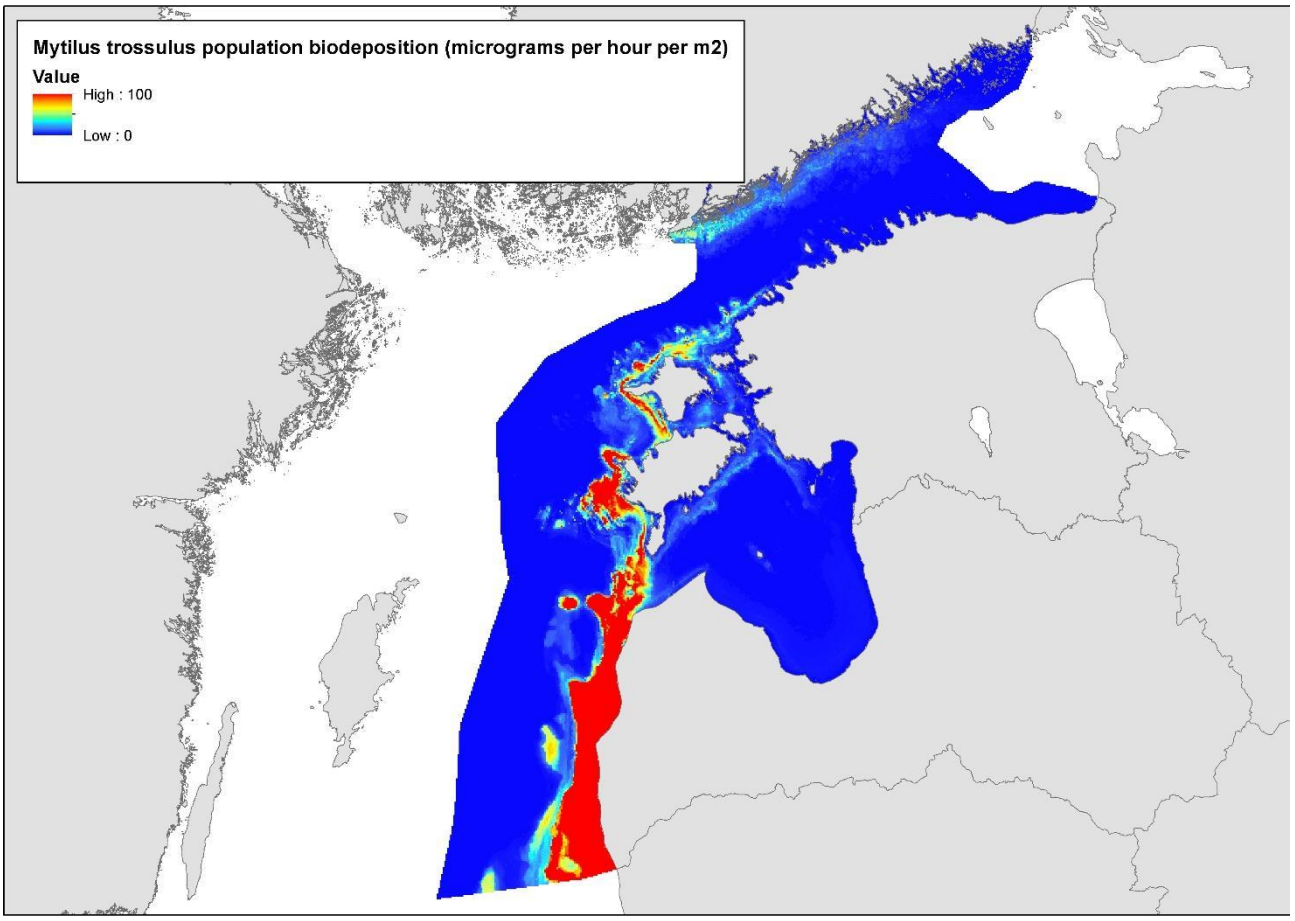
relationships were used to predict the biodeposit production potential for *M. trossulus* and *D. polymorpha* at the MAREA study area.

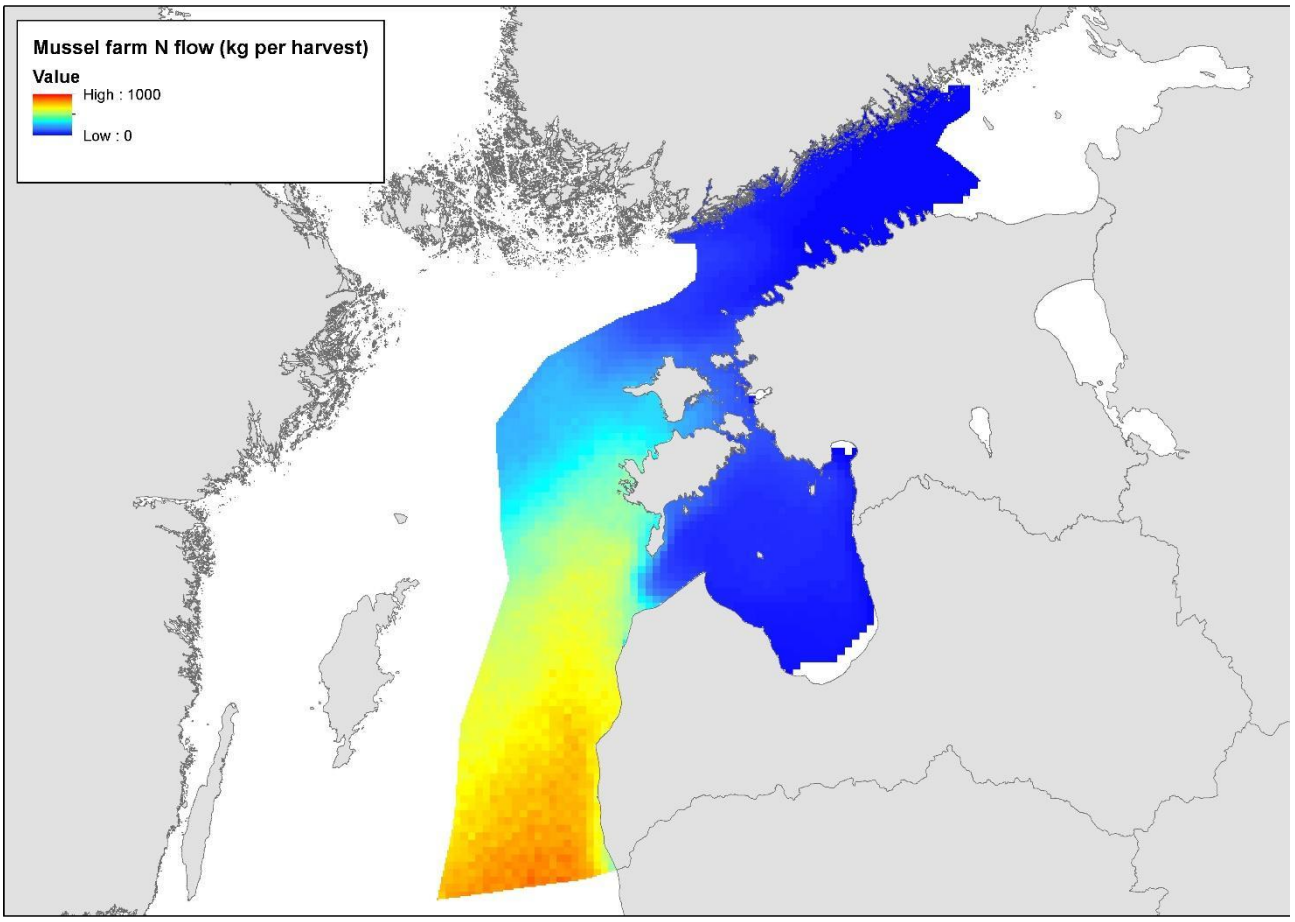
In addition, as alternative indicators of coastal filter the nutrient flows and sequestration by native population of mussels and artificial mussel farms were assessed using the DEB modelling (Kooijman, 2010).

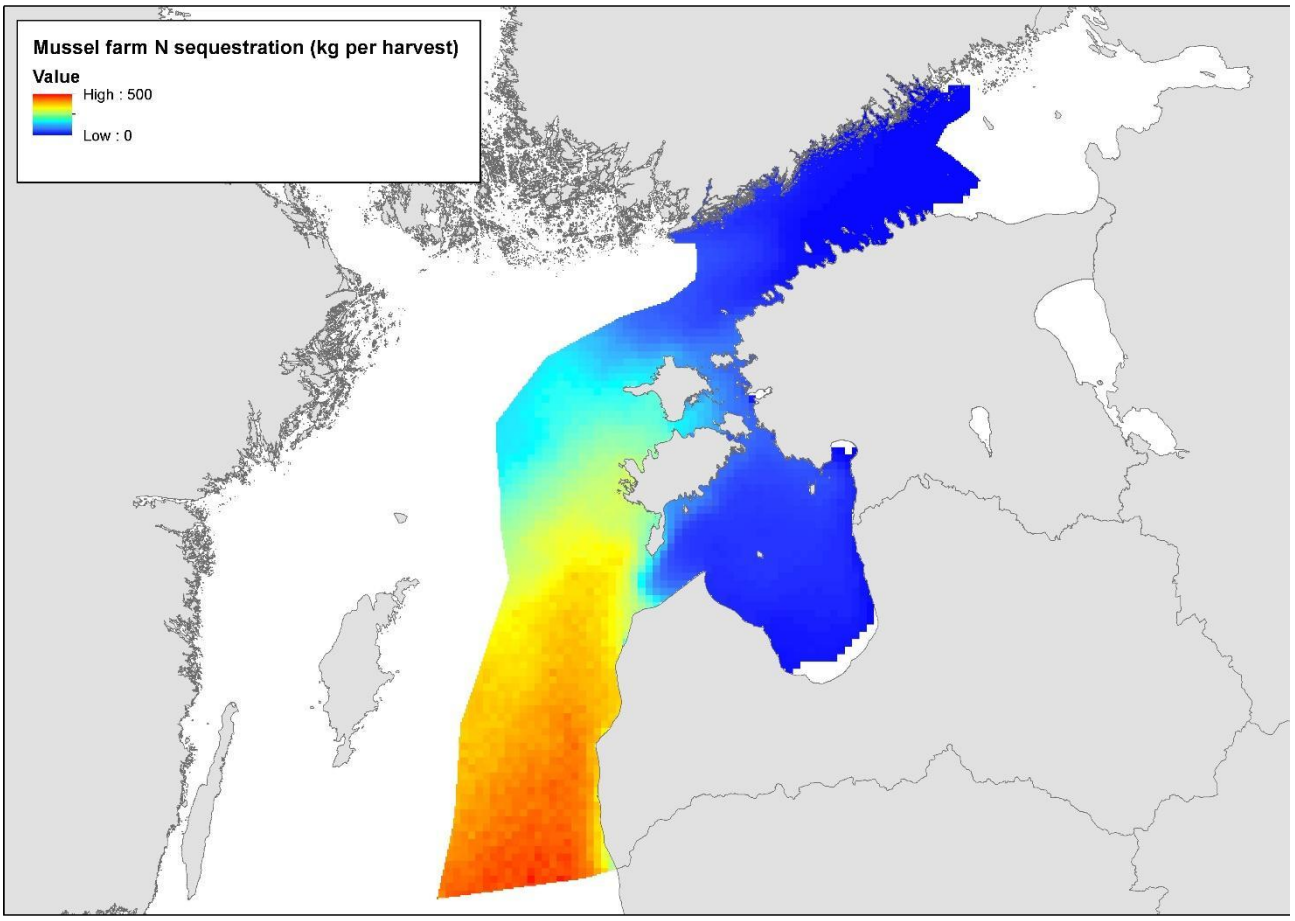


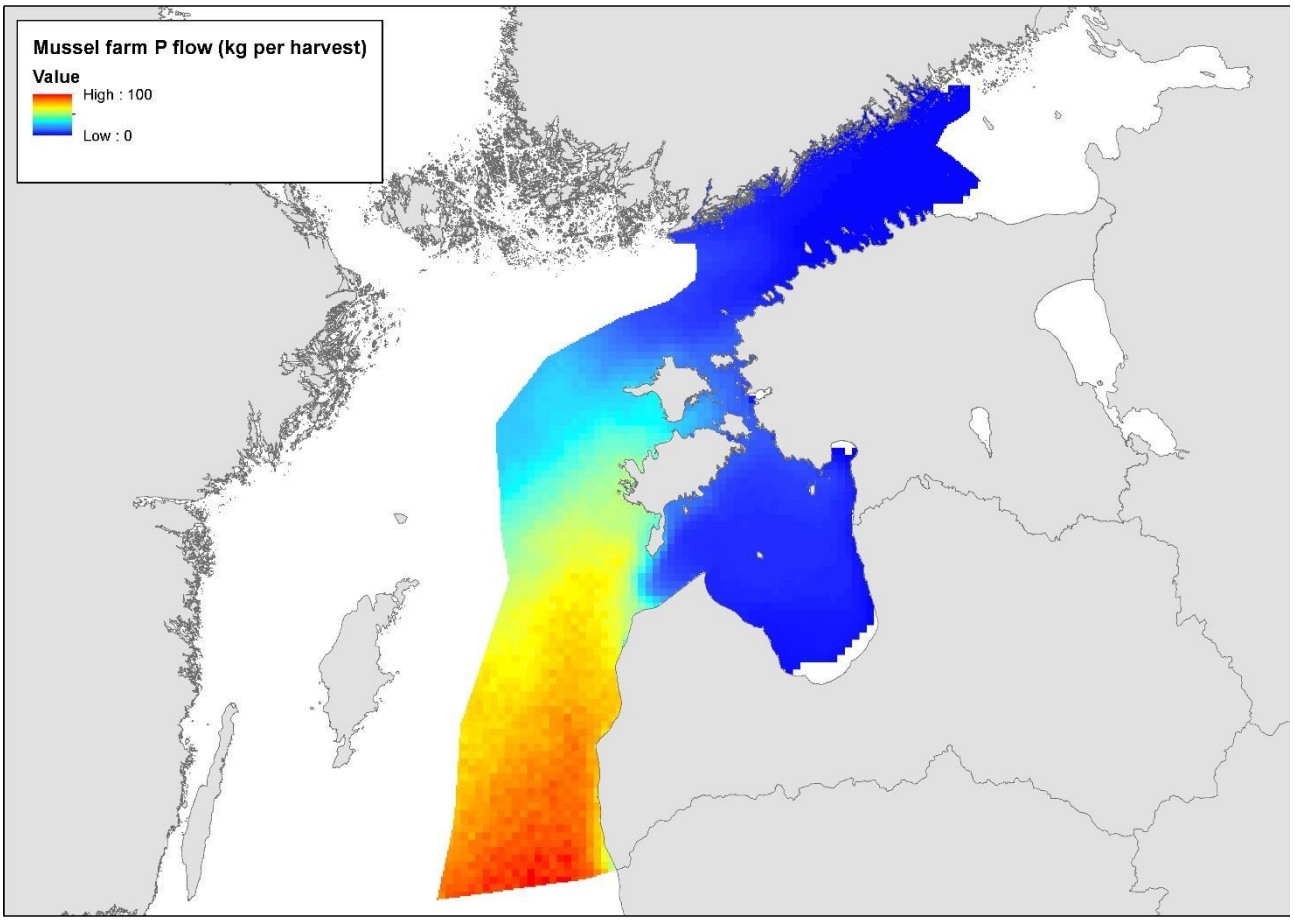

Dreissena polymorpha population biodeposition (micrograms per hour per m2)
Value
High : 100
Low : 0

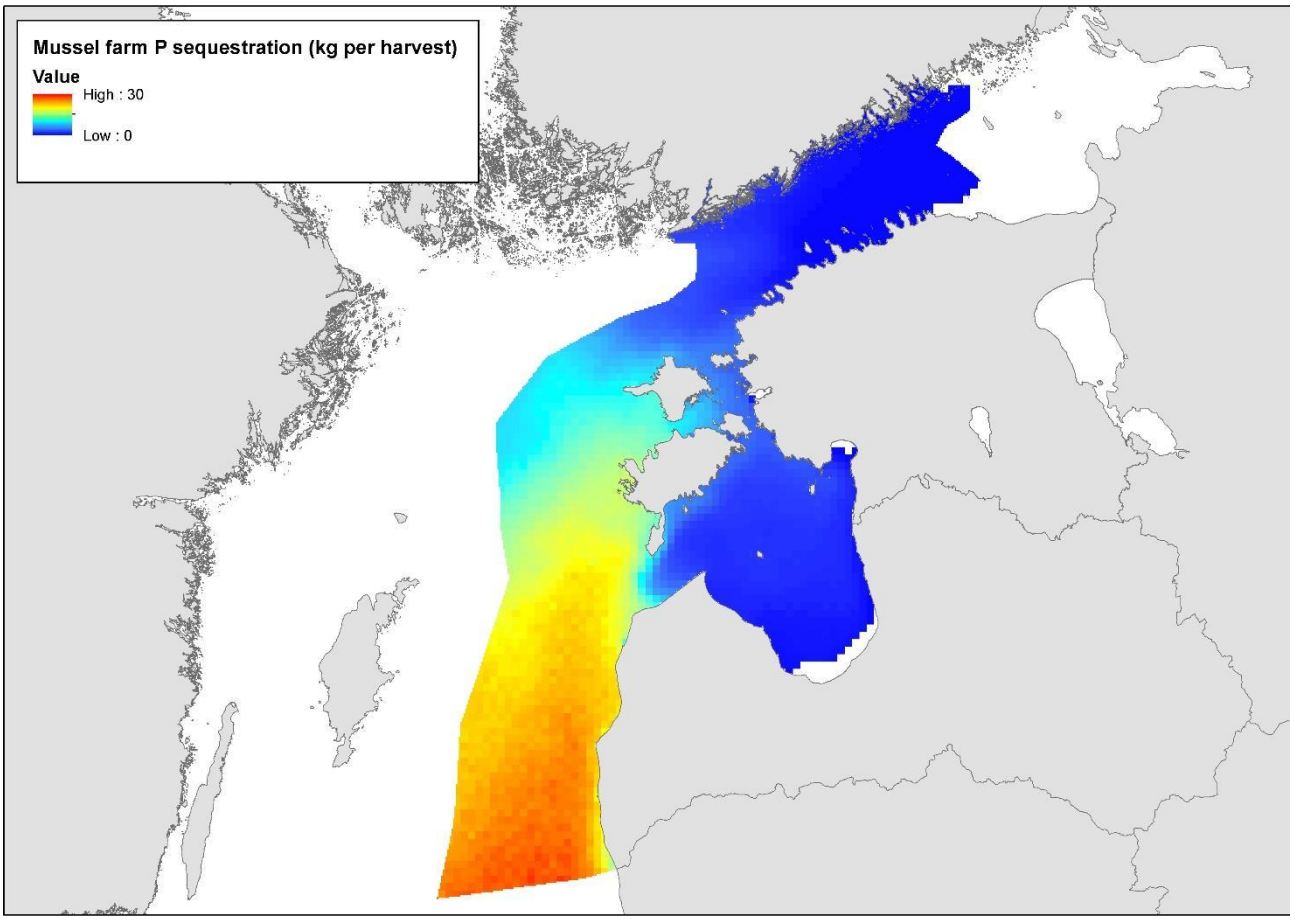

Mytilus trossulus biodeposition (micrograms per hour per 20mm individual)
Value
High : 1
Low : 0

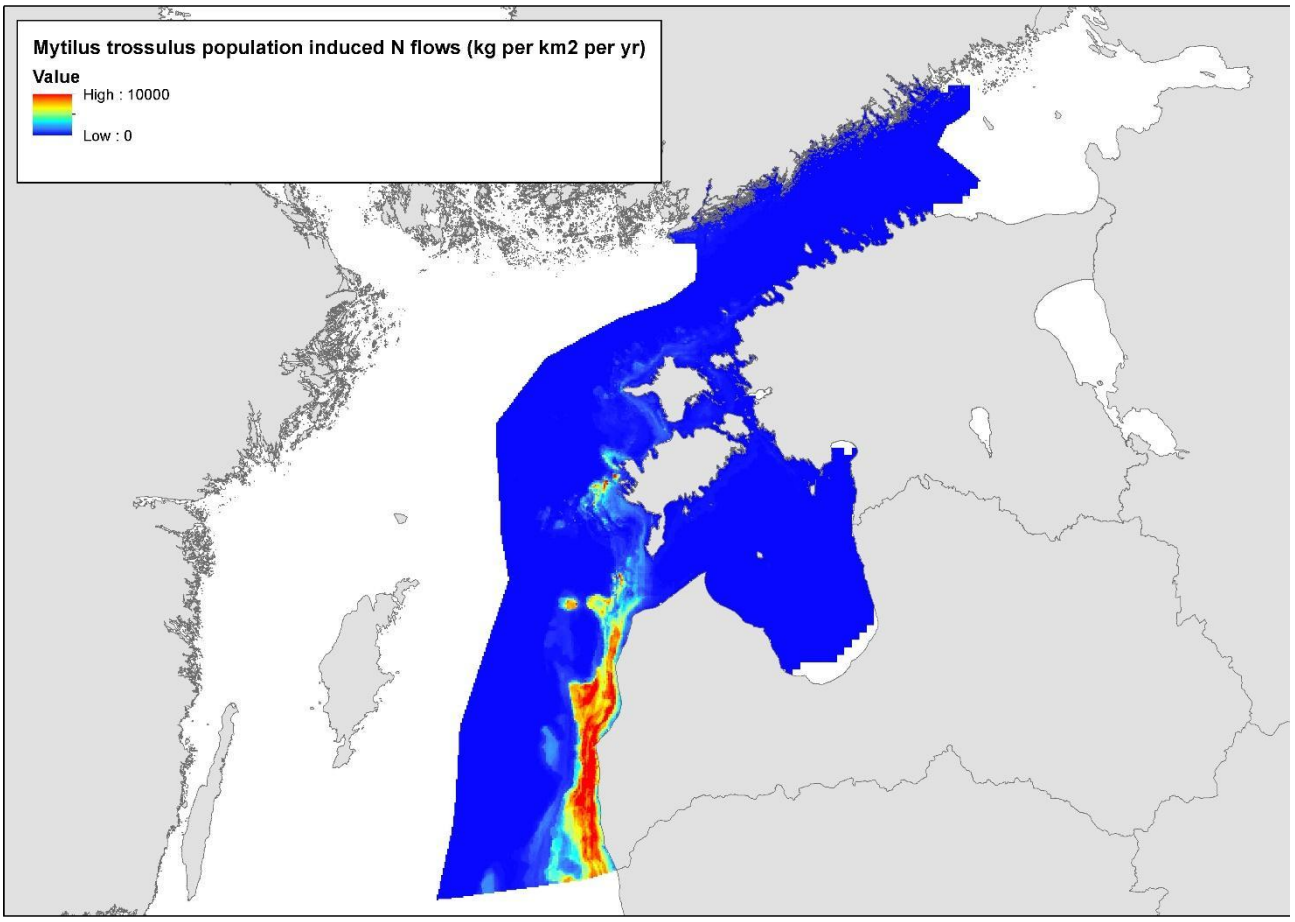

Mytilus trossulus population biodeposition (micrograms per hour per m2)
Value
High : 100
Low : 0

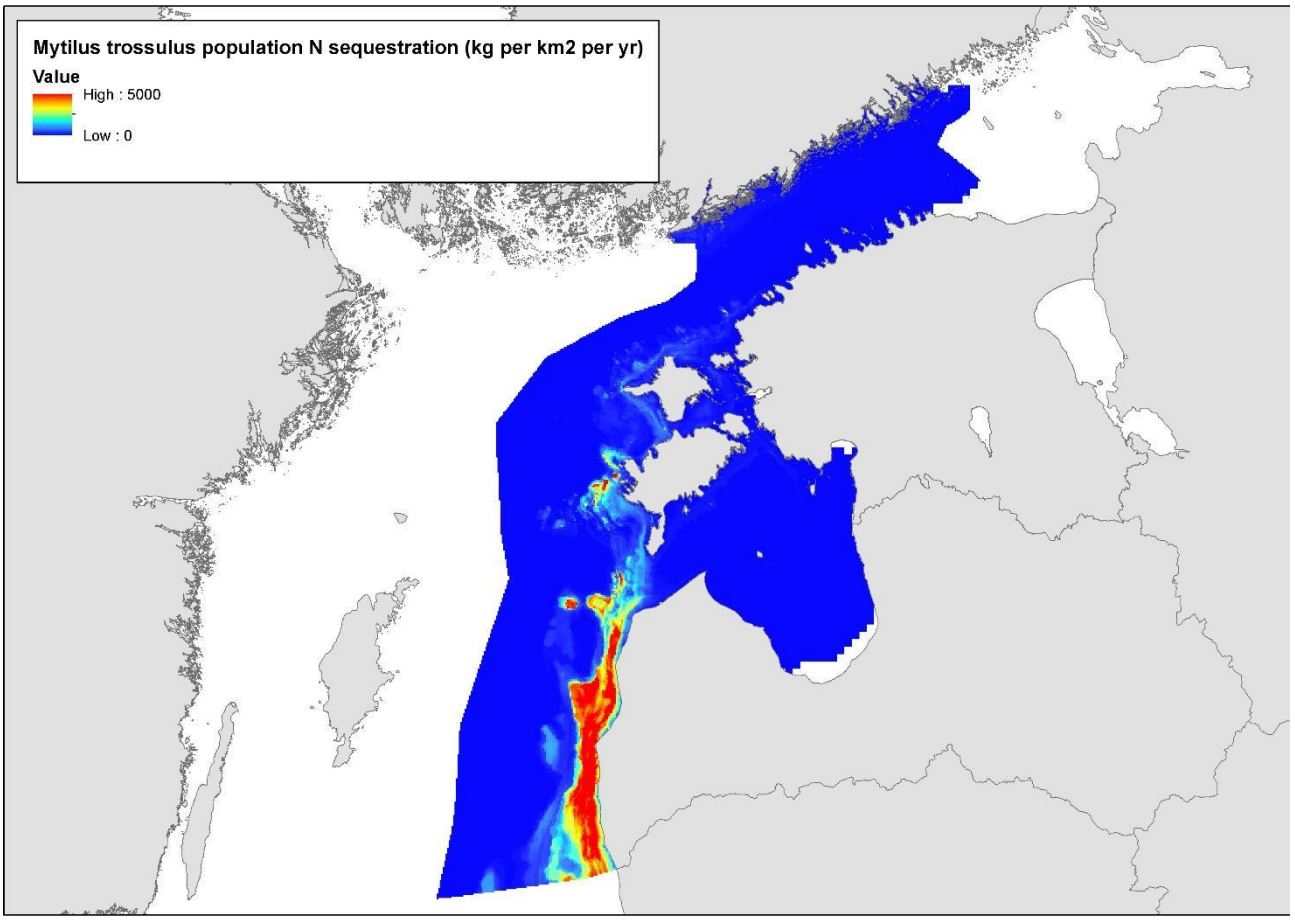

Mussel farm N flow (kg per harvest)
Value
High : 1000
Low : 0


Mussel farm N sequestration (kg per harvest)
Value
High : 500
Low : 0


Mussel farm P flow (kg per harvest)
Value
High : 100
Low : 0


Mussel farm P sequestration (kg per harvest)
Value
High : 30
Low : 0


Mytilus trossulus population induced N flows (kg per km2 per yr)
Value
High : 10000
Low : 0


Mytilus trossulus population N sequestration (kg per km2 per yr)
Value
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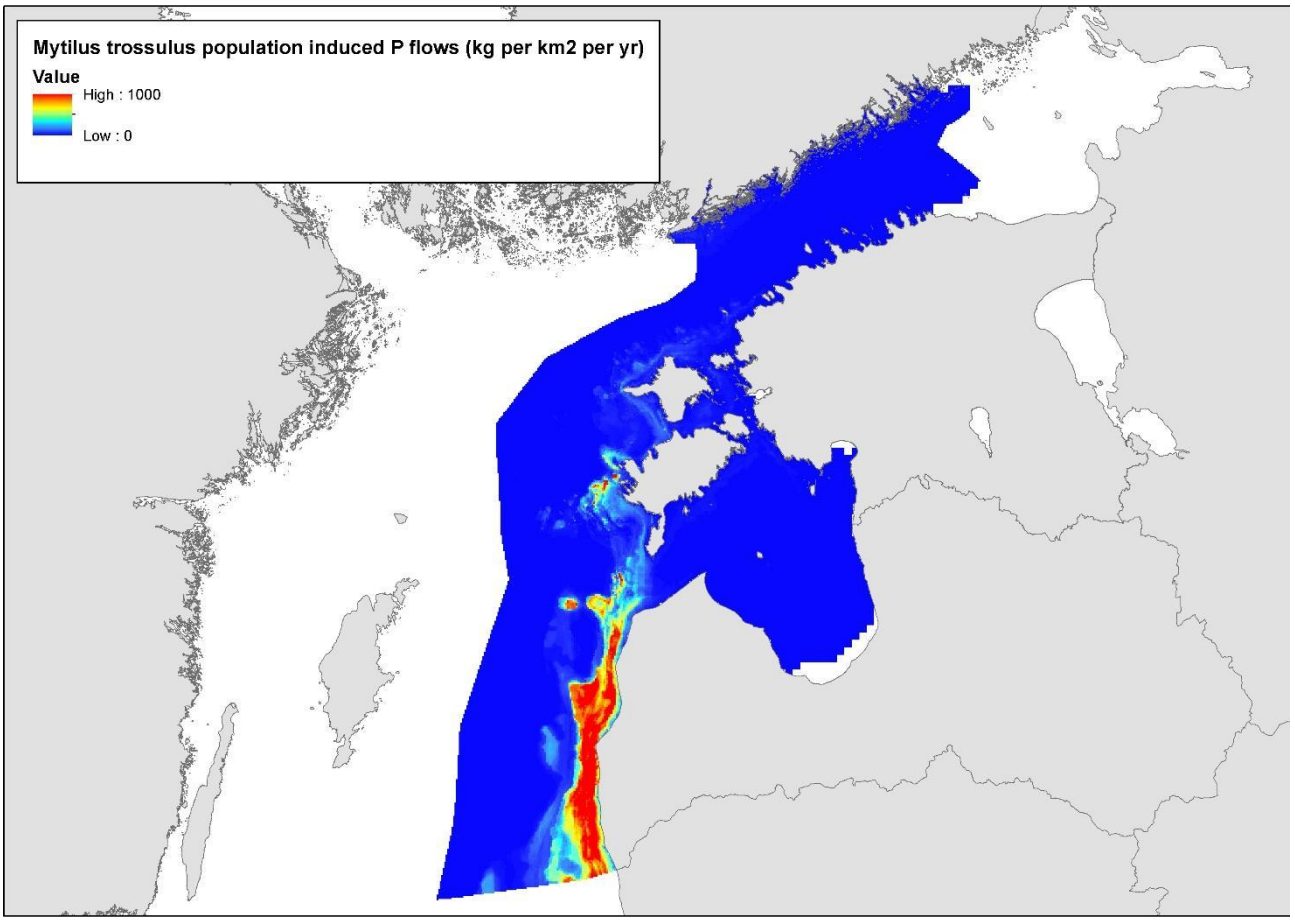
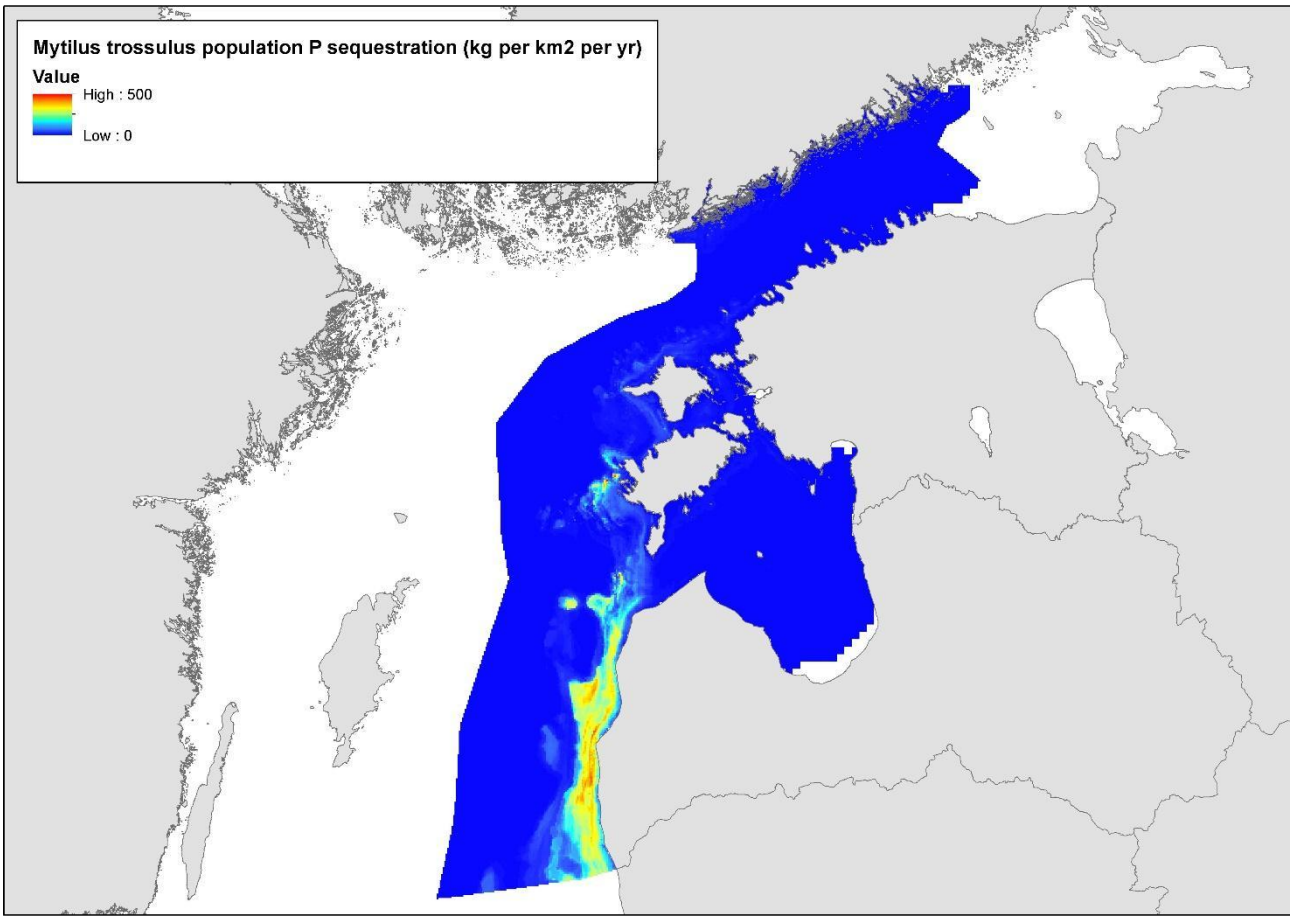
Low : 0

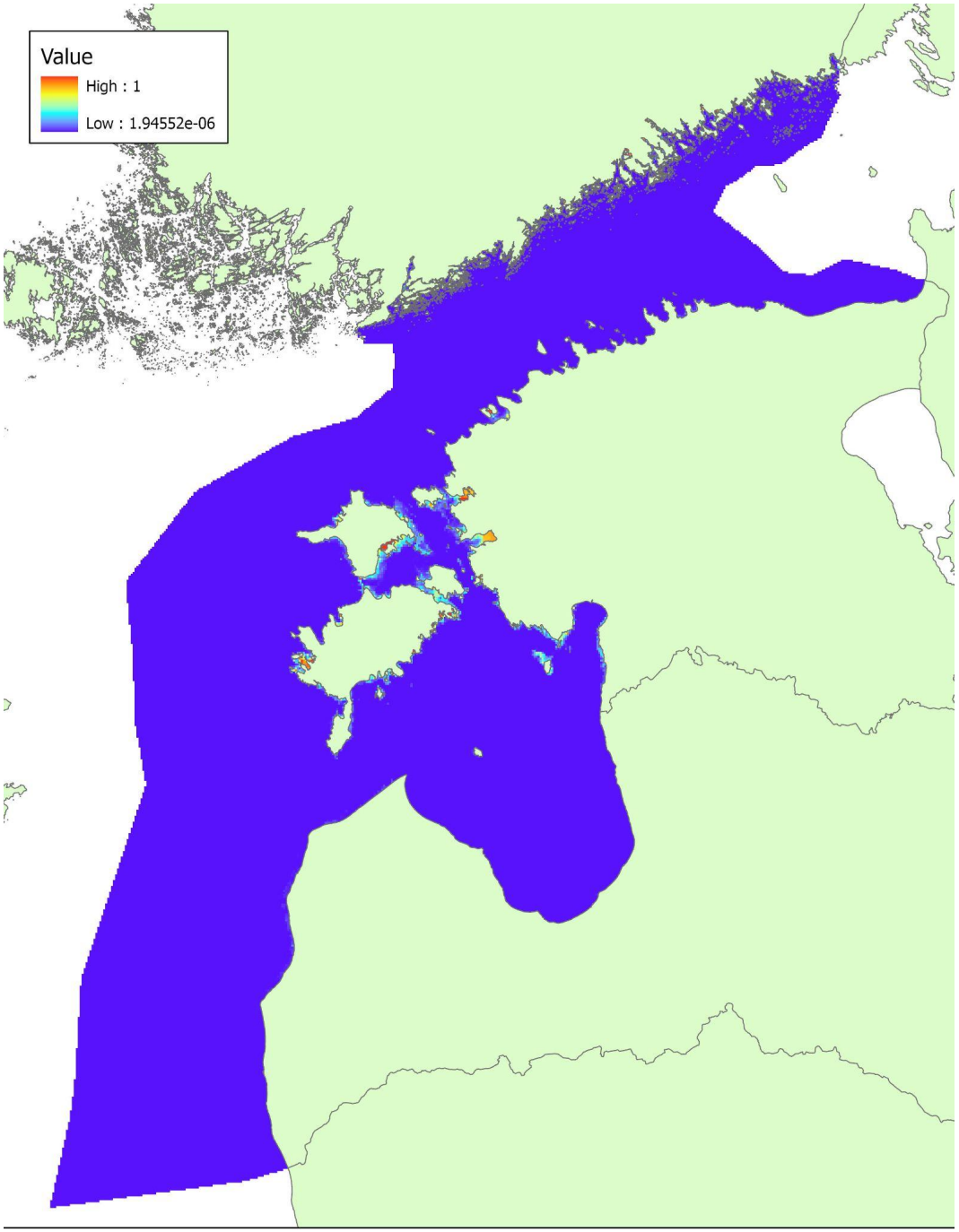

Mytilus trossulus population induced P flows (kg per km2 per yr)
Value
High : 1000
Low : 0



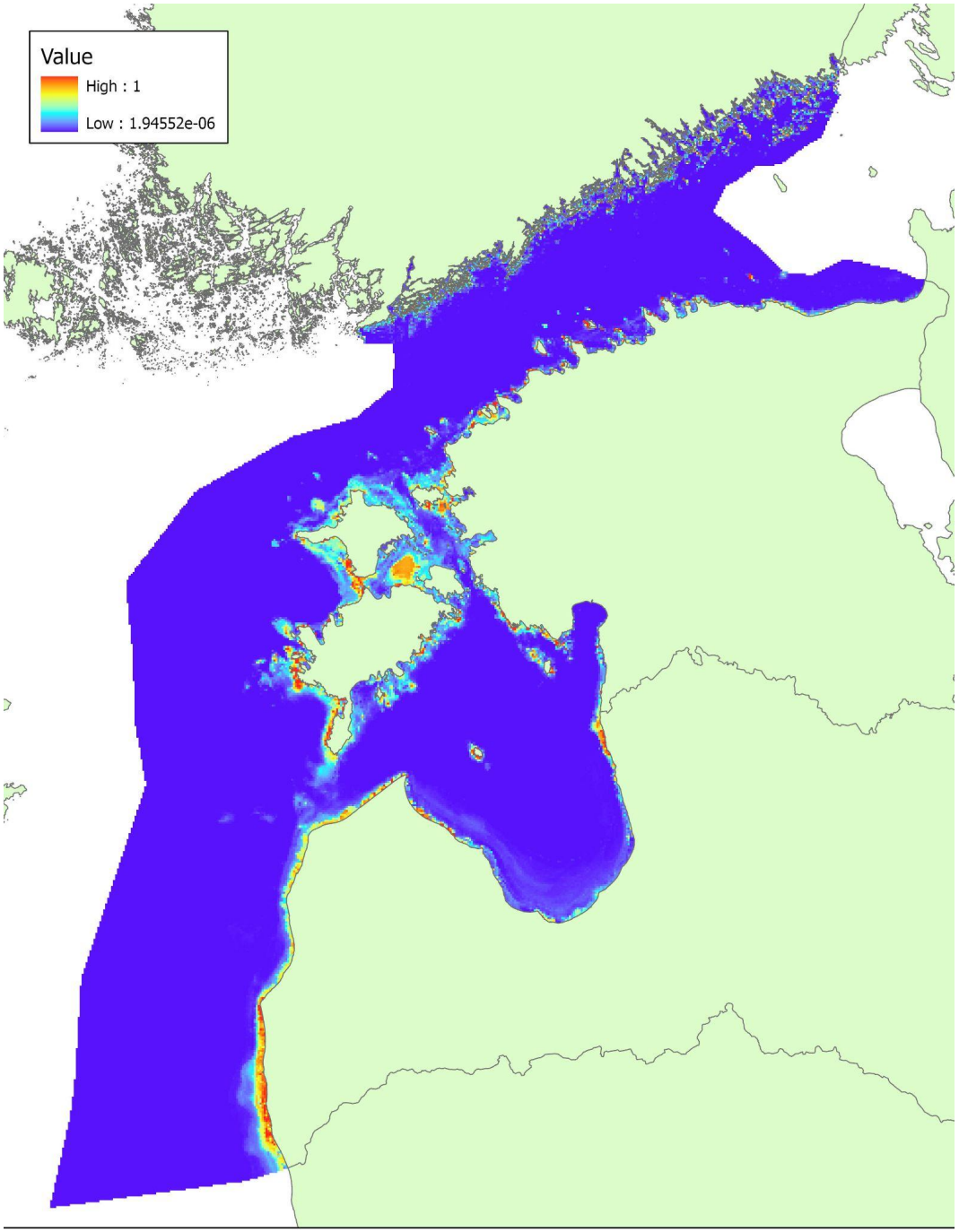
Sequestration and storage of nutrients and harmful substances by vegetation and fauna

Harmful substances and contaminants occur in the marine environment due to human activities. Many algae species such as *Fucus vesiculosus* and for example mussels take up the substances through their metabolic process and store them in their cells (Söderlund et al. 1988). The organisms thus serve as storage of the contaminants and thus contribute to the better water quality.

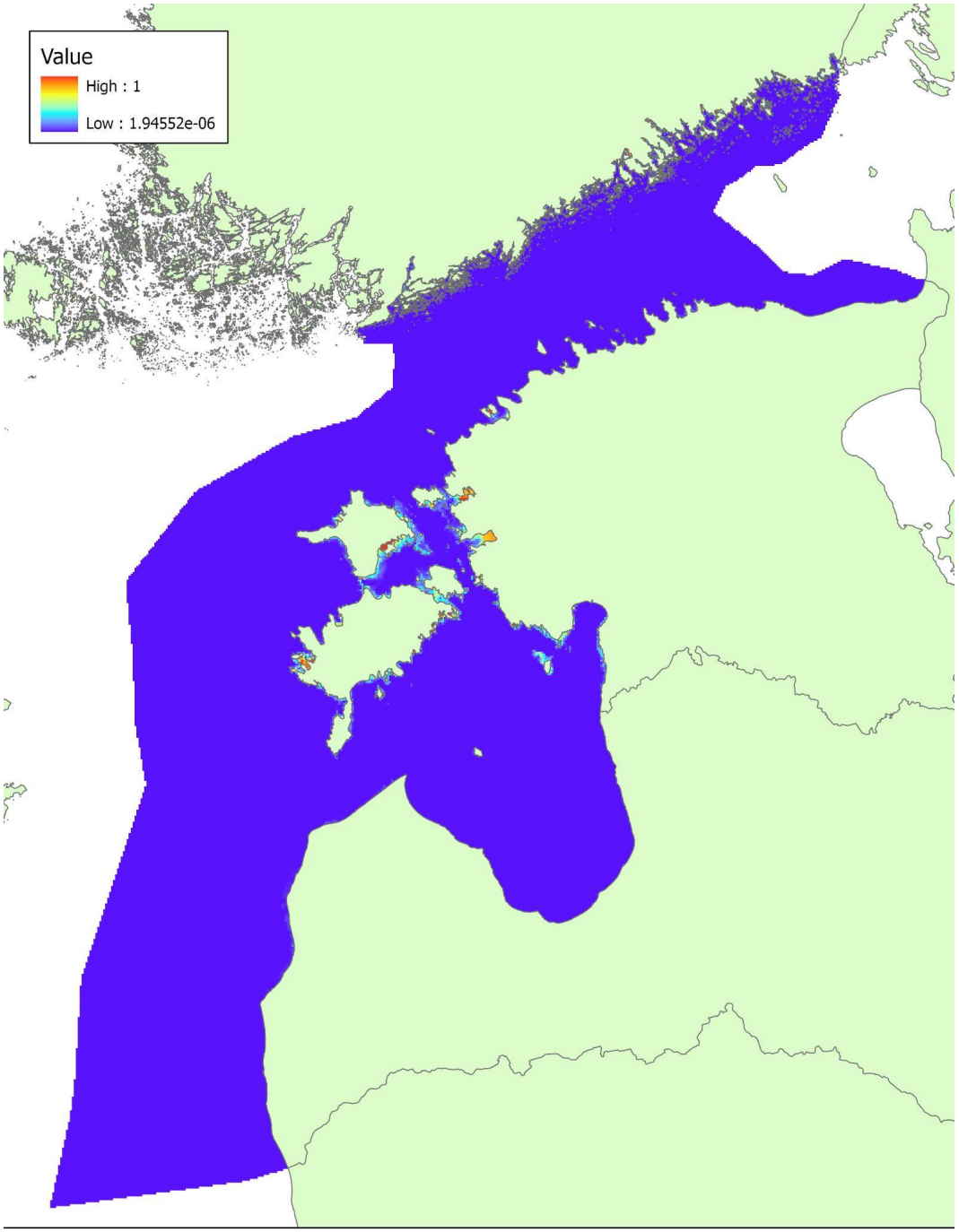
To produce aggregated maps on the service supply of filtration / sequestration / storage / accumulation of nutrients (hereafter nutrients) and harmful substances (hereafter toxins) provided by aquatic vegetation on soft and hard substrates, species distribution models on occurrence in the Finnish area and biomass in Estonian and Latvian areas were adjusted, aggregated and normalised. Species were summed based on expected contribution to the potential service supply (CICES: 2.1.1.2) and the resulting map layers were scaled to 0-1 for comparison of intensity between maps. Please see the section on *Materials* for methodology.



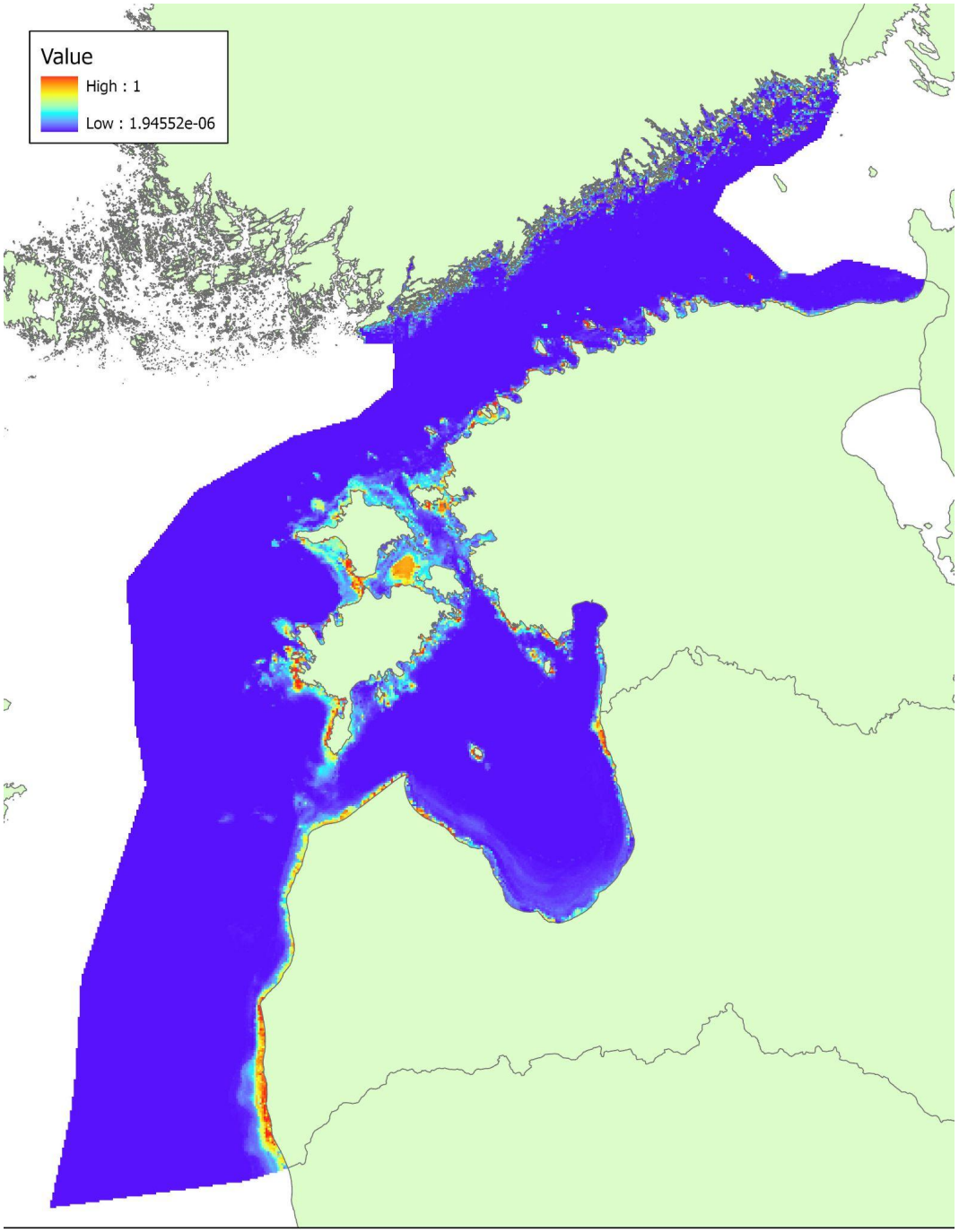
Sequestration and storage of harmful substances by aquatic vegetation on soft substrates



Sequestration and storage of harmful substances by aquatic vegetation on hard substrates



Sequestration and storage of nutrients by aquatic vegetation on soft substrates



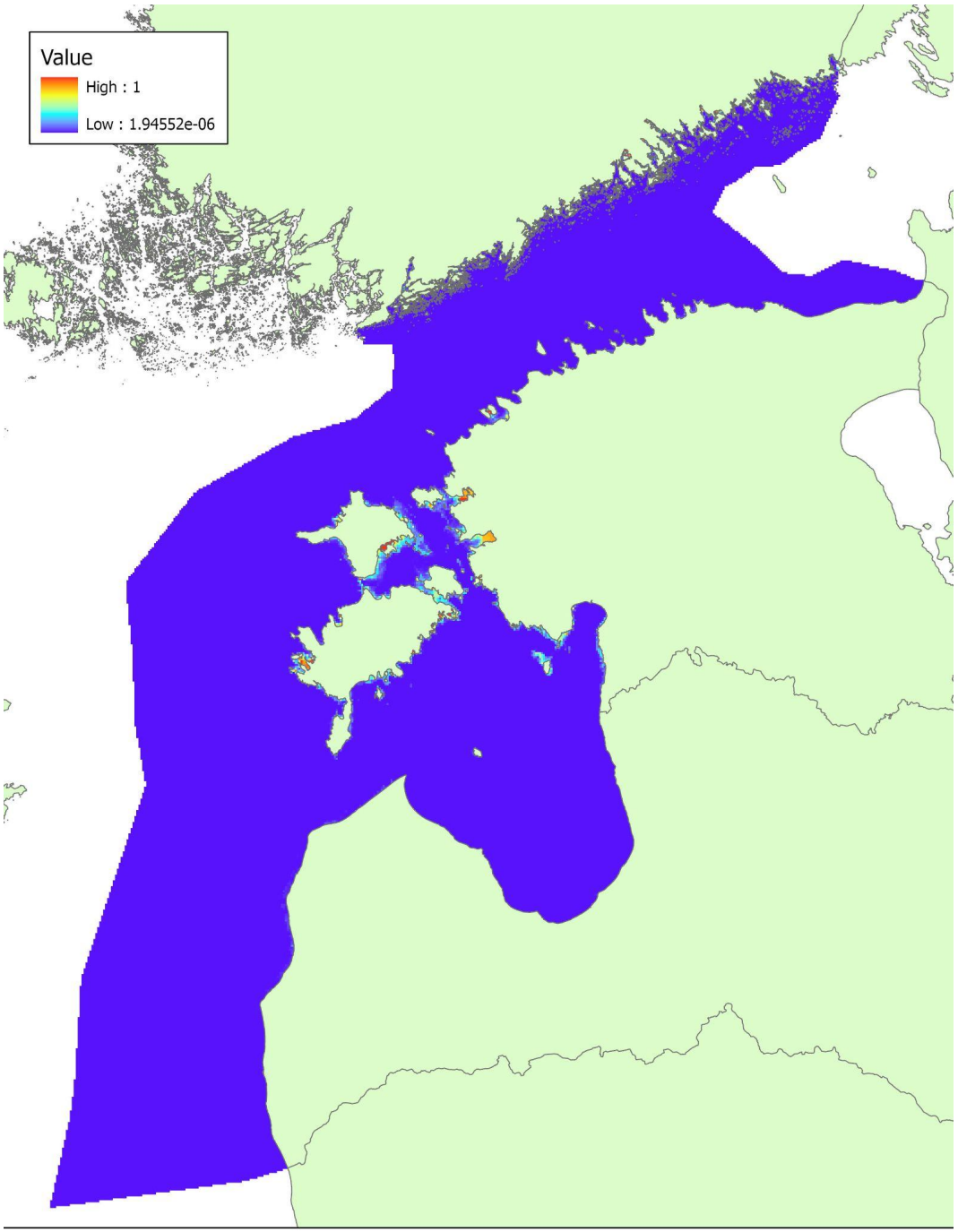
Sequestration and storage of nutrients by aquatic vegetation on hard substrates

Net oxygen production

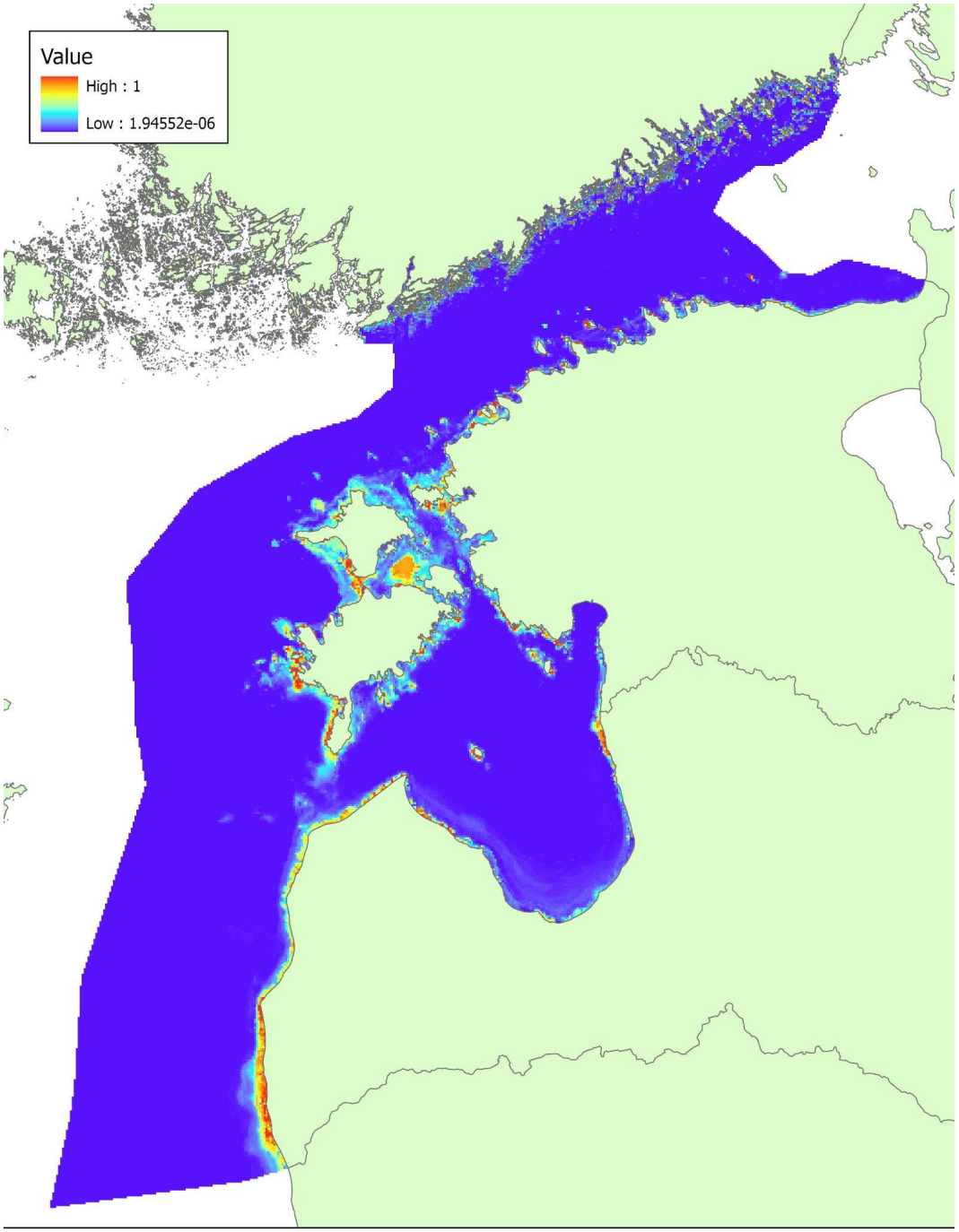
Most living organisms consume oxygen in their metabolism and thus, oxygen is essential in supporting life on Earth. In eutrophicated areas, anoxic conditions may occur when all oxygen is consumed near the bottom during decomposition. Photosynthetic organisms produce oxygen and regenerate the oxic conditions. Marine organisms are also important for producing oxygen to the atmosphere, and for example half of the oxygen we breathe originates from marine areas.

To produce aggregated maps on the service supply of the net oxygen production (belonging to services regulation of the chemical condition of salt waters) provided by aquatic vegetation on soft and hard substrates, species distribution models on occurrence in the Finnish area and biomass in Estonian and Latvian areas were adjusted, aggregated and normalised. Species were summed based on expected contribution to the potential service supply (CICES: 2.2.5.2) and the resulting

map layers were scaled to 0-1 for comparison of intensity between maps. Please see the section on *Materials* for methodology.



Net oxygen by aquatic vegetation on soft substrates



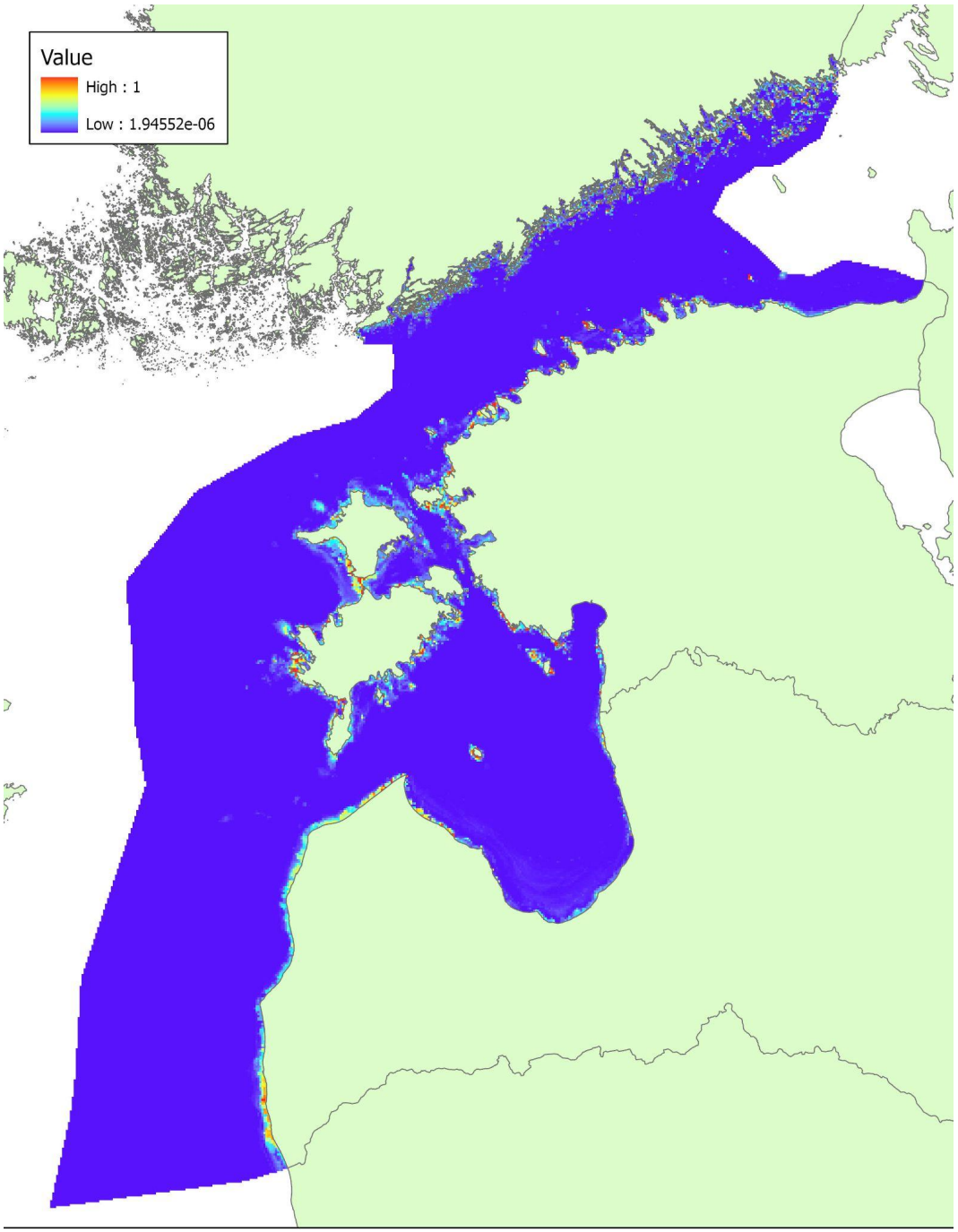
Net oxygen by aquatic vegetation on hard substrates

Bioremediation

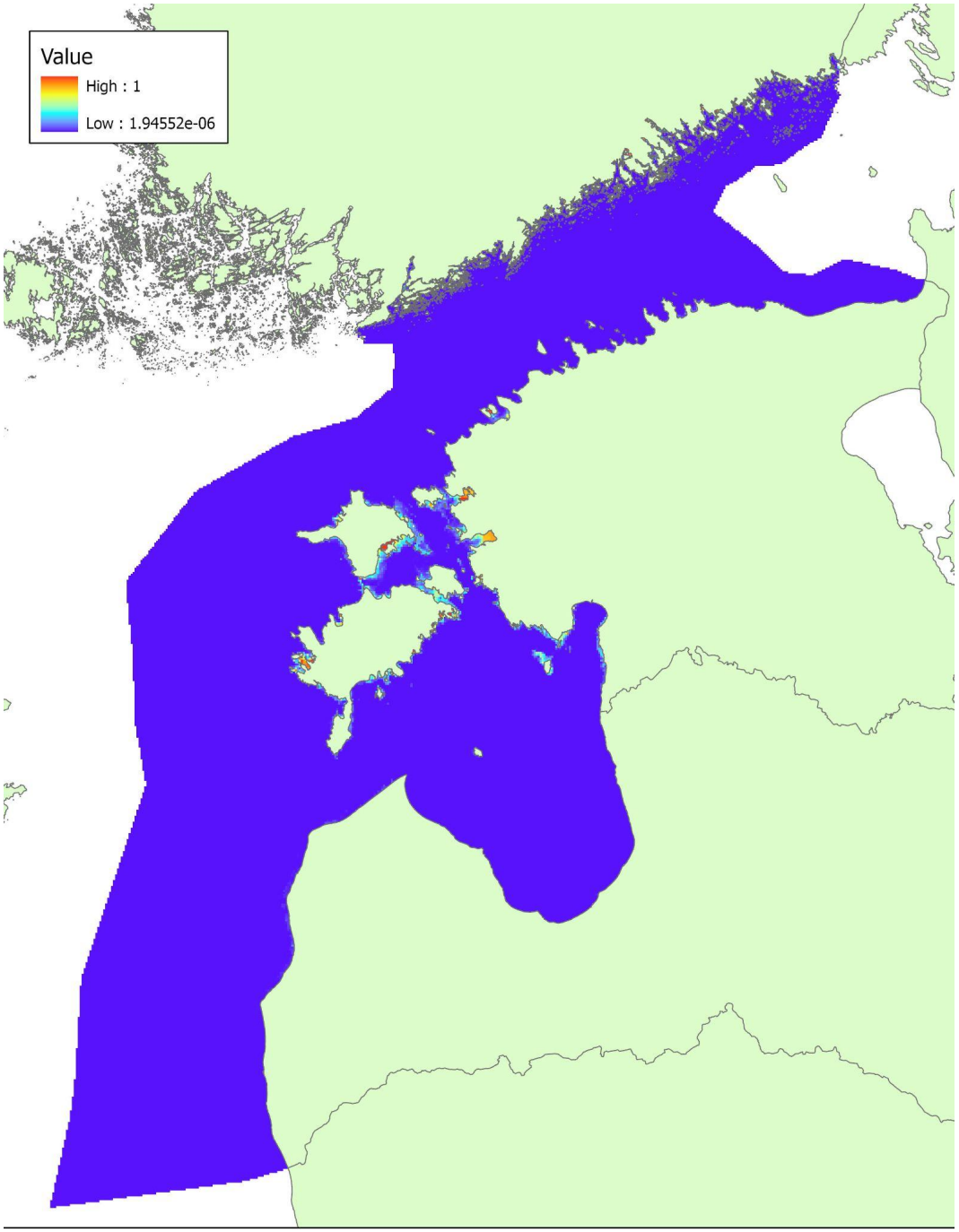
Many harmful substances and contaminants such as oil occur in marine waters due to human activities. Some mirco-organisms, algae and plants have an ability to bioremediate e.g. break down the harmful substance into less harmful format.

To produce aggregated maps on the service supply of the bioremediation (belonging to services regulation of the chemical condition of salt waters) provided by aquatic vegetation on soft and hard substrates, species distribution models on occurrence in the Finnish area and biomass in Estonian and Latvian areas were adjusted, aggregated and normalised. Species were summed based on expected contribution to the potential service supply (CICES: 2.1.1.1) and the resulting

map layers were scaled to 0-1 for comparison of intensity between maps. Please see the section on *Materials* for methodology.



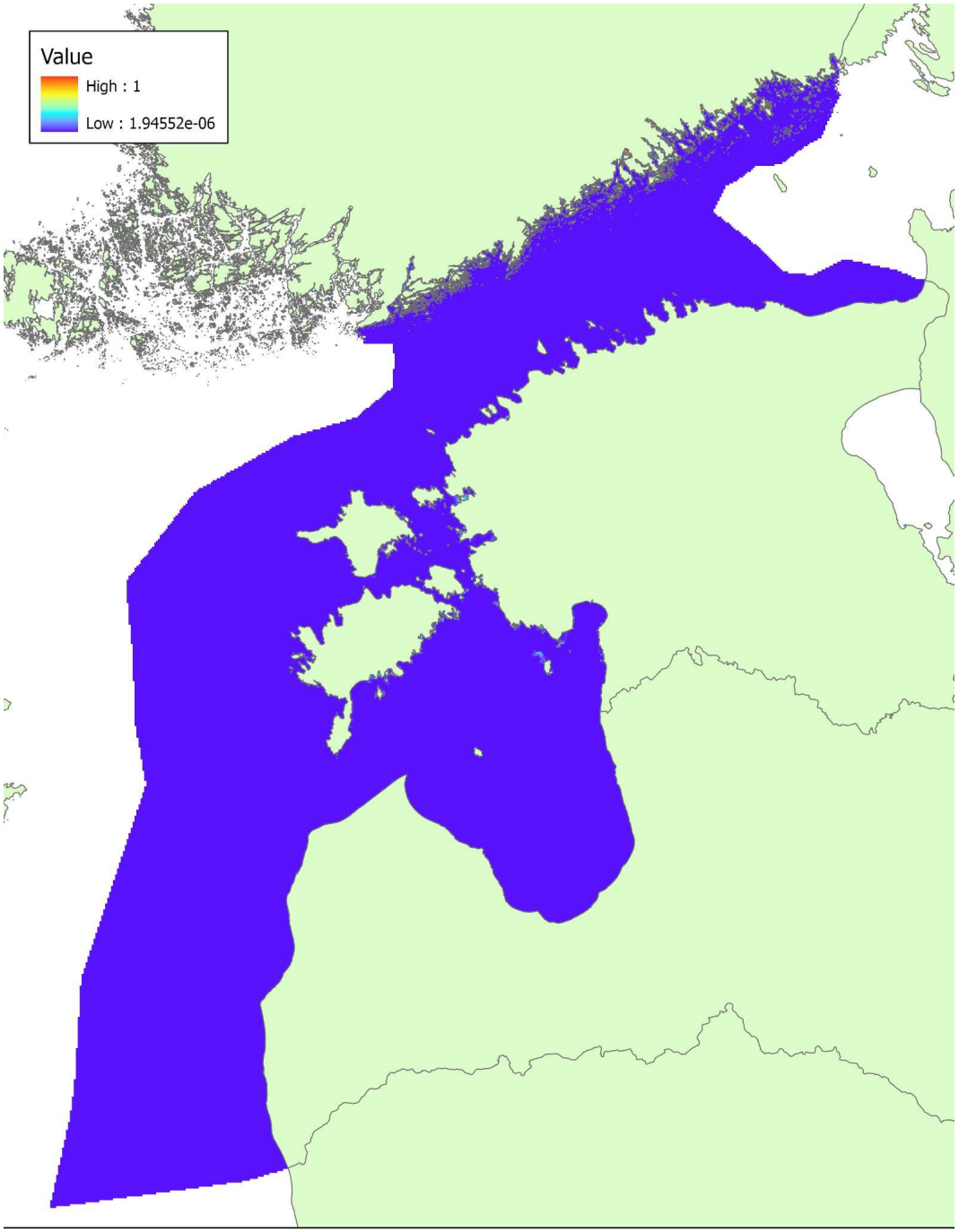
Bioremediation by aquatic vegetation on hard substrates



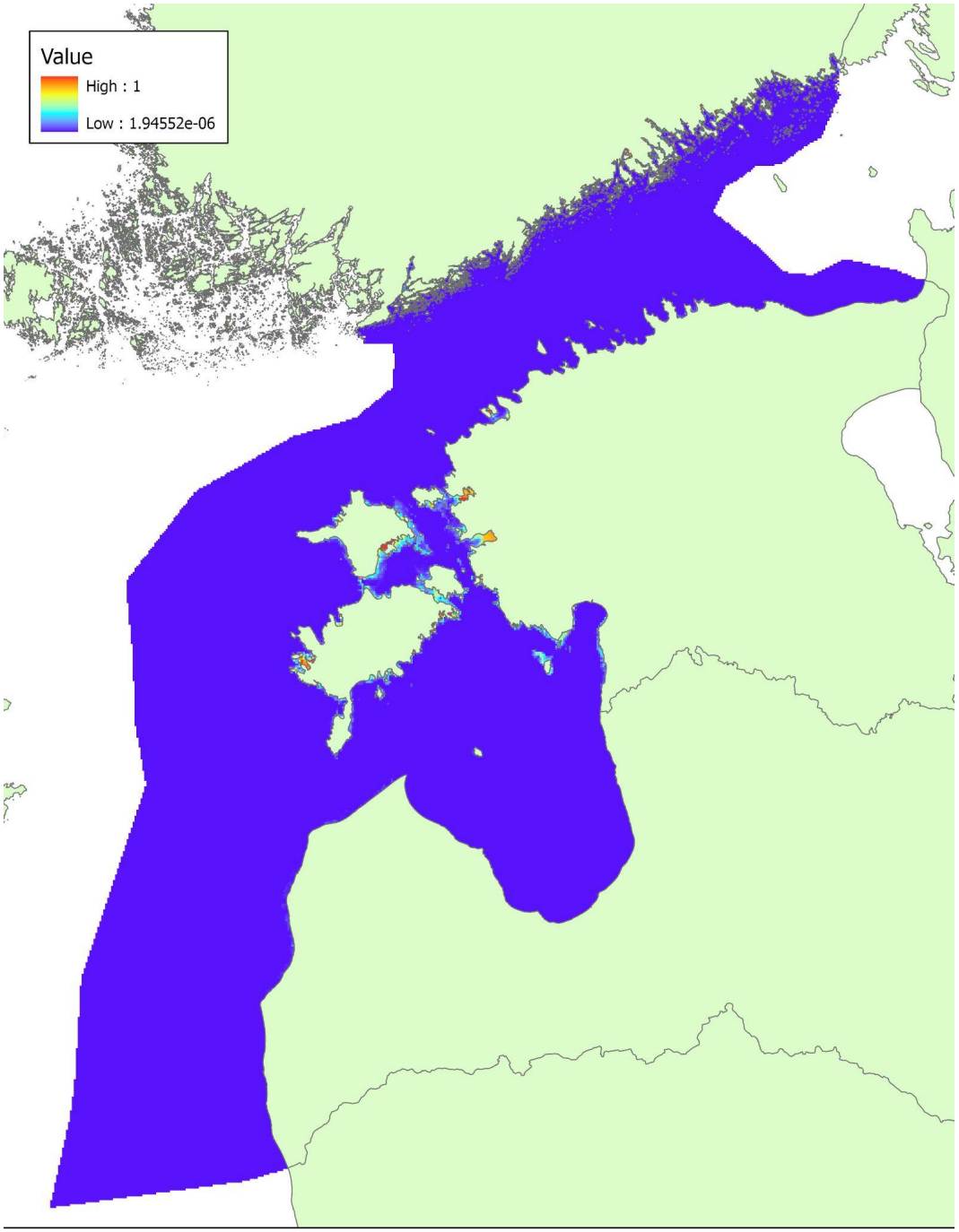
Bioremediation by aquatic vegetation on soft substrates

Flood and erosion protection

To produce aggregated maps on the potential service supply of flood and erosion prevention provided by aquatic vegetation on soft and hard substrates, species distribution models on occurrence in the Finnish area and biomass in Estonian and Latvian areas were adjusted, aggregated and normalised. Species were summed based on expected contribution to the potential service supply (CICES: 2.2.1.3 and CICES: 2.2.1.1 respectively) and the resulting map layers were scaled to 0-1 for comparison of intensity between maps. Please see the section on Materials and feed for methodology.



Flood protection by aquatic vegetation on soft substrates



Erosion protection by aquatic vegetation on soft substrates

Spawning and nursery grounds

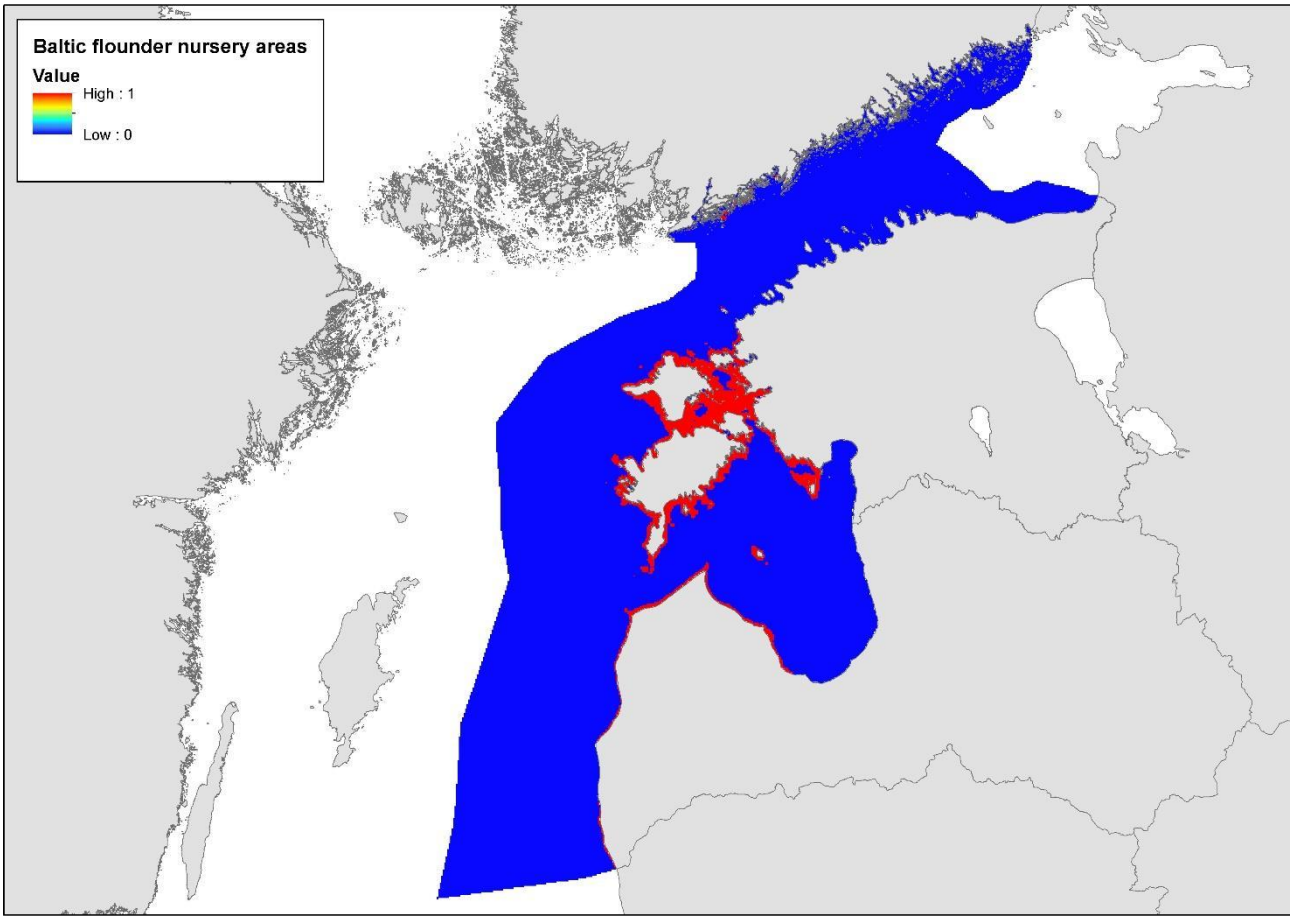
The maps of the spawning and nursery grounds were obtained by combining maps of the PanBalticScope project (expert judgement and overlay analysis; http://www.panbalticscope.eu/) with the modelling products of the MAREA project covering the Estonian marine waters only (MaxEnt spatial model products validated with field data). Due to the lack of field validation data from Finland and Latvia it was not possible to produce harmonised spatial model predictions for the entire MAREA region.

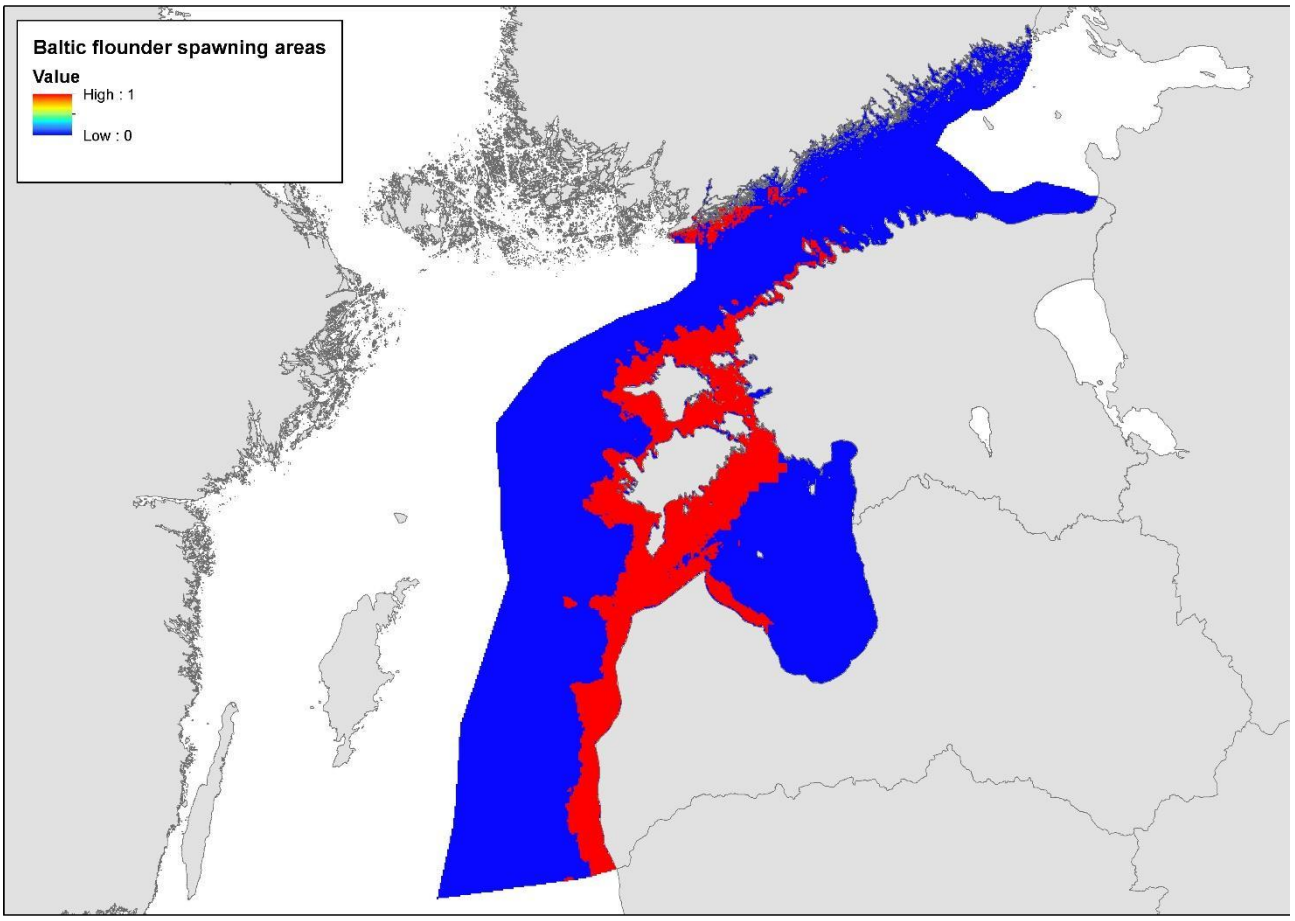
Two flounder species occur in the Baltic Sea: European flounder *Platichthys flesus* and Baltic flounder *P. solemdali*. Baltic flounder is the predominant flounder species, although mixing occurs between these two species in the catches (ICES, 2021). The two flounder species share not only nursery areas but also feeding areas along the coast during summer-autumn (Nissling et al., 2015). The European flounder (*P. flesus*) is spawning in the deep basins with larval migration to the upper part of the water mass and extensive larval dispersal, and Baltic flounder (*P. solemdali*), is spawning in coastal areas allowing for mainly local larval dispersal along the coast.

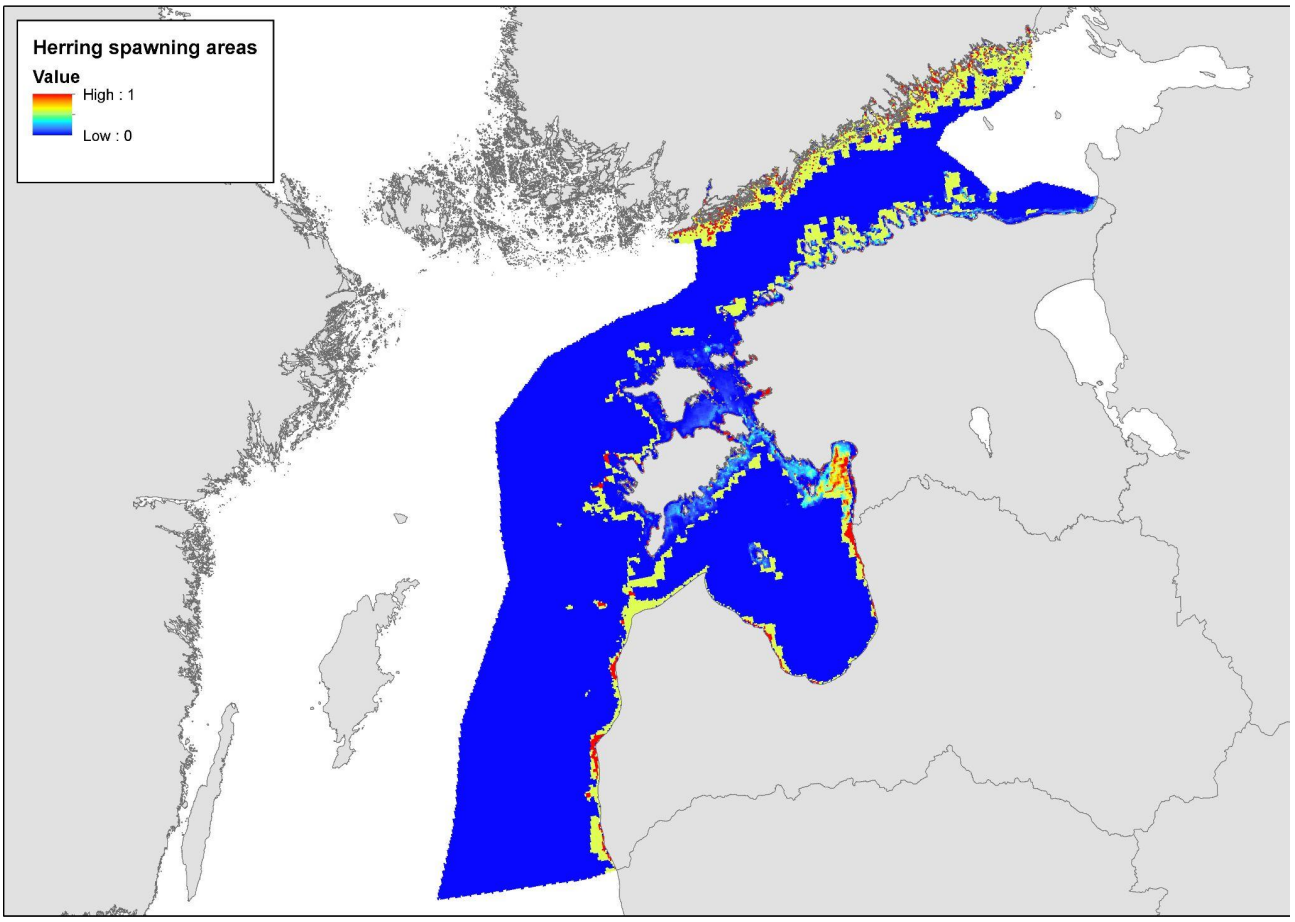
Herring spawns in shallow coastal areas, and in offshore shallows having demersal eggs, which are attached to the seabed substrate - there are populations of both spring spawning and autumn spawning herring in the Baltic Sea, out of which spring spawning herring strongly dominates today (HELCOM, 2021).

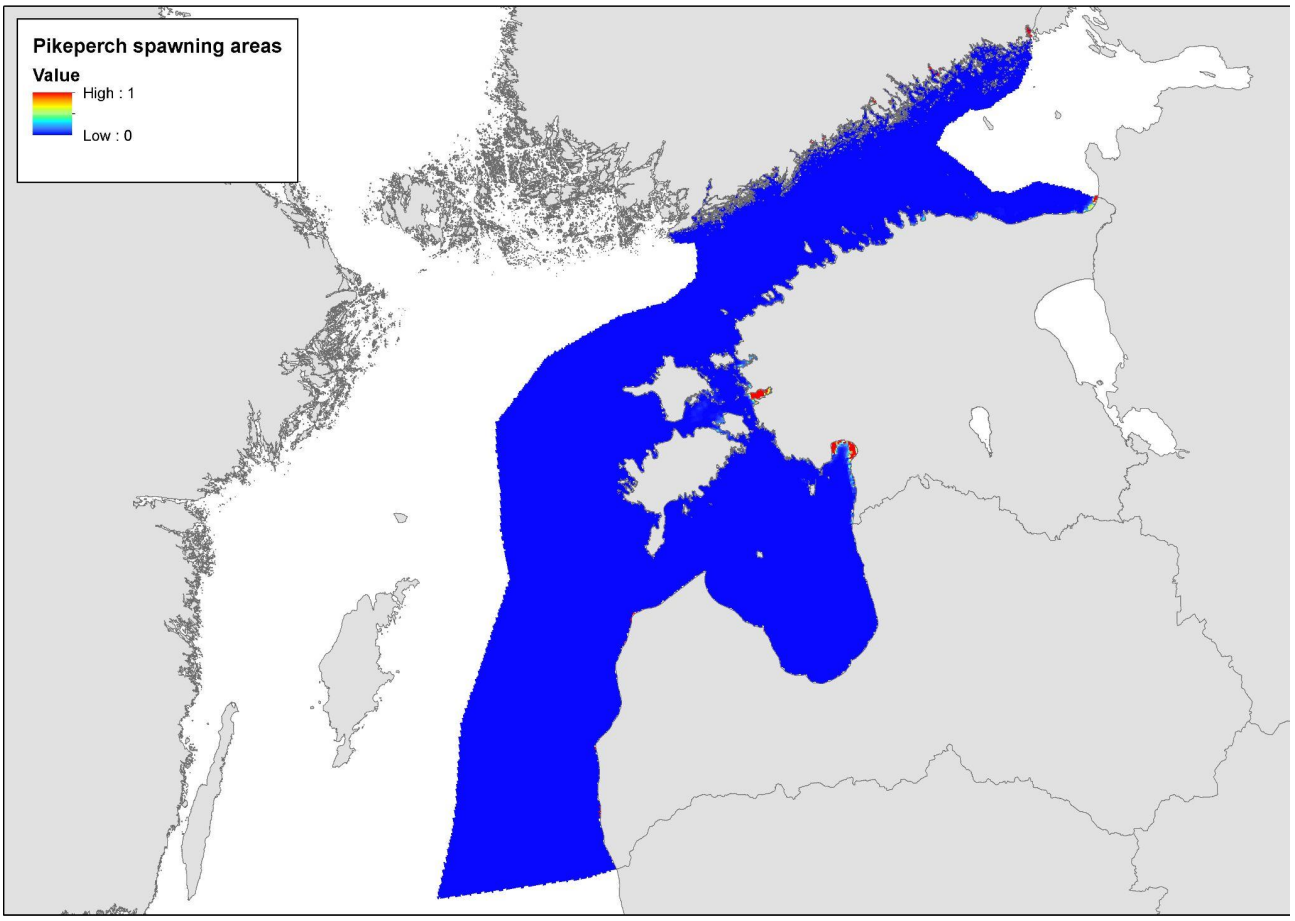
Pikeperch (*Sander lucioperca*) is a species of freshwater origin, which spawns predominantly in freshwater tributaries and has a relatively limited dispersal away from its recruitment area (HELCOM, 2021).

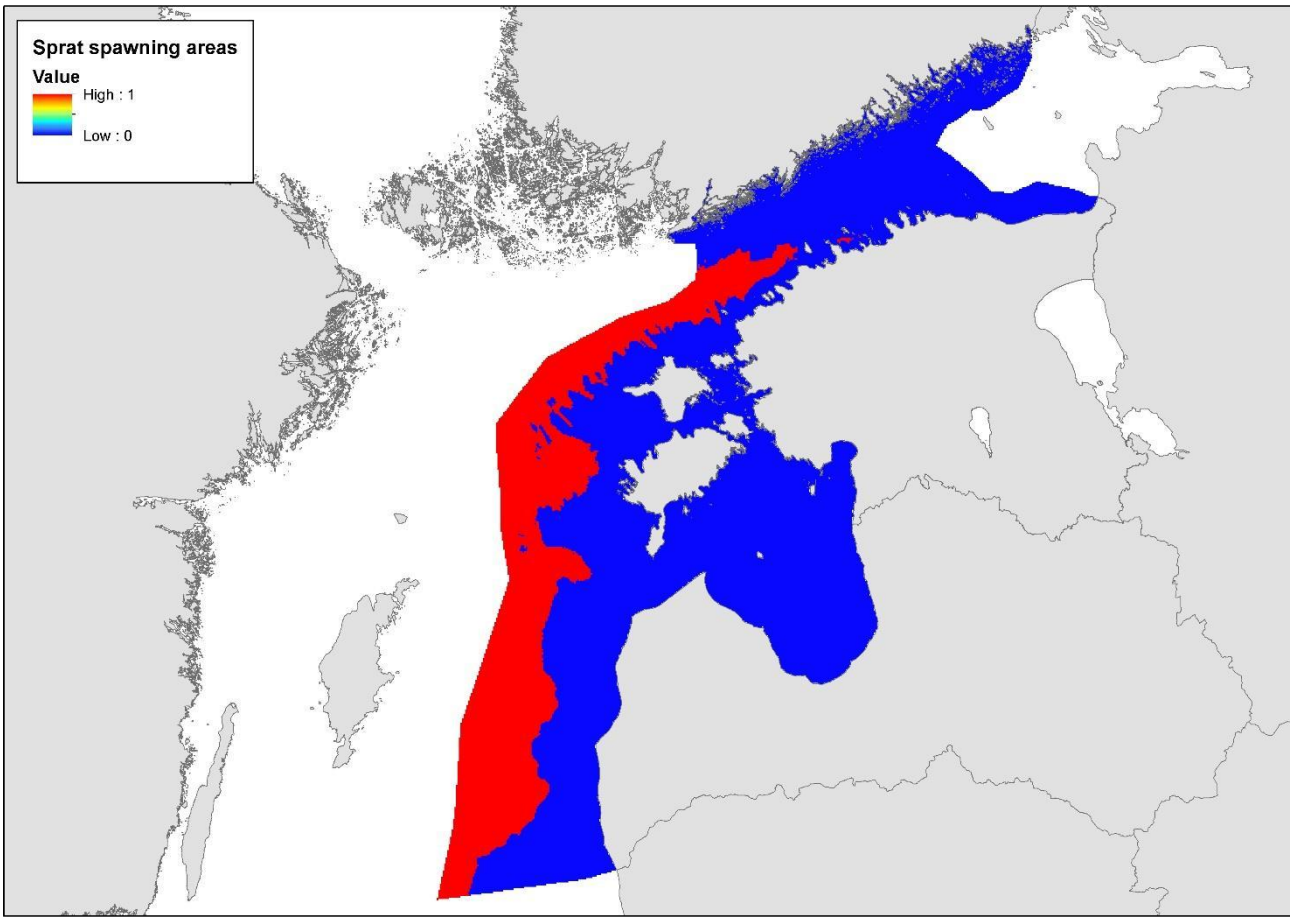
Sprat (Sprattus sprattus) occurs in the entire Baltic Sea, and mainly in open sea areas being assessed as a single stock in the Baltic Sea within fisheries management. Sprat eggs are pelagic, and sprat spawning is well known from the deep basins in the central Baltic, where it typically occurs from February to August (HELCOM, 2021).



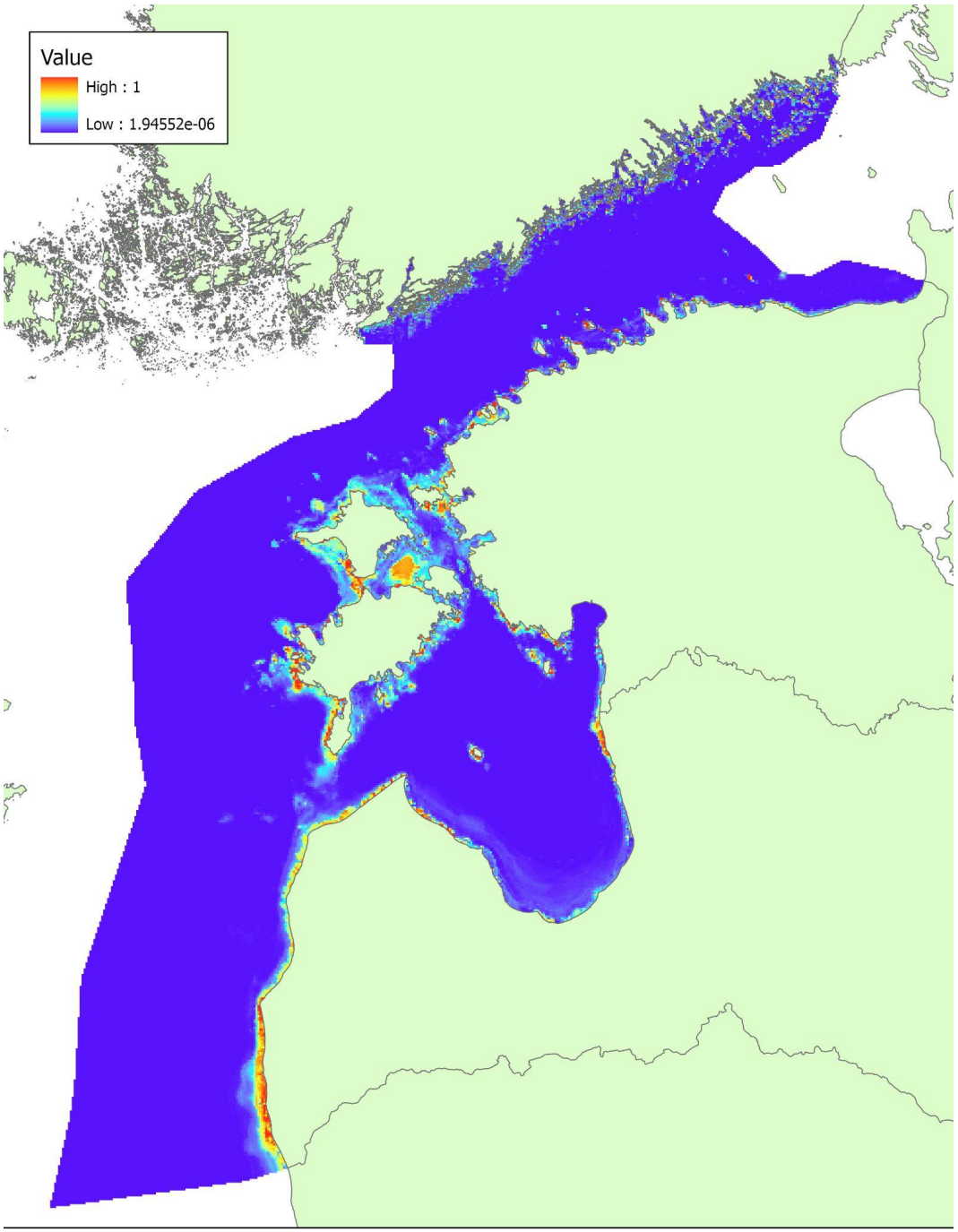

Baltic flounder spawning areas
Value
High : 1
Low : 0


Herring spawning areas
Value
High : 1
Low : 0

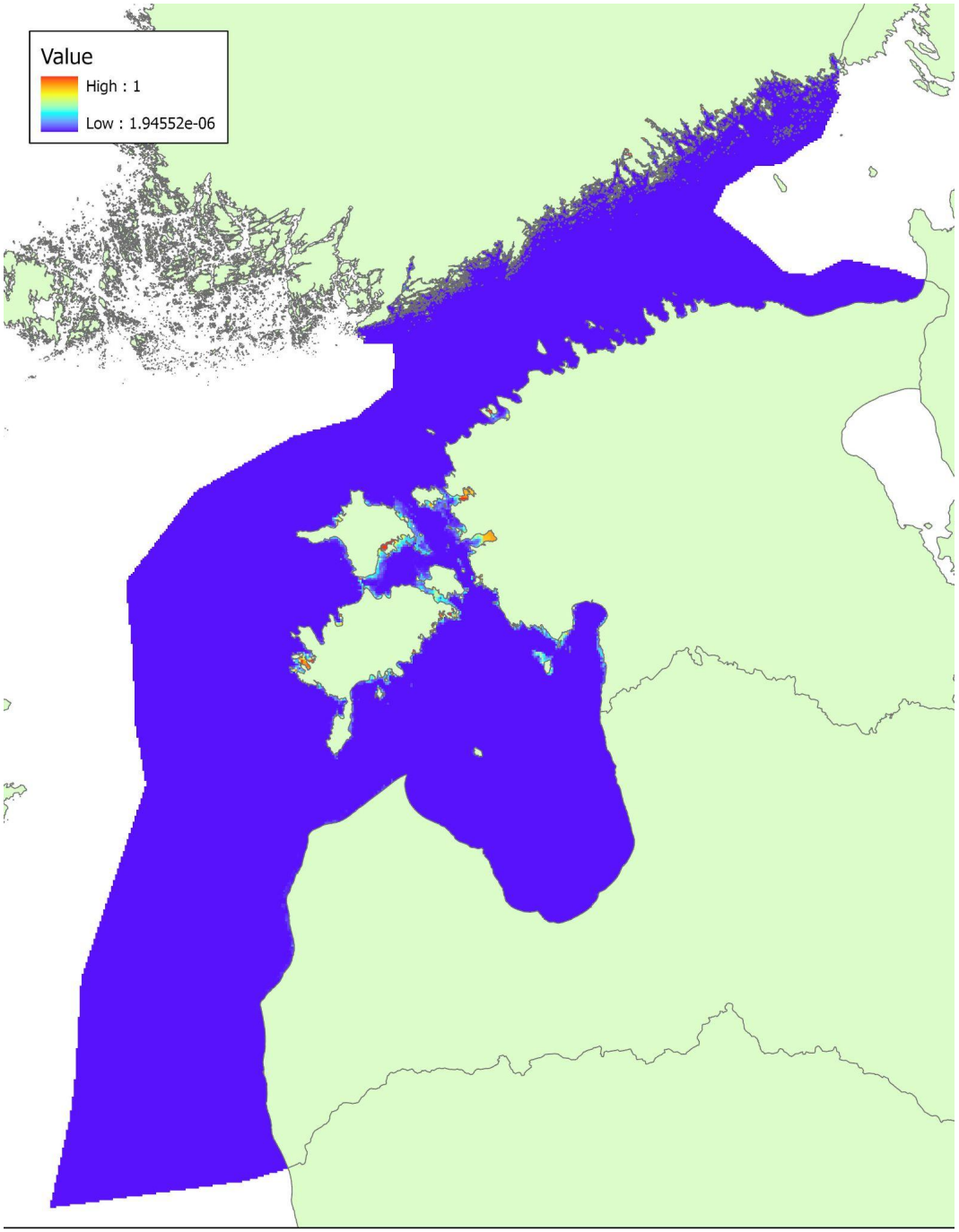

Pikeperch spawning areas
Value
High : 1
Low : 0


Sprat spawning areas
Value
High : 1
Low : 0

To produce aggregated maps on the service supply of habitats provided by aquatic vegetation on soft and hard substrates, species distribution models on occurrence in the Finnish area and biomass in Estonian and Latvian areas were adjusted, aggregated and normalised. Species were summed based on expected contribution to the potential service supply (CICES: 2.2.2.3) and the resulting map layers were scaled to 0-1 for comparison of intensity between maps. Please see section on *Materials* for methodology.



Habitat maintenance by aquatic vegetation on hard substrates



Habitat maintenance by aquatic vegetation on soft substrates

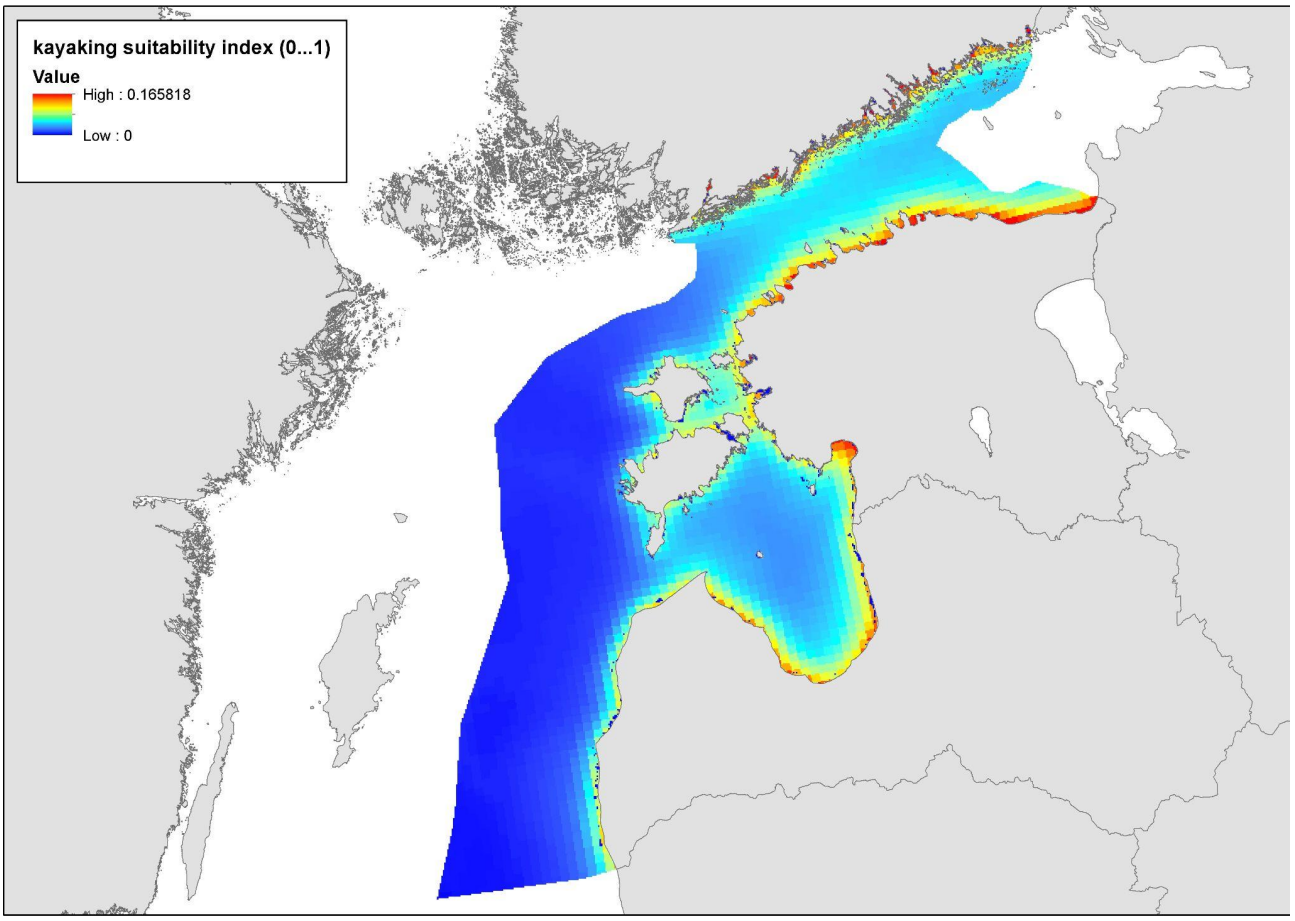
Cultural services

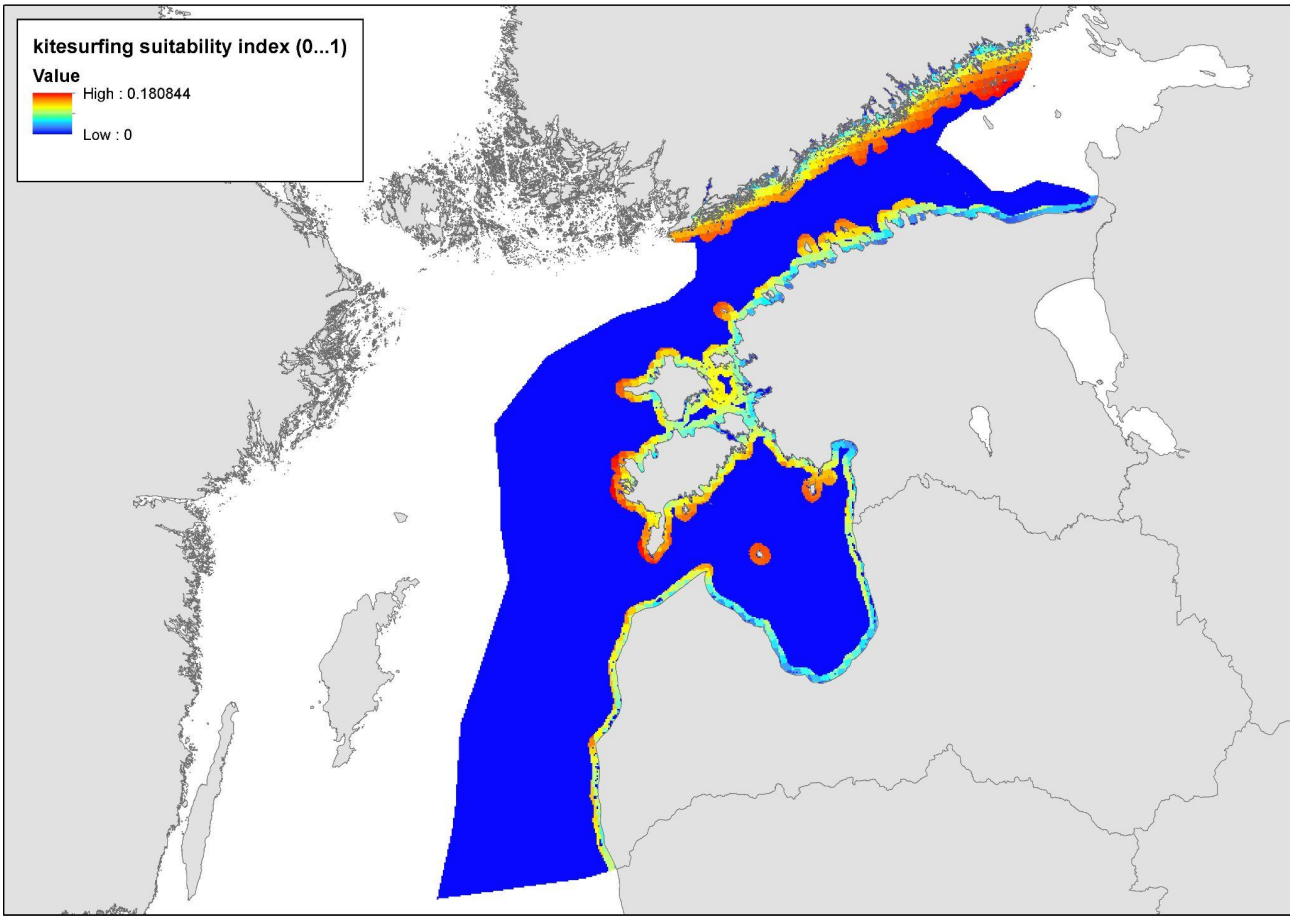
Recreation services

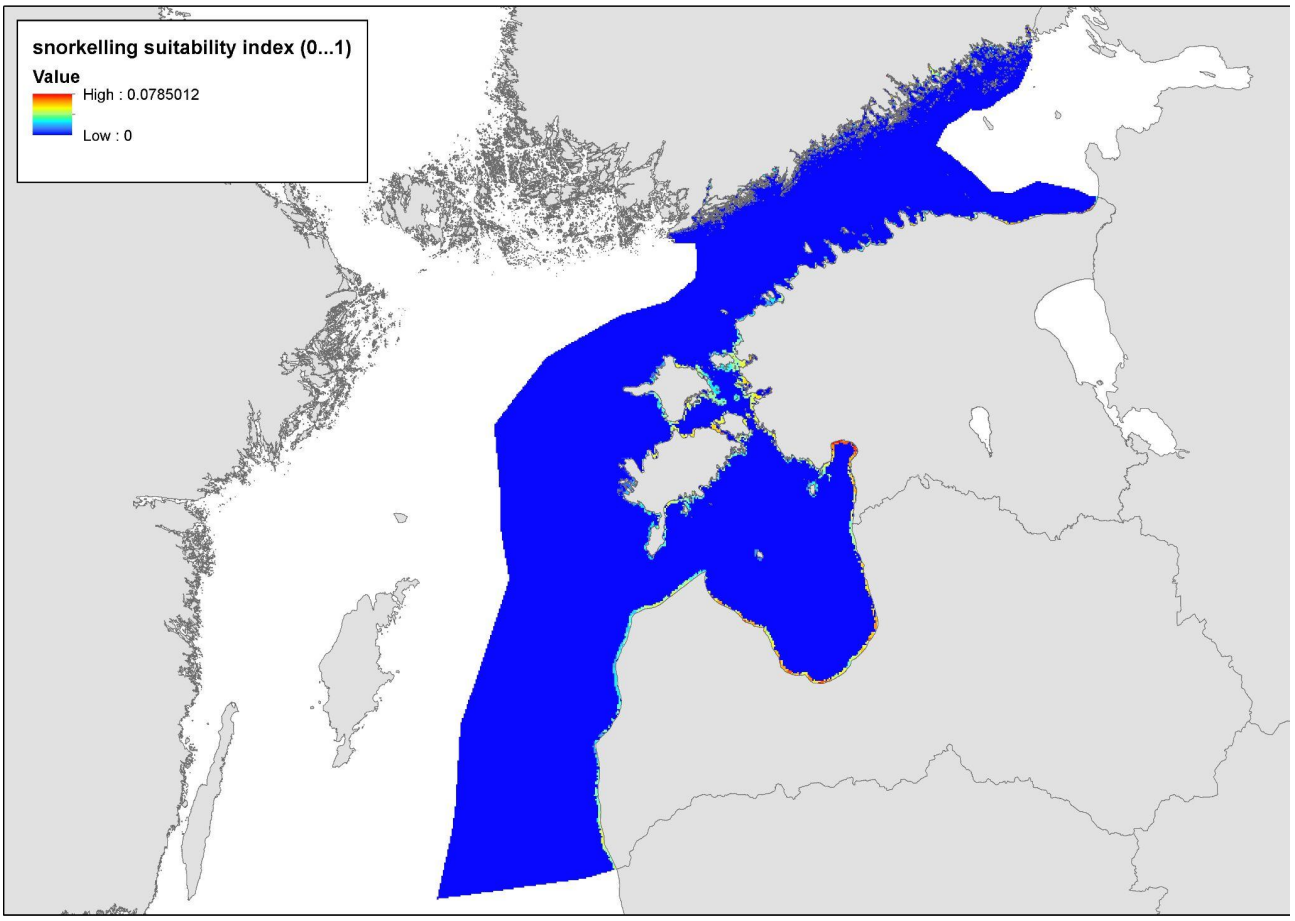
The definition of an index that summarises the features that make coastal areas suitable for the development of cultural and recreational activities is essential to meaningfully represent and communicate their value from a non-material perspective. Here relevant data layers were combined to produce a coastal suitability index (CSI) to spatially represent the value of Estonian, Latvian and Finnish coastlines for practising different recreational activities (kite-surf, wind-surf, sea-kayaking, swimming, snorkelling, sunbathing).

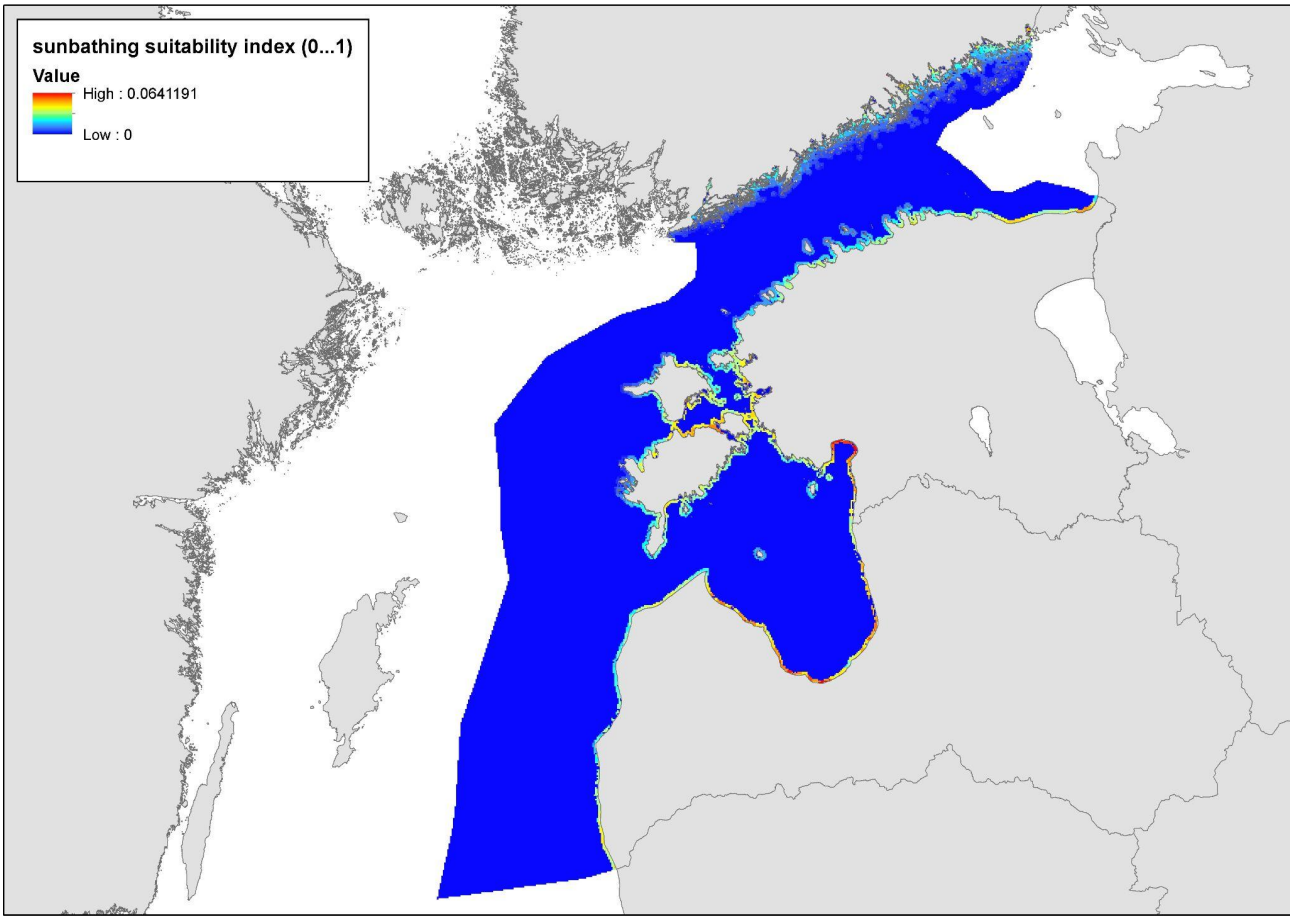
Data layers were used both for defining ideal spatial and temporal frames for practising different recreational activities (daylight hours, distance from the shore, bottom sediment characteristics and depth) and calculating the suitability index for each activity (wind speed, bottom sediment characteristics, water temperature). At first stages only these areas were selected that provided suitable conditions (depth, substrate, distance from shore) for different recreation activities. We have used hourly resolution for those layers that vary in time (wind, daylight hours, water temperature). In addition, only those time frames were selected that allowed practising the respective recreational activity. It was assumed that most activities take place during light hours. Then the normalised wind and temperature data was weighed according to their importance in practising the respective recreational activity. The respective importances (i.e. preferences) of these different environmental variables were obtained from surveys conducted in Estonia and Latvia. The summed normalised wind and temperature product represents the recreation-activity specific suitability index with higher value indicating higher suitability. The final products were expressed as monthly and yearly averages.

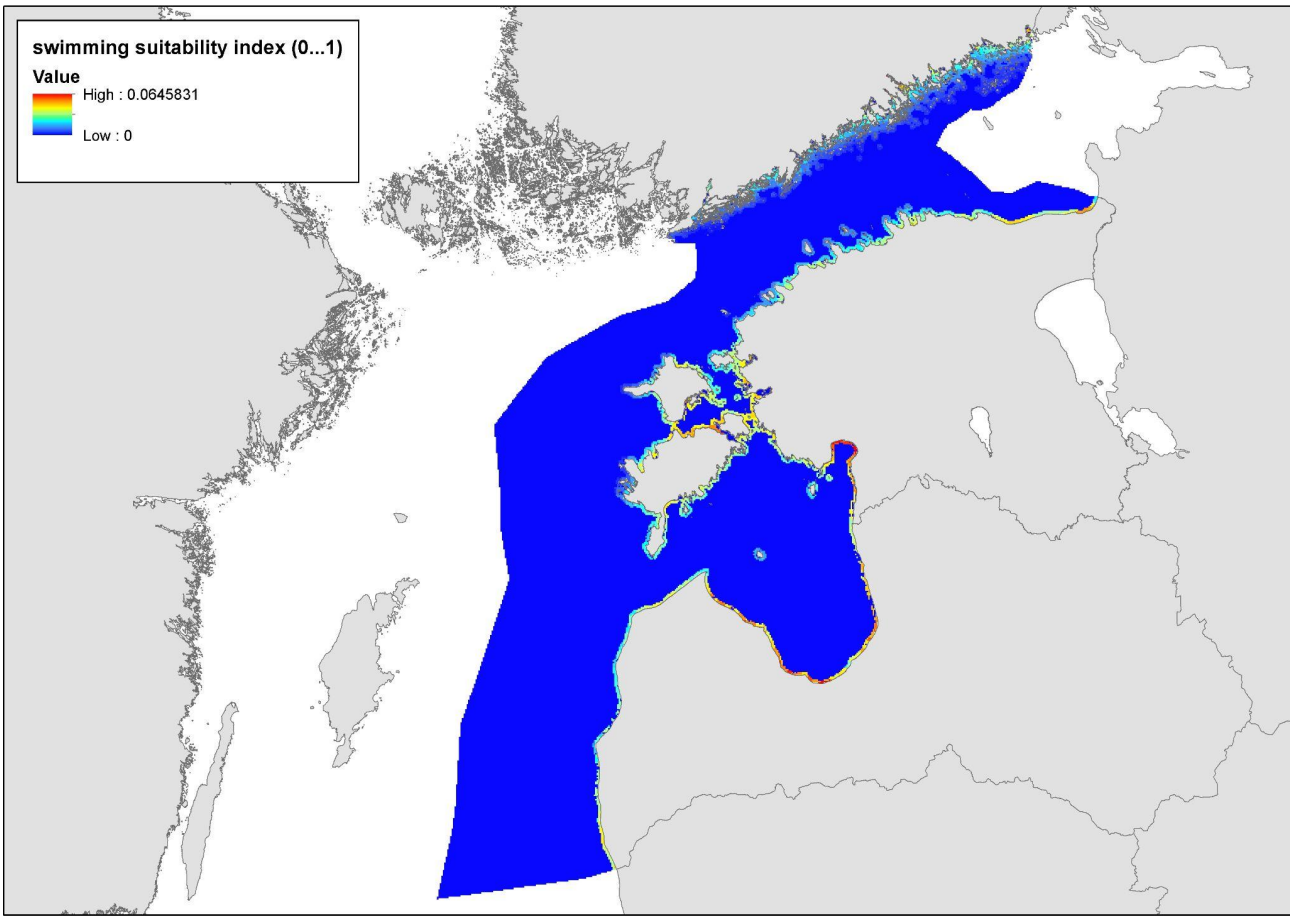
The current maps show the potential of these services in terms of environmental variability and do not necessarily reflect people's preferences. Preferences are a product of multiple factors e.g. natural conditions, infrastructure, cultural background, etc. which were not taken into account in the current modelling exercise. Moreover, as weighing factors were obtained from the Estonian and Latvian surveys, these may not accurately reflect Finnish conditions. Nevertheless, these maps can be viewed as an important input when starting developing the recreation services' sites in yet underdeveloped areas i.e. areas indicated with high CSI values show a high potential for these services in terms of natural environment.

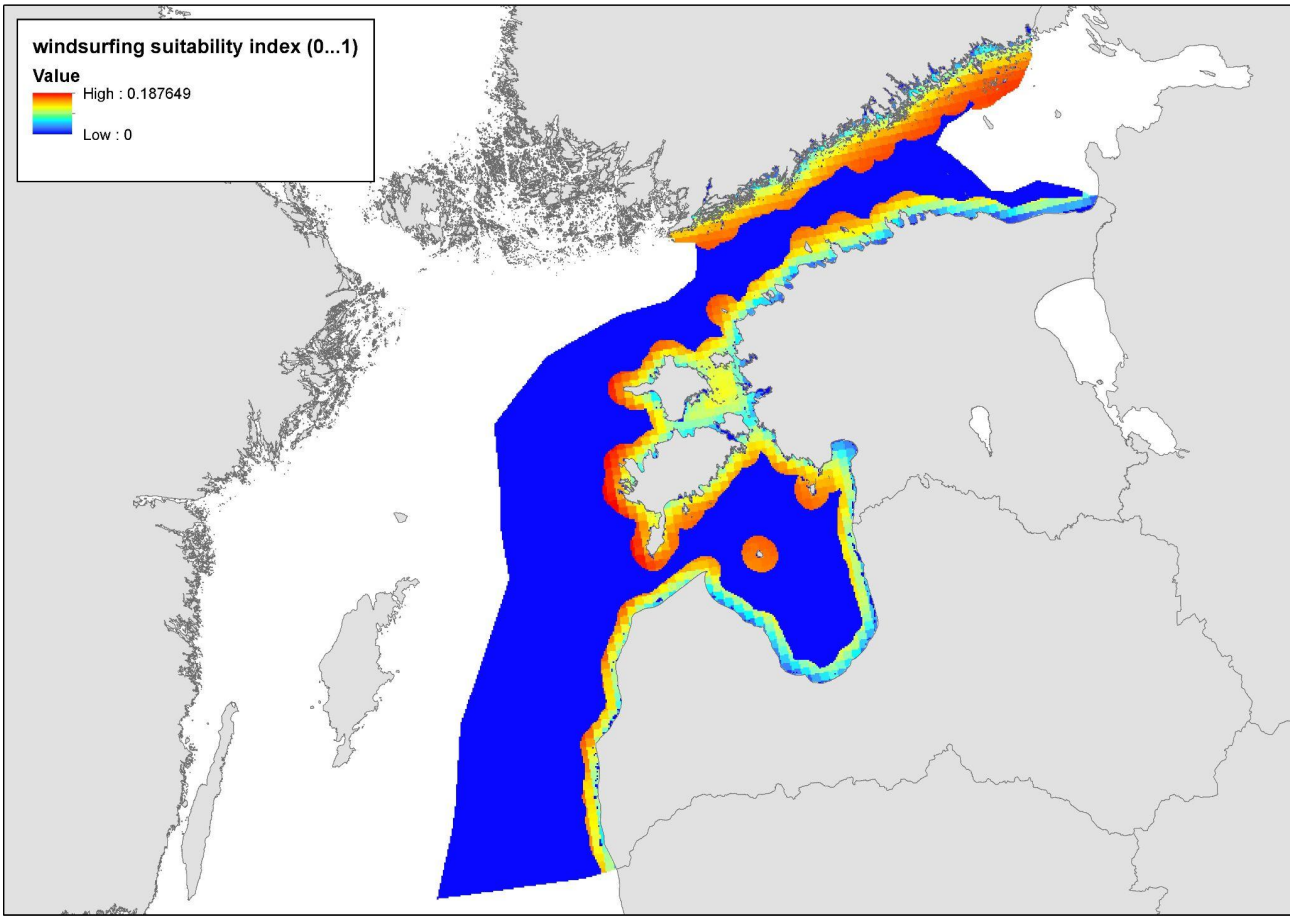

kayaking suitability index (0...1)
Value
High : 0.165818
Low : 0


kitesurfing suitability index (0...1)
Value
High : 0.180844
Low : 0


snorkelling suitability index (0...1)
Value
High : 0.0785012
Low : 0


sunbathing suitability index (0...1)
Value
High : 0.0641191
Low : 0


swimming suitability index (0...1)
Value
High : 0.0645831
Low : 0


windsurfing suitability index (0...1)
Value
High : 0.187649
Low : 0

Aesthetic services

The possibility of having a pristine nature landscape without any human made constructions was evaluated as the supply of aesthetic services. As aesthetic appeal is subjective we used the absence of human made constructions to represent high aesthetic value.

The ArcGIS tool Viewshed 2 was used to create 22 different viewsheds based on different human activities that occur at sea or near the coast. A weighted aggregated viewshed raster was also created from the 22 viewsheds. To produce the weighted aggregated viewshed, the 22 viewsheds were first normalized from 0 to 1, then weighted from 1 to 4 according to estimates on how disruptive the activity is from a scenic point of view, with activity permanency also considered, and subsequently summed.

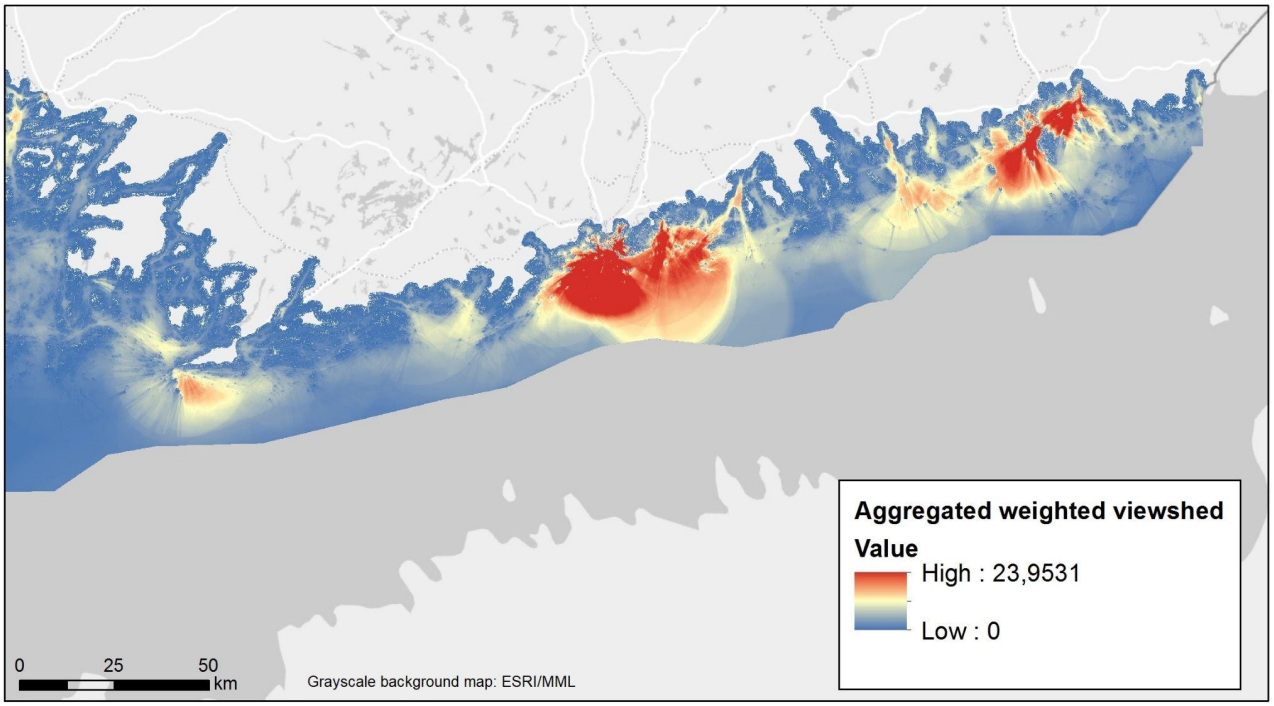
The viewshed rasters indicate how many “observers”, e. g. point data representing human activities in this case, can be seen from each raster cell. An aggregated raster including terrain elevation, vegetation elevation and building elevation was used as the input surface raster, i.e., the raster that defines visibility. The elevation models were produced by the National Land Survey of Finland.

The maximum outer radius was in most cases set to 20 km, although since the tool considers the curvature of the earth when calculating line of sights, only the tallest structures would have been visible beyond 20 km. Some smaller or less visually distracting activities were given a shorter outer radius.

Each human activity was given different observer elevations based on digital surface models and estimates on the average height of the activity or construct. In addition, the setting “observer offset” was set to 1.7 meters to represent the height of a human in addition to the observer elevations.

Most viewsheds were set to a cell size of 20 × 20 meters, but some had to be set up to 60 × 60 meters due to long processing times, as producing a viewshed with many observer points can be very resource intensive for a computer.

Viewsheds were produced for the following activities: anchorage sites, aquaculture, boat harbours, boat lanes, breakwaters, bridges, buildings divided into several categories (flats, industry, services, small housing, other), constructed shoreline (banks, levees), dumping sites for dredged material (due to dredging ship traffic), high voltage electric line towers, large or periodic dredging sites (due to dredging ship traffic), large harbours, piers, roads (due to car traffic), sand and gravel extraction sites , sea signs, shipping lanes, and wind power.



Weighted aggregated viewshed map. Produced by aggregating 22 normalized and weighted viewshed layers. Higher values indicate lower availability of service supply.

Table 1. Viewshed human activities, settings and sources table. The table lists all human activities that were used to produce the 22 viewsheds, as well as settings used in the Viewshed 2 tool and data sources. In this case observer height indicates the estimated or surveyed height of the human activity feature.

Activity	Weight	Resolution (m)	Outer radius (km)	Observer height (m)	Data source
Anchorage sites	2	20	20	20	Global Fishing Watch
Aquaculture	3	20	20	1	MHPW aerial survey
Boat harbours	2	20	20	2.5	Satamatietopalvelu (OTAVAMEDIA)
Boat lanes	1.5	20	20	2.5	Finnish Transport Infrastructure Agency
Breakwaters	2.5	20	10	1.5	MHPW aerial survey
Bridges	3	20	20	Heights extracted from digital surface model	MHPW laser scanning data
Buildings (flats)	3.5	20	20	Heights extracted from digital surface model	Building and apartment information RHR
Buildings (industry)	4	20	20	Heights extracted from digital surface model	Building and apartment information RHR
Buildings (services)	3.5	20	10	Heights extracted from digital surface model	Building and apartment information RHR
Building (small houses)	3	60	10	Heights extracted from digital surface model	Building and apartment information RHR

Buildings (other)	3	20	20	Heights extracted from digital surface model	Building and apartment information RHR
Constructed shoreline	3	20	10	1.5	MHPW aerial survey, SYKE (VESTY)
Dumping sites for dredged material	2	20	20	20	Finnish Transport Infrastructure Agency
High voltage electric line towers	3	20	20	33	National land survey of Finland
Large dredging sites	2	20	20	20	Finnish Transport Infrastructure Agency
Large harbours	4	20	20	Heights extracted from digital surface model	Building and apartment information RHR
Piers	2	40	6	0.5	MHPW aerial survey
Roads	2	20	6	1.5	Digiroad
Sand and gravel extraction sites at sea	2	20	20	35	MH-Kivi Oy
Sea signs	2	20	6	2 for floating features, 5 for fixed	Finnish Transport Infrastructure Agency
Shipping lanes	2.5	60	20	20	Finnish Transport Infrastructure Agency
Wind power	3	20	20	200	Ethawind, OpenStreetMap

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