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Förord

Föreliggande rapport återger första resultat från analyser av förväntad klimatpåverkan på kommersiellt viktiga fiskeresurser för svensk fiske. Syftet är att bidra med underlag om förväntad klimatpåverkan på kommersiellt viktiga fiskeresurser för svensk fiske, samt effekter för olika segment i svenska fiskeflottan och kustnära samhällen. Underlaget är en beställning inom ramen för projektet för GFP-rådgivning (#18. Löpande rådgivning, bl.a. inför rådsarbetsgruppen (RAG) och oförutsedda frågor gällande GFP och dess genomförande under året; Dnr 1638-20).

Sammanfattning

Den överenskomna rapporteringen består av en huvudtext samt sju bilagor. Huvudtexten inleds av en introduktion, följt av kortfattade sammanställningar av nuvarande kunskapsläge om klimatförändringar i svenska havs- och kustområden och aktuella klimatscenarios, samt när det gäller möjliga effekter på fisk och fiske. Dessa delar baseras på litteraturstudier. Därefter följer en analys av artspecifika toleranser för klimatrelaterade miljöförändringar hos fisk och utvalda skaldjursarter, med fokus på hur dessa kan förväntas reagera på ökad temperatur, och i förekommande fall minskad salthalt. Denna analys baseras på data från *Lektidsportalen* och litteraturstudier. Resultaten används för att beräkna så ”temperaturmarginaler” (Eng: TSM, eller temperature-safety-margins) för kommersiella bestånd. Analyserna kan användas för att identifiera bestånd som kan vara speciellt känsliga för klimatförändring i relation till deras ekonomiska betydelse. Rapporten innehåller även en analys av hur klimatförändringar kan påverka arters möjligheter till lek och rekrytering, baserat på information från nyligen uppdaterade kartor över potentiella lek- och rekryteringsområden i Östersjön, vilka kombineras med data från klimatscenarios och informationen om artspecifika toleranser. Slutligen innehåller rapporten en klimat-risk-analys, som integrerar information om beståndens specifika känslighet för klimatförändring (hazard), med information om systemens sårbarhet (vulnerability) respektive utsatthet (exposure) för klimatförändring. Riskanalysen integrerar resultat, dels för olika fiskesegment (fleets), dels för olika geografiska regioner i Sverige, för att identifiera deras relativa risk i förhållande till varandra och hur denna kan komma att utvecklas under gällande klimatscenarios. Rapporten avslutas med en bristanalys tillsammans med förslag på nästa steg för att förbättra kunskapsläget och möjliggöra mer precisa riskanalyser framöver, samt med sammanfattande slutsatser.

I bilaga A1-7 redovisas mer detaljerade resultat och bakgrundsmaterial i förhållande till huvudtexten.

Rapporten är skriven på engelska.

Summary

Oceans have been warming at an unprecedented rate over the last few decades and climate change is having profound effects on biodiversity and other ecosystem services that oceans provide for human well-being. The motivation for this report is a strong need to understand the consequences of climate change on aquatic ecosystems to develop strategies to minimize the impact on fished species, fisheries and society.

The introduction and first chapters of the report are based on a literature review, which summarizes the current state of knowledge about climate change in the Swedish marine and coastal areas, patterns emerging from the main climate scenarios, and potential effects on fish and fisheries.

This is followed by an analysis of species environmental limits and tolerances to a warming environment, focusing on selected fish and invertebrate species of commercial relevance. Thermal safety margins show a smaller buffer for species of boreal origin including the northern shrimp, the gadoids and vendace, among others. Analyses of preferred spawning temperatures and depths enable a preliminary overview of the potential sensitivities of species to a warming environment, showing *inter alia* that species requiring shallow and cold waters for reproduction are likely more sensitive to the effect of warming.

The report also includes a specific analysis of how changes in temperature, salinity and oxygen may affect the availability of suitable spawning and nursery habitats in the Baltic Sea. Using information from recently updated maps of potential spawning and recruitment areas in the Baltic Sea, the potential loss of reproductive grounds is evaluated in an ensemble analysis based on multiple climate scenarios.

Finally, the report includes a climate risk analysis, which integrates information on the stocks' specific susceptibilities to climate change (hazard), with information on the vulnerabilities of the evaluated systems and their exposure to climate change. The integration is carried out at the level of different fishing segments (fleets) and at the level of the different coastal administrative regions in Sweden. Thus, the risk analysis aims to identify the relative distribution of climate risk among fishing fleets and geographical regions, and explores how this may develop under alternative climate scenarios. The results show that the risk ranks higher for the salmon, vendace and shrimp fisheries, while geographically, the northern Baltic Sea ranks higher in risk compared to other regions. Most importantly, the analyses show that the risk is not equally driven by hazard, vulnerability and exposure for the different fleets and regions, suggesting that no single risk-reducing approach is sufficient and appropriate across all areas and fleets.

The report concludes with a gap analysis together with suggestions for next steps to improve the state of knowledge and enable more precise risk analyses in the future, as well as with summary conclusions.

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1. Introduction

The extent and scale of recent changes across the climate system and the present climate state are beyond comparison over centuries. Human activities have warmed the climate at an unprecedented rate, and each of the last four decades has been successively warmer than any decade that preceded it since 1850. Greenhouse gas concentrations have increased since the mid-1700s, and the causes are unequivocally related to human activities (IPCC 2021). Countries committing to the Paris agreement have agreed on limiting global warming to well below 2 ºC, preferably below 1.5 ºC, compared to pre-industrial levels. The Intergovernmental Panel on Climate Change (IPCC) concluded that climate change impacts will challenge human society to achieve the UN Sustainable Development Goals (SDGs) and "limiting global warming to 1.5 ºC rather than 2 ºC would make it markedly easier to achieve many aspects of sustainable development" (IPCC 2019). The oceans store by far the largest amount of heat produced by global warming in the atmosphere. Sea temperatures rise as air temperature increases, with transfer of heat from the surface down into the water column. Given their large heat storage capacity the oceans absorb the heat slowly, moderating temperature increases in the atmosphere. The "IPCC Special Report on the Ocean and Cryosphere in a Changing Climate" (IPCC 2019) confirms that the global upper ocean (0–700 m) has warmed since the 1970s. Anthropogenic carbon emissions are also causing the ongoing global acidification and oxygen loss in many upper ocean regions since the mid-20th century, and there is evidence that changes extend to nutrient cycling and primary production, as well as to the distribution and biology of species (IPCC 2019).

The oceans are essential for human well-being and livelihood, providing a wide variety of ecosystem services with regulating, supporting and provisioning functions (Tallis et al. 2010; Costanza et al. 2014; Sandifer and Sutton-Grier 2014). For example, the oceans contribute to climate regulation, via the energy budget, the carbon cycle and the nutrient cycles. They support a large part of the biosphere, and host biodiversity ranging from micro-organisms to marine mammals that form diverse ecosystems in pelagic and coastal areas. With their productivity, the oceans provide an invaluable source of food for human communities and sustain local as well as large fishing economies.

Climate models forecast a wide range of possible outcomes, but they all agree on projecting with high confidence a significant warming (>99 % probability) and associated changes in the ocean state over the coming century (IPCC 2019). Scenarios for different climate futures are described by so called Representative Concentration Pathways (RCPs) which include for example a “mitigation” scenario, under which global warming is kept below 2 °C above pre-industrial temperatures (RCP2.6), and a high emissions “worst case” scenario (RCP8.5), corresponding to a future without climate change mitigation. Both RCP8.5 and RCP2.6 predict widespread warming, increased stratification, increased ocean acidification, decreased stability of mineral forms of calcite, and oxygen loss. For RCP2.6, models predict that by the end of the 21st century the oceans will warm by 2 to 4 times compared to the changes observed from 1970 until now, and for RCP8.5 by 5 to 7 times as much. Due to the combined effect of warming, changes in stratification (which, among other consequences, will lead to reduced nitrate concentration in the photic layers), and reduced light penetration, the net primary production of the ocean is expected to decrease by 4–11 % on a global scale by the end of the 21st century for the RCP8.5 scenario (IPCC 2019).

Marine species are responding to a warming environment with geographical shifts which are on average an order of magnitude faster than for terrestrial organisms. The magnitude of distribution change differs considerably among taxa, with more pronounced changes in highly mobile species and pelagic species with high dispersal (Poloczanska et al. 2013). The changes in species distribution are very likely to alter ecosystems and community structure of marine organisms. IPCC (2019) states with high confidence that the body size, growth, reproduction and mortality of fishes will be altered by climate change, in many cases increasing the risk of their local decline, and with medium confidence that the global biomass of marine animals will decrease during the coming decades. This will include species contributing to fisheries catches and would lead to a projected decrease of the global maximum catch potential by 3.4 % to 6.4 % (RCP2.6) and 20.5 % to 24.1 % (RCP8.5) by the end of the 21st century.

The fishing sector is generally more dynamic than other sectors, as it is historically accustomed to dealing with large fluctuations and changes in marine resources (Baumgartner, Soutar and Ferreira-Bartrina, 1992). However, the magnitude and uni-directionality of the present and future climate-driven changes are unprecedented even in the history of fishing. Concerns exist on the effectiveness of existing ocean and fisheries governance in the light of climate change, highlighting the need for timely mitigation and adaptation responses (FAO 2018).
As impacts and risks will be heterogeneous in space, the capacity for adaptation is context dependent. FAO (2018) recognises that no single risk-reducing approach

will be appropriate across areas and components. Understanding the intensity and place of change, and ultimately the risks of climate change for species, ecosystems and human societies, is a prerequisite to develop and prioritise appropriate and effective adaptation options that could respond to the challenges of the climate crisis.

During the last two decades, climate research has achieved enormous progress in collecting and interpreting data on the Earth's climate in every region and across the climate system. Improved interpretation of historical data and a more recent period with many extreme events and unprecedented records (on the scale of hundreds to thousands of years) have consolidated our understanding of present and future climate trends at the time scale of few to several decades. Coupling of global climate models with regional hydrographic and bio-geochemical models allows better downscaling of climate projections. This provides an opportunity to investigate the consequences of climate change on species and ecosystems, including ecosystem services, at the scale of large marine ecosystems and basins.

This report addresses the effects of climate change on marine fish populations and other marine organisms living in Swedish and adjacent waters, with a focus on species with economic relevance for the Swedish fishing sector. It hence updates the last climate risk assessment of Swedish fish species and fisheries which was carried out already fifteen years ago (Fiskeriverket 2007). The report consists of three main parts: 1) a review and synthesis of best available scientific knowledge on fish responses to environmental variability and climate change, condensed and presented in species information sheets; 2) a review and analysis of species habitat specificities with a focus on the impact of climate change on spawning preferences and reproduction areas; 3) an evaluation of the climate hazard for the recreational fisheries and a new climate risk analysis evaluating the vulnerability and distribution of climate-related risk for the Swedish commercial fishing sector and coastal regions. The risk analysis considers possible responses of fish species to a warming environment, the dependence of Swedish fisheries on certain fish stocks, the distribution of landings and the adaptability at a fleet and regional level.

2. Climate change effects in Swedish marine waters

The extent of change in future temperature depends on the model applied, but multi-model ensemble projections show robust predictions of increasing regional temperatures towards the end of the century for both the North Sea and the Baltic Sea. The projections indicate an increase of 1 °C and 2 °C in mean annual sea surface temperature (SST) by the year 2100, for the RCP 4.5 and 8.5 scenarios, respectively, for both the North Sea and Baltic Sea. The projected increase is more pronounced in coastal areas and in the northern parts of the Baltic Sea.

2.1. North Sea

Most water entering the North Sea comes from the adjacent North Atlantic north of Scotland. The North Atlantic has had relatively cool periods (1900–1925, 1970–1990) and warm periods (1930–1960, 1990-present; Holliday et al. 2011; Dye et al. 2013a; Ivchenko et al. 2010 using 1999–2008 Argo float data). Variability at temporal scales from interannual to multidecadal is a great source of uncertainty, but there is strong evidence of exceptional warming, especially since the 1980s. After a minimum around 1988, the annual average SST for the whole North Sea has been increasing to a peak in 2008 (anomaly about 1 °C). A warming trend is recorded in all seasons despite winter-spring variability in SST exceeding summer-autumn variability. The temperature rise is not uniform in space. McQuatters-Gollop et al. (2007) reported a less pronounced warming in the north compared to the south (SST increased since the 1980s by <0.2 °C per decade in the north, and by 0.8 °C per decade in the south). The most pronounced increase, >1 °C since the end of the 19th century, has been recorded in the German Bight. In the Skagerrak coastal areas, winter temperatures were 0.8–1.3 °C higher in the period 2000–2009 than the period 1961–1990 (Albretsen et al. 2012) corresponding to a 0.6–0.8 °C temperature increase at 200 m. Observed winter-spring SST in the Kattegat and Danish Straits increased by about 1 °C between the early 1990s and the 1980s, and by another 1 °C during the 1990s-2000s (Henriksen 2009). With respect to salinity, variability in the Kattegat and Skagerrak exceeds that in the rest of the North Sea due to influence from the outflow of brackish water from the Baltic Sea.

Coherent findings from the climate change impact studies reviewed by Schrum et al. (2016) suggest an overall increase in sea level, water temperature and acidification as well as a freshening of the North Sea. However, the amplitude and spatial patterns of the projected changes are uncertain, given high variability among the various model projections for this region. Detailed studies of transport patterns are limited and predictions of future wind-associated hydrographic features (i.e., storminess, surface waves and circulation) for the North Sea remain difficult due to high natural variability which dominates long-term trends in wind patterns.

Overall, net primary production in the North Sea is expected to decrease, with a more pronounced reduction in its northern regions (Holt et al. 2016; Wakelin et al. 2012; Gröger et al. 2013; Pushpadas et al. 2015). In coastal areas, especially along the south-eastern part of the North Sea, projections show a slight increase in primary production, linked to an increase in river run-off and nutrient availability. For the Skagerrak region projections of net primary production are highly uncertain due to contrasting outcomes from different models (Schrum et al. 2016). Most North Sea studies assume that runoff from the catchment area and outflow from the Baltic Sea will increase under a future climate (e.g., Wakelin et al. 2012). Although this assumption has limited impact at the level of the whole North Sea, this is unlikely the case for the Skagerrak and south-eastern North Sea, where changes in water exchange with the Baltic Sea and in freshwater runoff represent an additional source of uncertainty on regionally downscaled climate forecasts.

2.2. Baltic Sea

Climate change effects are already evident in the Baltic Sea, where SST has increased more than the average for the global ocean (HELCOM/Baltic Earth 2021). SST has increased by 0.03 °C per decade in the northern areas of the Baltic Sea, and by 0.06 °C per decade in the southwestern areas, during the period 1856-2005 (Kniebusch et al. 2019). The rate of increase has accelerated lately, being 0.6 °C per decade during 1990-2018. Further, heatwaves have hit the region in the recent decade. SSTs exceeding the long-term mean of the last three decades by 4–5 °C were recorded during summer 2018, with increasing temperatures also observed in the deepest parts of the basin (Humborg et al. 2019, Naumann et al. 2019).

Warming also affects sea ice conditions during winter (Höglund et al. 2017, Luomaranta et al. 2014). The maximum spatial sea ice extent has decreased by 30 % over the last century in the Baltic Seathe ice season has become shorter during the same time. For example, the average temporal sea ice cover has decreased by 18 days in the farthest north and by 41 days in the Gulf of Finland (Schwegmann and Holfort 2020). Coupled atmosphere-ocean models identify the Baltic Sea as a hot spot for warming also in the future (Gröger et al. 2021). Depending on the climate model and assumed warming scenario, SST is projected to increase by 0.8-4.1 °C by 2100 compared to 1976-2005 (Saraiva et al. 2019a; Meier et al. 2019).

The salinity of the brackish Baltic Sea may also be affected by climate change. The Baltic Sea has a natural gradient of decreasing salinity from its opening to the inner areas, which is driven by sub-regional differences in precipitation, amounts of river runoff and influence from inflow of marine waters from the North Sea. Annual mean precipitation has increased over the northern Baltic Sea lately (HELCOM/Baltic Earth 2021). The level of precipitation is expected to increase also in the future, particularly in the northern Baltic region, while results of simulations for the intermediate and southern areas show uncertain directions of change (Christensen & Kjellström 2018, Chen et al. 2020). Projections also indicate a future increase in river runoff from the northern catchment area, which would decrease the upper-layer salinity of the Baltic Sea. A global sea level rise would, on the other hand, increase deeper-layer salinity (Meier et al. 2017). In the southern Baltic Sea, large, climate-driven saltwater inflows, so-called Major Baltic Inflows (MBIs), sporadically renew the deep water with saline, oxygen rich Atlantic water via the Kattegat, which is also the only process that effectively ventilates the deep waters of the Baltic Sea (Schinke and Matthäus 1998, Mohrholz 2018). The inflow of Atlantic waters is highly variable, and no trend in the frequency of major inflows has been detected since 1850, but the frequency is projected to slightly increase in the future (Meier et al. 2017).

Overall, Baltic Sea salinity has decreased over the past decades in the upper layer down to around 40-50 m depth and increased at the bottom (Liblik and Lips 2019). The upper-layer freshening is expected to continue, but there is high uncertainty in the projections, due to large natural variability, as well as uncertain projections for the regional water cycle, wind fields and global sea level (Meier et al. 2018, Saraiva et al. 2019a). Changes in precipitation and runoff might also cause salinity fluctuations in coastal areas (Wikner & Andersson 2012). Vertical stratification has increased in most of the Baltic Sea during 1982-2016, with the seasonal thermocline and the perennial halocline strengthening (Liblik and Lips 2019). Models predict that vertical stratification will increase during summer mainly due to warming, while the contribution of changes in salinity remains uncertain (Saraiva et al. 2019a).

Eutrophication has been the main driver of oxygen depletion in the Baltic Sea since the 1950s. Despite decreasing nutrient loads after the 1980s, the extent of hypoxic areas has increased, in both coastal areas and the deepest parts of the main basins (i.e., Bornholm Basin, Gdansk Deep and Gotland Basin; Gustafsson et al. 2012; Meier et al. 2018). The future development of oxygen conditions in the deep waters of the Baltic Sea will mainly depend on the nutrient loads. However, warming is expected to intensify future oxygen depletion (e.g., via reduced air-water exchange and vertical transport, and increased respiration) with larger impact in scenarios with high nutrient loads (Saraiva et al. 2019a,b).

2.3. Coherent climate scenarios

Reanalysis of observations (until 2019) and projections of different warming regimes are available from the Copernicus Marine Environment Monitoring Service (CMEMS) and the Swedish Meteorological and Hydrological Institute (SMHI). Also, specifically for the Baltic, the combined impact of changing nutrient loads from land and changing climate during the 21st century is currently intensely studied. The SMHI's coupled physical-biogeochemical circulation model RCO-SCOBI (Fig. 1) provides downscaled projections from global climate models (GCM) to the Baltic Sea region (Meier and Kauker 2003, Eilola et al 2009, Almroth-Rosell et al. 2011) for key variables including temperature, salinity and oxygen at different depths, at a high-resolution (3.7 km horizontal, 3 m vertical). RCO-SCOBI is calibrated on a hindcast period, and projections are carried out for two greenhouse gas concentration scenarios based on the IPCC RCP4.5 (mild warming) and RCP8.5 (intense warming, "worst case"), forced by four global climate models to account for uncertainties (i.e., HadGEM2-ES, EC-EARTH, MPI-ESM-LR and IPSL-CM5A-MR; Saraiva et al. 2019a,b). The climate scenarios are available in combination with different alternative nutrient load scenarios. The scenarios corresponding to the Baltic Sea Action Plan (BSAP) nutrient load were used for the analyses presented here (Fig. 2).

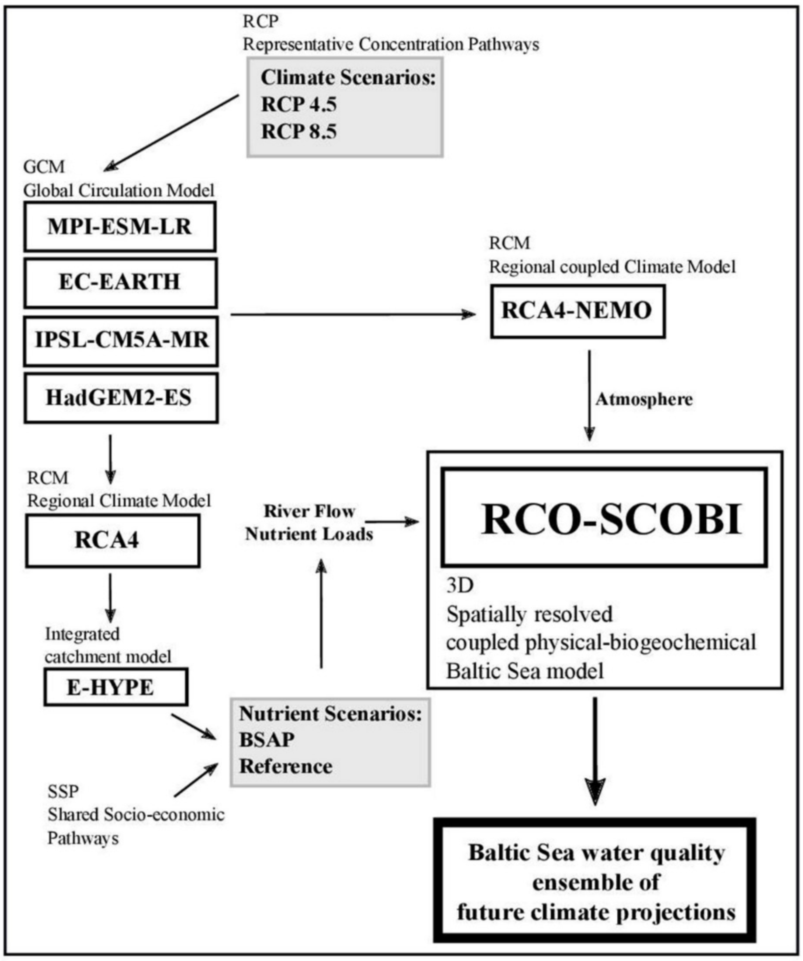

Figure 1. Conceptual diagram of the modeling framework providing hydrographic projections for the Baltic Sea (modified from Saraiva et al. 2019a).

For consistency, the temperature fields from CMEMS, which were used for calculation of the thermal safety margins for the Baltic Sea as well as the Greater North Sea and beyond (see section 5.2), were based on the HadGEM-ES global climate model (Hadley Centre Global Environment Model; Collins et al. 2008), which is one of the four GCM models used in the hydrographic forecast ensemble for the Baltic Sea, and the same RCP4.5 and RCP8.5 warming scenarios. It should be noted that differences between the projections done under the RCP4.5 and RCP8.5 are mainly visible at the medium (2050) and long-term horizon (2100). Moreover, the magnitude of changes expected for the next 10 years is relatively small, often much smaller than the interannual variations in the projections from these models.

Regarding plausible interactions with eutrophication in the Baltic Sea, projections from the RCO-SCOBI show that the impact of a warming climate may amplify the effects of eutrophication on a long-time scale (end of the 21st century), but only mildly in the time horizon of the next two decades. Nutrient supply, in particular phosphorus, controls the long-term response of eutrophication and biogeochemical fluxes in the Baltic. Within the range of the IPCC climate scenarios, the effects of changes in the nutrient loads appear to have a dominant effect on the occurrence of hypoxia in the deep waters (Saraiva et al. 2019a,b). Oxygen conditions have direct effects on for example the reproductive volumes of cod and European flounder. The oxygen conditions show similar levels between the RCP4.5 and RCP8.5 warming scenarios at least until 2040, but pronounced differences in relation to the nutrient loads already in the first decade of the projections.

Due to increased runoff volume, the RCO-SCOBI predicts decreasing average salinity by about 0.4 and 1.2 in RCP4.5 and RCP8.5, respectively, but no pronounced differences by 2030 compared to the historical period (Saraiva et al. 2019a,b). While absolute values of changes in temperature and salinity vary between the two warming scenarios, the main pattern of the average profiles of temperature and salinity does not change significantly, maintaining a strong stratification of the Baltic Sea.

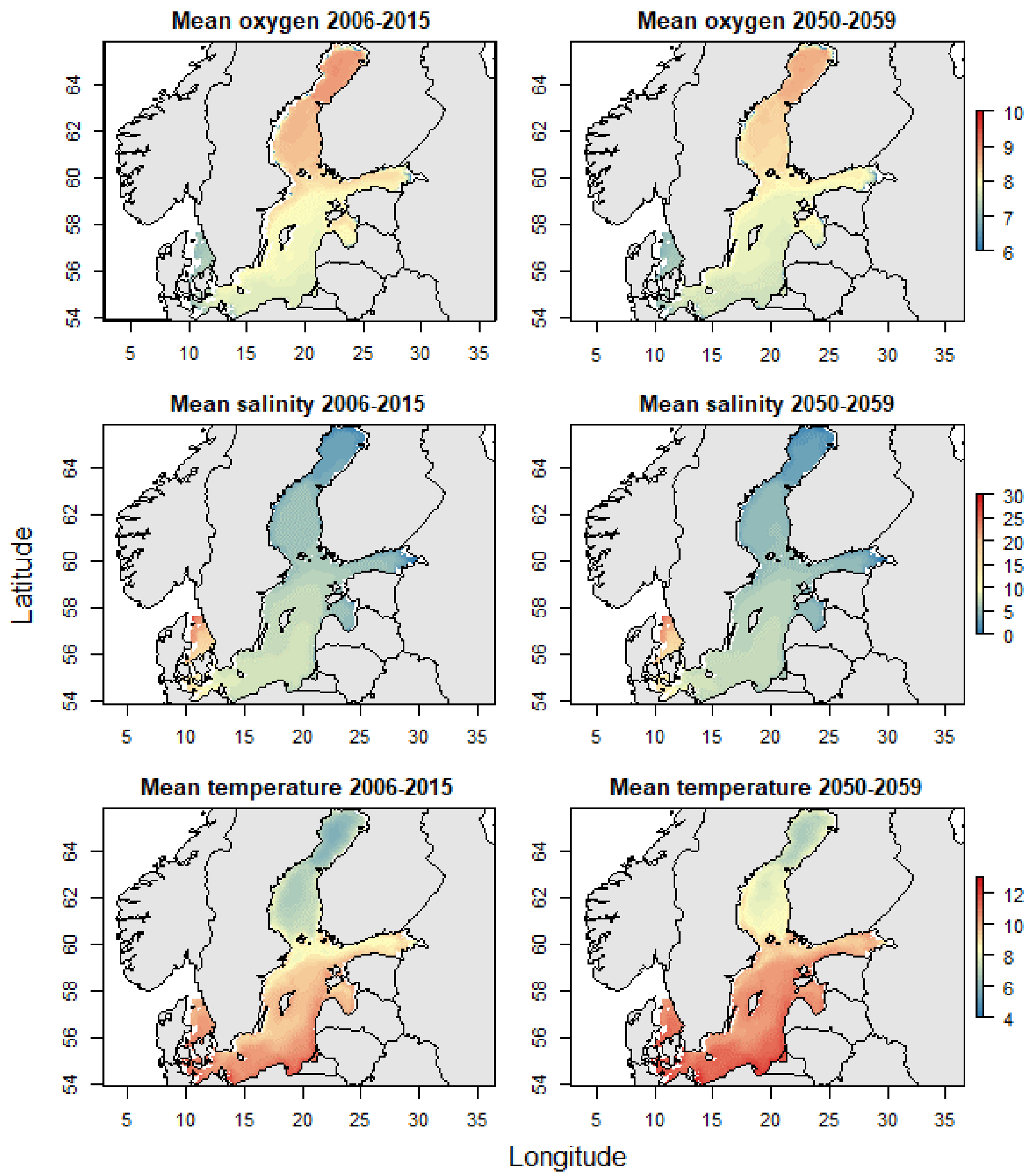

Figure 2. Hydrographic maps from the RCO SCOBI models calculated for the first ten and last ten years in the modeled period. The maps show the mean from all four different global scenarios with the RCP4.5 pathway and the nutrient scenario from the Baltic Sea Action Plan. Only values down to 4.5 m depth were used.

3. Climate-change effects on fish and other aquatic/marine organisms

Biological processes typically increase in speed with higher temperature (Brown et al. 2004). A fundamental process in animal metabolism is the conversion of compounds broken down from the diet into energy, which is used to grow, reproduce, maintain and repair the body, as well as for supporting behaviour and movement. Hence, fish and other aquatic organisms are directly affected by increased temperatures caused by climate change. In some areas, they may also be affected by other effects, such as freshening or reduced oxygen conditions in the Baltic Sea (see section 2). In addition to such direct effects on animal physiology and biology, indirect effects may occur through climate-related effects on for example predation patterns and competitive relationships, food web productivity, suitability of essential habitats or other ecosystem processes. Therefore, it can be said that climate change affects individual fitness, population abundances and consequently species composition in the marine food webs, as well as how these food webs work. All parts of the aquatic ecosystem are expected to be affected at least to some extent, directly and/or via multiple pathways of interaction, which has also been documented for Swedish waters (Bergström et al. 2020).

The effects on fish vary between species and life stages. Fig. 3.1 shows four principal stages in the life cycle of fish in relation to their likely responses. Early life stages are often more sensitive to changes in the external environment, and environmentally driven changes in the mortality of early life stages can result in order of magnitude differences in the recruitment to the adult populations. Spawning success and early survival of eggs (Stage 1) can be directly influenced by changes in temperature as well as by other changes in the spawning habitat, acting in either positive or negative direction. For example, decreasing salinity may affect the survival of marine species in the Baltic Sea negatively (MacKenzie et al. 2007), while the recruitment success of some freshwater species may increase (Härmä et al. 2008). Similarly, some freshwater species may have higher temperature preferences than current ambient conditions, or in comparison to marine or anadromous species (Veneranta et al. 2013, see also section 5.2).

The survival of fish larvae (Stage 2) also depends on suitable temperatures after hatching. Growth rates may increase within the thermal windows of the concerned life stage, which may reduce the risk for predation mortality and enhance fish development for some species, if also supported by food availability (Kjellman et al. 2001, Pekcan-Hekim et al. 2011, Kokkonen et al. 2011). If such conditions are not fulfilled, however, increased metabolic energetic cost may become detrimental, as can be seen as more likely for species with narrower thermal windows. Additionally, as many fish species have pelagic eggs and larvae, changes in the strength and patterns of water mass circulations due to alteration in water temperature, salinity and density as well as intensity and direction of dominant winds can influence connectivity between spawning and nursery habitats (Petitgas et al. 2013).

Young fish in nursery areas (Stage 3) are either pelagic, demersal/benthic or coastal, depending on the species. In addition to direct effects of temperature on for example the energy demands of fish (as noted above), factors that affect their survival and growth are for example habitat quality and food availability, which can also be affected by climate (HELCOM 2018b, HELCOM/Baltic Earth 2021). Fish may also be influenced by indirect climate-related effects on the quality of nursery areas, for example if climate change affects turbidity, as is potentially driven by changes in run-off or nutrient conditions (Bergström et al. 2013, van Dorst et al. 2019). Weather extremes, such as periods with drought during critical seasons, may have negative effects on recruitment, since coastal tributaries are important spawning and nursery areas for many coastal species (HELCOM 2018b). Such effects may, however, be more easily in the reach of management measures to alleviate negative impacts, as they are interlinked with pressures from human land use.

Similar factors affect the growth of adult fish (Stage 4). However, since the adult stage generally has a higher mobility and the species may have undergone changes in habitat preference or diet during its life cycle, the level of sensitivity to impacts may differ between juveniles and adults. The effect of water temperature on body growth and metabolism also differs among species and size-classes. A larger body requires more maintenance than a small one, and there are examples of fish species where warming increases the energy needs of large individuals more than of small ones (see also Chapter 5 in Bergström et al. 2020). Therefore, rising water temperatures can lead to small individuals growing faster, while large individuals may suffer from heat under corresponding conditions, as shown for instance in experiments on perch in the Baltic Sea (Huss et al. 2019). Moreover, in many fish species, the maturation process is influenced by temperature and food availability, among other factors conditioning the trade-off between growth and maturation.

These and other differences in body growth cause the size distribution to change within populations as the water gets warmer (Gårdmark and Huss 2020).

The outline presented in Fig. 3.1 focuses on fish, but can also be applied to crustaceans, such as for example the commercially important European lobster (*Homarus gammarus*), Norway lobster (*Nephrops norwegicus*) and northern shrimp (*Pandalus borealis*). Crustacean biology is strongly temperature dependent and elevated temperatures can benefit their growth, development and distribution ranges to a certain extent (e.g Goode et al. 2019, McGeady et al., 2021). Further increased temperature, however, can cause stress, as seen for example in lobster larvae (Steneck and Whale 2013). Although direct effects of temperature can be expected more pronounced in southern seas, effects on abundance driven by changes in the availability of food items for larvae (Calanus spp) could also occur at more northern latitudes, as for example studied for lobster and Norway lobster (Greenan et al., 2019, Oppenheim et al., 2019, Herraiz et al. 2009). Growth rates can be expected to increase with increasing temperatures, although trade-offs between consumption and metabolism can still lead to reduced body condition, as well as to changed sex at earlier ages in northern shrimp (Stickney and Perkins 1977; Bergstrom 2000; Daoud et al. 2007). Climate-related changes in pH and availability of oxygen may also have implications on crustaceans, although less studied than effects of temperature.

As a combined effect of such individual differences in biology and physiological tolerance among species and life stages, variable effects and sensitivities can be expected in different fish communities, reflecting that some species are more sensitive to climate change than others. On a general level, under the perspective of a warming climate, fish adapted to warmer temperature regimes could be expected to benefit relatively more at higher latitudes, contrary to boreal, cold-water species that would have their habitats shrink in the Swedish and adjacent waters. Freshwater fish species could benefit relatively more in the Baltic Sea compared to species of marine origin, given the current negative trend in sea surface salinity (see Section 2.2). Along the Swedish coast, such changes are particularly evident in the Baltic Proper, along the coast between southern Skåne and Uppland where many marine species live on the boundary of their distributional range. The brackish water makes marine species particularly sensitive to a decrease in salinity. For all species, the combined effect on populations is the result of climate-related impacts interacting with other impacts such as fisheries, habitat deterioration and eutrophication.

A previous risk assessment for Swedish fish species was most recently carried out by Fiskeriverket (2007). Given the climate scenarios used at that time, it was projected for 2041-2070 and the Baltic Sea that 1) cod spawning would not anymore be possible for the Eastern Baltic stock, while potential climate change effects on reproduction of the Western stock remained uncertain, 2) flatfish reproduction would be disadvantaged if climate change result in elevated algal growth in reproduction areas, and 3) salmon production along much of the Swedish coastlines would principally disappear while total Baltic salmon production could increase due to increasing production in the big northern rivers (Fiskeriverket 2007). Predicted climate change effects were less clear for North Sea fish, but in general it was expected that higher temperatures would positively affect the commercial fish stocks, as warm-adapted marine species could expand their ranges further north, potentially benefiting North Sea fisheries (Fiskeriverket 2007).

More lately, impacts on fish and fisheries were included in the holistic evaluation of climate effects on the Baltic Sea ecosystem carried out by the network HELCOM/Baltic Earth (2021). It was concluded that increasing temperatures and hypoxia have resulted in decreasing distributions of marine fish such as flatfish, herring and cod, and reduced growth and body condition of cod. Sprat recruitment was higher in warmer waters after winters with low ice cover. The report also concluded that coastal and migratory spring and summer-spawning fish species such as perch, cyprinids and pike benefit, and are predicted to further benefit, from warming, via earlier spawning, faster egg and larval development and increased larval survival. Autumn-and winter-spawning species such as salmonids, instead, are and will be disfavoured (Helcom/BalticEarth 2021). Migratory anadromous species, such as salmon, return earlier to rivers after a warm winter/spring. However, warm autumn and winter water temperatures seems to lower the survival of salmon migrating back to sea.

It was concluded that further warming is expected to cause growth effects that differ between species and size classes, generally with growth stimulation of small but not of large fish (Lindmark et al. 2022). For example, warmer water was expected to increase larval growth of herring, sprat and flatfish and body growth of adult sticklebacks. Herring and cod recruits, instead, would be disfavoured because the availability of areas with optimal temperature would decline. Currently, periods with low salinity are related to lower recruitment of herring, cod and several flatfishes as well as to lower abundance and lipid content of zooplankton, which in turn has resulted in lower body growth, condition and abundance of herring and sprat (Helcom Clime).

Marine mammals are represented by three species of seals in Swedish water areas (ringed seal, harbour seal and grey seal), and by harbour porpoise from Skagerrak to the Baltic Proper. The highest concerns for negative climate effects on marine mammals have been raised for ringed seal (*Pusa hispida*), which occurs in the inner Baltic Sea, mainly in the Bothnian Bay and Gulf of Finland (HELCOM 2018a). A reduced breeding success of ringed seal has been connected to decreased ice cover and duration of the ice season, particularly in its southern distribution in the Gulf of Finland (Sundqvist et al. 2012). The breeding success of ringed seal is expected to be further reduced by decreased sea ice quality and quantity, and by decreased snow for pupping lairs (Härkönen et al. 1998; Laider et al. 2008). This risk is emphasized by the fact that successful land breeding has not been observed in ringed seals. For example, grey seals, which occur throughout the Swedish coastline, can also breed on land sites, albeit with a reduced breeding success (Jüssi et al. 2008). In the southern Baltic Sea, a risk for flooding of haul-outs of harbour seals and grey seals has been identified (HELCOM/BalticEarth 2021), which may force out breeding seals from these areas.

Like for other top predators, the body condition of marine mammals depends on changes in the abundance and availability of prey, which can also be affected by climate change. For instance, a positive response of harbour porpoise to warming of the banks west of Greenland has been reported by Heide-Jørgensen et al. (2011), attributed to an increased residence time in areas with high densities of cod, resulting in improved feeding conditions. On the contrary, in the North Sea, it has been hypothesized that climate change have negative impacts on the conservation status of resident harbour porpoise, via reduced availability of prey, however to date this is not supported by evidence (Thompson et al. 2007).

3.1. Species-Climate Information sheets

A synthesis of the best available knowledge on the effects of environmental variability and climate change has been organized in technical "species-climate information" (SCI) sheets for selected fish species, available as an Aqua notes report (Bartolino et al. in press). The list includes fish and invertebrates, in some cases resolved to populations or stocks level, selected for their high commercial interest and ecological importance.

The scientific literature has been screened in search for indications and evidence of links between environmental drivers and biological processes regulating the physiology, life cycle and dynamics of these species. The analysed literature includes experimental work under controlled conditions, field observations and model-based inference, as well as outcomes from process-oriented and correlative analyses. It remains difficult to navigate the scientific literature with regard to the risk of spurious correlations, especially since in many cases formal validations are lacking. When contrasting results were found from different studies and they were assessed as equally supported, these have been reported in the form of uncertainty rather than mediated towards a single interpretation. To improve usability, the SCI-sheets present a common format designed around the life cycle of a generic fish, including the four main life stages: egg, larval, juvenile and adult (Fig. 3). Climate change can affect processes internal to each stage (i.e., survival, growth), and processes linking the different life stages (i.e., hatching, metamorphosis, settling, maturity, recruitment).

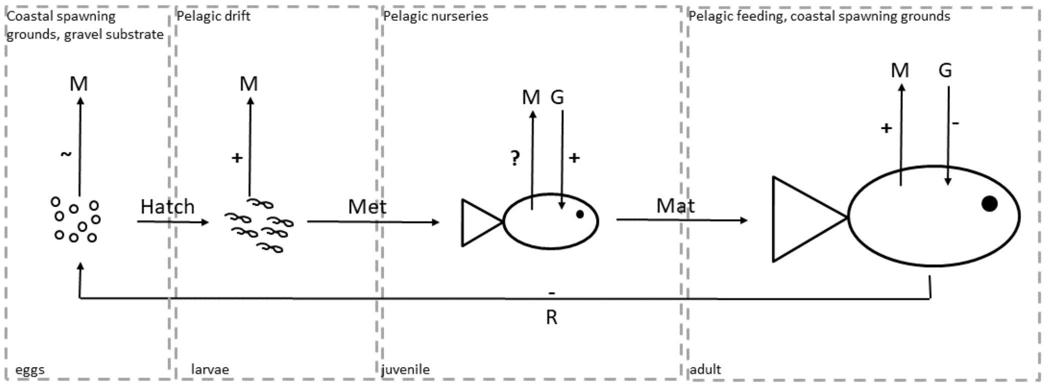

Figure 3. Schematic of expected impact of warming on main life stages and processes, using North Sea Autumn Spawning Herring as example, and including hatching (Hatch), metamorphosis (Met), maturity (Mat), natural mortality (M), growth (G) and recruitment (R). (+) refers to an expected increase in the rate of the process as a consequence of climate change, (-) to an expected decrease, (~) to no expected change, (±) to contrasting effects with uncertain net effect, and (?) to an unknown effect.

3.2. Non-indigenous species

Non-indigenous species (NIS) are non-native species that have not migrated actively to their new regional distribution, but the introduction has been facilitated by a human vector; HELCOM 2018a). Since the group is heterogenous and the biology of non-indigenous species is often poorly understood in their novel habitats, little is also known about how climate change can impact non-indigenous species. It has been suggested that in many cases invasive non-indigenous species share traits that will favour them in the light of global warming (Dukes and Mooney 1999). Climate change may, for instance, lead to more beneficial conditions for introduced species tolerant of high temperatures to establish, that is promoting their survival, reproduction, and expansion within their new area. However, changes in hydrography may both promote or constrain the establishment of NIS in specific sea areas. Simulations for the northern Baltic Sea showed that decreasing salinity under climate change could restrict the spread of some NIS in this area, such as polychaetes, gastropods and decapods, while some bivalves, amphipods and mysids could be favored (Holopainen et al 2016).

Several non-indigenous species occur in the Baltic Sea and in the North Sea, mainly introduced with ballast water from shipping or through mariculture. For example, the American comb jelly (*Mnemiopsis leidyi*) was first recorded in the North Sea in 2006 (Faasse and Bayha 2006). Jellyfish concentrations are expected to increase in the North Sea during the 21st century, mainly due to increasing water temperature and acidification (Attrill et al. 2007). Due to fast reproduction and growth under favorable conditions they have the potential to affect pelagic and coastal ecosystems within a short time period (Purcell 2005).

The Pacific oyster (*Crassostrea gigas*) was introduced in Scandinavian waters, including Sweden, during the 1970s, as a result of farming and aquacultural trials (Laugen et al. 2015). The species has thereafter spread and established in the wild during, especially once these activities were discontinued, interfering with the native oyster *Ostrea edulis* and the blue mussel *Mytilus edulis* (Laugen et al. 2015). The Pacific oyster is considered very tolerant to varying conditions with survival reported across a broad temperature range 0–30 °C (Strand et al. 2011), but experimental work has shown that oysters were immuno-compromised already at temperatures of 21 °C (Malham et al. 2009). Along the Swedish coast, mass mortality has been observed during occasionally extremely cold winters (e.g., 2009-2010) as well as during summers (e.g., 2014), but the species was always able to recover locally after some time. The causes of summer mortalities appear multifactorial, as also supported by experimental studies, and bacterial and viral infections may play a role (Samain & McCombie 2008; Mortensen et al. 2014). Laugen et al. (2015) suggest that global human-assisted distribution of *C. gigas* will likely continue in the future as global warming facilitates aquaculture in new areas.

As another example, the presence of the non-native American lobster *Homarus americanus* is documented in Swedish waters since the early 2000s (Øresland et al. 2017). Concerns raised in relation to the presence of American lobster in European waters, include the risk of spreading the fatal bacterial infection gaffkemia (*Aerococcus viridans*), which has likely been introduced in populations of the native European lobster (*H. gammarus*) via this American lobster. The prevalence of the disease in wild European lobsters is assumed to be low today, although there is considerable concern about its potential impact if it would become prevalent. At higher latitude, warming stimulates metabolic growth in many decapods including lobsters, but may compromise their immune defenses, hence contributing to their susceptibility to epizootic disease including gaffkemia (Groner et al. 2018). Water temperature has a significant effect on the severity of gaffkemia outbreaks with mortality occurring more quickly as temperature increases (Stewart et al. 2011). Implications under the effects of climate change remain unclear.

In the Baltic Sea, the non-indigenous fish species round goby (*Neogobius melanostomus*) was first established in the southern areas, and it is progressively expanding its distribution range. Round goby has been speculated to benefit from warming temperatures, so that its establishment northwards would be facilitated with a warming climate (HELCOM/Baltic Earth 2021). The species was reported as spawning in the southern Baltic Sea at temperature 18 °C (Tomczak and Sapota, 2006). It is currently frequent to common northwards up to the southern Bothnian Sea (SLU unpubl,). The round goby is a commercial resource in the southern Baltic Sea, but is currently not utilized in Sweden. Several concerns have been raised about its potential to interact with and outcompete local fauna as it is a highly efficient benthic feeder (Almqvist 2008, Ojaveer et al. 2015).

4. Effects of climate change on fisheries

Climate change is expected to result in environmental conditions at sea which are beyond the range of variability experienced since the advent of industrialized fishing. Effects of climate change on total wild fisheries production have so far been small, but this is likely to change as temperatures rise, oxygen and pH levels decline and extreme events increase the risk of direct and indirect impacts on fisheries production (Brander et al 2017). Effects on fisheries can be identified along three main pathways: 1) via direct and indirect effects on target species (see section 3); 2) via changes in the environmental conditions which could affect operations at sea, e.g. number of days with unsuitable weather; 3) via changes in the climate policies and governance, i.e. limitation of green-house gas (GHG) emissions. The potential consequences of climate change on the different fisheries are, however, challenging to predict, and scientific evidence remains sparse (Helcom Clime; Kjesbu et al. 2021; Pinsky 2021).

Effects of climate change on fish growth, size distributions and species composition affect yields that can be obtained by fisheries, and hence how fishing can be carried out in a sustainable way. Since warming tends to favour small individuals, while large individuals in some cases grow more slowly in warm water, the total production of fish biomass may decrease with warming. Moreover, if warming reduces primary production in many areas, which according to the IPCC report is very likely, fish productivity is expected to decrease. Similar calculations have not been made for the Baltic Sea, but simple estimates at the global level show that the total catch of fish in the world's oceans may decrease by 20–25 % by the year 2100 under the most severe warming scenarios (RCP8.5), and around 3–5 % already under the most optimistic scenarios (RCP2.6) (Cheung et al. 2018).

Further, shifts in the distribution of commercial fish stocks will influence the availability of target species. Some species will decrease and disappear from certain areas where they were previously exploited, and will appear and increase in other areas (Engelhard et al. 2011, 2014). In the EU Common Fisheries Policy, the total annual catch per species in each management area is shared among member states according to a fixed proportional allocation known as ‘Relative Stability’ which largely follows old agreements and catch distributions from the 1970s. However, changes in stock distribution are already occurring, and as patterns will become more pronounced, a mismatch between quota shares and regional abundances within management areas will increasingly challenge the current resource allocation among countries and fleets, with potential detrimental effects for the status of fish stocks and for the fisheries depending on them (Baudron et al. 2020). New types of demands on cooperation in both national and international fisheries management will be required to be sustainable in the long term, and the extraction of species will in many cases need to be adapted to the new conditions affecting distribution and productivity of the stocks (Muhling et al. 2017).

Regarding effects on fisheries operations, models generally suggest that climate change could result in a north-eastward shift of storm frequency in the North Atlantic, but no clear trend is found in observations from the North Sea and Baltic Sea, and regional projections of storminess remain highly uncertain for these two regions (Pinnegar et al. 2016; EN-Clime 2021). Evaluations of the risks and adaptations to climate change from other regions suggest that increasing storminess is likely to disturb fishing operations and limit the number of active fishing days. Effects are often expected to the whole fishing sector but the small-scale fishery is generally considered more vulnerable because of its smaller vessels, more limited geographical range and ability to replace damaged equipment (Gregg et al. 2016; Poulain and Wabbes 2018).

The fishing sector is commonly exempted from GHG taxation in most countries, despite the fact that fossil fuel combustion is one of the main contributors to the environmental impacts of fishing activities (Avadí and Fréon 2013), and that fisheries account for >1 % of the global oil consumption (Tyedmers et al. 2005). A comparative analysis of fuel taxes for fisheries among Nordic countries showed that an efficient fleet management for stock recovery would have a larger effect on the emission level than lowering fuel subsidies or additional CO_2 taxation (Waldo et al. 2016).

Differences in the fuel efficiency and capacity to internalise costs by the different fishing fleets as well as additional objectives (e.g., promoting small-scale fisheries, regulation of fisheries in marine protected areas, more selective fisheries) complicate predictions on how the EU and other coastal states' policies to limit GHG emission will affect the different fishing segments. In a recent analysis of the Swedish fishing sector, Waldo and Paulrud (2017) showed that 1) technological innovation will affect the fleet structure differently depending on the size of the CO_2 cost imposed by regulation; 2) larger fuel saving potentials are expected for the active than the passive gears; 3) under high CO_2 cost scenarios, innovation will strongly affect the fishing sector and will be a prerequisite to maintain profitability of some of the major fisheries. Considering the vision of the *Nordic Council of Ministers* of the Nordics becoming the most sustainable and integrated region of the world (ICES 2022) and the general ambition to reduce GHG emissions by 30–50 % among many Nordic countries during the next 10–20 years (e.g., Norway 55 % reduction by 2030 as compared to the level in 1990 , Iceland 50 % reduction by 2030 and fossil fuel free by 2040/50, EU's nationally determined contribution of 40 % reduction by 2030 compared to the level in 1990 following the Paris agreement) important innovations should be expected in both the captured fisheries and aquaculture to reduce the climate footprint of the seafood industry. The upcoming evaluation and update the EU Common Fisheries Policy will likely play a role on this.

5. Species tolerance and environmental limits

The relative sensitivity to climate change, specifically in relation to effects of warming and freshening, was evaluated for 49 species occurring in Swedish sea areas, distributed over 34 marine fish species, 11 freshwater fish species and 4 crustaceans. For herring, sprat and cod, the evaluation was conducted by stocks. The relative sensitivities of species/stocks to changes in climate-related abiotic variables were evaluated as described in the next section, focusing on spawning habitat preferences. Each fish species was also assigned origin (marine or freshwater) and feeding habit as described in Koehler et al. 2022 (Appendix A1).

5.1. Spawning habitat preferences

For each study species and stock that has been reported to spawn in Swedish seas we compiled information on the physical environmental conditions of their current spawning habitats, specifically concerning spawning depth and temperature. The compilation was mainly based on information in the SLU-hosted database *Lektidsportalen* ("Spawning time portal"; Havs- och vattenmyndigheten 2022), which covers all fish species in Swedish waters. Bluefin tuna, European bass (S Kullander et al., 2012) and European eel, which occur regularly or frequently in Swedish sea areas, were not included as they are not reported to spawn in Swedish waters. For round goby, which is a non-indigenous fish species in the Baltic Sea, the required information was not available in "*Lektidsportalen*". For that species we used an upper temperature of 18 °C as reported for spawning of round goby in the southern Baltic Sea. As lower temperature we used 12 °C, which is the temperature when spawning starts in the species' native environment. While spawning in the Baltic Sea has so far only been reported in water temperatures of 17–18 °C (Tomczak and Sapota, 2006), females with eggs have been observed in early May at water temperatures far below 17 °C (I. Wallin, personal communication). For sandeels, we used deeper maximum spawning depths as those noted in *Lektidsportalen*, with 40 m for *Ammodytes tobianus* and of 70 m for *Ammodytes marinus*, based on information of depths where this species has found and the fact that they have strong site connection (Bergstad et al. 2001; Jensen et al. 2003; MacDonald et al. 2019).

To account for how the spawning of marine fish species in the Baltic Sea could be affected by changing salinities (see section 2.2) we also included information on their natural salinity tolerance limits during critical life stages (Table 1). In addition, a minimum oxygen requirement of 1.5 ml/L was assumed for the marine stocks in the Baltic Sea (HELCOM 2021).

Table 1. Salinity tolerance limits of marine species during critical life stages.

Species	**Lower salinity limit**	**Assessed feature**	**Reference**
Baltic cod	11	Fertilization and normal egg development, egg buoyancy	Westin and Nissling, 1991
Western Baltic cod	18	Activation of spermatozoa (noted at salinity 16), egg buoyancy (ca. 20)	Nissling and Westin, 1997
Sprat	6	Minimum limit for egg survival and buoyancy	Petereit et al., 2009
Herring	2	Known to spawn in all of the Baltic Sea, including the Bothnian Bay	Gunnartz et al., 2011
European flounder	10	Field observations and studies on egg buoyancy	Florin and Höglund, 2008; Nissling et al., 2002
Baltic flounder	6	Spermatozoa mobility and fertilization rates	Nissling et al., 2002; Hinrichsen et al., 2017
Dab	11–18	Spermatozoa activation and studies on egg buoyancy	Nissling et al., 2002
Plaice	12	Egg buoyancy	Nissling et al., 2002
Turbot	7	Spermatozoa activity and fertilisation rate	Nissling et al., 2006

Next, based on the compiled species preferences for spawning reported for Swedish waters, we classified the species into four spawning groups, specifically “shallower colder”, “shallower warmer”, “deeper colder” and “deeper warmer”. Species spawning ≤20 m or >20 m were classified as shallower and deeper, respectively, and species spawning ≤12 or >12 °C were classified as colder and warmer, respectively (Table 2). For this classification, the warmest observed spawning temperature and the deepest observed spawning depth, according to *Lektidsportalen*, were used. This choice of approach was based on that even if a species under current climate conditions may spawn more frequently in more shallow or colder waters, we assume based on their full range of observed spawning conditions that they can adapt/shift within their maximum observed ranges concerning temperature and depth.

Table 2. Classification of fish species (and in some cases stocks) based on their assessed relative sensitivity to temperature effects on spawning conditions. The classification was restricted to negative effects of temperature modulated by spawning depth range, and to addressing the relative sensitivity of different species. Hence, it does not express absolute levels of sensitivity, nor consider the availability of suitable spawning conditions in relation to other key factors, such as presence of spawning habitat. “Shallower” and “deeper” was categorized as ≤ and >20 m, respectively. "Colder” and “warmer” was categorized as ≤ and > 12 °C, respectively. Please see Table 3 for species names in English.

Spawning category	**Sensitivity**	**Number of species/stocks**	**Species names (stock information)**
Shallower colder	Very high	5	*Coregonus lavaretus*
			Coregonus maraena
			Salmo salar
			Salmo trutta
			Thymallus thymallus
Shallower warmer	High	12	Abramis brama
			Clupea harengus (Baltic Sea/Gulf of Bothnia/Western Baltic spring-spawners)
			Ctenolabrus rupestris
			Esox lucius
			Gasterosteus aculeatus
			Neogobius melanostomus
			Perca fluviatilis
			Raja clavata
			Rutilus rutilus
			Sander lucioperca
			Scomber scombrus
			Scophthalmus maximus

Spawning category	Sensitivity	Number of species/stocks	Species names (stock information)
Deeper colder	Low	18	*Ammodytes marinus*
			Ammodytes tobianus
			Cancer pagurus
			Coregonus albula
			Gadus morhua
			Hippoglossus hippoglossus
			Lophius piscatorius
			Melanogrammus aeglefinus
			Merlangius merlangus
			Merluccius merluccius
			Micromesistius poutassou
			Microstomus kitt
			Pandalus borealis
			Pleuronectes platessa
			Pollachius pollachius
			Pollachius virens
			Squalus acanthias
			Trisopterus esmarkii
Deeper warmer	Very low	15	*Amblyraja radiata*
			Anarhichas lupus
			Clupea harengus (North Sea autumn spawners Kattegat/Skagerrak)
			Cyclopterus lumpus
			Dipturus batis
			Glyptocephalus cynoglossus
			Homarus gammarus
			Hyperoplus lanceolatus
			Labrus bergylta
			Molva molva
			Nephrops norvegicus
			Platichthys flesus
			Platichthys solemdali
			Sprattus sprattus
			Symphodus melops

According to the achieved classification, spawning in shallower waters is more typical for freshwater fish species, while spawning in deeper waters is more typical for marine fish species (Fig. 4). Overall, 34 % and 66 % of the 50 species/stocks assessed spawn in shallower and deeper waters, respectively, and 46 % and 54 % of the species/stocks spawn in colder and warmer water, respectively (Fig. 4). The applied approach does, however, not consider that the presence of suitable spawning conditions at deeper depths/under higher temperatures will also be dependent on other criteria than those in focus here. For example, successful spawning also requires that there are suitable structures and adequate sea floor properties. In that sense, the evaluation represents an optimistic scenario. However, the main purpose of the evaluation was not to identify species that may benefit or be insensitive to climate-related changes in relation to spawning temperature, but to compare the potential sensitivities of different species and species groups.

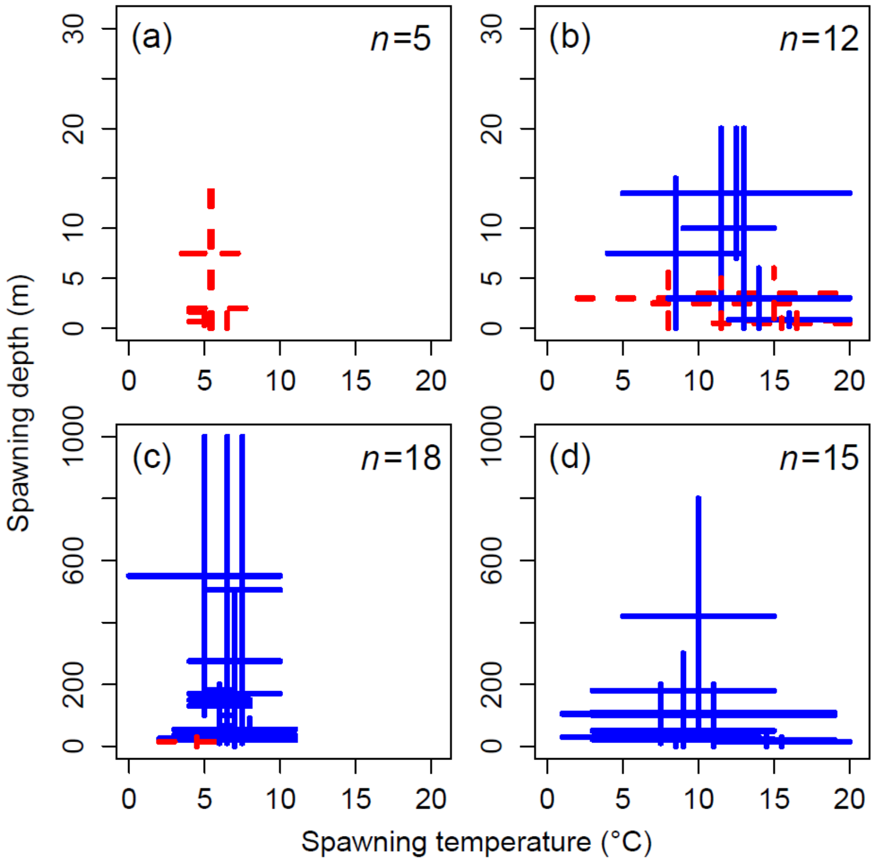

Figure 4. Depth- and temperature intervals of the current spawning habitats of the studied fish species in Swedish waters. Every species is represented by a vertical line showing the spawning depth interval, and a horizontal line showing the spawning temperature interval (blue and red colour for marine and freshwater species, respectively). For clarity, the species were grouped into four classes, with species that spawn in (a) shallower colder water (≤20 m and ≤12 °C), (b) shallower warmer water (≤20 m and >12 °C), (c) deeper colder water (>20 m and ≤12 °C) and (d) deeper warmer water (>20 m and >12 °C). On a simplified level, the relative species sensitivity to warming due to global change can be expected to decrease from groups (a) to (d).

5.2. Current Thermal Safety Margin

The ability of fish and marine invertebrates to tolerate a warming environment was evaluated in terms of the "thermal safety margin" (TSM). For widely distributed species represented by more than one stock in Swedish waters the TSM was calculated separately for each stock, by comparison between the forecasted temperature within the distributional area of the stock and a thermal limit of tolerance for the species (Payne et al., 2021; Vinagre et al., 2019). The stocks are assumed to represent populations in the evaluation below. See Table 3 for species codes used in this and other sections.

Table 3. Species list used for calculation of the current TSM

Species code	Scientific name	English name
BLL	*Scophthalmus rhombus*	Brill
CAA	*Anarhichas lupus*	Atlantic wolffish
COD	*Gadus morhua*	Atlantic cod
CRE	*Cancer pagurus*	Edible crab
ELE*	*Anguilla anguilla*	European eel
FBM*	*Abramis brama*	Freshwater bream
FLE	*Platichthys flesus*	European flounder
FPE*	*Perca fluviatilis*	European perch
FPI*	*Esox lucius*	Northern pike
FPP*	*Sander lucioperca*	Pike-perch
FVE	*Coregonus albula*	Vendace
HAD	*Melanogrammus aeglefinus*	Haddock
HAL	*Hippoglossus hippoglossus*	Atlantic halibut
HER	*Clupea harengus*	Atlantic herring
HKE	*Merluccius merluccius*	European hake
HOM	*Trachurus trachurus*	Atlantic horse mackerel
LBE	*Homarus gammarus*	European lobster
LEM	*Microstomus kitt*	Lemon sole
LIN	*Molva molva*	Ling
LUM	*Cyclopterus lumpus*	Lumpfish
MAC	*Scomber scombrus*	Atlantic mackerel
MON	*Lophius piscatorius*	Angler (=Monk)
NEP	*Nephrops norvegicus*	Norway lobster
OYF	*Ostrea edulis*	European flat oyster
PLE	*Pleuronectes platessa*	European plaice
POK	*Pollachius virens*	Saithe (=Pollock)
POL	*Pollachius pollachius*	Pollack
PRA	*Pandalus borealis*	Northern prawn

Species code	Scientific name	English name
SAL	*Salmo salar*	Atlantic salmon
SAN	*Ammodytes spp*	Sandeels (=Sandlances) nei
SOL	*Solea solea*	Common sole
SPR	*Sprattus sprattus*	European sprat
TBR	*Ctenolabrus rupestris*	Goldsinny-wrasse
TRS	*Salmo trutta*	Sea trout
TUR	*Psetta maxima*	Turbot
USB	*Labrus bergylta*	Ballan wrasse
WEG	*Trachinus draco*	Greater weever
WHE	*Buccinum undatum*	Whelk
WHF	*Coregonus spp*	Whitefish
WHG	*Merlangius merlangus*	Whiting
WIT	*Glyptocephalus cynoglossus*	Witch flounder
YFM	*Symphodus melops*	Corkwing wrasse

* *not included in the calculation of the current TSM*

Species with a larger TSM are expected to better tolerate the impact of warming, while species with a smaller TSM are expected to be more sensitive because they already are closer to their upper thermal limit. While TSMs do not consider potential phenotypical acclimation or genetic adaptation to future temperatures they provide important reference values concerning, e.g., the species' adaptation capacity, potential future distribution shifts and risk for local extinction (Vinagre et al., 2019). In assessing TSMs for aquatic organisms it is important to consider that many species are exposed to different thermal regimes since they occupy different habitats throughout their life cycles (Vinagre et al., 2019). However, for simplification in the current evaluation, the TSM was computed on the overall life cycle of each species or stock, and not specifically for the different life stages.

Specifically, we computed current population specific TSMs by combining species distribution maps from Aquamaps (www.aquamaps.org, accessed on 13th January 2022) with information on population distributions as approximated by stock management areas (www.ices.dk), and with reconstructions of present sea surface temperatures from the HadGEM2 global climate model (accessed on 19th January 2022 https://esgf-data.dkrz.de/search/cmip5-dkrz/). Forecasts from the HadGEM2 model were preferred for consistency with the hydrographic forecasts used in the climate risk analysis (see section 7.1), but this restricted availability of temperature data for calculation of the TSM to sea surface temperatures. For 17 species, information on stock management areas was not available and ICES rectangles with occurrence of the species in the Swedish catches were used as proxy for population distribution. When alternative versions of the native distribution maps were available in Aquamaps we selected the map ranked with the highest quality according to the internal classification. The TSM was not calculated for FBM, FPE, FPI, FPP because species distribution maps were not available in Aquamaps for freshwater species. ELE was also not included because of the large part of the life cycle spent in freshwaters.

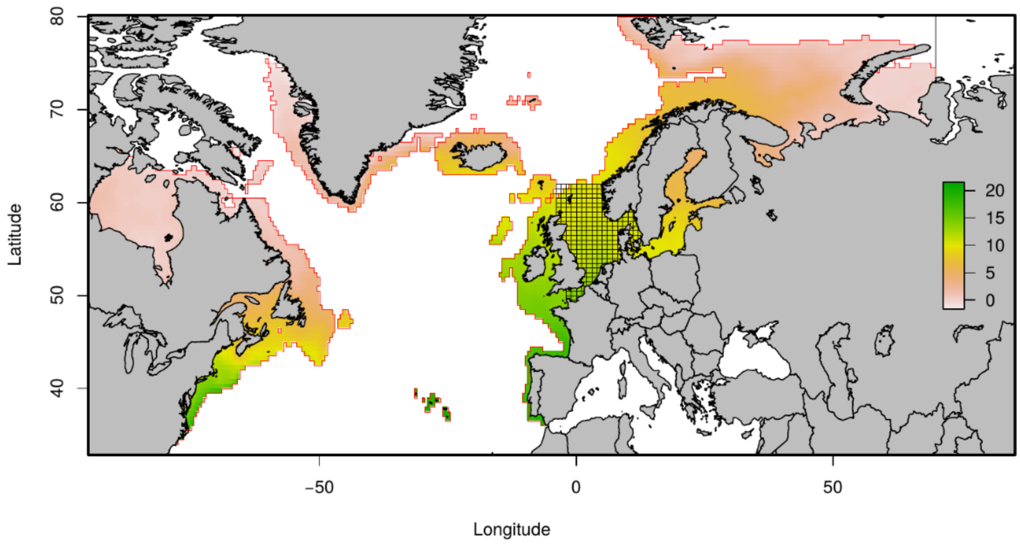

Figure 5. Map showing the SST throughout the species distribution for herring over which the 90th percentile of the temperature(p90) is calculated. The grid illustrates the management area for the North Sea Autumn spawning herring stock where the TSM is calculated.

Each species distribution map was overlayed on sea surface temperature (SST) predictions for the period 2016-2021 (present conditions), and the 90th percentile of the temperature (p90) was calculated and used as a proxy for the upper thermal tolerance of the species (Fig. 5). Current TSM for each population was estimated from the difference between the species-specific p90 and the SST in each pixel of the population distribution, and was calculated as the annual median value over all pixels within the reference period for the present climate conditions (2016-2021; Appendix A2).

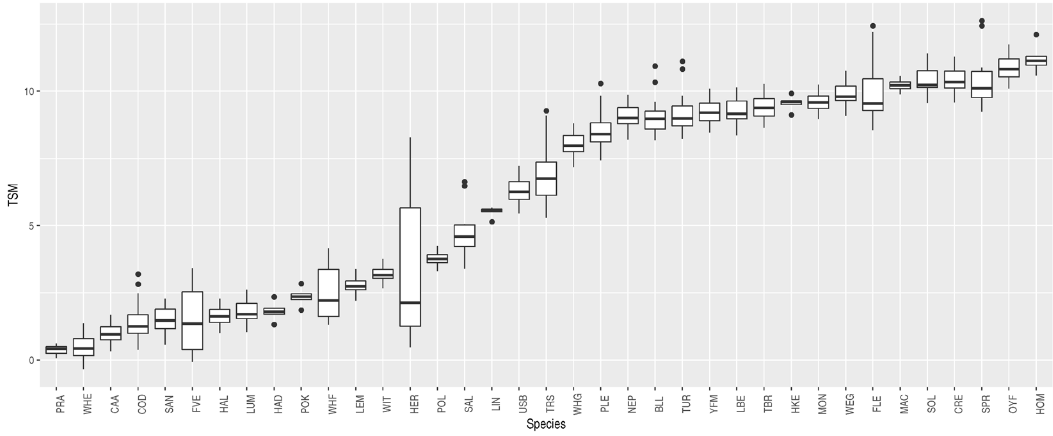

Figure 6. Calculated current TSM for the main species contributing to the Swedish catch (99 % of the economic value of landings). Boxplots reflect variability in the current population specific TSM over the period 2016-2021.

Results were presented at a species level with boxplots representing variability in the current TSM over the period 2016-2021 and among populations (Fig. 6). The current TSM ranges between 0ºC and approximately 11ºC. Higher TSMs are estimated for species with a wide distribution and/or origin in temperate waters, i.e. hake, sprat, mackerel and horse mackerel, and for most flatfish, i.e. plaice, brill, turbot, sole and flounders, except witch flounder. With the exception of the northern shrimp (see text below), the crustaceans considered show generally high TSMs, with increasing values for Norway lobster (8.3–9.8 ºC), European lobster (8.4–10.1 ºC), and crab (9.6–11.2 ºC). Species with a wide distribution but occurring predominantly in boreal and sub-arctic waters, such as halibut and herring, show lower TSMs. Herring in the Swedish catches are mainly represented by five geographically defined stocks across a wide distribution. This is reflected in the large TSM variability estimated for herring, with the western Baltic herring and the Norwegian herring showing the lowest and highest values, respectively. The two *Coregonus* spp. (vendace and whitefish) show low TSM values with a median in the range 1.4–2.2 ºC. Gadoids generally also show relatively low TSM, with cod presenting the lowest value of these, followed by haddock, saithe and pollack. Finally, northern shrimp shows the lowest TSM among all the species analysed, since the Skagerrak and North Sea stocks exploited by the Swedish fishery are found at the southern distribution of this boreal species.

No correlation was found between the current TSM and the economic value of the species (Fig. 7). Among the species with highest economic value, the current TSM value is high for SPR, MAC and NEP, but low for HER, PRA, COD, FVE and SAN.

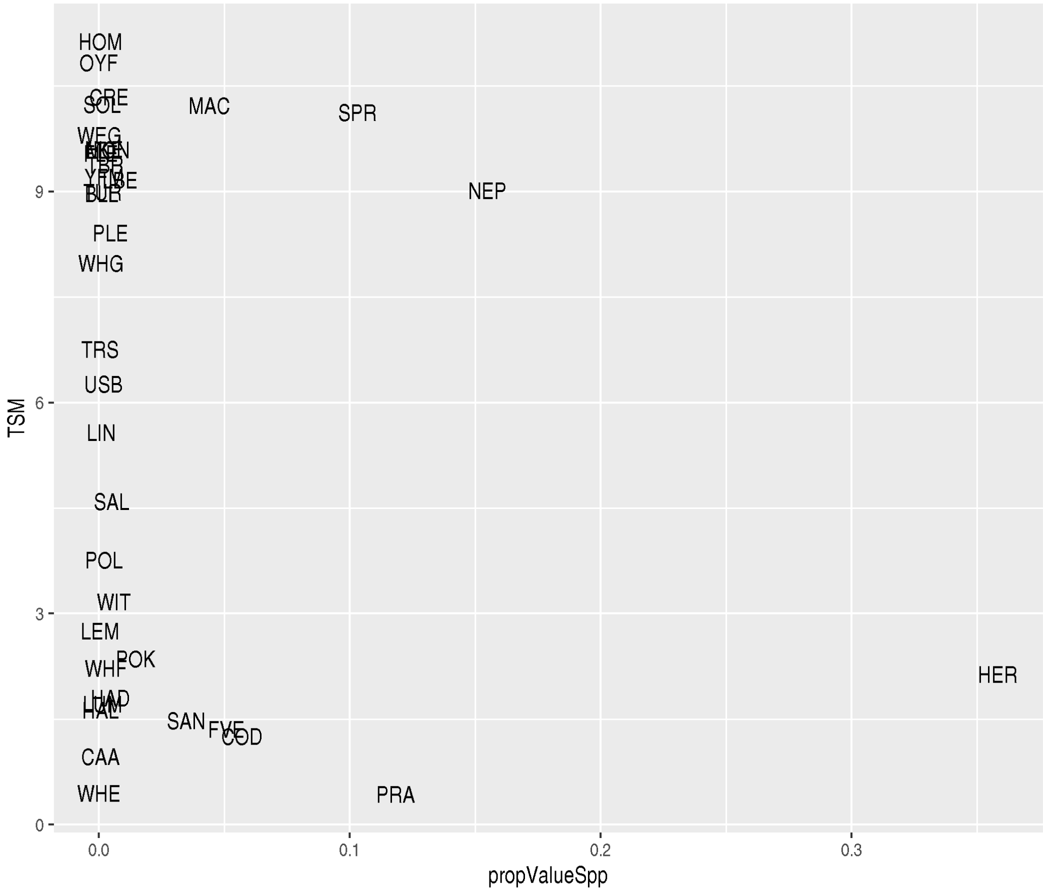

Figure 7. Scatterplot of the species' mean relative annual value from the Swedish fishery logbooks and the median current thermal safety margin (TSM).

6. Potential effects of climate change on spawning and nursery habitats in the Baltic Sea

More detailed spatial analyses were carried out for fish spawning in the Baltic Sea, to assess how climate change may affect the availability of suitable spawning and nursery habitats. The analyses considered species spawning in coastal as well as open sea areas.

For species spawning in coastal areas, the analyses were based on the data underlying the maps presented by Erlandsson et al. (2021). These were produced using an ensemble approach, which combines outputs from several spatial models to predict distributions of coastal fish nursery areas in Swedish coastal waters. The models were based on species-environment relationships for several environmental factors characterising coastal habitats, and their interactions, considering environmental conditions and species distributions in the past 15 years. Species for which habitat models were built were perch, pike, bleak, breams, minnow, rudd, pikeperch, ide, roach, European smelt, crucian carp, sand goby, common rudd, two-spotted goby, nine-spined stickleback, three-spined stickleback, tench, and black goby. The maps covered coastal areas from the southern mouth of the Sound to the northern Bothnian Bay.

For internationally assessed fish stocks, the corresponding analyses were based on Baltic regional essential fish habitat maps as presented by HELCOM (2021). The data used were the spatial data representing potential spawning areas for cod, Baltic flounder, European flounder, herring, and sprat. The maps for cod, sprat and herring covered the entire Baltic Sea including the Kattegat, while the maps for flounder covered the Baltic region out until and including the Arcona basin. The data were split by ICES sub-basin so that analyses were carried out separately for different stocks, as defined by ICES (http://stockdatabase.ices.dk/default.aspx).

Information on the species' temperature ranges for spawning and on seasonality, given as the range of months during which the species is currently considered to be spawning, was derived from the database *Lektidsportalen* (Havs- och vattenmyndigheten 2022), which holds data on the spawning season and required spawning environment of Swedish fish species. Additionally, information on the minimum salinity requirements for spawning were considered for the marine species (see Table 1). For cod, sprat, and European flounder, which spawn in the open sea, a minimum oxygen requirement of 1.5 mL/L was assumed (HELCOM 2021).

Scenarios for changes in climate regimes were based on the RCO-SCOBI model forced by the global scenarios MPI-ESM-LR, EC-EARTH, IPSL-CM5A-MR and HadGEM2-ES, assessed separately for RCP45 (available in all models) and RCP85 (all global models but the IPSL-CM5A-MR; see section 2.3). The applied scenarios included the assumption of improving nutrient status in line with the Baltic Sea Action Plan. The choice of nutrient scenario did not influence the results for species spawning in coastal areas (all freshwater species, herring and European flounder). Since oxygen conditions are not only affected by climate change, but also negatively affected by eutrophication (Meier et al. 2018), the choice of nutrient scenario had implications on results for cod, sprat and European flounder, for which the availability of potential spawning areas is also limited by hypoxia and anoxia (HELCOM 2021).

The total area of the predicted habitat was computed based on the data underlying Erlandsson et al (2021) and HELCOM (2021), separately for each species (all freshwater species) or stock (cod, herring, flounders). In the next step, the proportion of this area agreeing with requirements for spawning concerning temperature, salinity and oxygen, respectively, was computed, as identified in *Lektidsportalen* as well as Table 1. This was repeated separately for each month during which the species/stock is spawning according to the same sources, and for all climate scenarios and the years 2006-2059. To allow comparison between species, given differences in total area covered, an index representing the resulting value for each month and year divided by the corresponding average for years 2015–2020 was computed for each species/stock. This enabled plotting the relative progression of change over time in relation to the mean areal extent in 2015–2020 for each climate scenario, as well as on average for all scenarios.

The analyses focused on estimating the potential loss of spawning habitats. Potential habitat enlargements were not explicitly assessed, as the underlying maps were not solely developed based on the envelope of climate-related variables, but in most cases considered a wide range of environmental variables, such as for example depth and wave exposure. Hence, identifying potential shifts to entirely new areas would have required rerunning of the original models. However, some flexibility to this limitation was achieved for analyses using recruitment areas as defined by Erlandsson et al. (2021) as a basis, as nursery areas for coastal-spawning freshwater species (which were modelled) are typically more wide-ranging than their spawning areas albeit typically located in proximity to these. Hence, any predicted expansion of suitable spawning area within the delineation of the recruitment area would be captured. For the spawning/recruitment areas delineated in the HELCOM maps (HELCOM 2021) corresponding flexibility was achieved by basing the analyses on the more relaxed option (i.e. ”likely” rather than “potential”), hence also allowing for some expansion compared to the situation in the beginning of the studied time-period.

According to these simulations, the last ten simulated years (2050-2059) generally showed a higher area of available spawning/nursery grounds earlier on in the species’ spawning period, compared to the first ten years (2006-2015), but a lower available area later on in the species’ spawning period (Tables 4–5). Considering the entire spawning period, most of the species showed a slight increase in simulated available habitat for the last ten model-years. The patterns were similar for both the RCP4.5 and RCP8.5 scenarios.

The analyses further predicted that the area of available spawning habitat for European flounder and Baltic sprat will increase considerably during the modeled period (Fig. 8 and 9), mainly driven by improved oxygen conditions, and in the case of sprat also due to increasing temperatures, according to the applied models. Similar evaluations are shown for cod, flounder, herring and perch in the Baltic Sea in Figs. 10-13 and for detailed results concerning spawning habitat of the further other fish species we refer to Appendix A3. The underlying models included a nutrient-reduction scenario in alignment with the Baltic Sea Action Plan, which predicts a reduction in nutrient loading during the simulation period, and thus also an increase in oxygen conditions close to the seabed. In a less optimistic nutrient scenario the here simulated increase in spawning habitat area would probably not be as prominent.

In the analyses, the percentages of available habitat were generally quite low, especially for species that prefer warm water for spawning. This could be explained by a relatively low resolution of the temperature models, with 2x2 km. When the pixel size of the model is that large, this could result in that warmer temperatures occurring in small shallow bays, which are commonly used as spawning and nursery grounds, are not correctly resolved but “evened out” with comparatively colder waters in the deeper habitats occurring in the same pixel.

Table 4. Ratio between areas of available nursery/spawning habitat during the first and last ten simulated years (i.e., 2006-2015 vs. 2050-2059). Values are the mean from all four global scenarios used in the RCB-SCOBI model, and the RCP4.5 warming scenario. Column "Hab." (habitat) shows whether the species' spawning (S) or nursery (N) habitat is considered.

FAO	Hab.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year
SPR	S	1.68	2.18	2.59	2.61	2.22	2.04	1.98	1.89		2.08
FID	N					1.90					1.90
FLE	S	1.74	1.76	1.75	1.62						1.72
HER	S	1.42	1.93	1.77	1.33	0.99	0.93	0.92			1.18
FPE	N				25.7	0.98	0.75	0.00			1.16
FRO	N					1.48	1.00				1.15
SRE	N					Inf	1.06				1.10
FPP	N					1.24	1.00				1.09
ALR	N						1.48	1.05	1.03		1.08
PXP	N					2.04	1.01	1.00			1.08
ACC	N				2.69	1.04	0.58	0.92			1.08
GTA	N				14.7	1.25	1.00	1.00	1.00		1.05
FPI	N			1.39	1.03	0.94	0.69				1.05
FBM/ABK	N					2.16	1.01	1.00	1.00		1.04
GPT	N				Inf	1.60	1.01	1.00	1.00	1.01	1.03
GBF	N				Inf	1.69	1.00	0.87	0.95		1.02
FTE	N						1.15	0.76	1.07		1.01
GBN	S				Inf	1.77	0.99	0.84	0.91		1.01
FCC	N					3.42	0.93	0.61			0.98
Sand goby	N					1.44	0.96	0.77	0.88		0.98
COD	S			1.13	1.08	0.89	0.82	0.91	0.98		0.97
SME	N		Inf	869	1.28	0.74					0.96
Baltic Flounder	S				0.94	0.85	0.81				0.87

Table 5. Ratio between areas of available nursery/spawning habitat during the first and last ten simulated years (i.e., 2006-2015 vs. 2050-2059). Values are the mean from all four global scenarios used in the RCB-SCOBI model, and the RCP8.5 warming scenario. Column "Hab." (habitat) shows whether the species' spawning (S) or nursery (N) habitat is considered.

FAO	Hab.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Year
SPR	S	1.57	2.06	2.40	2.38	1.95	1.73	1.64	1.59		1.86
FLE	S	1.74	1.76	1.67	1.52						1.67
FID	N				1.64					1.64	
ALR	N					1.73	1.07	1.17		1.21	
HER	S	1.46	1.86	1.72	1.28	0.98	0.91	0.92			1.19
FPE	N			3.89	0.98	0.33	0.35			1.14	
SRE	N				Inf	1.05				1.11	
PXP	N				1.97	1.00	1.00			1.11	
FTE	N					1.19	0.97	1.08		1.11	
FRO	N				1.27	1.00				1.10	
ACC	N			2.04	1.01	0.52	1.20			1.09	
FPP	N				1.24	1.00				1.09	
FBM/ABK	N				2.52	1.00	1.00	1.00		1.09	
GPT	N				2.01	1.01	1.00	1.00	1.00	1.06	
GTA	N			5.29	1.19	1.00	1.00	1.00		1.05	
GBF	N			Inf	1.53	0.96	0.92	0.97		1.03	
FPI	N		1.30	1.00	0.89	0.19				1.01	
GBN	S				1.58	0.96	0.87	0.86		0.99	
FCC	N				3.94	0.82	0.64			0.97	
SME	N	12.0	3.13	1.12	0.81					0.97	
Baltic Flounder	S			0.97	0.94	0.88				0.93	
Sand Goby	N				1.40	0.88	0.77	0.72		0.92	
COD	S		1.03	0.90	0.83	0.82	0.88	0.94		0.90	

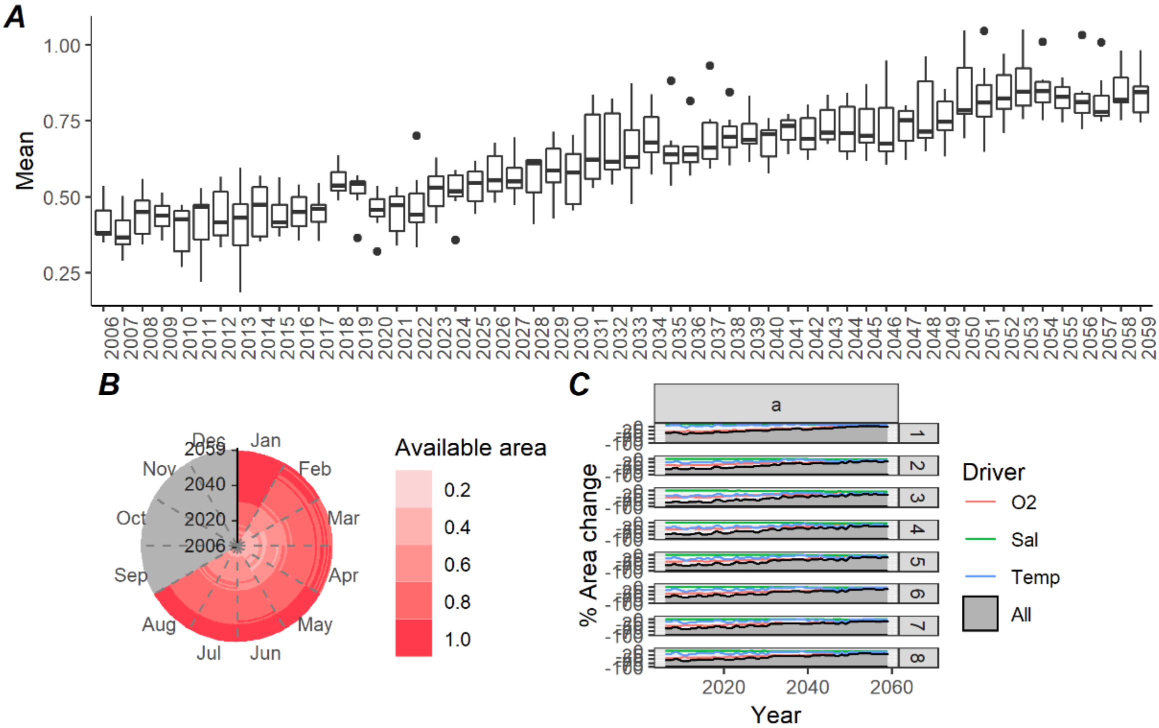

Figure 8. Sprat in the Baltic Sea. A) yearly boxplot of the available area of spawning habitat after considering the species spawning preferences of temperature, salinity, and oxygen. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of spawning habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used. C) The available area of spawning habitat for every month, year, and stock. The lines show the available area after only considering one driver. The grey area shows all three drivers considered at the same time. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used.

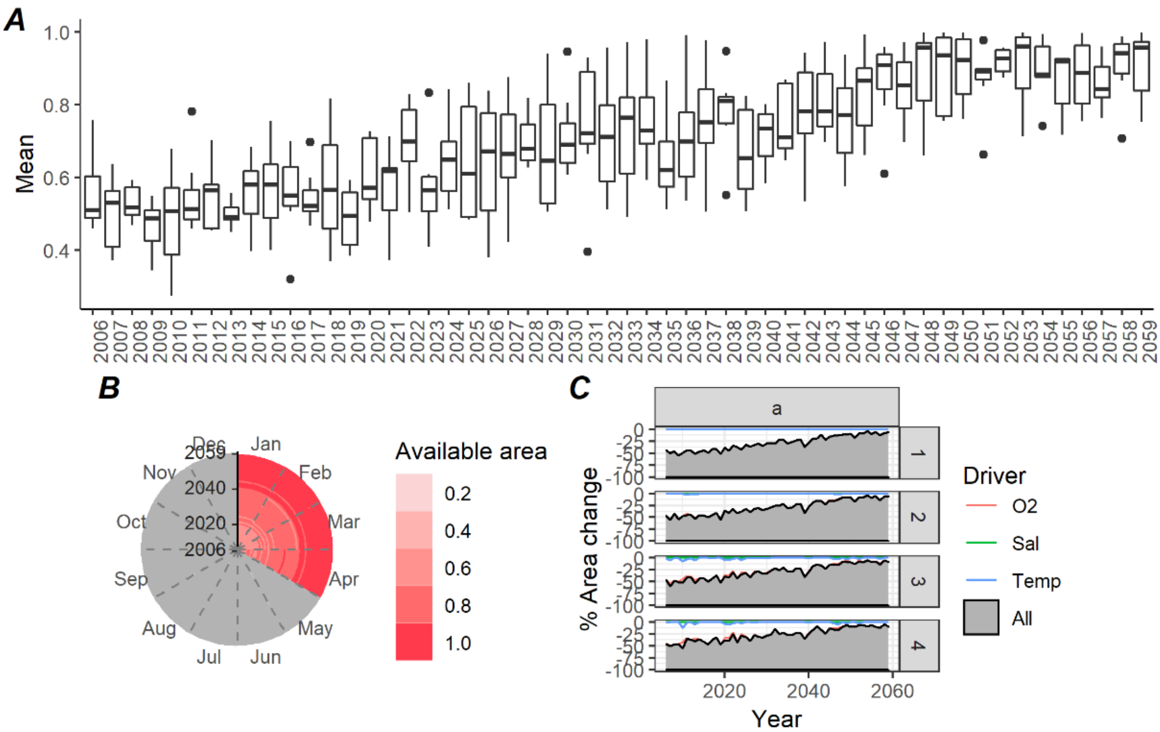

Figure 9. European flounder in the Baltic Sea. A) yearly boxplot of the available area of spawning habitat after considering the species spawning preferences of temperature, salinity, and oxygen. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of spawning habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used. C) The available area of spawning habitat for every month, year, and stock. The lines show the available area after only considering one driver. The grey area shows all three drivers considered at the same time. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used.

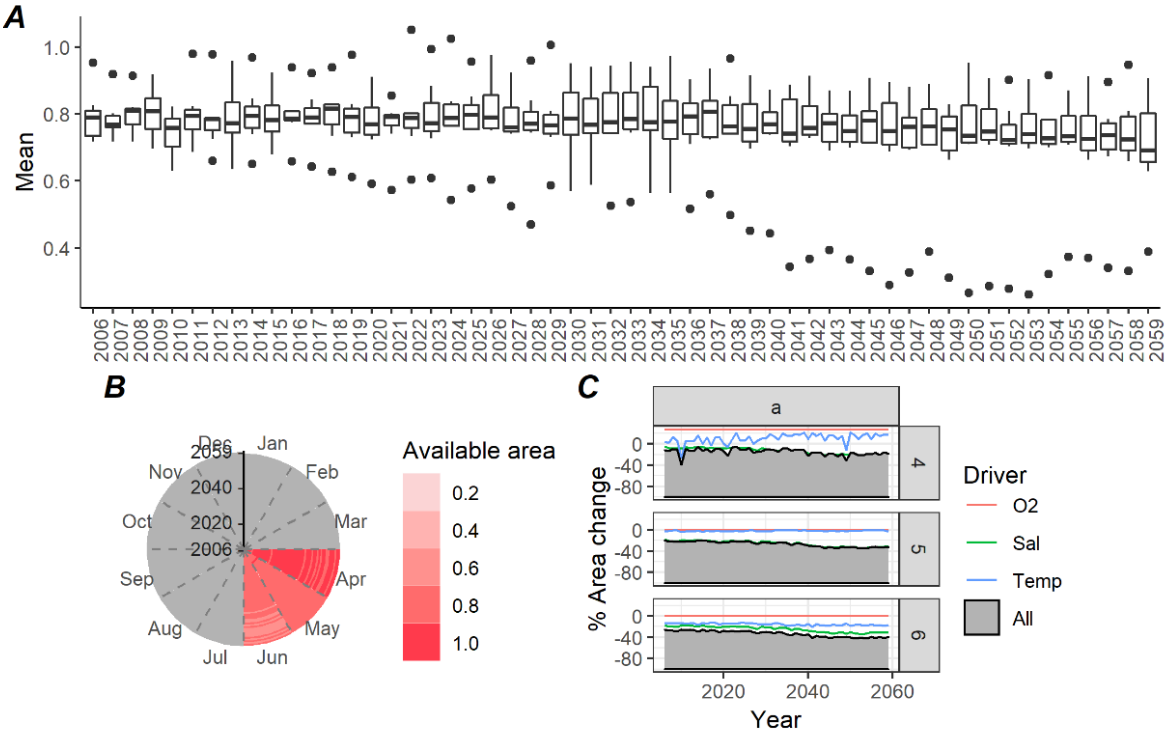

Figure 10. Baltic flounder. A) yearly boxplot of the available area of spawning habitat after considering the species spawning preferences of temperature, salinity, and oxygen. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of spawning habitat for every month and year in polar coordinate. The first modeled year is in the center and increases to the last modeled year at the edges. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used. C) The available area of spawning habitat for every month, year, and stock. The lines show the available area after only considering one driver. The grey area shows all three drivers considered at the same time. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used.

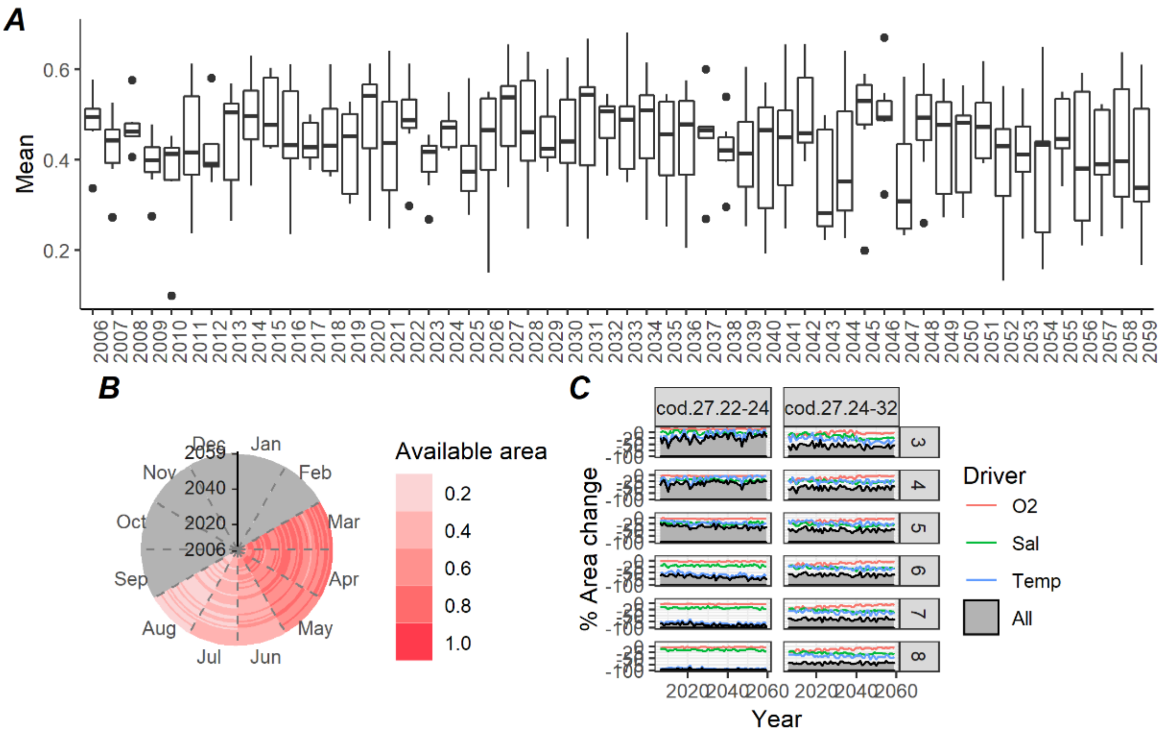

Figure 11. Cod in the Baltic Sea. A) yearly boxplot of the available area of spawning habitat after considering the species spawning preferences of temperature, salinity, and oxygen. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of spawning habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used. C) The available area of spawning habitat for every month, year, and stock. The lines show the available area after only considering one driver. The grey area shows all three drivers considered at the same time. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used.

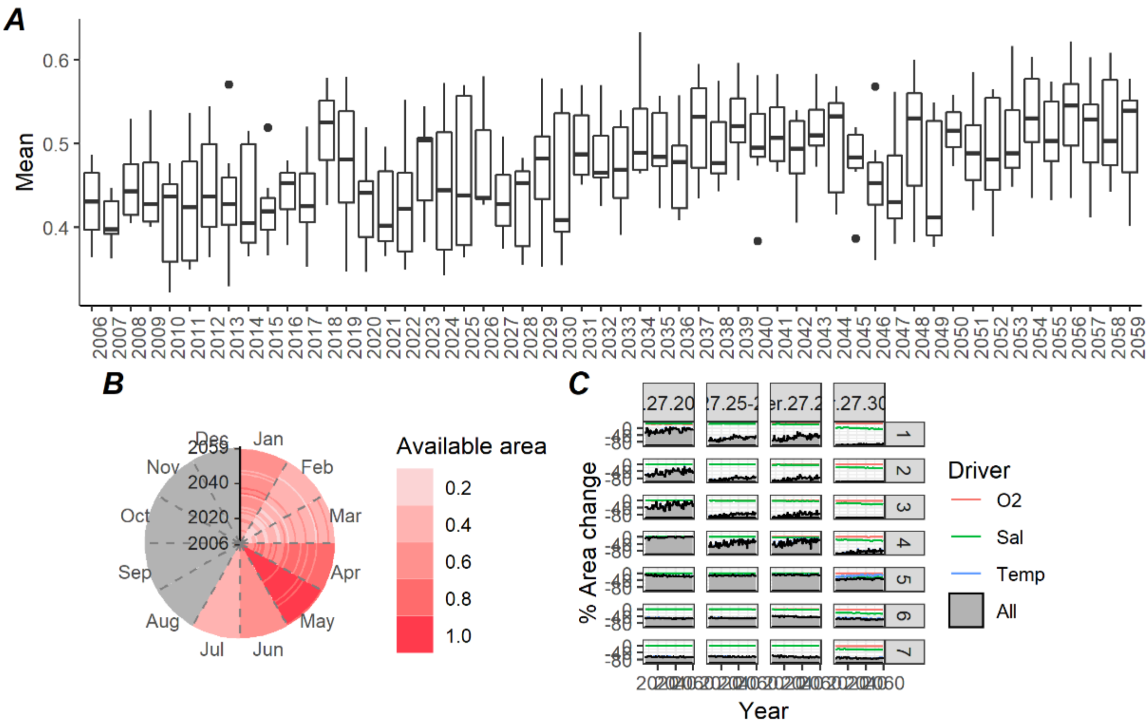

Figure 12. Herring in the Baltic Sea. A) yearly boxplot of the available area of spawning habitat after considering the species spawning preferences of temperature, salinity, and oxygen. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of spawning habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used. C) The available area of spawning habitat for every month, year, and stock. The lines show the available area after only considering one driver. The grey area shows all three drivers considered at the same time. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used.

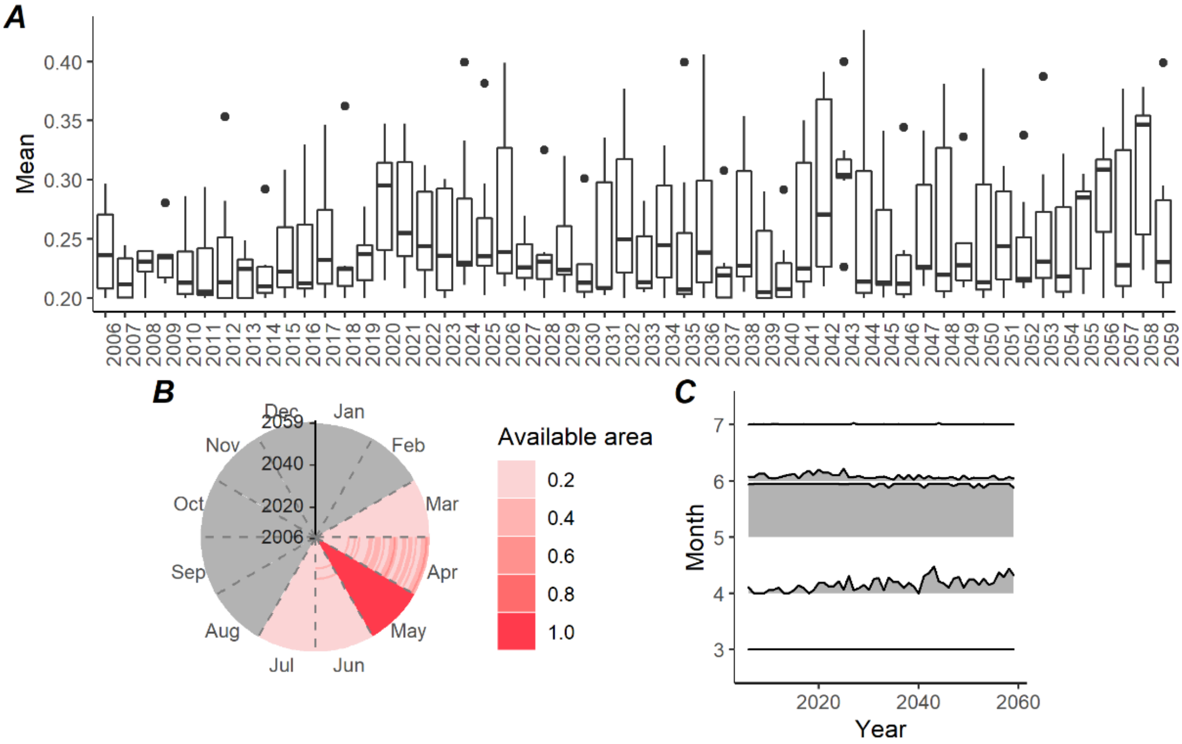

Figure 13. Perch in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP4.5 warming scenario was used.

7. Climate Risk Analysis

Climate vulnerability and risk assessments have been increasingly developed in the past decades to support prioritisation and decision making on climate change adaptation activities, such as for fisheries in different seas (Kjesbu et al., 2021, Payne et al. 2021, Pita et al. 2021; Aragão et al., 2022). The IPCC has in the last ten years moved from a vulnerability-based to a risk-based conceptualisation (IPCC, 2012), to better understand the challenges posed by climate change, identify adaptation options, and build resilience to the changing climate (Connelly et al., 2018).

Climate risk analyses (CRA) evaluate risk at the intersection between hazard, exposure and vulnerability (Fig. 14). The concept considers that the presence of a hazard does not per se indicate a risk. Rather, a hazard becomes a risk when a system is exposed to the hazard and is vulnerable to it upon exposure (Connelly et al., 2018). Thus, risk is also a function of the underlying environmental and socioeconomic context in which climate change occurs.

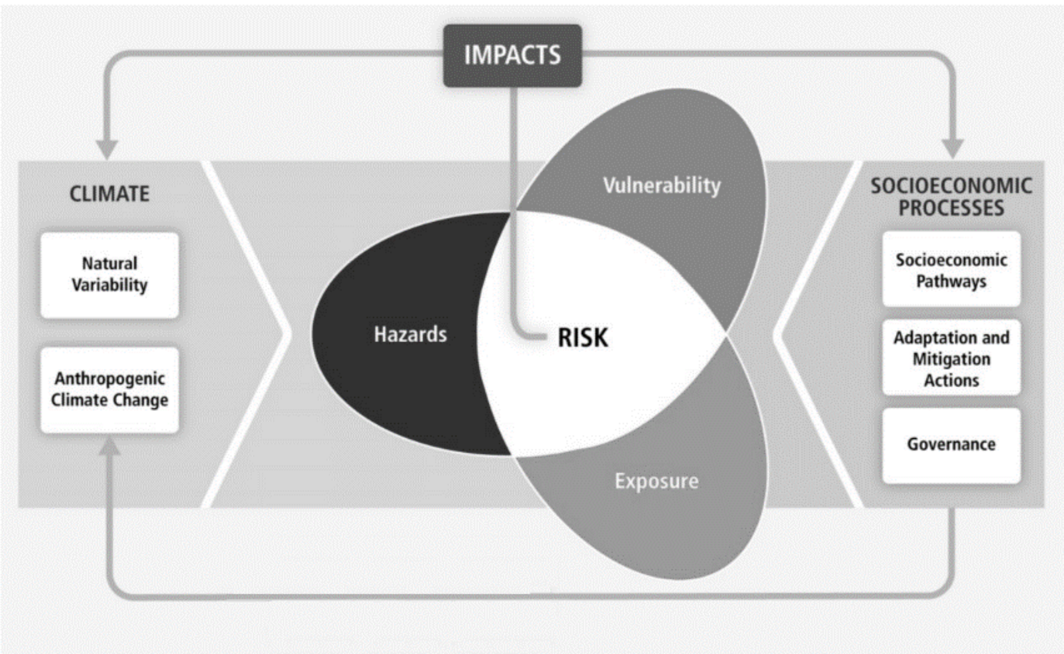

Figure 14. The IPCC conceptual framework for assessment of climate risk (modified from Connelly et al. 2018).

As reflected in the IPCC AR5 approach, there is a functional relationship between the elements of risk, which are broken down to reflect the hazard, exposure and vulnerability (IPCC 2014). Hazard relates to the probability that [hazardous] events/trends occur, whilst exposure and vulnerability combine as their consequences (‘the impacts, if these [hazardous] events/trends occur’). Hence, risk tries to capture both the language of probability/consequence in addition to the spatial relationships between hazard, exposure and vulnerability:

$$Risk = f(P(Hazard) + Exposure + Vulnerability)$$

In the present climate risk analysis:

- **Hazard** is the potential for and severity of climate change impacts on fish populations contributing to the catches of Swedish fisheries. Following Payne et al. (2021) we focus explicitly on negative impacts, following from the definition of risk as being an adverse consequence.
- **Exposure** focuses on which components of a system are exposed to significant climatic variations. Exposure of a fishery or region relates also to their degree of sensitivity to climate hazard, which is their likelihood of being affected by changes in the living marine resources.
- **Vulnerability** is the degree to which fishing fleets and regions are susceptible to, or unable to cope with, changes induced by climate variability and extremes, here quantified as climate hazard. Vulnerability is the weakness or gap in the ability of a fishery and regions to address, manage, and overcome adverse conditions. It is a measure of their adaptive capacity when exposed to climate change.

We implemented a CRA of the Swedish marine fisheries at the level of fishing fleets and at a sub-national regional level, using coastal administrative regions (”län") as regional units. The climate-related hazard was calculated for all the fish and shellfish species contributing to the Swedish catch, and results were integrated for the different fishing fleets or for coastal areas where they are landed. This allowed to derive fleet- and regional-level estimates of hazard. Evaluation of the climate-related risk was then completed with fleet- and regional-level metrics of exposure and vulnerability.

The analyses were based on information about the amount and origin of catches in the Swedish fisheries, retrieved from the official fishing logbooks and journals over the period 2016-2020. This comprised a total of 121 561 fishing trips performed by 1 125 vessels operating primarily throughout the Baltic Sea and the Greater North Sea ecoregion, with some catches occurring west of Scotland and the Norwegian

Sea. The fisheries operate a variety of active and passive gears harvesting a broad range of organisms in the benthos, demersal and pelagic communities, with an average biomass extraction of 193 500 tons per year in total for all fleets.

Value of the landings at a vessel, species, month and subdivision level were derived from the sale notes (providing sales prices) available from the Swedish Agency for Marine and Water Management (SwAM), and were linked to the fishing logbooks and journals for the large and small vessels respectively, to calculate the average value of each species in the catch at a trip level (on a monthly base for the journals). Of the 83 species reported in the logbook catches over this period, 39 species contributed to 99 % of the catch value at either a fleet or regional level. The rest of the CRA focuses on this subset of species including 30 marine, 6 freshwater and 3 diadromous species (Table A6.1).

Fleets ("fisheries" is also used as synonym throughout the text) were defined according to the classification in the Fishery Atlas (Bergenius et al. 2018), which is based on a combination of gear and area definitions (Table 6). A total of 13 fleets are defined and were used for the fleet-level CRA.

Table 6. Fleet definitions according to the Fishery Atlas (Bergenius et al., 2018)

Acronym	**Name in the Fishery Atlas**	**Definition**
BNPASSIV	*Fiske med passiva redskap i norra Östersjön*	Fishing by metiers with passive gears fishing in the northern Baltic Sea (SD30-31), excl. gears targeting salmon.
BSPASSIV	*Fiske med passiva redskap i Södra Östersjön*	Fishing by metiers with passive gears fishing in the southern Baltic Sea (SD22-29) excl. gears that require a special permit under the cod recovery plan (see CODPASSIV). These gears are included for vessels shorter than 8 meters.
CODPASSIV	*Fiske med passiva redskap efter torsk i södra Östersjön med redskap som kräver särskilt tillstånd*	Fishing by vessels longer than 8 meters fishing in the southern Baltic Sea (SD22-29, excl. SD23) with gears that require special permit under the cod recovery plan. Gears include bottom nets, gillnets with a mesh size of 110 mm or more and longlines targeting cod.
CODTRAWL	*Fiske med trål efter torsk i Östersjön*	All demersal trawlers fishing in the southern Baltic Sea (SD22-29, excl. SD23).
NEP	*Fiske med trål efter fisk och kräfta i Kattegatt och Skagerrak*	All bottom trawlers, with and without grid, fishing in the Kattegat and Skagerrak.
NEPPOT	*Fiske med bur efter kräfta i Kattegatt, Skagerrak och Nordsjön*	Fishing by traps for Norway lobster in the Kattegat, Skagerrak and North Sea.
NSTRAWL	*Fiske med trål efter fisk och kräfta i Nordsjön*	All bottom trawlers fishing for fish and crustaceans in the North Sea.
PAND	*Fiske med trål efter räka*	All demersal trawlers fishing for northern shrimp with and without grid.
PEL	*Pelagiskt fiske med aktiva Redskap + Fiske med trål och snörpvad med överförbara rättigheter (Pelagiska systemet)*	All metiers engaged in pelagic fishing with active gear.
SAL	*Fiske med passiva redskap efter lax*	Fishing by metiers with gears targeting salmon.
SOUND	*Fiske i Öresund*	All fishing activity in the Öresund (SD23).
VEN	*Fiske med trål efter siklöja*	All bottom trawlers with vendace as target species.
WCPASSIV	*Fiske med passiva redskap i Kattegatt och Skagerrak*	Fishing by metiers with passive gears fishing in the Kattegat, Skagerrak and the North Sea, excl. traps for Norway lobster.

Three fisheries, the pelagic (PEL), the Norway lobster (NEP) and the shrimp (PAND) fisheries, represent together 80 % of the Swedish landing value (Fig. 15). The PEL fleet alone exceeded 50 % of the overall value over the period 2016-2020, with herring and sprat contributing to 67 % and 19 % of this, respectively, followed by mackerel and sandeel. For the NEP fleet, 79 % of the value was contributed by Norway lobster followed by a 7 % of landing value from cod. The landing value of the PAND fleet was even more homogenous with respect to species, with the northern shrimp representing almost 93 % of the landing value.

The remaining 20 % of the total fishing value is distributed among the other ten fleets (Fig. 16) represented in order of landing value by the monospecific VEN (5 %) and NEPPOT (4 %) fleets, followed by the WCPASSIV, NSTRAWL and CODTRAWL which contribute to approx. 2–3 % of the total value. The landing value for the CODTRAWL fleet is entirely dependent on cod, but it should be noted that following the closure of the Baltic cod fisheries, since the second half of 2019 on the eastern Baltic stock and since 2022 on the western Baltic stock, this fleet is nowadays disappeared. In the NSTRAWL fleet the landing value is more spread among the gadoids The WCPASSIV fleet is the most diverse in terms of species contribution to the landing as it covers many different gears and species. An overview of the species contribution to the fleets' values is also given in Appendix A4.1.

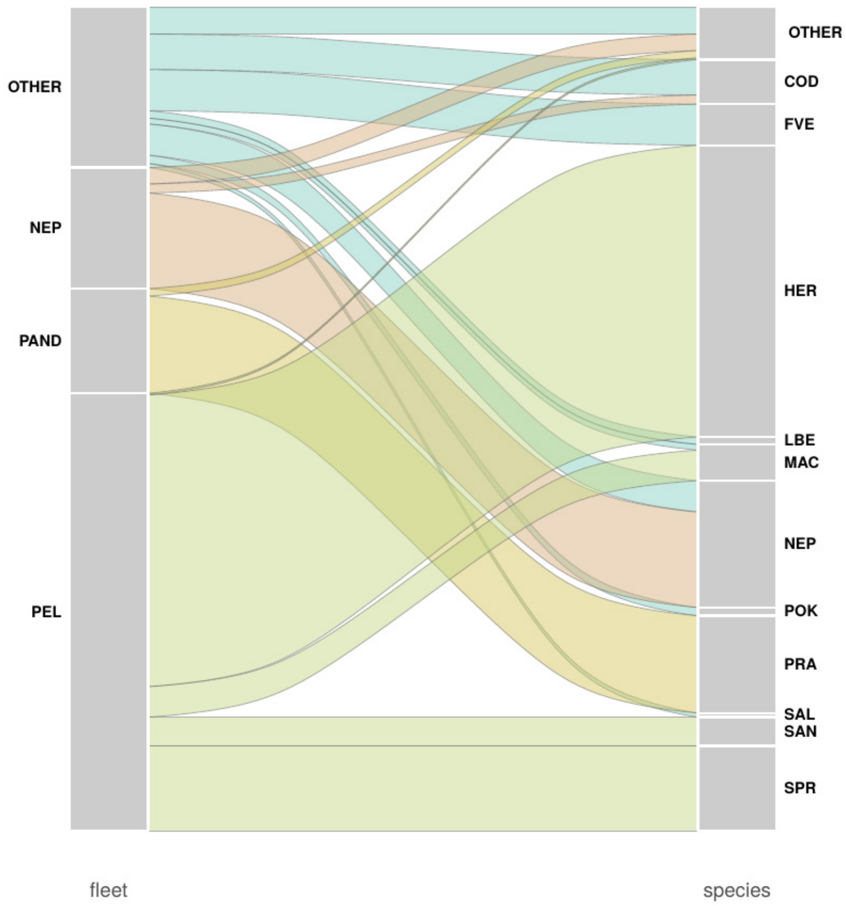

Figure 15. Species contribution to the landing value of the fleets PEL, NEP, PAND and all the OTHER fleets grouped. The width of the flux is proportional to the landing value on both fleets and species.

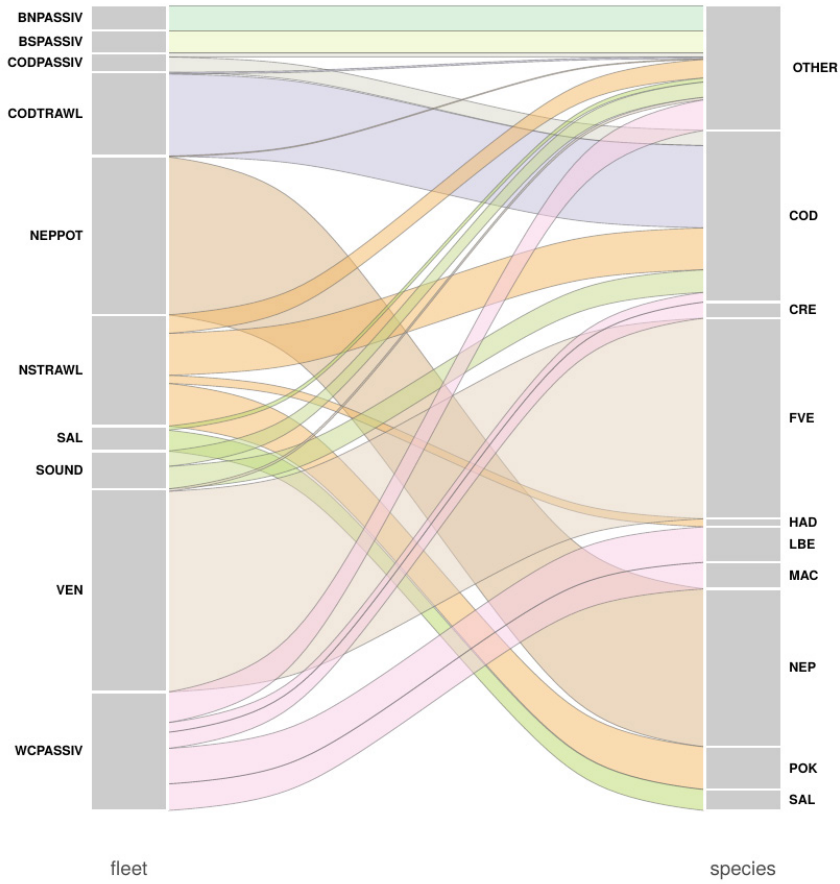

Figure 16. Species contribution to the landing value of different fleets (excl. PEL, NEP, PAND because of their larger values compared to the other fleets, see Fig. 15). The width of the flux is proportional to the landing value on both fleets and species.

Regional analyses were performed at the level of counties ("län", Fig. 17). Logbook- and journal-based landing data with associated value at the level of landing harbour were aggregated over counties (Nomenclature of Territorial Units for Statistics, NUTS3), based on the geographical coordinates of the harbour. Landings outside Sweden were aggregated into a single group. Socio-economic data at the level of individual vessels and coastal regions are available from SwAM and from Statistics Sweden (SCB) (last accessed: 7th September 2021), respectively, and were integrated at the appropriate scale for calculation of vulnerability metrics for the fleet- and regional-level CRA. Please see Appendix A5 for more details on data sources.

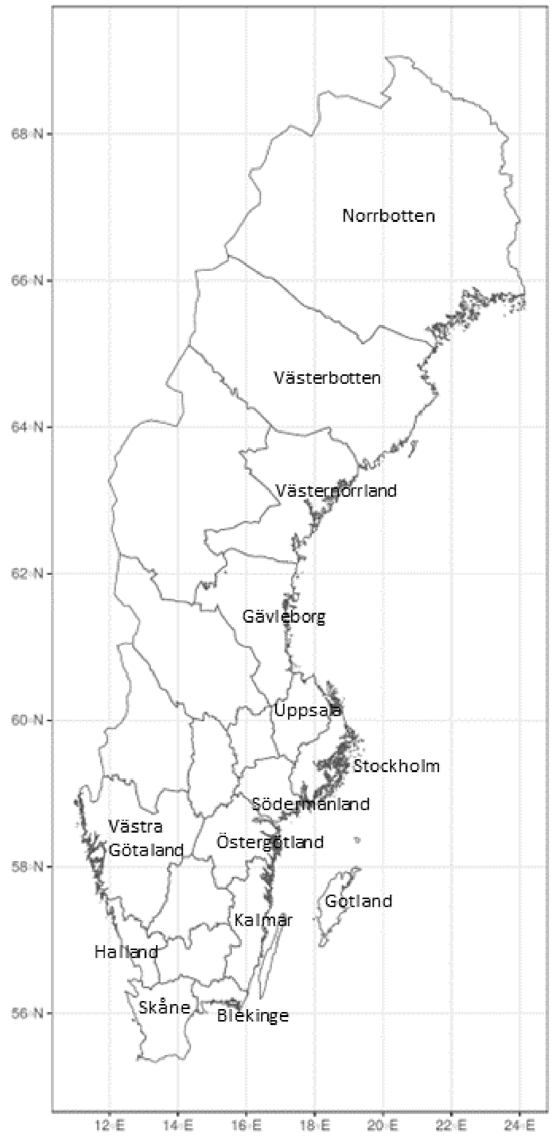

Figure 17. Map of Sweden, showing the 14 coastal administrative regions.

Based on the period 2016-2020, landings abroad and in the county of Västra Götaland have represented 37 % and 34 % of the total Swedish fishery landing value (Fig. 18). The value of the landings outside Sweden is contributed by herring 50 %, sprat 18 %, mackerel 10 % and sandeel 9 %. The major part of the value of the landings abroad is from landings in Denmark (89 %) followed by Norway (6–7 %) and UK (3 %; Fig. 19). The value of the landings in Denmark is dominated by herring followed by sprat and sandeel, while the value of the landings in Norway and UK are dominated by mackerel. Landing value in the Baltic countries is <0.5 % of the total Swedish fishery landing value, as a result of the crash of the cod fishery. Approximately 95 % of the value of northern shrimp and 73 % of the value of Norway lobster at a national level are landed in Västra Götalands county. They have a similar contribution to the landing value in this region (33 % each) followed by herring with 17 %. Figures 18 and 20 show that herring dominates the landings value in a number of regions, including Gävleborg (91 %), Gotland (82 %), Kalmar (68 %), Södermanland (62 %), Västernorrland (60 %) and Skåne (47 %). In Kalmar and Södermanland, sprat is the following species in terms of landed value, contributing with 29 % and 34 %, respectively, while in Skåne sprat contributes to 15 % of the value. Cod contributes a high share to the regional landing value in Blekinge and Stockholm where it represents 59 % and 39 %, respectively. The largest amount of salmon is landed in Norrbottens county, but in relative terms the contribution is hidden by vendace which represents >90 % of the landing value in that region. Norway lobster dominates the value of landings in the county of Halland with an 80 % share representing approximately 25 % of the national value for this species. An overview of the species contribution to the value landed by region is in Appendix A4.2.

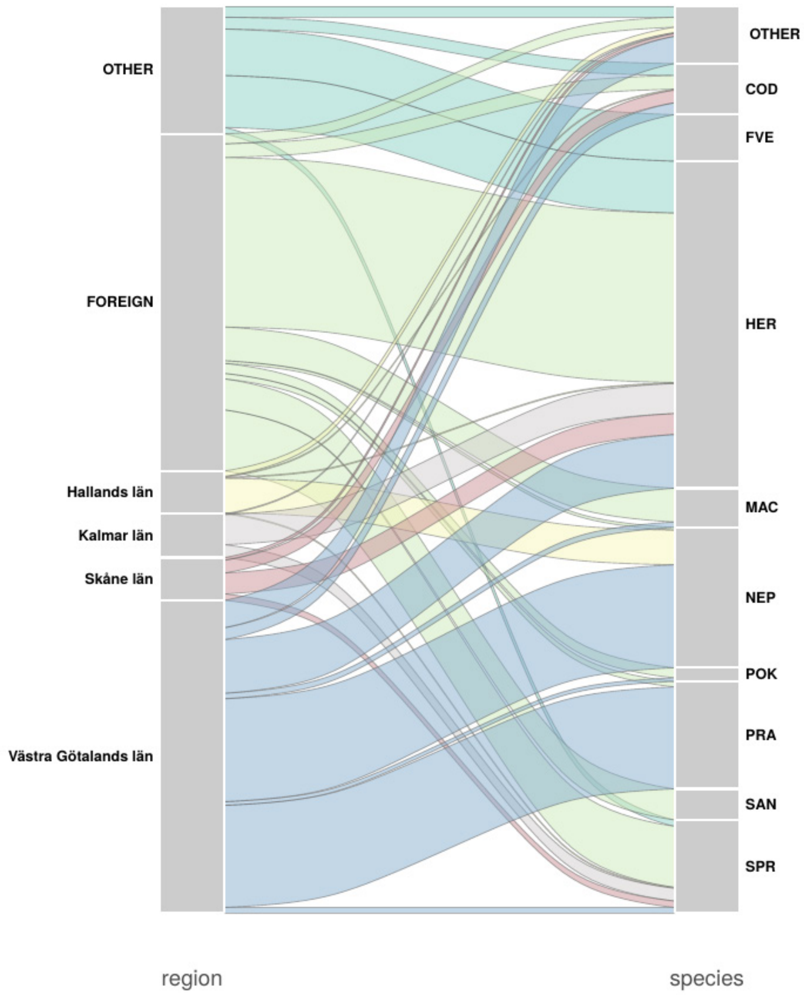

Figure 18. Species contributions to the landing value abroad (FOREIGN), in Västra Götalands, Skåne, Kalmar, Hallands, Gotland and all the OTHER regions grouped. The width of the flux is proportional to the landing value on both regions and species.

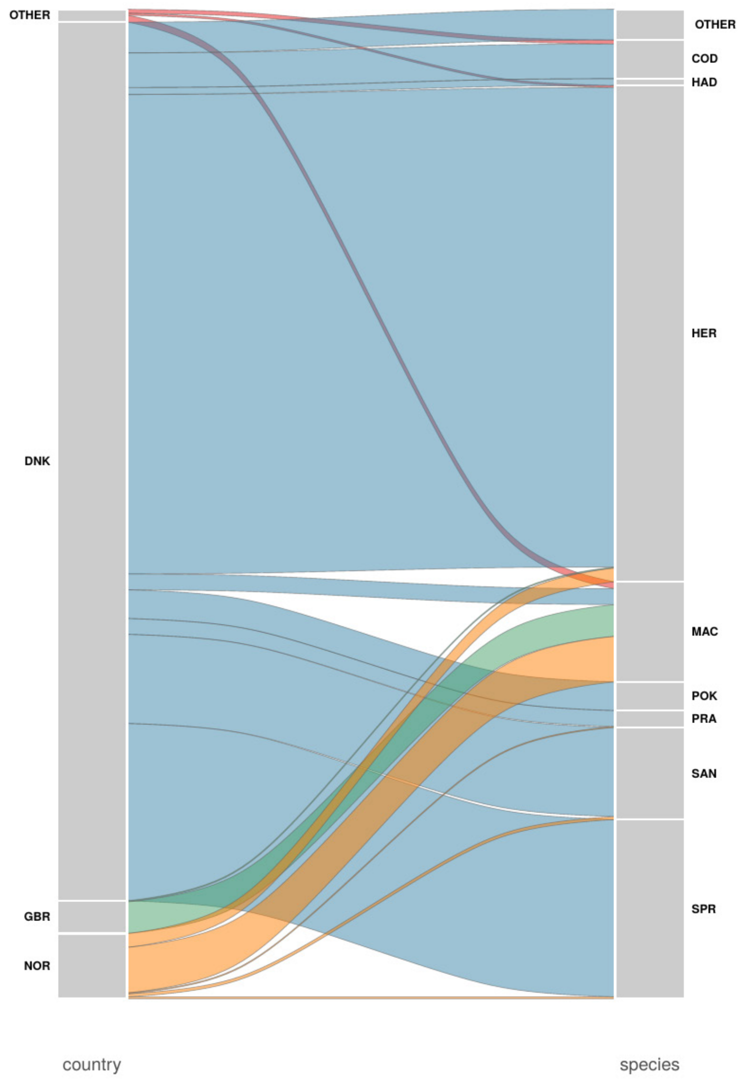

Figure 19. Species contributions to the landing value abroad by landing country. The width of the flux is proportional to the landing value on both landing country and species.

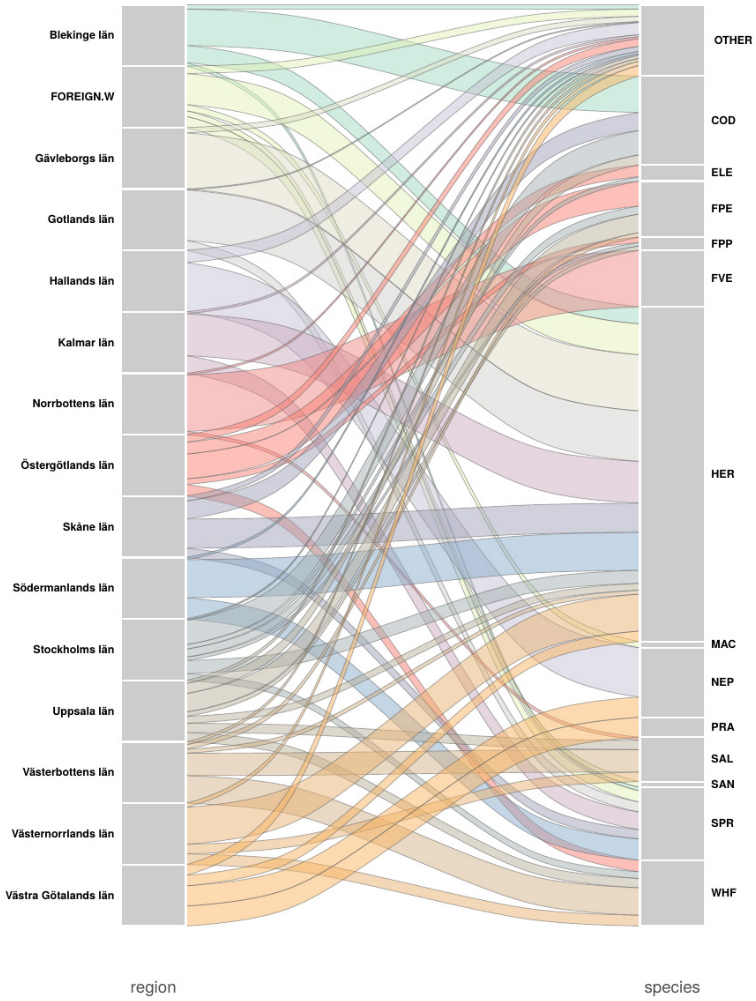

Figure 20. Species contributions to the landing value of different regions. The width of the flux is only proportional to the landing value within each region and not on the species.

7.1. Hazard metrics

Hazard is calculated as a combination of both species- and population-level processes following Payne et al. (2021). Our definition of the hazard is restricted to the negative impacts of climate change. While this comes with some limitations it simplifies the interpretation of the results.

Species-specific processes capture the species response to climate change based on life-history traits theory and information on habitat specificities. The basic idea is that correlation among different traits can be used to draw inference about complex aspects of the fitness and response of a species based on the observation of more simple traits. Numerous studies have integrated life history and ecological characteristics of marine fishes to estimate their intrinsic vulnerability to pressures such as fishing or environmental variability (Cheung et al. 2005; Jones and Cheung 2018). Lifespan is a commonly used metric as it generally correlates well with size and growth. Moreover, short lifespans are often associated with highly variable environments, which likely reflects better adaptation to highly variable conditions (Pecuchet et al. 2017). Lifespan data were retrieved from the website Fishbase and the website SeaLifeBase, and integrated with data from Payne et al. (2021).

Habitat-specificities refer to the species preference for certain habitats more sensitive to the impacts of climate change, or to species behaviour which may restrict its ability to cope with variability and disruption. For instance, shallow coastal habitats are expected to be more affected by climate change than mesopelagic and deep habitats (Farr et al. 2021), resulting in different hazard levels for the species they host. Moreover, mobile species can better cope with unfavourable conditions by moving into more suitable habitats compared to sedentary species, resulting in a higher hazard for the latter. Information on mobility, vertical and horizontal distribution of each species was available from Payne et al. (2021) based on definitions of traits from Engelhard et al. (2011). These three traits were combined into a habitat score as presented in Table A6.1.

Population-specific processes were accounted for by evaluating the population's ability to tolerate future warming of their environment. For this CRA, we extended the TSM concept described above (see Sect. 5.3) to better capture future risks. Warming will be heterogenous in space, in other words some areas will experience larger increase in temperature than others in the coming decades. For this reason, the future TSM is expected to be more informative than the current TSM about the potential hazard posed by a warming environment. Calculation of future TSM followed the approach described in section 5.3, but related the thermal limit of each species to predictions of the thermal environment that each population will experience in the near future. In this case, forecast sea surface temperatures from global climate projections were used (the HadGEM2 global climate model accessed on 19th January 2022 https://esgf-data.dkrz.de/search/cmip5-dkrz/). Future TSMs for each population were calculated as the median of the difference between the species-specific p90 (based on the present climate, 2016-2021) and the SST forecasted in each pixel of the population distribution for each year of the forecast period 2021-2059. In the Baltic Sea, other relevant hydrographic features such as salinity and oxygen levels are strong determinants of species habitat suitability and the only projection of the TSM was considered insufficient to evaluate the potential risk of climate change. Therefore, for the Baltic species reproducing in the Baltic Sea, the analysis of population-specific processes was extended to include also the expected change in the extent of the reproductive habitat as a consequence of climate change (see section 6). For marine species reproducing in the Baltic and included in the CRA (i.e., cod, herring, sprat and flounder) the change in the reproductive habitat was based on climate projections of temperature, salinity and oxygen, while only temperature was considered for species of freshwater origin (i.e., bream, perch, pike, pikeperch). For plaice, turbot and vendace, estimates of reproductive habitat were unavailable and only the TSM metric was included. For consistency with calculation of the future TSM, estimates of the reproductive habitat change used in the CRA were based on hydrographic projections from SMHI forced by the same global climate model (HadGEM2, see section 2.3). See Appendix A6.2 for a summary of the scores of the hazard-related metrics.

Ultimately, the population hazard score was calculated as a weighted average of the species- and population-specific metrics. For the species-level metrics, a 0.25 weight was assigned to the habitat-specificities and 0.25 to the lifespan, and for the population-level metrics a 0.25 weight was assigned to the future TSM and 0.25 to the reproductive habitat change (0.5 weight for the future TSM was applied instead for the species reproducing outside the Baltic Sea or for those Baltic species for which it was not possible to calculate the change in reproductive habitat). An equal weighting of 0.33 was applied for the freshwater species FBM, FPE, FPI, FPP because of missing TSM metric (see section 5.2). While the absolute values of these metrics for each population or species have no meaning, their relative values represent the reciprocal level of hazard for the different populations. For this reason, percentile ranks were calculated for each metric before averaging. Finally, the population hazard scores were integrated into a fleet hazard and a regional hazard based on the landing value of the different populations contributing to the landing of the fleets or to the landing in the regions.

7.2. Exposure metrics

Exposure metrics capture the degree of sensitivity to climate hazard, based on the assumption that fleets with a more diverse portfolio of species and regions with more diverse landings should be more resilient and less susceptible to species that are lost or decrease in abundance. Exposure was calculated as the average of two complementary metrics to characterize the diversity of landings of the fleets and regions: the Shannon diversity index and the Simpson's dominance index (May 1976). Both indices were computed based on the landing value by fleet or region, and their percentile rank was calculated before averaging. It is important to note that the diversity of fleets' portfolios is conditioned to the time period used for the analyses (2016-2020). The opportunities associated to the quota system (especially the ITQ system for the largest vessels) represent a source of uncertainty when using historical portfolios to predict future exposure to the risk.

7.3. Vulnerability metrics

Vulnerability metrics capture the resilience of the fleet or region to climate variability. In practice, it describes their ability to cope with the hazard via adaptation. The fleet vulnerability is based on the net profit margin. This is calculated by dividing the net profit by the total profit of the fleet. Such normalization allows direct comparison of the profitability of the different fleets regardless of the absolute size of their economy. It is assumed that a higher net profit margin allows a fleet to cope better with loss and instabilities due to climate change. At a regional level, vulnerability is calculated as a combination of two metrics, namely 1) the per capita gross domestic product (GDP) and 2) the ratio between the value added by the fishery in the region where the landing occurs and the GDP of the region which is considered as a proxy for the fishery contribution to the regional GDP. We assume that the per capita GDP of a region negatively correlates with its vulnerability, or, in other words, that a higher per capita GDP reflects in a better regional adaptative capacity. Moreover, we assume that vulnerability of a region, via the effects of climate change on the landing value, increases with the fishery contribution to the regional GDP. In practice, if the economy of a region is more dependent on fishing it can be assumed to be more vulnerable to the risks of climate change, although it is noted that fisheries contribute very little to the economy of the different Swedish regions which could result in an overestimation in the influence of this metric. Also in this case, the average of the percentile rank of the two metrics is computed as a vulnerability score before calculation of the risk.

7.4. Climate risk metrics

Overall climate risk is calculated for both the fleet and regional CRA as the mean of the hazard, exposure and vulnerability metrics above. Equal weight is assigned to each metric, and their percentile rank is computed before risk calculation.

7.5. Climate Risk Analysis (CRA)

7.5.1. CRA fleets

Our results show that fleets with passive gears tend to have generally broader species portfolios, with some exceptions, resulting in a lower exposure to the risk of climate change (Fig. 22). The lowest exposure is found for the WCPASSIV fleet because of its broadest species portfolio. Also, BNPASSIV and BSPASSIV rank with low exposure levels, as does the PEL fleet. On the contrary, exposure to the risk of climate change is highest in fleets characterized by nearly monospecific landing value portfolios such as the NEPPOT and VEN fleets followed by the CODTRAWL and PAND (i.e., one species contributing to >90 % of the fleet landing value).

Vulnerability is highest among all the fleets with passive gears except for the NEPPOT fishery which ranks as the fourth less vulnerable (Fig. 22). Vulnerability is lowest for the VEN fleet followed by the NSTRAWL, PAND and NEPPOT fleets. A general negative relationship is found between exposure and vulnerability of the fleets (Fig. 21).

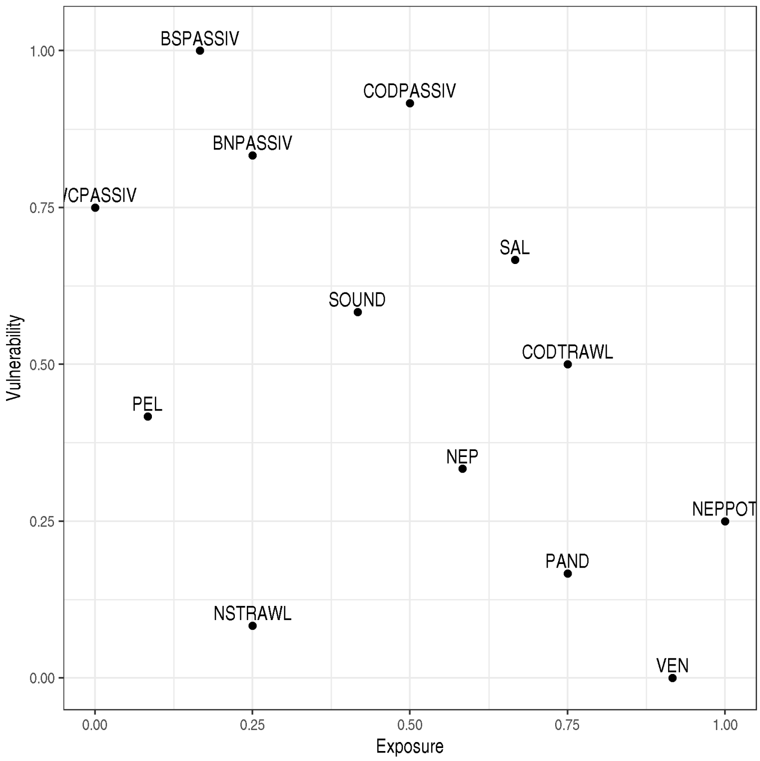

Figure 21. Fleet vulnerability-exposure plot.

Evaluation of the hazard in the forecast period, is presented as the average of the pentads 2025-2029, 2035-2039, 2045-2049 and 2055-2059. A general increase in the level of hazard is estimated for both warming scenarios for most of the fleets. As a consequence of the high interannual variability of the projected temperatures the most severe warming scenario (i.e. RCP8.5) does not always result in a higher hazard throughout the forecasts. However, in the long term the hazard is higher under the most severe warming scenario for all the fleets. Specifically, the VEN and PAND fleets show the highest hazard followed by the BNPASSIV and SAL fleets. The hazard for the passive gear fleets from both the west coast and southern

Baltic (WCPASSIV and BSPASSIV), and in the long-term period also for the PEL fleet, rank consistently among the lowest throughout the whole forecast period.

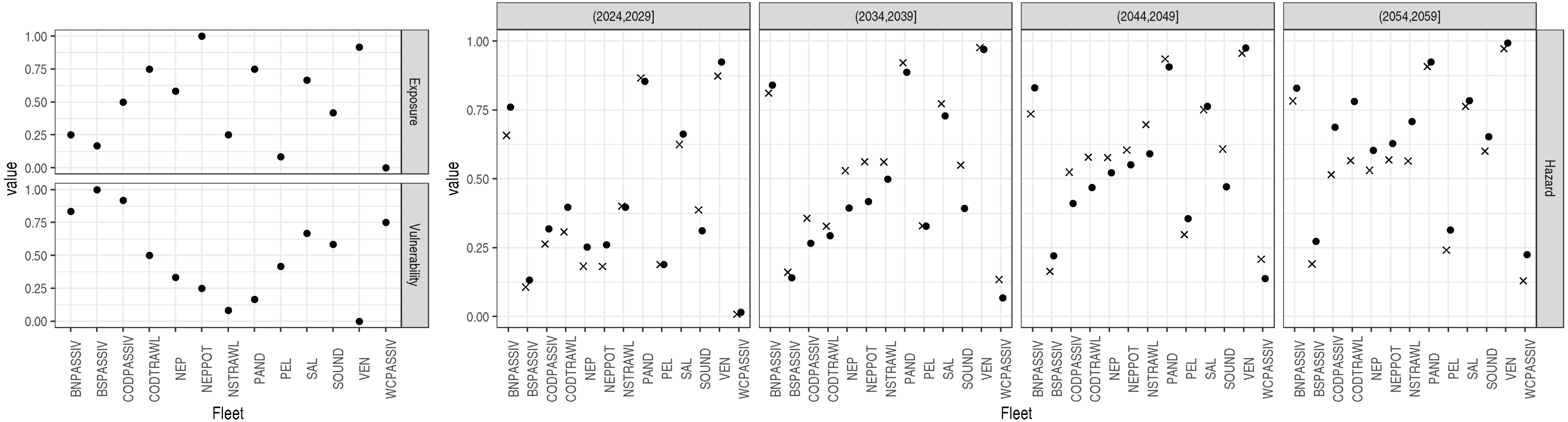

Figure 22. Percentile rank of the exposure, vulnerability and hazard metric for the main Swedish fleets. The hazard is calculated for different time horizons in the future (average 2025-2029, 2035-2039, 2045-2049, 2055-2059) and for the two warming scenarios (RCP 4.5 as crosses and RCP 8.5 as points).

The combination of hazard, exposure and vulnerability (Appendix A6.3) into a score of climate risk shows that the SAL fishery has consistently the highest risk compared to the other fleets during the whole forecast period and for both warming scenarios (Fig. 23). The VEN and BNPASSIV fisheries, which are the other two main fisheries from the northern Baltic, rank with also a predicted high risk. The level of risk for the CODTRAWL and CODPASSIV fisheries in the southern Baltic is in the long-term expected to have a more pronounced increase compared to other fisheries. In the west coast, the PAND fleet shows the highest risk independently of the intensity of warming. In the long-term, however, a similar level of risk is also reached by the NEPPOT fishery. The SOUND fishery in the Sound and the NEP fishery rank with a medium level risk. The NSTRAWL and WCPASSIV fleets rank among the fleets with lower risk. The PEL fleet shows the lowest risk among all especially on the medium- and long-term.

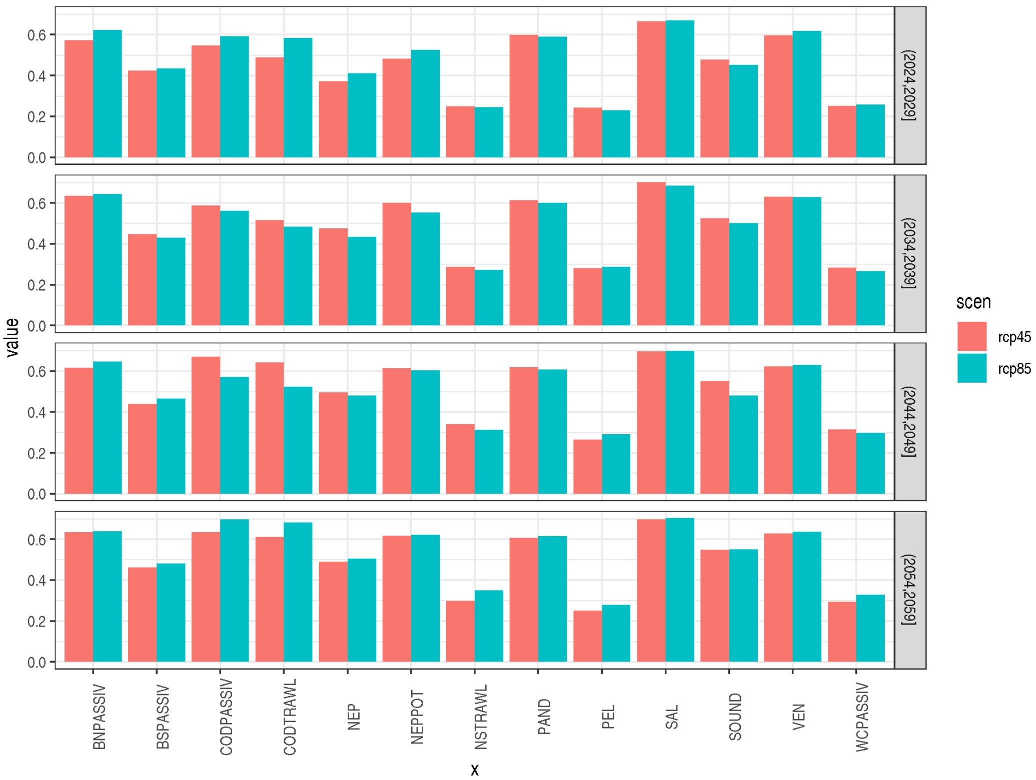

Figure 23. Climate risk for the main Swedish fleets calculated at different time horizons in the future (average 2025-2029, 2035-2039, 2045-2049, 2055-2059) and for the two warming scenarios.

7.5.2. CRA regions

Catches landed outside Sweden were not included in the risk analysis because it was not possible to derive comparable valid metrics for the exposure and vulnerability. Regional exposure does not show a clear geographical pattern, with the highest level in the Norrbotten region, followed by Gävleborg, Gotland, Kalmar and Halland (Fig. 25). Similarly, the regions with the lowest exposure are found on the west coast (Västra Götaland), in the south (Skåne) and in the central Baltic (Uppsala). The other regions rank at intermediate exposure level, with the regions of Södermanland and Västerbotten showing some larger exposure among those.

The economic orientation of the adopted vulnerability metrics results in the region of Stockholm ranking with the lowest vulnerability followed by Uppsala and Östergötland (Fig. 25). Despite the high per capita income, Västra Götaland ranks at an intermediate level of vulnerability, likely due to the higher contribution of fishery to the regional economy. Also, the northern Baltic regions of Norrbotten, Västerbotten and Västernorrland rank with medium vulnerability scores. The southern Baltic regions of Kalmar, Gotland and Blekinge rank with the highest vulnerability.

Norrbotten and Västerbotten show a consistently higher hazard compared to the other regions throughout the whole forecast period and regardless of the warming scenario applied (figs. 24-25). The regions of Uppsala, Östergötland and Västra Götaland follow in terms of hazard level. The Stockholm region ranks with a lower hazard compared to these regions but shows a pronounced increase on the long-term especially under the most severe warming scenario. The hazard is ranked among the lowest in the regions of Gävleborg, Gotland, Kalmar and Södermanland. Interannual variability in the hazard is generally high, but tendency for an increasing risk on the long-term is found in several regions including Blekinge, Skåne, Stockholm, Halland and Västra Götaland (for Blekinge and Stockholm especially under the most severe warming scenario). Also for the landings abroad (not included in the CRA but for which the hazard can still be calculated, Fig. 24) the hazard tends to increase in the long-term.

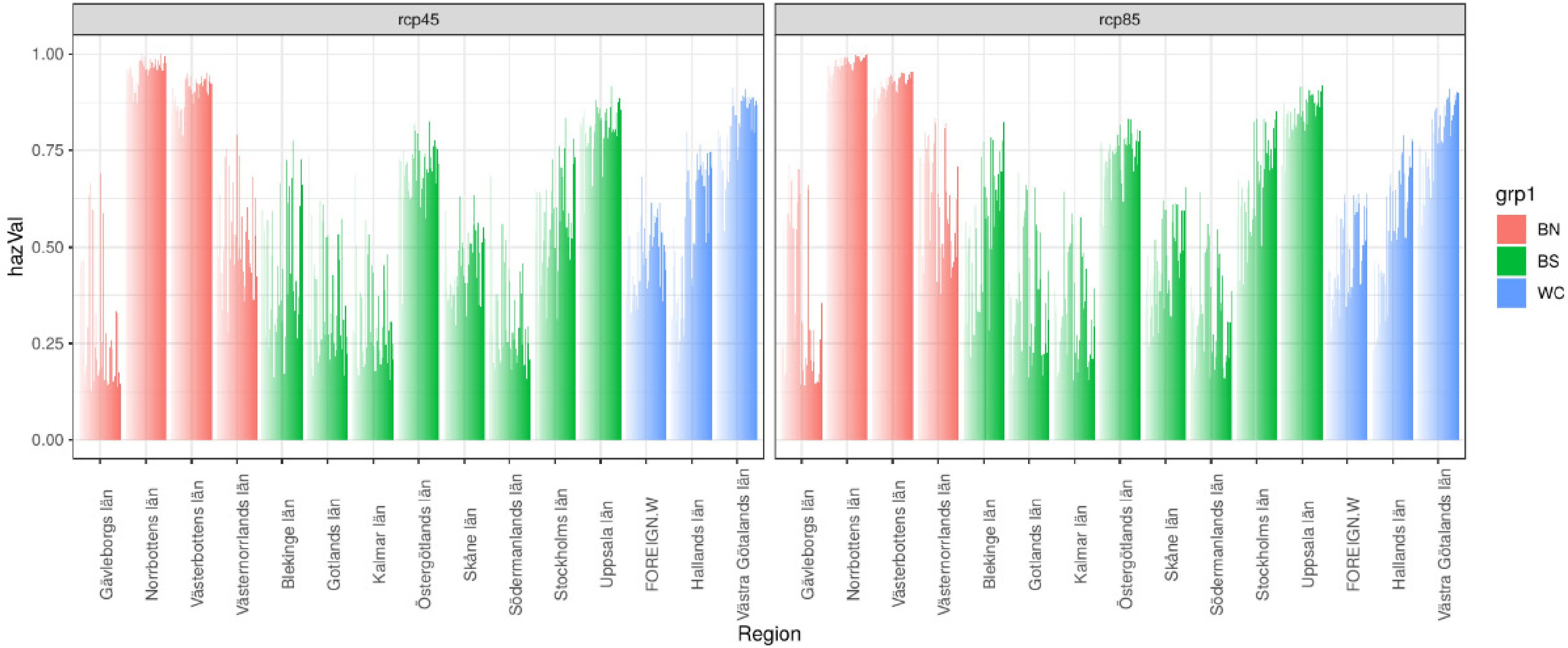

Figure 24. Percentile rank of the hazard metric by Swedish region (hazard for landings abroad is included as FOREIGN.W) and warming scenario (left RCP4.5 and right RCP8.5) calculated over the period 2021-2059, according to the approach described in the text ordered within each region and presented with different shades. The color scheme separates regions in the northern Baltic (BN), southern Baltic (BS) and west coast (WC).

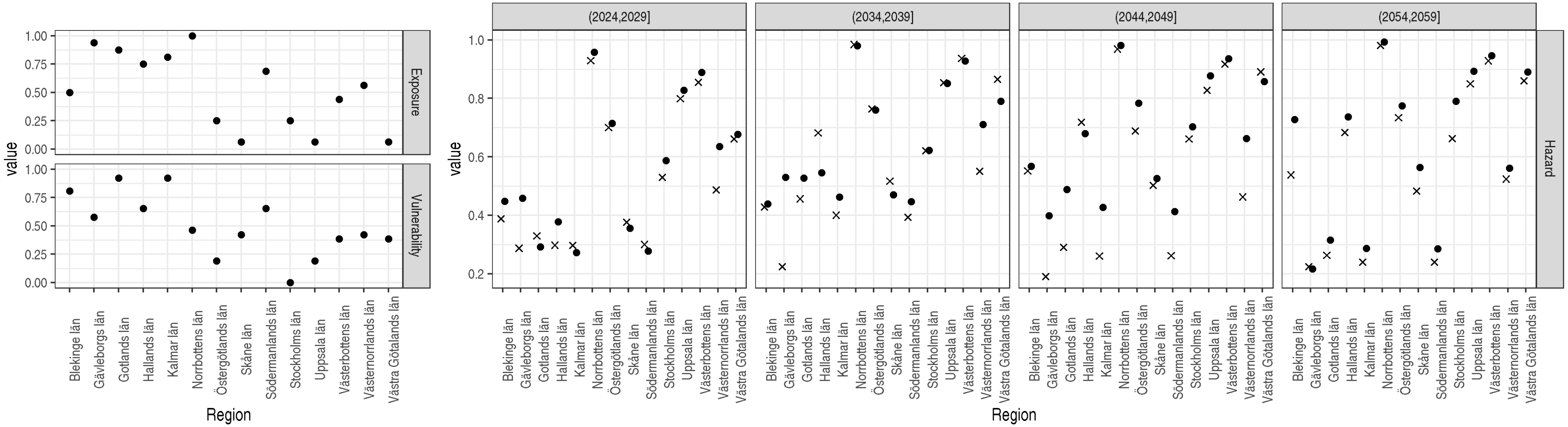

Figure 25. Percentile rank of the exposure, vulnerability and hazard metric by Swedish region. The hazard is calculated at different time horizons in the future (average 2025-2029, 2035-2039, 2045-2049, 2055-2059) and for the two warming scenarios (RCP 4.5 as crosses and RCP 8.5 as points).

The CRA (see Appendix A6.4) shows the highest risk for Norrbotten as direct consequence of a high exposure and hazard of this region to the effect of climate change on the fishery landings (Fig. 26). For the same reason, the risk level ranks high for Gävleborg, but mainly in the short-term and under the most severe warming scenario. High risk is also estimated for the island of Gotland consistently on the short-, medium- and long-term. The southern regions of Blekinge, Kalmar and Halland follow in the ranking, with a medium to high risk level mainly influenced by high vulnerability, and for Kalmar and Halland also exposure. A medium risk level is estimated for Västerbotten and Västernorrland where the relatively high hazard is compensated by medium levels of both vulnerability and exposure. For Västernorrland in the short- and medium-term the risk appears consistently higher under the most severe warming scenario. Västra Götaland, Östergötland and Uppsala rank similarly with a medium to low risk level as they are all three characterized by a low exposure, especially Västra Götaland, while for Östergötland and Uppsala it combines with a particularly low vulnerability. The regions of Stockholm and Skåne rank with the lowest risk markedly driven by an expected high adaptation capacity (low vulnerability due to top economic indicators) for Stockholm, and more of a blend of low exposure, medium vulnerability and medium to low hazard for the region of Skåne. For both these regions the long-term risk to climate change is increased under a most severe warming.

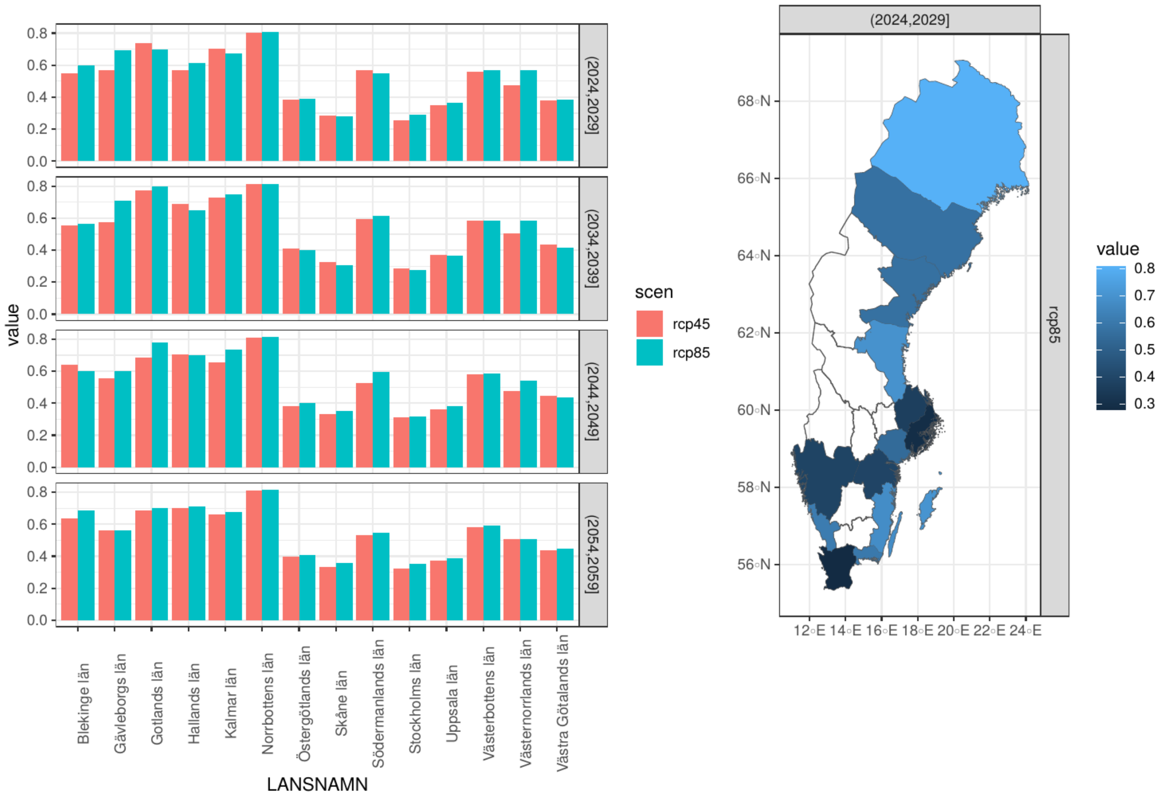

Figure 26. Climate risk for the different Swedish per regions. Left panel: barplots with climate risk at different future time horizons (average 2025-2029, 2035-2039, 2045-2049, 2055-2059) and for the two warming scenarios. Right panel: map of the mean regional climate risk estimated in 2025-2029 under the warming scenario RCP8.5.

7.6. Climate hazard for the recreational fisheries

The climate hazard for the Swedish recreational fisheries was analysed as well, using the same hazard metrics calculated for the CRA of commercial fisheries (see section 8.1), namely the species lifespan and habitat-specificities, the population level future TSM and, for the species spawning in the Baltic, the change in reproductive habitat. In this case, the future TSM was calculated over a ten-year period (2023-2032). The relative species composition is based on the 2013-2017 SCB statistics on recreational fisheries, which is available disaggregated for the following geographical areas: northern, central and southern Baltic, Öresund, Kattegat and Skagerrak (Fig. 27; Havs- och vattenmyndigheten 2019). The population hazard scores were integrated over the recreational fisheries taking place in different regions, and based on the relative contribution of the different populations to the recreational catch. Flatfish is reported in the SCB statistics as a single group and was disaggregated based on the species composition in the commercial logbooks of the gillnets and longlines (Table 7). Species catch composition was disaggregated at a population level where possible by approximation to the stock management areas defined by ICES. As part of the sensitivity analysis, an alternative species disaggregation scheme was evaluated based only on longlines commercial data. Results from the sensitivity analysis show that conclusions on the distribution of the hazard for the Swedish recreational fisheries across main geographical areas were not affected by the flatfish species disaggregation scheme (Appendix A7.1).

Table 7. Species contribution to the flatfish species in the recreational fishery based on commercial species composition of the gillnets and longlines (approximated to the most abundant species).

Area	Flatfish species	Proportion
North Baltic	-	-
Central Baltic	FLE	1.00
South Baltic	FLE	0.57
	PLE	0.19
	TUR	0.24
Öresund	FLE	0.43
	PLE	0.57
Kattegat	PLE	0.44
	SOL	0.37
	TUR	0.19
Skagerrak	PLE	1.00

The geographical area of the southern Baltic used for the recreational statistics is approximated by the ICES subdivisions 24–25. It overlaps with the distribution of two cod stocks (western and eastern Baltic cod stocks) and two herring stocks (western and central Baltic herring stocks), and a 50:50 contribution of each stock was assumed in this geographical area.

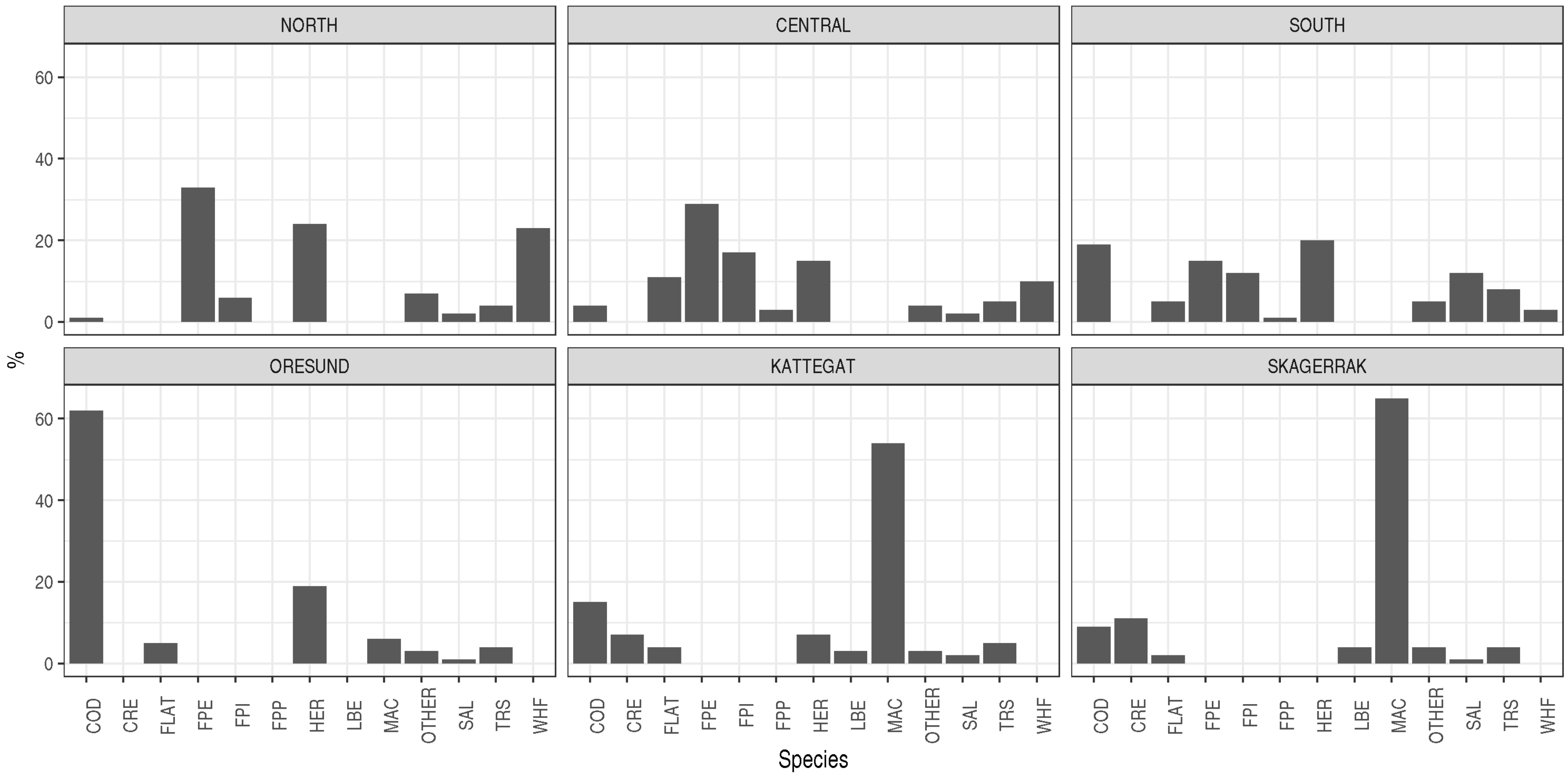

Figure 27. Species composition (in percentage) of the Swedish recreational fisheries across the main geographical areas (from SCB statistics in Havs- och vattenmyndigheten 2019). For species codes please see Table 3.

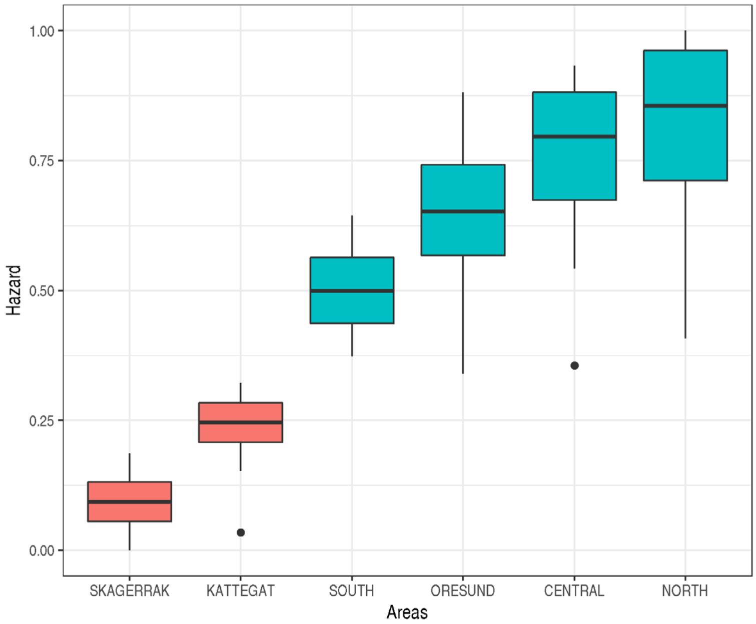

Figure 28. Percentile rank of the hazard metric for the Swedish recreational fisheries across main geographical areas. Colours separate the west waters (red) from the Öresund and Baltic Sea (blue).

Climate hazard for the Swedish recreational fisheries shows a marked North Sea-Baltic Sea geographical gradient (Fig. 28) with the exception of the Öresund where the hazard is estimated to be higher than for the southern Baltic. The lowest hazard was estimated for the Skagerrak followed by the Kattegat due to the large contribution of mackerel which has one of the highest TSM among the species considered. The hazard increases considerably from the Kattegat to the Öresund where mackerel is replaced by cod. In the southern Baltic Sea the hazard slightly decreases as result of a more diverse combination of marine and freshwater species contributing to the recreational catches. Moving into the central and northern Baltic the hazard increases further as we move at the boundary of the distribution of marine species like cod, herring and flatfish and also species sensitive to warming like white fish (WHF) are important in the recreational catches.

8. Limitations, knowledge gaps and ways forward

Evaluating sectorial risks to climate changes, with respect to temporal development and spatial distribution, is fundamental for the prioritarization and development of compensatory, adaptive and transformative strategies. The presented climate risk analysis (CRA) attempts to describe potential impacts and responses of complex ecological-social-economic systems, through use of a limited number of relatively simple metrics of synthesis. The relative simplicity of the CRA approach facilitates interpretation of patterns, while still being able to capture expected differences in the relative distribution of risks. However, the approaches presented in this report also come with important limitations which need to be considered in the interpretation of their results. The main identified limitations, as well as some knowledge gaps and proposed ways forward, are:

Future social-economic development and adaptive capacity
Projection and assessment of risk and vulnerabilities also depend strongly on scenarios of future social-economic development, besides the climate change scenarios and ecological responses considered here. The use of simple metrics for exposure and vulnerability, that were assumed to be static throughout the projections, are oversimplifications of the actual adaptive capacity of the fishing system. Changes in species distribution (see below) are likely to affect fisheries in a dynamic and interactive way, creating challenges and opportunities, and representing a driver of changes in the fisheries.

Knowledge gaps: Regional scenarios of future social-economic development. For instance, it is difficult to predict how the quota system will adapt to increasing mismatch between quota shares and regional stock abundances within management areas.

Ways forward: Consider scenarios of future social-economic development and associated socio-economic indicators/metrics. Develop more advanced and flexible metrics for exposure and vulnerability, for example in terms of adaptive capacity, such as behavioural responses of fisheries and regions/administrations, mobility of a fleet or the ability to use multiple gears.

Potential expansions of habitat and/or changes in spawning season or spawning area characteristics
Changing conditions were evaluated only in relation to risk for loss of suitable reproductive habitats, but not in relation to possible expansions, although new suitable habitats may in some cases become available under new climate conditions. Similarly, potential expansions or changes in the spawning season were not included at this stage. Also, the apparent sensitivities to warming were based on currently observed spawning depths and temperatures in species, which may not capture all the relevant constraints for spawning. Presumably, expansion of the reproductive habitat is currently mainly limiting the predictions in the later part of each spawning period.

Knowledge gaps: Species-specific suitability maps predicted specifically for habitat and spawning areas under potential future climate conditions. Such maps could be readily produced with respect to changes in the physical environment in a first step, although they are more challenging for aspects that depend on interactions with other biological components such as benthos and plankton, as relevant for example to consider changes in food availability, competition and predation. Also, data on potential maximum spawning temperatures is lacking for several fish species. A third knowledge gap concerns the intensity and frequency of extreme events such as heat waves, droughts, inflow of Atlantic waters and stagnation, which may affect both suitability of reproductive habitats and have effects on recruitment.

Ways forward: Rerun spatial predictive habitat models to support the analyses with scenario and/or data-informed option for expansion of habitats, spawning area as well as spawning season, and for larger suitable thermal windows. This requires also complementing empirical field observations with physiological studies on thermal tolerance. Include the effects of extreme events.

Bottlenecks in life cycles
Focus on the reproductive areas is driven by considerations on the relevance of these as essential fish habitats but also by the availability of information. While reproduction is one of the key processes governing the dynamics of fish stocks, other processes, especially those governing the survival of early life stages (i.e., eggs and larvae), are even more sensitive to a changing environment and represent major bottlenecks for the productivity.

Knowledge gaps: An understanding of the contribution of all the different life stages to the productivity and dynamics of most fish populations is still missing.

Information remains fragmented among the different species and for the different life stages. Knowledge on the sensitivity of early life stages is still limited, challenging our ability to characterise major bottlenecks within a quantitative framework.

Ways forward: specific quantitative studies across different life stages with the objective to integrate information into full close life cycle models.

Indirect effects on fish species
Effects of trophic interactions (i.e., food availability, predator-prey dynamics) were not considered but could play relevant roles under large spatial redistributions of species.

Knowledge gaps: Limited understanding of how foodwebs will respond to the effects of climate change.

Ways forward: Expand on multispecies and ecosystem modelling including the effects of a warming environment on the different species. This also requires an understanding of how trophic interactions (i.e., predator-prey overlap, competition) change in space and time as a consequence of climate change.

Regional value generated by fisheries catches
The CRA analysis at a regional level assumed that the value of the catch stays in the region where the landings occur. While it is arguably true that the landings generate some economic value at the landing harbour, it is likely that large part of the profits go to other regions in cases when the landing is directly moved outside the landing region for processing and when the owner of the vessel and the crew are not from the landings' region.

Knowledge gaps: At present it is not possible to separate economic value generated at the landing region from value transferred to the home regions of the vessel owner, the crew or the buyer. Lack of information on the added value from landings.

Ways forward: Develop economic analyses that map the seafood products value from the vessel to the region.

Lack of linkages with populations' status or exploitation level
Evaluation of the climate hazard was not linked to the populations' status or exploitation level by the fisheries. Healthy and sustainably exploited populations are more resistant and resilient to perturbations (including those induced by climate change) than populations in poor conditions and overexploited stocks.

Knowledge gaps: Lack of understanding of how exploitation status of stocks links to resistance and resilience to climate change.

Ways forward: Expand and/or integrate the present analyses to include information on stock status and develop approaches where the stock productivity is treated dynamically within the projections. Inclusion of environmental drivers in stock assessment and in multispecies models would allow to expand the use of those models into the evaluation of climate hazard on exploited fish populations.

Fleet definitions
For simplicity and consistency, the fleets were integrated in the analyses using previously existing fleet definitions. However, these were not developed to provide the optimal representation of risk of climate change across the diversity of the Swedish fisheries.

Knowledge gaps: none specific

Ways forward: Consider other fleet definitions, for example based on vessel size, to evaluate other aspects of the distribution of risk to climate change on the Swedish fisheries. Tune fleet definitions for the purposes of climate risk analysis with managers needs/questions.

Weighting of the risk components
A parsimonious approach (that is, equal weights) has been applied for the relative weighting of different components within the calculation of the hazard, vulnerability and exposure, as well as their contribution to the whole risk metric.

Knowledge gaps: An analysis of how different weighting schemes influence the results is lacking, although some preliminary sensitivity analyses have been run to build confidence on the outcomes presented in this study (results not presented).

Ways forward: Extend sensitivity analyses for a systematic evaluation of the impact of the weighting scheme on the outcomes.

Inclusion of uncertainty sources into the risk analysis
Several additional sources of uncertainty affect the outcomes presented. Their inclusion in the analyses remains difficult and is still limited. For instance, structural uncertainties from global climate models are included in the reproductive habitat change analyses, but not in the CRA. Several of the limitations listed here

are the result of gaps in knowledge and data but are not transferred to the outcomes in the form of uncertainties.

Knowledge gaps: Lack of quantification of the multiple sources of uncertainties, their interaction and propagation throughout the system.

Ways forward: Dedicated work on quantification of process, observation and model uncertainties

Resolution and precision for predictive hydrographic layers

The type of large-scale multispecies analyses presented here require hydrographic data across large spatial domains and at high resolution. Available hydrographic model outputs generally provide the required spatial coverage and resolution but with some limitations. For instance, we could not find forecasts of temperature at depth over the large distribution of some species (i.e., in some cases the entire Northeast Atlantic and beyond) forced by the same global climate models used by the RCO-SCOBI for the Baltic Sea hydrographic projections. This restricted our choice of suitable SST for the calculation of the thermal safety margin. Moreover, the high resolution hydrographic projections from RCO-SCOBI used in our analyses have been primarily validated to describe patterns at spatial scales larger than those required to capture dynamics for some of the more coastal habitats and species.

Knowledge gaps: The spatial resolution from regional hydrographic models was insufficient for adequate habitat modelling in coastal habitats.

Ways forward: accessibility of hydrographic products, already constantly in rapid expansion (e.g., Copernicus initiative); improvement of hydrographic models in coastal habitats.

9. Conclusions

- Climate models suggest a diversity of outcomes but agree on:
  - Overall warming in all the marine waters of Swedish interest throughout the Baltic Sea and the Greater North Sea ecoregion (incl. Kattegat and Skagerrak)
  - In the Baltic Sea warming will be more pronounced in the northernmost areas with implications also for the duration and extent of ice coverage
  - In the Baltic Sea warming will most likely be accompanied by freshening of the upper-water layers
  - In the Baltic Sea, oxygen conditions are more influenced by nutrients management than by climate change, but hypoxia and its effects will be more pronounced under the high warming scenarios
  - In the North Sea warming will be more pronounced in the southern part of North Sea

- Regional downscaled climate model projections are available and offer unprecedented opportunities to evaluate impacts on marine resources at basin and more local scales

- The cross-diagram method based on spawning temperature and depth may be a simple estimator that can provide a tentative classification on the sensitivity of a species to climate change

- Impacts and risks of climate change will be heterogeneous in space. The risk is evaluated as a combination of hazard (potential for and severity of climate change impacts), exposure (degree of sensitivity to climate hazard) and vulnerability (susceptibility and adaptive capacity to adverse conditions):
  - The hazard ranks highest in the northern Baltic and translates into the highest risk for the Norrbotten region, which also presents a high level of exposure due to the low number of species contributing to the landing value.
  - The regions of Gotland and Kalmar show low hazard but rank high in overall risk because of a combination of both high vulnerability and exposure
  - The regions of Stockholm, Uppsala and Östergötland show high hazard but overall rank lower in risk because of a combination of both low vulnerability and exposure

  - Low risk is also estimated for the Skåne region but as a result of a combination of low exposure, medium vulnerability and medium to low hazard
  - Landings abroad and in Västra Götaland have the largest contribution to the total landing value (37 % and 34 %, respectively), and in the long-term rank with a medium and high hazard, respectively. The risk is ranked medium for Västra Götaland because of the low exposure resulting from a highly diverse set of species landed

- Impacts and risks of climate change will be heterogeneous among different fleets:
  - The pelagic fishery (PEL) exceeds 50 % of the national landing value (over the period 2016-2020) and ranks lowest in risk among all fisheries as a result of having one of the most diverse species portfolio and one of the lowest long-term hazard
  - The salmon (SAL) fishery ranks consistently highest in the risk compared to the other fisheries
  - The vendace (VEN) and shrimp (PAND) fisheries both show a high net profit in comparison to other fisheries but rank high in risk due to their narrow species portfolios (almost monospecific) and relatively highest hazard
  - The CODTRAWL and CODPASSIV fisheries, which recently disappeared due to the collapse of the Baltic cod stocks, show in the long-term a substantially higher risk
  - The NSTRAWL and WCPASSIV fleets rank among the fleets with lower risk

- Risk is not equally driven by hazard, vulnerability and exposure for the different fleets and regions. This suggests that no single risk-reducing approach is considered sufficient and appropriate across all areas and fleets:
  - measures for intervention to buffer the risk of climate change are likely to be more effective if they are able to consider specificities at a fleet and regional level. For instance, the WCPASSIV and the NSTRAWL fleets rank at similar risk but for different reasons. The NSTRAWL fleet shows a higher hazard than the WCPASSIV fleet because of the larger contribution of gadoids to its landing value. The WCPASSIV is also less exposed to risk because of its highly diverse portfolio but it ranks particularly high in vulnerability as a result of its lower profit compared to the NSTRAWL which may result in a lower adaptive capacity. Another example is represented by the regions of Blekinge and Gotlands that in the long-term show comparable rank in the risk to climate change mainly driven by an increase of the hazard in Blekinge despite its more diverse landing value composition (proxy for a lower exposure).

- Risk will develop differently through time among fleets and regions. In the present analysis, temporal development of the risk is limited to changes in the hazard.

  - The CODTRAWL, CODPASSIVE, SOUND, NEP and NEPPOT fleets show larger increase of the hazard (and consequently risk) in the long-term compared to the other fisheries
  - The regions of Blekinge and Halland show a larger increase in the hazard (and consequently risk) in the long-term compared to the other regions.

- Consensus in the scientific literature is that management strategies will likely need to be more adaptive, flexible and environmentally explicit in the future, if fisheries resources are to be sustainably managed. However, climate related impacts as well as capacity for adaptation are context-dependent
  - Some climate-induced changes are irreversible and impossible to halt, which is why management should work towards building resistance and resilience at the level of resources (towards fisheries objectives), at the level of ecosystems (towards ecological objectives), and at the level of the fishing sector as a whole (towards economic objectives). For instance, when warming decreases the size/age of maturity of a population, a reduction in anthropogenic pressures (i.e., fishing) that also results in early maturation would contribute to building resilience and resistance and should be promoted. Also, if climate change reduces time windows for reproduction, management can counteract negative impacts by promoting population diversity, for example in cases when different ages and/or spawning components are documented to contribute differently within the spawning window of the stock.

- The relative level of risk in the short- and medium-term is highly variable between the two warming scenarios, but in the long-term the most severe warming scenario has a higher risk for most fleets and regions

- Analyses of climate change impacts on species distribution indicate that:
  - the expansion of temperate species (i.e., anchovy, sardine, hake) is expected to continue in the North Sea as a result of warming waters
  - The distribution of marine species in the Baltic Sea will be further limited by decreasing salinity and warming. Projections for cod, European flounder and likely also other species are strongly dependent on the progress of eutrophication abatement management, as this is connected to the oxygen conditions in spawning areas.
  - A shift in reproductive window can be expected in many coastally spawning species, the effects of which would need to be assessed further

- Life cycles of aquatic organisms are often complex, i.e. size of fish and numerous invertebrates change orders of magnitude with implications on how climate change can affect them throughout their life. The result is that climate change affects marine species through multiple pathways with different, at time even contrasting, effects on the different life stages

- The climate hazard for the Swedish recreational fisheries shows a marked geographical gradient. In relation to the current species composition of the recreational fishery, the relative hazard ranks lowest in the Skagerrak followed by the Kattegat (both characterised by high proportion of mackerel in the catch), to increase in the Sound and southern Baltic (where cod and herring are more frequent in the caches). Highest hazard is estimated for the recreational fisheries in the central and northern Baltic Sea.

- Seasonal changes in the reproductive habitats of the Baltic species are more pronounced than yearly trends. Major changes are related to a loss of reproductive habitats during the end of the spawning periods. However, the possibility of finding new, suitable spawning areas under the changed climate conditions was not considered.

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Appendices list

A1. Spawning limits and traits
Table A1. Information on functional characteristics, on the most sensitive life stage, typical spawning depth, temperature and salinity in Swedish waters (for species spawning in Swedish waters occurs), and the resulting sensitivity class concerning warming and freshening.

A2. Current Thermal Safety Margin
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A3. Changes of the reproductive habitats for the Baltic Sea species
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A5. Data sources CRA
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A6. Species traits and metrics of the climate risk analysis

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Table A6.2. Populations hazard. Percentile ranks of the species and population level metrics contributing to calculation of the population hazard. These are summarized as thermal safety margin scores, longevity scores, habitat scores and spawning habitat change scores. The TSM and the spawning habitat scores are reported as the range of scores calculated over the period 2021-2059 separately for the two warming scenarios RCP4.5 and RCP8.5.

Table A6.3. Swedish fleets climate change risk. Percentile rank of the hazard, exposure and vulnerability, and the climate risk calculated as the median of the percentile rank under the RCP 4.5 and 8.5 warming scenarios for the pentads of years 2025-2029, 2035-2039, 2045-2049, 2055-2059.

Table A6.4. Regional climate change risk. Percentile rank of the hazard, exposure and vulnerability, and the climate risk calculated as the median of the percentile rank under the RCP 4.5 and 8.5 warming scenarios for the pentads of years 2025-2029, 2035-2039, 2045-2049, 2055-2059.

A7. Sensitivity analysis recreational fishery

Table A7.1. Species contribution to the flatfish species in the recreational fishery based on commercial species composition of the longlines (approximated to the most abundant species).

Figure A7.1. Percentile rank of the hazard metric for the Swedish recreational fisheries across main geographical areas using the flatfish species disaggregation scheme based on the commercial longlines flatfish species composition. Colours separate the west waters (red) from the Öresund and Baltic Sea (blue).

Appendix A1

Table A1. *Information on functional characteristics, on the most sensitive life stage, typical spawning depth, temperature and salinity in Swedish waters (for species spawning in Swedish waters occurs), and the resulting sensitivity class concerning warming and freshening. M: Marine. F: Freshwater. NA: not available.*

Species code	Scientific name	English name and description	Origin	Feeding type	Most sensitive life stage	Egg	Larval stadium	Spawning depth (m)	Spawning temperature (°C)	Temperature-depth class	Minimal reproduction salinity	Warming sensitivity	Freshening sensitivity
ABZ	*Ammodytes tobianus*	Sandeel in the Central North Sea. Skagerrak. Kattegat	M	PL		B	P	0-10	3-11	shallower colder	NA	highest	NA
BFT	*Thunnus thynnus*	Bluefin tuna	M	Pi		P	P	NA	NA	NA	NA	NA	NA
BSS	*Dicentrarchus labrax*	European Bass	M	Pi		NA	NA	NA	NA	NA	NA	NA	NA
COD	*Gadus morhua*	Cod in the North Sea. Skagerrak	M	Pi	All/ different	P	P	20-80	4-8	deeper colder	NA	lower	NA
COD	*Gadus morhua*	Cod in the Kattegat	M	Pi	All/ different	P	P	20-80	4-8	deeper colder	NA	lower	NA
COD	*Gadus morhua*	Western cod stock in the Baltic Sea	M	Pi	All/ different	P	P	10-270	5-8	deeper colder	18	lower	higher
COD	*Gadus morhua*	Eastern cod stock in the Baltic Sea	M	Pi	All/ different	P	P	10-270	5-8	deeper colder	11	lower	higher
CRE	*Cancer pagurus*	Crab	M	NA	Larvae	On female	P	10-40	2-10	deeper colder	NA	lower	NA
DGS	*Squalus acanthias*	Spurdog	M	Pi	Accumulation at birth	In female	B	20-80	4-10	deeper colder	NA	lower	NA

Species code	Scientific name	English name and description	Origin	Feeding type	Most sensitive life stage	Egg	Larval stadium	Spawning depth (m)	Spawning temperature (°C)	Temperature-depth class	Minimal reproduction salinity	Warming sensitivity	Freshening sensitivity
ELE	*Anguilla anguilla*	European eel	M	IF	In hibernation under 5°C	P	P	NA	NA	NA	NA	NA	NA
FBM	*Abramis brama*	Common bream	F	I		B		0-1.5	>=13	shallower warmer	0	high	none
FLE	*Platichthys flesus*	European flounder	M	IF	Larvae	P	P	0-100	3-15	deeper warmer	10	lowest	Medel
FLE	*Platichthys solemdali*	Baltic flounder	M	IF	Larvae	B	P	0-100	3-15	deeper warmer	6	lowest	lower
FPE	*Perca fluviatilis*	Perch East Coast	F	Pi		B	P	0-5	7-16	shallower warmer	0	high	none
FPP	*Sander lucioperca*	Pikeperch East Coast	F	Pi		B		1-6	>=10	shallower warmer	0	high	none
FRO	*Rutilus rutilus*	Roach	F	O		B		0-1	>=11	shallower warmer	0	high	none
FVE	*Coregonus albula*	Vendace in the Baltic Sea. The Gulf of Bothnia	F	PL	Spawning/ Egg/Larvae	B	p	0-30	2-7	deeper colder	0	lower	none
GTA	*Gasterosteus aculeatus*	Three-spined stickleback	M	IF		B		0-6	>=8	shallower warmer		high	lower
HAK	*Merluccius merluccius*	Hake	M	Pi	Larvae	P	P	100-1000	6-7	deeper colder	NA	lower	NA
HAL	*Hippoglossus hippoglossus*	Atlantic halibut	M	Pi	Larvae	P	P	>183	5-7	deeper colder	NA	lower	NA

Species code	Scientific name	English name and description	Origin	Feeding type	Most sensitive life stage	Egg	Larval stadium	Spawning depth (m)	Spawning temperature (°C)	Temperature-depth class	Minimal reproduction salinity	Warming sensitivity	Freshening sensitivity
HER	*Clupea harengus*	Herring in the central Baltic Sea except the Gulf of Riga	M	PL		B	P	0-15	4-13	shallower warmer		high	lower
HER	*Clupea harengus*	Herring in the Gulf of Bothnia	M	PL		B	P	0-15	4-13	shallower warmer	2	high	lower
HER	*Clupea harengus*	Autumn-spawning herring in the North Sea. Kattegat. Skagerrak	M	PL		B	P	0-40	4-13	deeper warmer	NA	lowest	NA
HER	*Clupea harengus*	Spring-spawning herring in the Skagerrak. Kattegat. Southwestern Baltic Sea	M	PL		B	P	0-15	4-13	deeper warmer	NA	lowest	NA
LBE	*Homarus gammarus*	Lobster	M	NA	Larvae	On female	P	<40	10-19	deeper warmer	NA	lowest	NA
MAC	*Scomber scombrus*	Mackerel in the Northeast Atlantic	M	Pi		P	P	0-20	9-14	deeper warmer	NA	lowest	NA
NBU	*Neogobius melanostomus*	Round goby	M	IF		B	P	0.2-1.5	12-20	shallower warmer	8	high	Medel
NEP	*Nephrops norvegicus*	Norway lobster in the Skagerrak. Kattegat	M	NA	Larvae	On female	P	40-800	5-15	deeper warmer	NA	lowest	NA

Species code	Scientific name	English name and description	Origin	Feeding type	Most sensitive life stage	Egg	Larval stadium	Spawning depth (m)	Spawning temperature (°C)	Temperature-depth class	Minimal reproduction salinity	Warming sensitivity	Freshening sensitivity
NOP	*Trisopterus esmarkii*	Norway pout	M	IF		P	P	40-300	4-10	deeper colder	NA	lower	NA
PIK	*Esox lucius*	Pike East Coast	F	Pi		B		0-6	2-14	shallower warmer	0	high	none
PLE	*Pleuronectes platessa*	Plaice	M	IF	Larvae	P	P	20-90	6-10	deeper colder	12	lower	higher
PLN	*Coregonus lavaretus*	European whitefish	F	PL	Spawning/ Egg/Larvae	B	P	0-15	4-7	shallower colder	0	highest	none
POK	*Pollachius virens*	Saithe North Sea. Skagerrak. Kattegatt	M	Pi	Larvae	P	P	60-200	4-8	deeper colder	NA	lower	NA
PRA	*Pandalus borealis*	North Sea shrimp Skagerrak. Kattegat. Norwegian channel.	M	PL		On female	P	50-500	4-10	deeper colder	NA	lower	NA
QLH	*Ammodytes marinus*	Sandeel in the Central North Sea. Skagerrak. Kattegat.	M	PL		B	P	0-10	3-11	shallower colder	NA	highest	NA
RJB	*Dipturus batis*	Common skate	M	IF	Accumulation at birth	NA	B	0-200	3-19	deeper warmer	NA	lowest	NA
RJC	*Raja clavata*	Thornback ray	M	Pi	Egg development	B	B	7-20	>=5	deeper warmer	NA	lowest	NA
RJR	*Amblyraja radiata*	Starry ray	M	IF	Egg development	B	B	<30	1-14	deeper warmer	NA	lowest	NA
SAL	*Salmo salar*	Atlantic salmon	F	Pi	Spawning migration	B		0.3-3	4-6	shallower colder	0	highest	none

Species code	Scientific name	English name and description	Origin	Feeding type	Most sensitive life stage	Egg	Larval stadium	Spawning depth (m)	Spawning temperature (°C)	Temperature-depth class	Minimal reproduction salinity	Warming sensitivity	Freshening sensitivity
SPR	*Sprattus sprattus*	Sprat in the North Sea. Skagerrak.	M	PL		P	P	0-40	5-13	deeper warmer	NA	lowest	NA
SPR	*Sprattus sprattus*	Sprat in the Baltic Sea	M	PL		P	P	0-40	5-13	deeper warmer	6	lowest	lower

Appendix A2

Table A2. *Current Thermal Safety Margin (TSM). Median and 95% CI of the current TSM calculated over the period 2016-2020.*

Species	Stock	Low	Median	High
BLL	bll.27.22-32	8.56	9.11	10.86
BLL	bll.27.3a47de	8.23	8.71	9.51
CAA	caa	6.13	6.29	6.81
COD	cod.27.21	0.45	1.2	1.96
COD	cod.27.22-24	0.48	1.03	2.41
COD	cod.27.24-32	0.84	1.4	3.15
COD	cod.27.47d20	0.8	1.26	1.78
CRE	cre	6.76	7.04	7.35
FLE	fle.27.2223	8.61	9.3	10.62
FLE	fle.27.3.d.Bal	9.8	10.52	12.41
FLE	fle.27.3.d.Eur	8.94	9.46	11.3
FLE	fle.27.3a4	8.85	9.34	9.95
FVE	fve.27.30-31	-0.05	1.35	3.33
HAD	had.27.46a20	1.37	1.8	2.29
HAL	hal	6.83	6.99	7.5
HER	her.27.1-24a514a	7.54	7.98	8.26
HER	her.27.20-24	0.54	1.14	2.25
HER	her.27.25-2932	1.23	1.89	3.53
HER	her.27.3031	3.09	4.48	6.37
HER	her.27.3a47d	0.84	1.29	1.85
HKE	hke.27.3a46-8abd	9.16	9.6	9.88
HOM	hom.27.3a4bc7d	10.63	11.13	12
LBE	lbe	7.24	7.55	7.67
LEM	lem.27.3a47d	2.25	2.75	3.33
LIN	lin.27.346-91214	5.19	5.57	5.67
LUM	lum	7.08	7.26	7.78
MAC	mac.27.nea	9.89	10.22	10.55
MON	mon	8.51	8.93	9.33
NEP	nep.fu.3-4	8.27	9.01	9.81

Species	Stock	Low	Median	High
OYF	oyf	3.77	4.26	4.65
PLE	ple.27.21-23	7.5	8.15	9.36
PLE	ple.27.24-32	7.91	8.43	10.23
PLE	ple.27.420	8.07	8.47	8.91
POK	pok.27.3a46	1.91	2.36	2.79
POL	pol.27.3a4	3.34	3.76	4.2
PRA	pra.27.3a4a	0.08	0.41	0.6
PRA	pra.27.4a	0.18	0.46	0.6
SAL	sal.27.20-21	3.46	4.21	4.97
SAL	sal.27.22-31	4.29	5.03	6.61
SAN	san.sa.1r	0.6	1.09	2.02
SAN	san.sa.2r	0.6	1.09	2.02
SAN	san.sa.3r	1.29	1.74	2.24
SAN	san.sa.4	1.41	1.84	2.22
SOL	sol.27.20-24	9.63	10.23	11.34
SPR	spr.27.22-32	10.08	10.78	12.6
SPR	spr.27.3a4	9.28	9.73	10.29
TBR	tbr	5.8	6.09	6.59
TRS	trs.27.20-21	5.35	6.08	6.88
TRS	trs.27.22-32	6.73	7.42	9.24
TUR	tur.27.22-32	8.76	9.41	11.07
TUR	tur.27.3a	8.28	8.98	9.78
TUR	tur.27.4	8.29	8.67	9.48
USB	usb	5.32	5.79	6.48
WEG	weg	6.69	6.94	7.24
WHE	whe	8.93	9.48	9.84
WHF	whf	0.65	1.4	3.22
WHG	whg.27.3a	7.24	7.98	8.75
WIT	wit.27.3a47d	2.71	3.16	3.72
YFM	yfm	7.14	7.45	7.59

Appendix A3

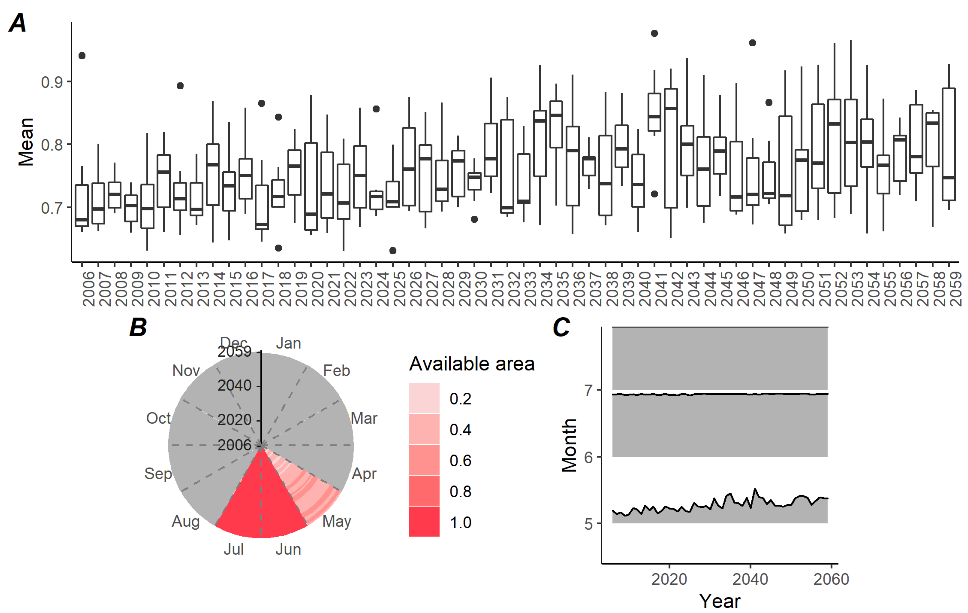

Figure A3.2. Minnow in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

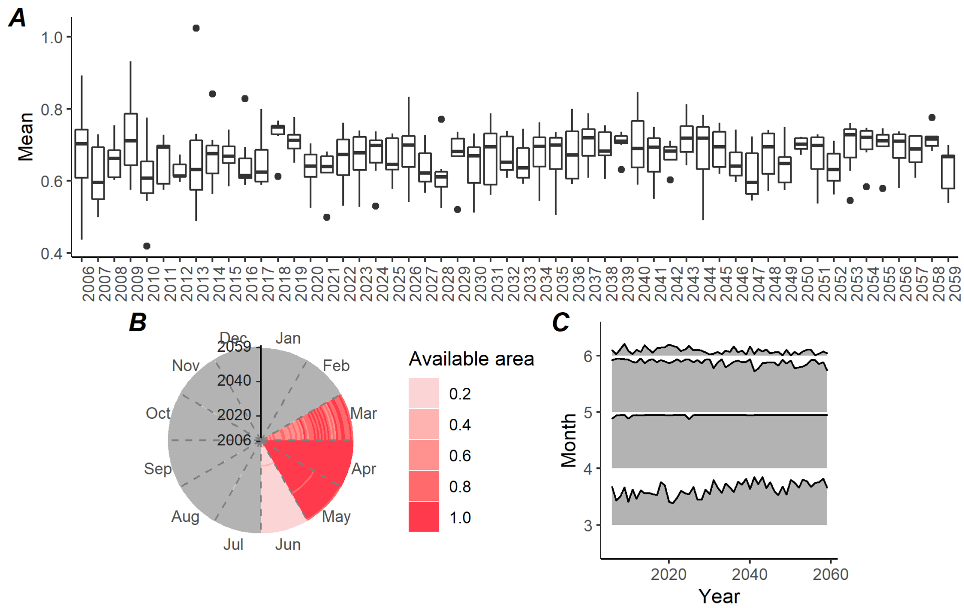

Figure A3.3. Pike in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

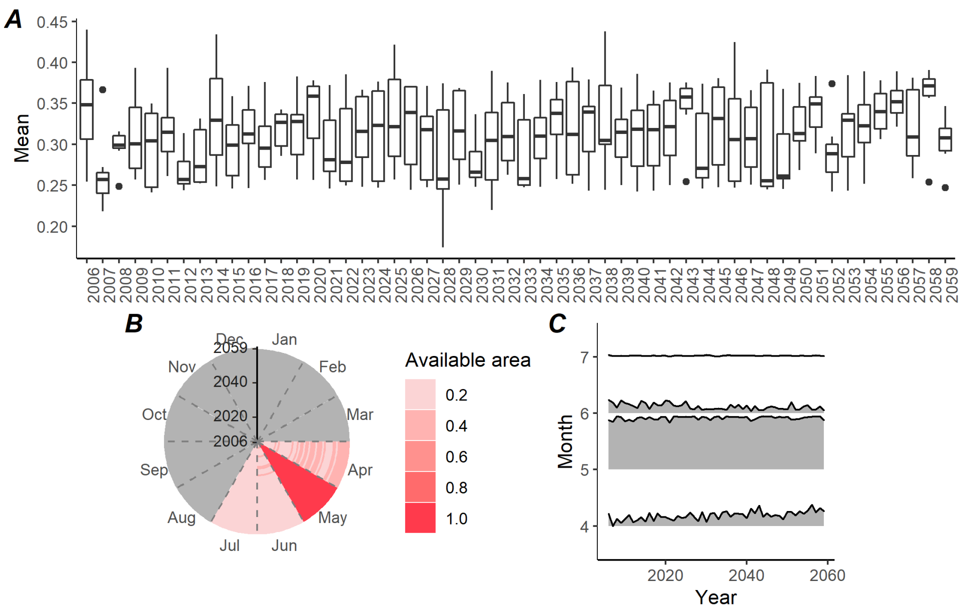

Figure A3.4. Ruffe in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

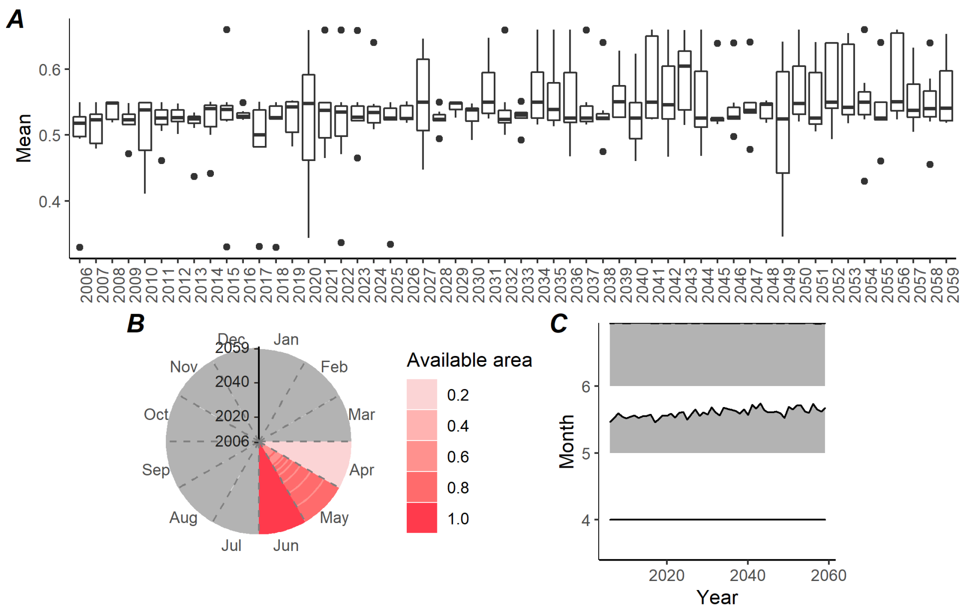

Figure A3.5. Pikeperch in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

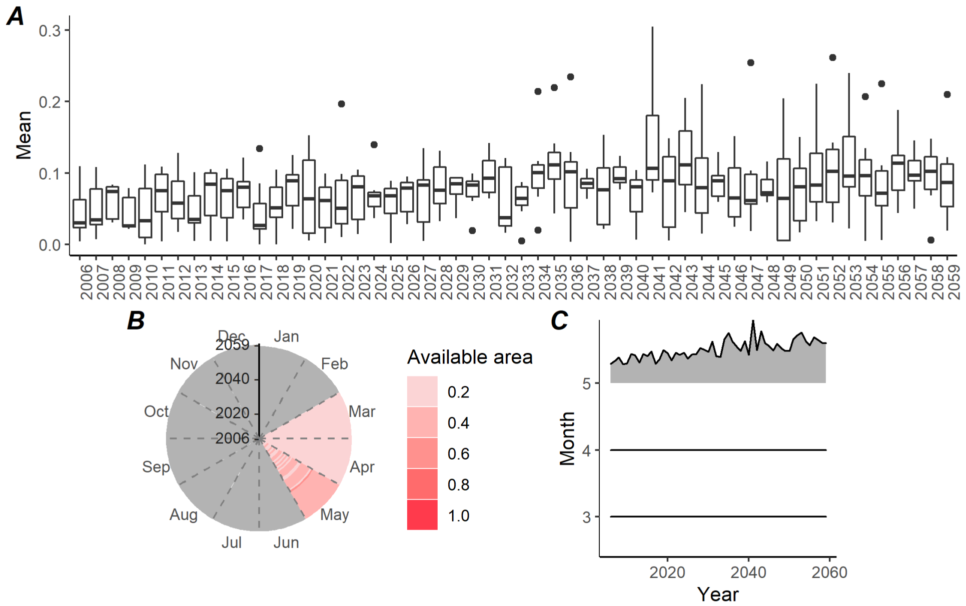

Figure A3.6. Ide in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

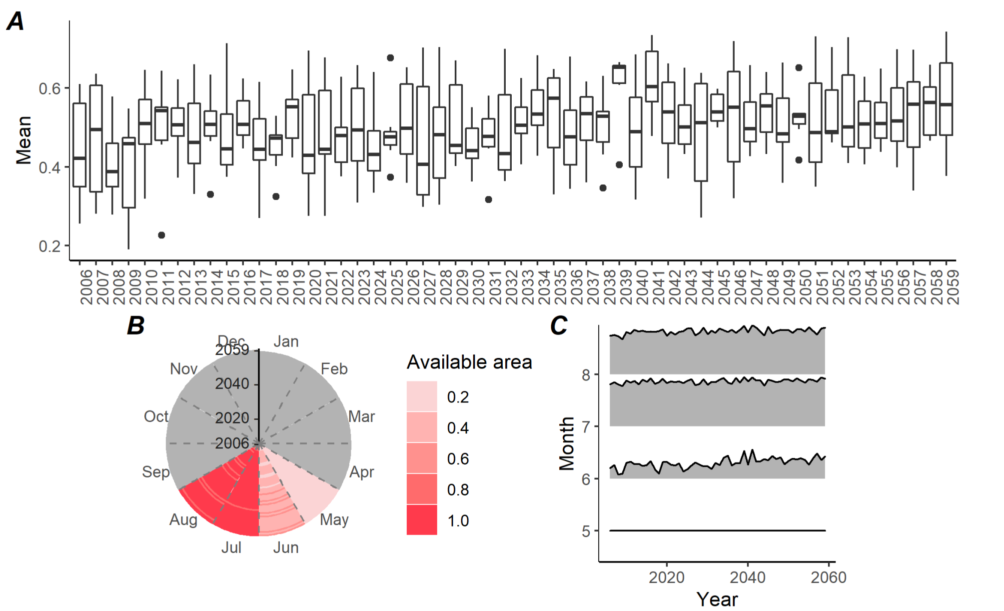

Figure A3.7. Bleak in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat considering the species spawning preferences of temperature. The boxes show all combinat between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) available area of nursery habitat for every month and year in polar coordinates. The first modeled is in the center and increases to the last modeled year at the edge. The months where the species not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, only the RCP45 were used. C) The available area of spawning habitat for every month and year. result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

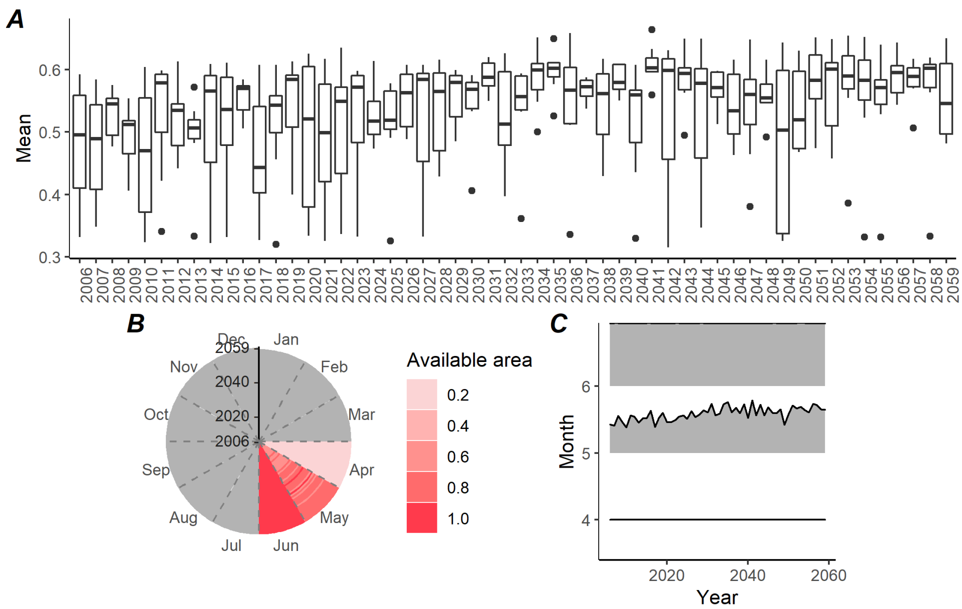

Figure A3.8. Roach in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

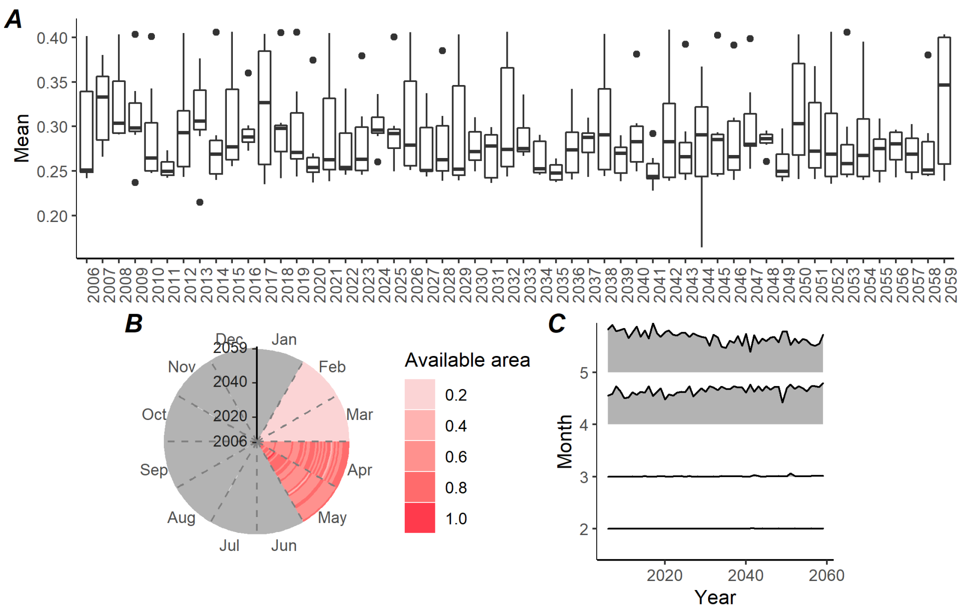

Figure A3.9. Smelt in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

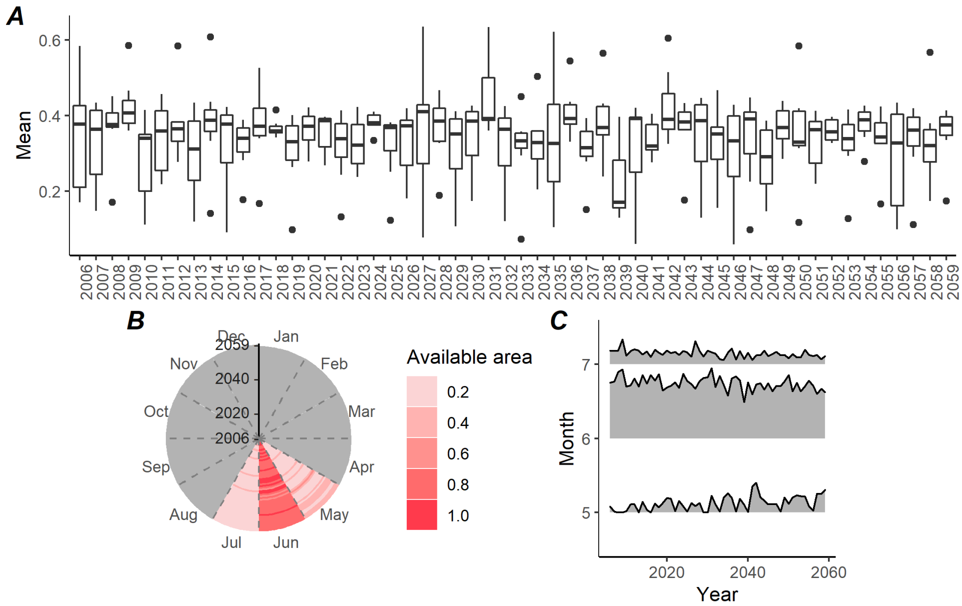

Figure A3.10. Crucian carp in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

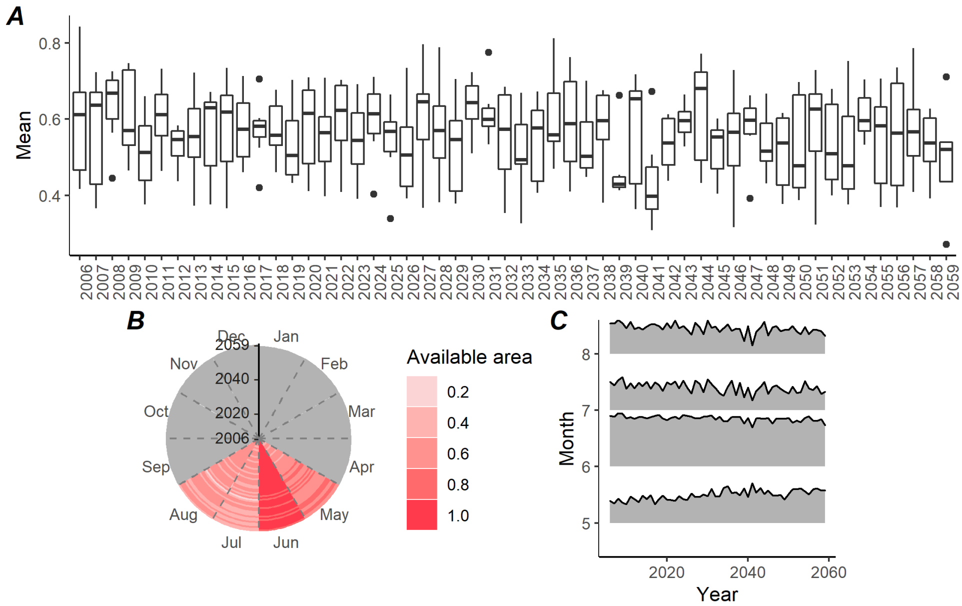

Figure A3.11. Sand goby/Common goby in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

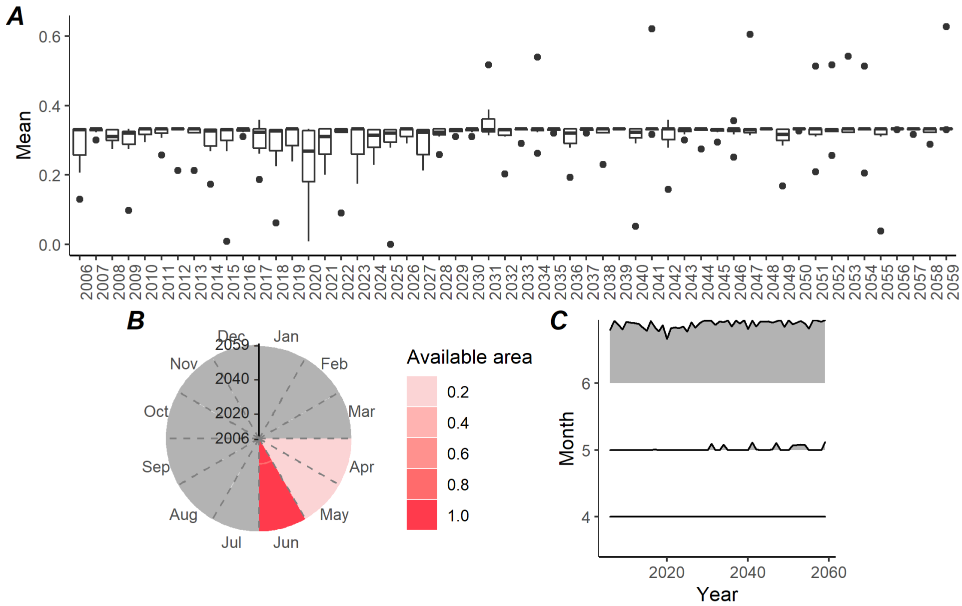

Figure A3.12. Rudd in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

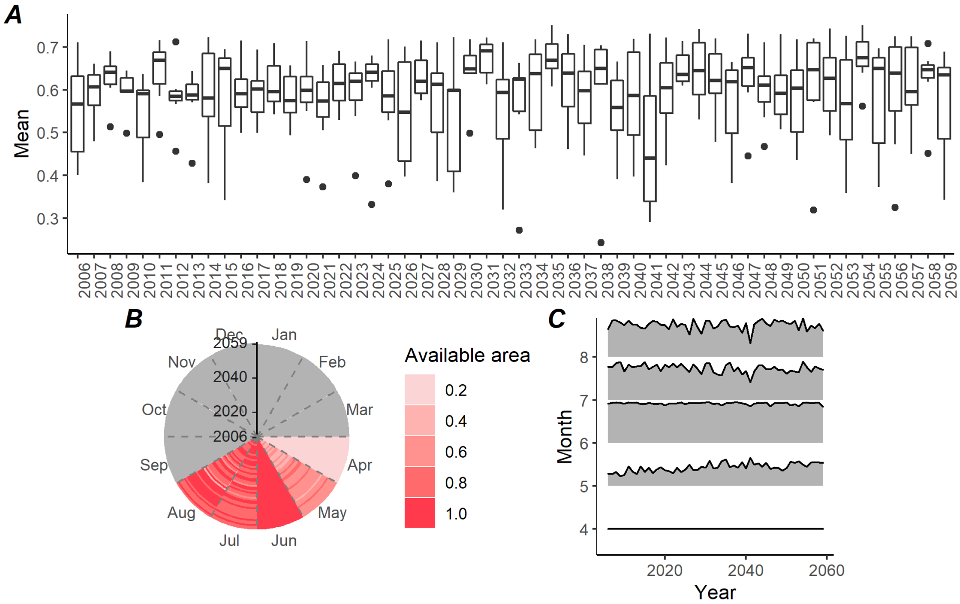

Figure A3.13. Two-spotted goby in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

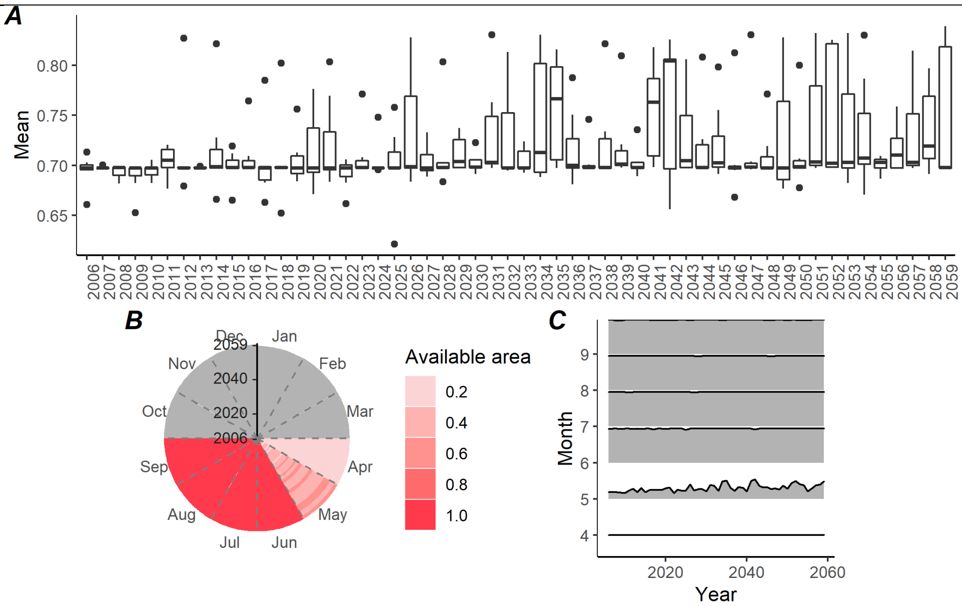

Figure A3.14. Nine-spine stickleback in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

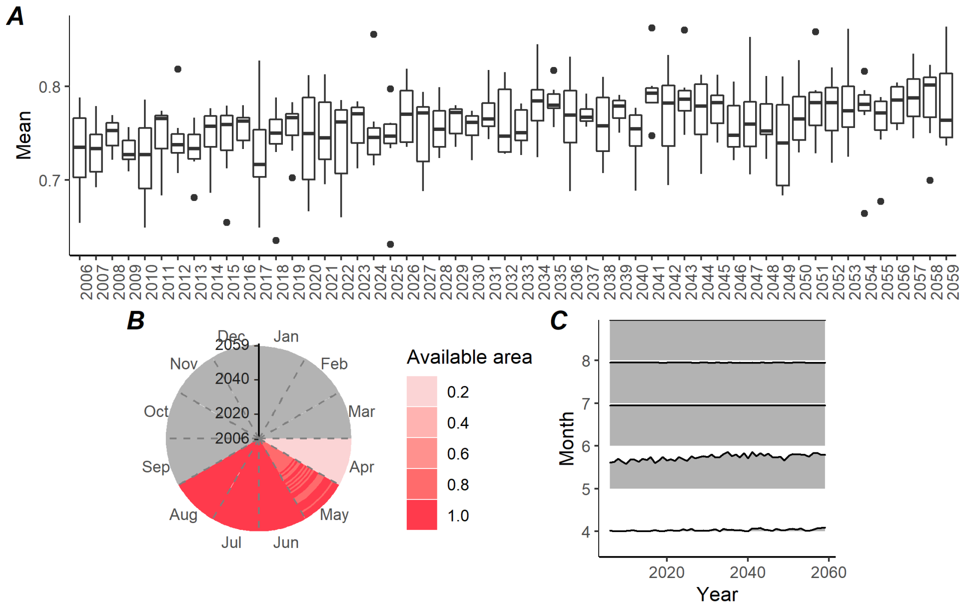

Figure A3.15. Three-spine stickleback in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

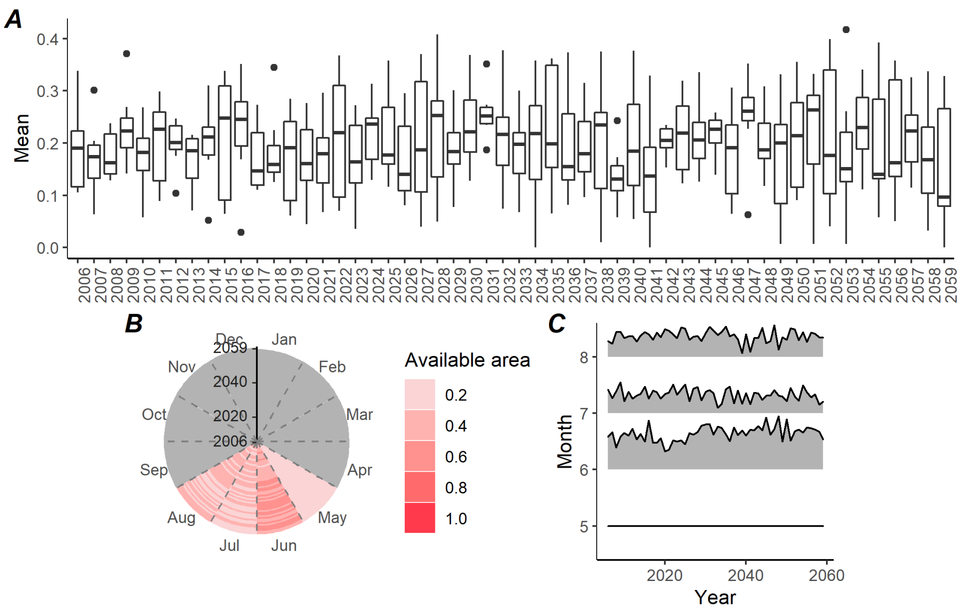

Figure A3.16. Tench in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

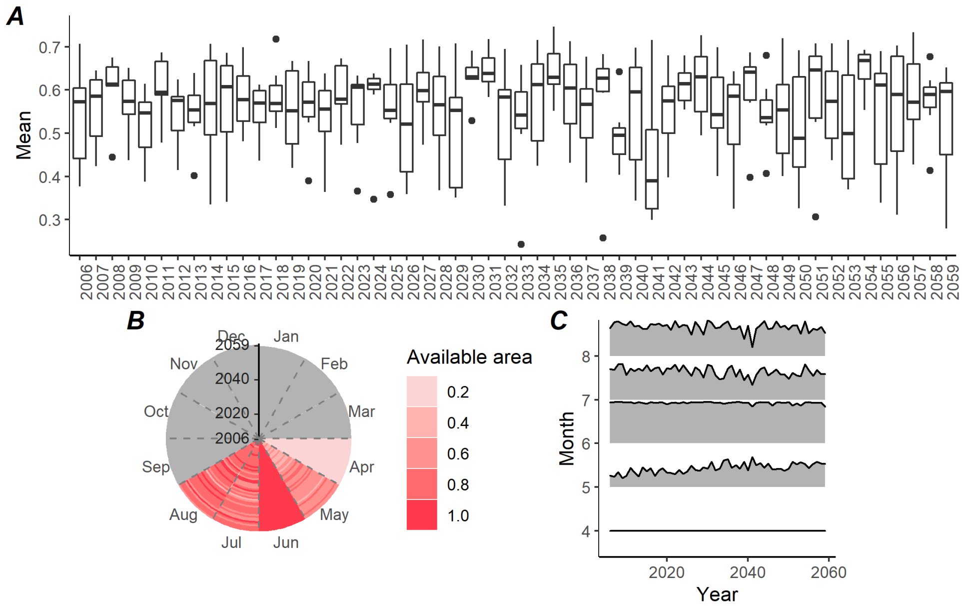

Figure A3.17. Black goby in the Baltic Sea. A) yearly boxplot of the available area of nursery habitat after considering the species spawning preferences of temperature. The boxes show all combinations between the global scenarios and the two different RCP pathways in the RCO-SCOBI model. B) The available area of nursery habitat for every month and year in polar coordinates. The first modeled year is in the center and increases to the last modeled year at the edge. The months where the species does not spawn is shown in grey. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used. C) The available area of spawning habitat for every month and year. The result is a mean of all global scenarios in the RCO-SCOBI model, but only the RCP45 were used.

Appendix A4

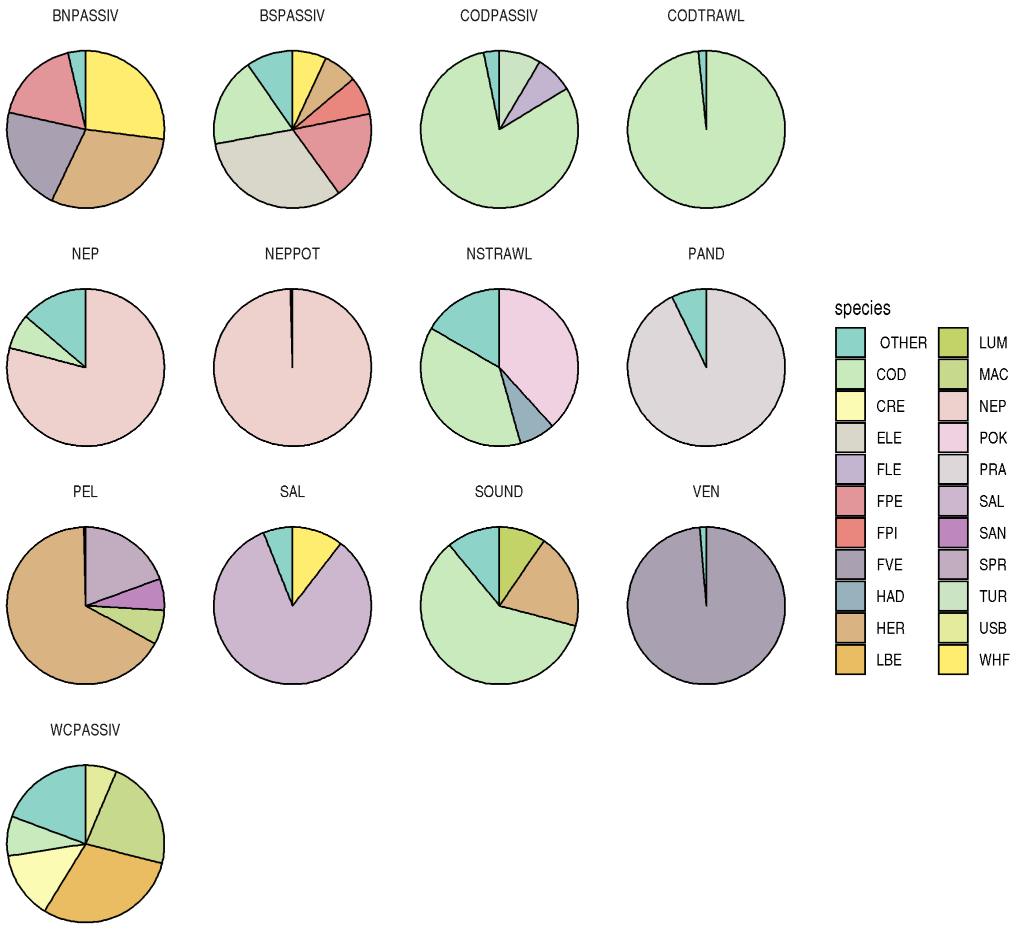

Figure A4.1. Species contributions to the landing value by fleet, calculated over the period 2016-2020

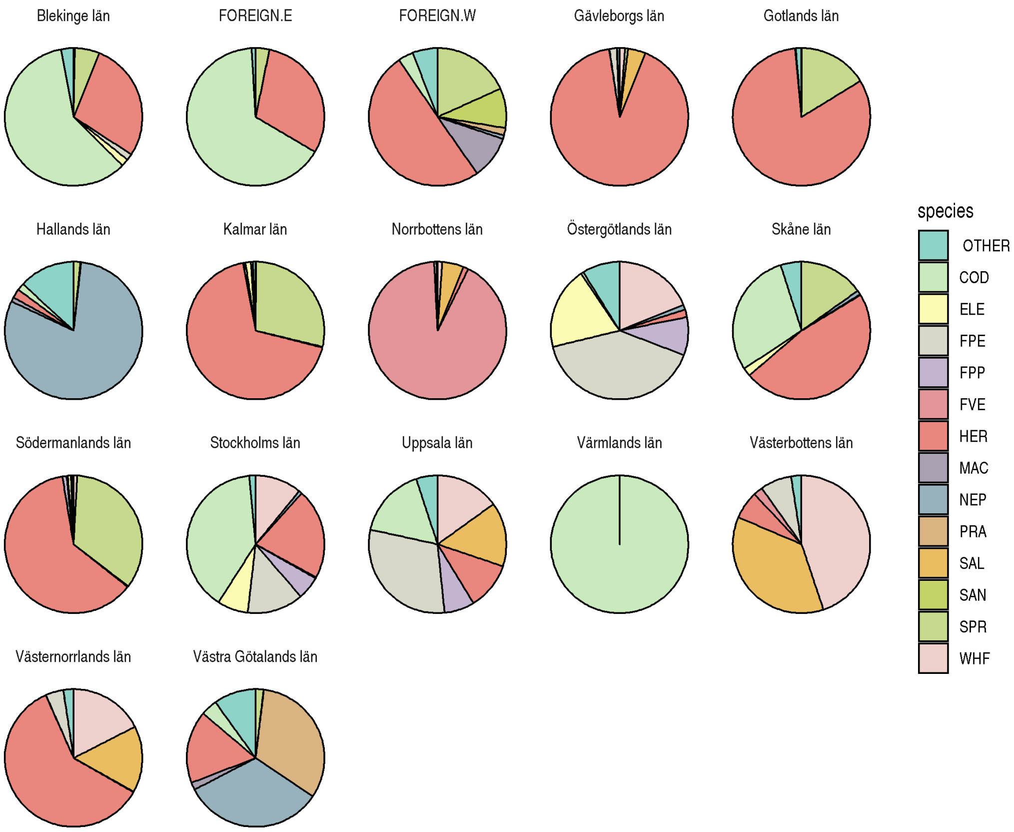

Figure A4.2. Species contributions to the landing value by region, calculated over the period 2016-2020.

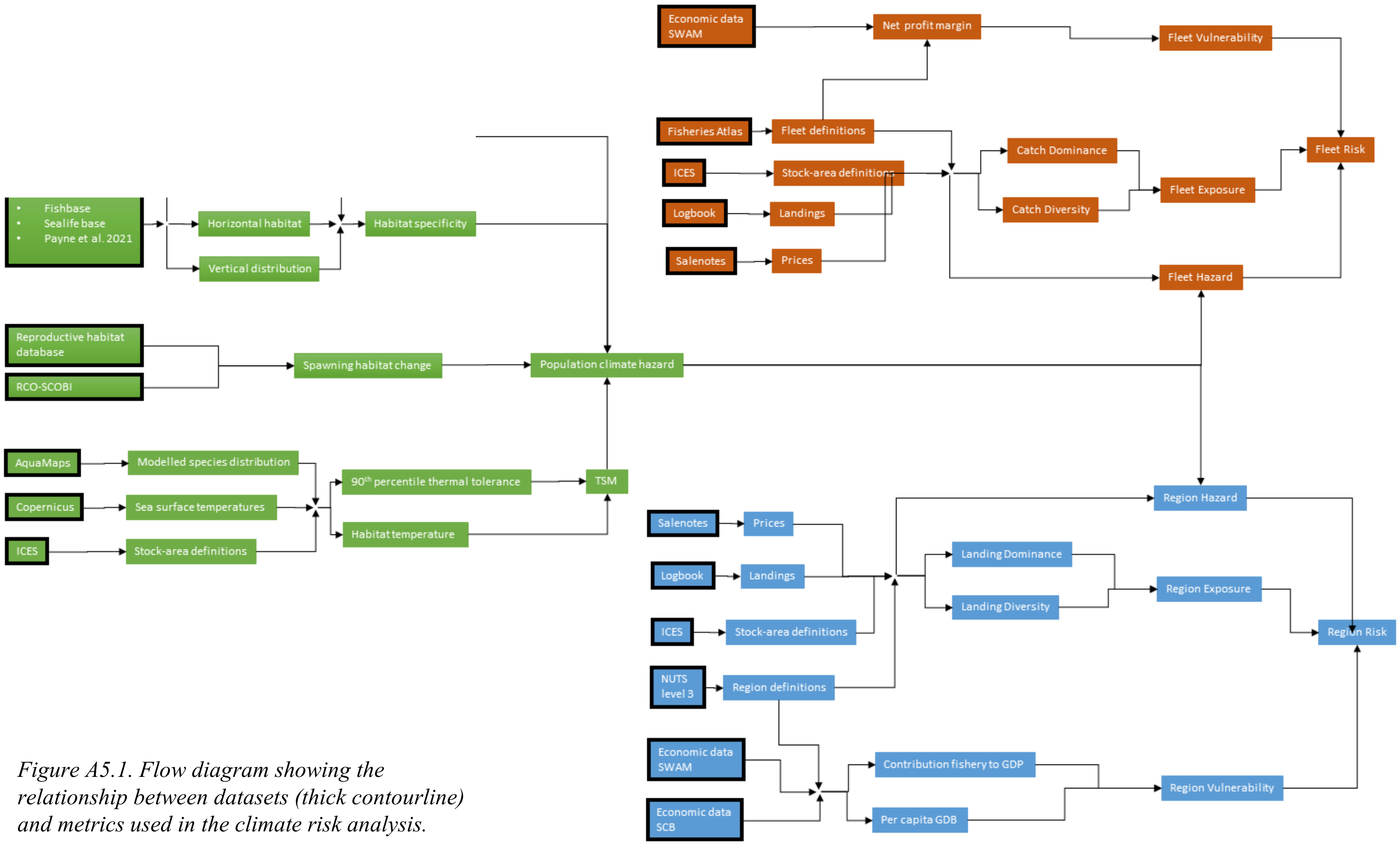

Figure A5.1. Flow diagram showing the relationship between datasets (thick contourline) and metrics used in the climate risk analysis.

Table A5.1. Overview of the datasets used in the climate risk analysis.

Data	Description	Use in the analysis	Source
Gross Regional Domestic Product	Gross Regional Domestic Product (GRDP) (ESA2010) by region (NUTS1-3). Year 2012-2019	Calculate average per capita GDP by Swedish region to assess regional vulnerability	Statistics Sweden (SCB) https://www.scb.se
Population size	Population size per region		
Added value of landings	Added value of landings per vessel and year value after all operational costs of the vessel are payed (2015-2019)	Calculate the % contribution of fishery to the region GDP to assess regional vulnerability as the ratio between the value added by the fishery in the region where the landing occurs and the GDP of the region	Swedish Agency for Marine and Water Management
Net profit	Net profit of vessels per year (2015-2019)	Calculate the net profit margin by fleet as a metric of fleet vulnerability	
Landed biomass	Fish and shellfish landing by vessel and trip based on fishery logbook (2016-2020)	Association of landed biomass and price by species formed the landing value used to integrate the hazard, exposure and vulnerability metrics at fleet and regional levels	
Price per kg	Price per kg per species by vessel and landing event from sale notes (2008-2020)		
Regions NUTS level 3 polygons	Swedish administrative units	Association of landing harbours with administrative regions used as spatial units for aggregation of hazard, exposure and vulnerability metrics	https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/nuts
County and municipality polygons			https://www.lantmateriet.se/en/geodata/geodata-products/product-list/administrative-division-download-inspire/
Harbour list	Geographical position of Swedish harbours		Swedish Agency for Marine and Water Management

Data	Description	Use in the analysis	Source
Traits	Lifespan	Calculation of species hazard	Froese, R. & Pauly, D. Fishbase. (2019) http://www.fishbase.org Palomares, M. L. D. & Pauly, D. Sealifebase. (2019). https://www.sealifebase.ca
	Horizontal habitat, Vertical habitat, Migratory behaviour and Mobility of species		Payne, M.R., Kudahl, M., Engelhard, G.H., Peck, M.A. & Pinnegar, J.K. (2021) Climate risk to European fisheries and coastal communities. Proceedings of the National Academy of Sciences, 118(40), e2018086118. Engelhard, G. H., Ellis, J. R., Payne, M. R., ter Hofstede, R. & Pinnegar, J. K. Ecotypes as a concept for exploring responses to climate change in fish assemblages. *ICES J. Mar. Sci.* 68, 580–591 (2011).
Hydrography	Salinity, oxygen and temperature	Association of reproductive habitats for Baltic Sea species with relevant hydrography	Swedish Meteorological and Hydrological Institute (SMHI) Saraiva, S., Meier, H.E.M., Andersson, H.C., Höglund, A., Dieterich, C., Gröger, M., Hordoir, R. & Eilola, K. (2019) Uncertainties in projections of the Baltic Sea ecosystem driven by an ensemble of global climate models. Frontiers in Earth Science 6, 244, https://doi.org/10.3389/feart.2018.00244
Sea surface temperature	Modelled sea surface temperature by the HadGEM2-ES model for a historical and forecast period (2050-2100)	Sea surface temperature calculated throughout the distribution of the species and populations were used to calculate the species 90th percentile of thermal tolerance	World Climate Research Programme https://esgf-data.dkrz.de/search/cmip5-dkrz/

Data	Description	Use in the analysis	Source
Species distributional area	Modelled suitable habitat distribution for each selected species on a 1x1 degree grid	(T90), and the present (2016-2021) and future (2021-2059) thermal safety margins	Aquamaps www.aquamaps.org
Stocks-area definitions	Definition of ICES areas representative of the distribution of the ICES stocks	Association of species catches from the logbook with stock area definitions	International Council for the Exploration of the Sea (ICES)
Fleet definitions	Definition of the main Swedish fisheries for the Baltic Sea and Swedish west coast	Association of fishing operations from the logbook with fleets definition used for aggregation of hazard, exposure and vulnerability metrics	Bergenius, M., Ringdahl, K., Sundelöf, A., Carlshamre, S, Wennhage, H. Valentinsson, D. (2018). Atlas över svenskt kust- och havsfiske 2003-205. Aqua reports 2018:3. Sveriges lantbruksuniversitet, Institutionen för akvatiska resurser, Drottningholm Lysekil Öregrund. 245 s
Nursery areas	Modelled distribution of nursery habitats of Baltic species	Association of hydrographíc features and reproductive areas and calculation of possible future changes in the extent of the reproductive habitats in the Baltic Sea	Erlandsson, M., Fredriksson, R., Bergström, U. (2021). Kartering av uppväxtområden för fisk i grunda områden i Östersjön. Aqua reports 2021:17. Sveriges lantbruksuniversitet, Institutionen för akvatiska resurser, Drottningholm Lysekil Öregrund.
Spawning areas	Distribution of spawning habitats of internationally assessed Baltic stocks		HELCOM (2021). Essential fish habitats in the Baltic Sea – Identification of potential spawning, recruitment and nursery areas.
Range of spawning temperatures and months	species' temperature ranges for spawning and range of months during which the species is considered to be spawning		Lektidsportalen (Swedish Agency for Marine and Water Management) https://www.havochvatten.se/arter-och-livsmiljoer/atgarder-skydd-och-rapportering/lektidsportalen.html

Appendix A6

Table A6.1. *Lifespan, habitat use information, and the resulting habitat score for the fish and invertebrate species included in the climate risk analysis following Payne et al., 2021. NA: not available.*

Species code	**Scientific name**	**English name**	**Lifespan (years)**	**Horizontal habitat**	**Vertical habitat**	**Migratory category**	**Mobility**	**Habitat specificity score**
BLL	*Scophthalmus rhombus*	Brill	5.8	Shelf	Demersal	Oceanodromous	Mobile	0.33
CAA	*Anarhichas lupus*	Atlantic wolffish	20	Shelf	Demersal	Oceanodromous	NA	0.33
COD	*Gadus morhua*	Atlantic cod	16.9	Shelf	Demersal	Oceanodromous	Mobile	0.33
CRE	*Cancer pagurus*	Edible crab	9	Shelf	Demersal	NA	Sedentary	1
ELE	*Anguilla anguilla*	European eel	88	NA	Benthopelagic	Catadromous	Highly migratory	0.67
FBM	*Abramis brama*	Freshwater bream	23	Coastal	Benthopelagic	NA	Mobile	0.67
FLE	*Platichthys flesus*	European flounder	12.4	Coastal	Demersal	Catadromous	Mobile	0.67
FPE	*Perca fluviatilis*	European perch	22	Coastal	Demersal	Anadromous	Mobile	0.67
FPI	*Esox lucius*	Northern pike	30	Coastal	Pelagic	NA	Mobile	0.67
FPP	*Sander lucioperca*	Pike-perch	17	Coastal	Pelagic	NA	NA	0.67
FVE	*Coregonus albula*	Vendace	10	Coastal	Benthopelagic	Anadromous	Mobile	0.67
HAD	*Melanogrammus aeglefinus*	Haddock	14.3	Shelf	Demersal	Oceanodromous	Mobile	0.33
HAL	*Hippoglossus hippoglossus*	Atlantic halibut	50	Slope	Benthopelagic	Oceanodromous	Mobile	0.33
HER	*Clupea harengus*	Atlantic herring	6.9	Shelf	Benthopelagic	Oceanodromous	Mobile	0.33
HKE	*Merluccius merluccius*	European hake	19.1	Shelf	Demersal	NA	Mobile	0.33

Species code	Scientific name	English name	Lifespan (years)	Horizontal habitat	Vertical habitat	Migratory category	Mobility	Habitat specificity score
LBE	*Homarus gammarus*	European lobster	72	Shelf	Demersal	NA	Sedentary	1
LEM	*Microstomus kitt*	Lemon sole	17.8	Shelf	Demersal	Oceanodromous	Mobile	0.33
LIN	*Molva molva*	Ling	20.6	Slope	Demersal	Oceanodromous	Mobile	0.33
LUM	*Cyclopterus lumpus*	Lumpfish	13	Slope	Benthopelagic	Oceanodromous	Mobile	0.33
MAC	*Scomber scombrus*	Atlantic mackerel	11	Shelf	Epipelagic	Oceanodromous	Mobile	0.33
MON	*Lophius piscatorius*	Angler(=Monk)	26.5	Shelf	Demersal	NA	Mobile	0.33
NEP	*Nephrops norvegicus*	Norway lobster	15	Shelf	Demersal	NA	Sedentary	1
PLE	*Pleuronectes platessa*	European plaice	47.8	Shelf	Demersal	Oceanodromous	Mobile	0.33
POK	*Pollachius virens*	Saithe(=Pollock)	14.4	Shelf	Demersal	Oceanodromous	Mobile	0.33
POL	*Pollachius pollachius*	Pollack	16	Shelf	Demersal	Oceanodromous	Mobile	0.33
PRA	*Pandalus borealis*	Northern prawn	11	Outer shelf	Benthopelagic	NA	Mobile	0.33
SAL	*Salmo salar*	Atlantic salmon	13	NA	Pelagic	Anadromous	Mobile	0.67
SAN	*Ammodytes spp*	Sandeels(=Sandlances) nei	6.1	Inner shelf	Benthopelagic	NA	Mobile	0.67
SOL	*Solea solea*	Common sole	7.9	Inner shelf	Demersal	Oceanodromous	Mobile	0.67
SPR	*Sprattus sprattus*	European sprat	9.4	Shelf	Pelagic	Oceanodromous	Mobile	0.33
TBR	*Ctenolabrus rupestris*	Goldsinny-wrasse	8	NA	Reef-associated	NA	Mobile	1
TRS	*Salmo trutta*	Sea trout	38	Coastal	Pelagic	Anadromous	Mobile	0.67
TUR	*Psetta maxima*	Turbot	9.2	Shelf	Demersal	Oceanodromous	Mobile	0.33
USB	*Labrus bergylta*	Ballan wrasse	29	NA	Reef-associated	NA	Mobile	1

Species code	Scientific name	English name	Lifespan (years)	Horizontal habitat	Vertical habitat	Migratory category	Mobility	Habitat specificity score
WHE	*Buccinum undatum*	Whelk	20	Shelf	Demersal	NA	Sedentary	1
WHF	*Coregonus spp*	Whitefish	10	Coastal	Pelagic	Anadromous	Mobile	0.67
WHG	*Merlangius merlangus*	Whiting	8.4	Shelf	Demersal	Oceanodromous	Mobile	0.33
WIT	*Glyptocephalus cynoglossus*	Witch flounder	14.2	Shelf	Demersal	Oceanodromous	Mobile	0.33
YFM	*Symphodus melops*	Corkwing wrasse	9	NA	Reef-associated	NA	NA	1

Table A6.2. Populations hazard. Percentile ranks of the species and population level metrics contributing to calculation of the population hazard. These are summarized as thermal safety margin scores, longevity scores, habitat scores and spawning habitat change scores. The TSM and the spawning habitat scores are reported as the range of scores calculated over the period 2021-2059 separately for the two warming scenarios RCP4.5 and RCP8.5.

Species	Scientific name	Stock	TSM score		Longevity score	Habitat score	Spawning habitat score	
			RCP4.5	RCP8.5			RCP4.5	RCP8.5
bll	*Scophthalmus rhombus*	bll.27.22-32	0.04-0.42	0.03-0.44	1	0.33	NA	NA
bll	*Scophthalmus rhombus*	bll.27.3a47de	0.12-0.47	0.14-0.46	1	0.33	NA	NA
caa	*Anarhichas lupus*	caa	0.62-1	0.64-0.99	0.68	1	NA	NA
cod	*Gadus morhua*	cod.27.21	0.59-0.99	0.61-0.99	0.51	0.33	NA	NA
cod	*Gadus morhua*	cod.27.22-24	0.62-0.99	0.62-0.99	0.51	0.33	0.15-0.95	0.01-0.97
cod	*Gadus morhua*	cod.27.24-32	0.56-0.96	0.57-0.98	0.51	0.33	0.05-1	0.07-1
cod	*Gadus morhua*	cod.27.47d20	0.65-0.98	0.65-0.97	0.51	0.33	NA	NA
cre	*Cancer pagurus*	cre	0.02-0.33	0.02-0.34	0.1	1	NA	NA
ele	*Anguilla anguilla*	ele.2737.nea	0-0.02	0-0.02	0.02	0.67	NA	NA
fbm	*Abramis brama*	fbm	NA	NA	0.56	0.67	0.19-0.82	0.08-0.8
fle	*Platichthys flesus*	fle.27.2223	0.04-0.45	0.05-0.45	0.77	0.67	NA	NA
fle	*Platichthys flesus*	fle.27.3.d.Bal	0.02-0.25	0.02-0.35	0.77	0.67	0.5-0.73	0.44-0.68
fle	*Platichthys flesus*	fle.27.3.d.Eur	0.03-0.38	0.02-0.42	0.77	0.67	0.02-0.73	0.03-0.72
fpe	*Perca fluviatilis*	fpe	NA	NA	0.6	0.67	0.16-0.99	0.66-0.97
fpi	*Esox lucius*	fpi	NA	NA	0.13	0.67	0-0.91	0.04-0.9
fpp	*Sander lucioperca*	fpp	NA	NA	0.72	0.67	0.26-0.65	0.23-0.66
fve	*Coregonus albula*	fve.27.30-31	0.55-1	0.59-1	0.9	0.67	NA	NA
had	*Melanogrammus aeglefinus*	had.27.46a20	0.61-0.92	0.61-0.92	0.68	0.33	NA	NA
hal	*Hippoglossus hippoglossus*	hal	0.58-0.97	0.6-0.96	0.1	0.33	NA	NA

Species	Scientific name	Stock	TSM score		Longevity score	Habitat score	Spawning habitat score	
			RCP4.5	RCP8.5			RCP4.5	RCP8.5
her	*Clupea harengus*	her.27.1-24a514a	0.31-0.51	0.35-0.54	0.51	0.33	NA	NA
her	*Clupea harengus*	her.27.20-24	0.59-0.99	0.62-0.99	0.51	0.33	0.4-0.75	0.29-0.75
her	*Clupea harengus*	her.27.25-2932	0.54-0.92	0.56-0.95	0.51	0.33	0.07-0.83	0.07-0.85
her	*Clupea harengus*	her.27.3031	0.44-0.7	0.47-0.81	0.51	0.33	0-0.91	0.01-0.91
her	*Clupea harengus*	her.27.3a47d	0.64-0.98	0.64-0.97	0.51	0.33	NA	NA
hke	*Merluccius merluccius*	hke.27.3a46-8abd	0.08-0.4	0.06-0.37	0.68	0.33	NA	NA
lbe	*Homarus gammarus*	lbe	0.04-0.45	0.05-0.44	0.03	1	NA	NA
lem	*Microstomus kitt*	lem.27.3a47d	0.56-0.8	0.56-0.82	0.56	0.33	NA	NA
lin	*Molva molva*	lin.27.346-91214	0.5-0.55	0.47-0.54	0.51	0.33	NA	NA
lum	*Cyclopterus lumpus*	lum	0.57-0.97	0.59-0.96	0.8	0.33	NA	NA
mac	*Scomber scombrus*	mac.27.nea	0.05-0.29	0.03-0.23	0.72	0.33	NA	NA
mon	*Lophius piscatorius*	mon	0.04-0.41	0.05-0.41	0.54	0.33	NA	NA
nep	*Nephrops norvegicus*	nep.fu.3-4	0.05-0.46	0.07-0.46	0.6	1	NA	NA
ple	*Pleuronectes platessa*	ple.27.21-23	0.09-0.49	0.17-0.49	0.1	0.33	NA	NA
ple	*Pleuronectes platessa*	ple.27.24-32	0.05-0.46	0.06-0.48	0.1	0.33	NA	NA
ple	*Pleuronectes platessa*	ple.27.420	0.2-0.47	0.21-0.46	0.1	0.33	NA	NA
pok	*Pollachius virens*	pok.27.3a46	0.59-0.84	0.58-0.83	0.51	0.33	NA	NA
pol	*Pollachius pollachius*	pol.27.3a4	0.54-0.66	0.54-0.66	0.94	0.33	NA	NA
pra	*Pandalus borealis*	pra.27.3a4a	0.77-1	0.76-0.98	0.9	0.33	NA	NA
pra	*Pandalus borealis*	pra.27.4a	0.79-1	0.76-0.98	0.9	0.33	NA	NA
sal	*Salmo salar*	sal.27.22-31	0.44-0.58	0.46-0.59	0.8	0.67	NA	NA
san	*Ammodytes marinus*	san.sa.1r	0.65-0.99	0.66-0.99	0.9	0.67	NA	NA

Species	Scientific name	Stock	TSM score		Longevity score	Habitat score	Spawning habitat score	
			RCP4.5	RCP8.5			RCP4.5	RCP8.5
san	*Ammodytes marinus*	san.sa.3r	0.61-0.94	0.61-0.94	0.9	0.67	NA	NA
san	*Ammodytes marinus*	san.sa.4	0.62-0.92	0.61-0.91	0.9	0.67	NA	NA
sol	*Solea solea*	sol.27.20-24	0.02-0.33	0.02-0.35	0.17	0.67	NA	NA
spr	*Sprattus sprattus*	spr.27.22-32	0.02-0.22	0.02-0.31	0.96	0.33	0.03-0.68	0.03-0.65
spr	*Sprattus sprattus*	spr.27.3a4	0.05-0.38	0.05-0.39	0.96	0.33	NA	NA
tbr	*Ctenolabrus rupestris*	tbr	0.04-0.44	0.04-0.43	0.94	1	NA	NA
trs	*Salmo trutta*	trs.27.22-32	0.1-0.51	0.19-0.52	0.12	0.67	NA	NA
tur	*Scophthalmus maximus*	tur.27.22-32	0.03-0.42	0.03-0.43	0.21	0.33	NA	NA
tur	*Scophthalmus maximus*	tur.27.3a	0.05-0.47	0.07-0.46	0.21	0.33	NA	NA
tur	*Scophthalmus maximus*	tur.27.4	0.12-0.47	0.15-0.45	0.21	0.33	NA	NA
usb	*Labrus bergylta*	usb	0.38-0.55	0.41-0.55	0.14	1	NA	NA
whe	*Buccinum undatum*	whe	0.65-1	0.67-1	0.68	1	NA	NA
whf	*Coregonus maraena*	whf	0.52-0.96	0.56-0.99	0.9	0.67	NA	NA
whg	*Merlangius merlangus*	whg.27.3a	0.12-0.5	0.21-0.51	0.68	0.33	NA	NA
wit	*Glyptocephalus cynoglossus*	wit.27.3a47d	0.55-0.73	0.55-0.75	0.51	0.33	NA	NA
yfm	*Symphodus melops*	yfm	0.05-0.45	0.05-0.44	0.91	1	NA	NA

Table A6.3. *Swedish fleets climate change risk. Percentile rank of the hazard, exposure and vulnerability, and the climate risk calculated as the median of the percentile rank under the RCP 4.5 and 8.5 warming scenarios for the pentads of years 2025-2029, 2035-2039, 2045-2049, 2055-2059.*

Fleet	Year	RCP scenario	Hazard score	Exposure score	Vulnerability score	Risk
BNPASSIV	(2024,2029]	rcp45	0.638	0.250	0.833	0.574
BNPASSIV	(2024,2029]	rcp85	0.784	0.250	0.833	0.622
BNPASSIV	(2034,2039]	rcp45	0.821	0.250	0.833	0.635
BNPASSIV	(2034,2039]	rcp85	0.846	0.250	0.833	0.643
BNPASSIV	(2044,2049]	rcp45	0.766	0.250	0.833	0.616
BNPASSIV	(2044,2049]	rcp85	0.856	0.250	0.833	0.646
BNPASSIV	(2054,2059]	rcp45	0.820	0.250	0.833	0.635
BNPASSIV	(2054,2059]	rcp85	0.836	0.250	0.833	0.640
BSPASSIV	(2024,2029]	rcp45	0.106	0.167	1.000	0.424
BSPASSIV	(2024,2029]	rcp85	0.139	0.167	1.000	0.435
BSPASSIV	(2034,2039]	rcp45	0.176	0.167	1.000	0.447
BSPASSIV	(2034,2039]	rcp85	0.120	0.167	1.000	0.429
BSPASSIV	(2044,2049]	rcp45	0.151	0.167	1.000	0.439
BSPASSIV	(2044,2049]	rcp85	0.231	0.167	1.000	0.466
BSPASSIV	(2054,2059]	rcp45	0.221	0.167	1.000	0.463
BSPASSIV	(2054,2059]	rcp85	0.278	0.167	1.000	0.482
CODPASSIV	(2024,2029]	rcp45	0.226	0.500	0.917	0.548
CODPASSIV	(2024,2029]	rcp85	0.359	0.500	0.917	0.592
CODPASSIV	(2034,2039]	rcp45	0.342	0.500	0.917	0.586
CODPASSIV	(2034,2039]	rcp85	0.265	0.500	0.917	0.560
CODPASSIV	(2044,2049]	rcp45	0.596	0.500	0.917	0.671
CODPASSIV	(2044,2049]	rcp85	0.293	0.500	0.917	0.570
CODPASSIV	(2054,2059]	rcp45	0.486	0.500	0.917	0.634
CODPASSIV	(2054,2059]	rcp85	0.678	0.500	0.917	0.698
CODTRAWL	(2024,2029]	rcp45	0.217	0.750	0.500	0.489
CODTRAWL	(2024,2029]	rcp85	0.501	0.750	0.500	0.584
CODTRAWL	(2034,2039]	rcp45	0.297	0.750	0.500	0.516
CODTRAWL	(2034,2039]	rcp85	0.203	0.750	0.500	0.484
CODTRAWL	(2044,2049]	rcp45	0.679	0.750	0.500	0.643
CODTRAWL	(2044,2049]	rcp85	0.321	0.750	0.500	0.524
CODTRAWL	(2054,2059]	rcp45	0.581	0.750	0.500	0.610
CODTRAWL	(2054,2059]	rcp85	0.800	0.750	0.500	0.683
NEP	(2024,2029]	rcp45	0.197	0.583	0.333	0.371
NEP	(2024,2029]	rcp85	0.316	0.583	0.333	0.411
NEP	(2034,2039]	rcp45	0.507	0.583	0.333	0.475

Fleet	Year	RCP scenario	Hazard score	Exposure score	Vulnerability score	Risk
NEP	(2034,2039]	rcp85	0.387	0.583	0.333	0.435
NEP	(2044,2049]	rcp45	0.568	0.583	0.333	0.495
NEP	(2044,2049]	rcp85	0.527	0.583	0.333	0.481
NEP	(2054,2059]	rcp45	0.555	0.583	0.333	0.490
NEP	(2054,2059]	rcp85	0.599	0.583	0.333	0.505
NEPPOT	(2024,2029]	rcp45	0.194	1.000	0.250	0.481
NEPPOT	(2024,2029]	rcp85	0.326	1.000	0.250	0.525
NEPPOT	(2034,2039]	rcp45	0.548	1.000	0.250	0.599
NEPPOT	(2034,2039]	rcp85	0.408	1.000	0.250	0.553
NEPPOT	(2044,2049]	rcp45	0.594	1.000	0.250	0.615
NEPPOT	(2044,2049]	rcp85	0.561	1.000	0.250	0.604
NEPPOT	(2054,2059]	rcp45	0.600	1.000	0.250	0.617
NEPPOT	(2054,2059]	rcp85	0.617	1.000	0.250	0.622
NSTRAWL	(2024,2029]	rcp45	0.413	0.250	0.083	0.249
NSTRAWL	(2024,2029]	rcp85	0.400	0.250	0.083	0.244
NSTRAWL	(2034,2039]	rcp45	0.526	0.250	0.083	0.286
NSTRAWL	(2034,2039]	rcp85	0.484	0.250	0.083	0.272
NSTRAWL	(2044,2049]	rcp45	0.689	0.250	0.083	0.341
NSTRAWL	(2044,2049]	rcp85	0.601	0.250	0.083	0.312
NSTRAWL	(2054,2059]	rcp45	0.565	0.250	0.083	0.299
NSTRAWL	(2054,2059]	rcp85	0.720	0.250	0.083	0.351
PAND	(2024,2029]	rcp45	0.878	0.750	0.167	0.598
PAND	(2024,2029]	rcp85	0.854	0.750	0.167	0.590
PAND	(2034,2039]	rcp45	0.922	0.750	0.167	0.613
PAND	(2034,2039]	rcp85	0.886	0.750	0.167	0.601
PAND	(2044,2049]	rcp45	0.936	0.750	0.167	0.618
PAND	(2044,2049]	rcp85	0.905	0.750	0.167	0.607
PAND	(2054,2059]	rcp45	0.902	0.750	0.167	0.606
PAND	(2054,2059]	rcp85	0.927	0.750	0.167	0.615
PEL	(2024,2029]	rcp45	0.227	0.083	0.417	0.242
PEL	(2024,2029]	rcp85	0.190	0.083	0.417	0.230
PEL	(2034,2039]	rcp45	0.344	0.083	0.417	0.281
PEL	(2034,2039]	rcp85	0.364	0.083	0.417	0.288
PEL	(2044,2049]	rcp45	0.294	0.083	0.417	0.265
PEL	(2044,2049]	rcp85	0.369	0.083	0.417	0.290
PEL	(2054,2059]	rcp45	0.255	0.083	0.417	0.252
PEL	(2054,2059]	rcp85	0.335	0.083	0.417	0.278
SAL	(2024,2029]	rcp45	0.660	0.667	0.667	0.665
SAL	(2024,2029]	rcp85	0.677	0.667	0.667	0.670

Fleet	Year	RCP scenario	Hazard score	Exposure score	Vulnerability score	Risk
SAL	(2034,2039]	rcp45	0.769	0.667	0.667	0.701
SAL	(2034,2039]	rcp85	0.722	0.667	0.667	0.685
SAL	(2044,2049]	rcp45	0.753	0.667	0.667	0.696
SAL	(2044,2049]	rcp85	0.764	0.667	0.667	0.699
SAL	(2054,2059]	rcp45	0.757	0.667	0.667	0.697
SAL	(2054,2059]	rcp85	0.776	0.667	0.667	0.703
SOUND	(2024,2029]	rcp45	0.432	0.417	0.583	0.477
SOUND	(2024,2029]	rcp85	0.355	0.417	0.583	0.452
SOUND	(2034,2039]	rcp45	0.575	0.417	0.583	0.525
SOUND	(2034,2039]	rcp85	0.503	0.417	0.583	0.501
SOUND	(2044,2049]	rcp45	0.654	0.417	0.583	0.551
SOUND	(2044,2049]	rcp85	0.444	0.417	0.583	0.481
SOUND	(2054,2059]	rcp45	0.648	0.417	0.583	0.549
SOUND	(2054,2059]	rcp85	0.651	0.417	0.583	0.550
VEN	(2024,2029]	rcp45	0.874	0.917	0.000	0.597
VEN	(2024,2029]	rcp85	0.937	0.917	0.000	0.618
VEN	(2034,2039]	rcp45	0.976	0.917	0.000	0.631
VEN	(2034,2039]	rcp85	0.964	0.917	0.000	0.627
VEN	(2044,2049]	rcp45	0.953	0.917	0.000	0.623
VEN	(2044,2049]	rcp85	0.972	0.917	0.000	0.630
VEN	(2054,2059]	rcp45	0.967	0.917	0.000	0.628
VEN	(2054,2059]	rcp85	0.992	0.917	0.000	0.636
WCPASSIV	(2024,2029]	rcp45	0.008	0.000	0.750	0.253
WCPASSIV	(2024,2029]	rcp85	0.023	0.000	0.750	0.258
WCPASSIV	(2034,2039]	rcp45	0.099	0.000	0.750	0.283
WCPASSIV	(2034,2039]	rcp85	0.045	0.000	0.750	0.265
WCPASSIV	(2044,2049]	rcp45	0.192	0.000	0.750	0.314
WCPASSIV	(2044,2049]	rcp85	0.141	0.000	0.750	0.297
WCPASSIV	(2054,2059]	rcp45	0.135	0.000	0.750	0.295
WCPASSIV	(2054,2059]	rcp85	0.239	0.000	0.750	0.330

Table A6.4. *Regional climate change risk. Percentile rank of the hazard, exposure and vulnerability, and the climate risk calculated as the median of the percentile rank under the RCP 4.5 and 8.5 warming scenarios for the pentads of years 2025-2029, 2035-2039, 2045-2049, 2055-2059.*

Region	Year	RCP scenario	Hazard score	Exposure score	Vulnerability score	Risk
Blekinge län	(2024,2029]	rcp45	0.339	0.500	0.808	0.549
Blekinge län	(2024,2029]	rcp85	0.490	0.500	0.808	0.599
Blekinge län	(2034,2039]	rcp45	0.362	0.500	0.808	0.557
Blekinge län	(2034,2039]	rcp85	0.385	0.500	0.808	0.564
Blekinge län	(2044,2049]	rcp45	0.614	0.500	0.808	0.640
Blekinge län	(2044,2049]	rcp85	0.495	0.500	0.808	0.601
Blekinge län	(2054,2059]	rcp45	0.606	0.500	0.808	0.638
Blekinge län	(2054,2059]	rcp85	0.748	0.500	0.808	0.685
Gävleborgs län	(2024,2029]	rcp45	0.193	0.938	0.577	0.569
Gävleborgs län	(2024,2029]	rcp85	0.563	0.938	0.577	0.693
Gävleborgs län	(2034,2039]	rcp45	0.209	0.938	0.577	0.574
Gävleborgs län	(2034,2039]	rcp85	0.617	0.938	0.577	0.710
Gävleborgs län	(2044,2049]	rcp45	0.152	0.938	0.577	0.555
Gävleborgs län	(2044,2049]	rcp85	0.286	0.938	0.577	0.600
Gävleborgs län	(2054,2059]	rcp45	0.175	0.938	0.577	0.563
Gävleborgs län	(2054,2059]	rcp85	0.170	0.938	0.577	0.562
Gotlands län	(2024,2029]	rcp45	0.417	0.875	0.923	0.738
Gotlands län	(2024,2029]	rcp85	0.300	0.875	0.923	0.699
Gotlands län	(2034,2039]	rcp45	0.525	0.875	0.923	0.774
Gotlands län	(2034,2039]	rcp85	0.592	0.875	0.923	0.797
Gotlands län	(2044,2049]	rcp45	0.250	0.875	0.923	0.683
Gotlands län	(2044,2049]	rcp85	0.544	0.875	0.923	0.781
Gotlands län	(2054,2059]	rcp45	0.267	0.875	0.923	0.688
Gotlands län	(2054,2059]	rcp85	0.311	0.875	0.923	0.703
Hallands län	(2024,2029]	rcp45	0.304	0.750	0.654	0.569
Hallands län	(2024,2029]	rcp85	0.430	0.750	0.654	0.611
Hallands län	(2034,2039]	rcp45	0.667	0.750	0.654	0.690
Hallands län	(2034,2039]	rcp85	0.542	0.750	0.654	0.649
Hallands län	(2044,2049]	rcp45	0.713	0.750	0.654	0.706
Hallands län	(2044,2049]	rcp85	0.697	0.750	0.654	0.700
Hallands län	(2054,2059]	rcp45	0.707	0.750	0.654	0.704
Hallands län	(2054,2059]	rcp85	0.737	0.750	0.654	0.714
Kalmar län	(2024,2029]	rcp45	0.367	0.813	0.923	0.701
Kalmar län	(2024,2029]	rcp85	0.291	0.813	0.923	0.675
Kalmar län	(2034,2039]	rcp45	0.453	0.813	0.923	0.729
Kalmar län	(2034,2039]	rcp85	0.510	0.813	0.923	0.748

Region	Year	RCP scenario	Hazard score	Exposure score	Vulnerability score	Risk
Kalmar län	(2044,2049]	rcp45	0.232	0.813	0.923	0.656
Kalmar län	(2044,2049]	rcp85	0.475	0.813	0.923	0.737
Kalmar län	(2054,2059]	rcp45	0.249	0.813	0.923	0.661
Kalmar län	(2054,2059]	rcp85	0.296	0.813	0.923	0.677
Norrbottens län	(2024,2029]	rcp45	0.940	1.000	0.462	0.801
Norrbottens län	(2024,2029]	rcp85	0.957	1.000	0.462	0.806
Norrbottens län	(2034,2039]	rcp45	0.984	1.000	0.462	0.815
Norrbottens län	(2034,2039]	rcp85	0.974	1.000	0.462	0.812
Norrbottens län	(2044,2049]	rcp45	0.966	1.000	0.462	0.809
Norrbottens län	(2044,2049]	rcp85	0.981	1.000	0.462	0.814
Norrbottens län	(2054,2059]	rcp45	0.978	1.000	0.462	0.813
Norrbottens län	(2054,2059]	rcp85	0.992	1.000	0.462	0.818
Östergötlands län	(2024,2029]	rcp45	0.715	0.250	0.192	0.386
Östergötlands län	(2024,2029]	rcp85	0.719	0.250	0.192	0.387
Östergötlands län	(2034,2039]	rcp45	0.795	0.250	0.192	0.412
Östergötlands län	(2034,2039]	rcp85	0.759	0.250	0.192	0.400
Östergötlands län	(2044,2049]	rcp45	0.702	0.250	0.192	0.381
Östergötlands län	(2044,2049]	rcp85	0.767	0.250	0.192	0.403
Östergötlands län	(2054,2059]	rcp45	0.753	0.250	0.192	0.398
Östergötlands län	(2054,2059]	rcp85	0.775	0.250	0.192	0.406
Skåne län	(2024,2029]	rcp45	0.376	0.063	0.423	0.287
Skåne län	(2024,2029]	rcp85	0.348	0.063	0.423	0.278
Skåne län	(2034,2039]	rcp45	0.498	0.063	0.423	0.328
Skåne län	(2034,2039]	rcp85	0.429	0.063	0.423	0.305
Skåne län	(2044,2049]	rcp45	0.507	0.063	0.423	0.331
Skåne län	(2044,2049]	rcp85	0.565	0.063	0.423	0.350
Skåne län	(2054,2059]	rcp45	0.512	0.063	0.423	0.332
Skåne län	(2054,2059]	rcp85	0.594	0.063	0.423	0.360
Södermanlands län	(2024,2029]	rcp45	0.361	0.688	0.654	0.567
Södermanlands län	(2024,2029]	rcp85	0.297	0.688	0.654	0.546
Södermanlands län	(2034,2039]	rcp45	0.444	0.688	0.654	0.595
Södermanlands län	(2034,2039]	rcp85	0.497	0.688	0.654	0.613
Södermanlands län	(2044,2049]	rcp45	0.237	0.688	0.654	0.526
Södermanlands län	(2044,2049]	rcp85	0.445	0.688	0.654	0.595
Södermanlands län	(2054,2059]	rcp45	0.251	0.688	0.654	0.531
Södermanlands län	(2054,2059]	rcp85	0.305	0.688	0.654	0.549
Stockholms län	(2024,2029]	rcp45	0.516	0.250	0.000	0.255
Stockholms län	(2024,2029]	rcp85	0.619	0.250	0.000	0.290

Region	Year	RCP scenario	Hazard score	Exposure score	Vulnerability score	Risk
Stockholms län	(2034,2039]	rcp45	0.601	0.250	0.000	0.284
Stockholms län	(2034,2039]	rcp85	0.582	0.250	0.000	0.277
Stockholms län	(2044,2049]	rcp45	0.681	0.250	0.000	0.310
Stockholms län	(2044,2049]	rcp85	0.701	0.250	0.000	0.317
Stockholms län	(2054,2059]	rcp45	0.716	0.250	0.000	0.322
Stockholms län	(2054,2059]	rcp85	0.808	0.250	0.000	0.353
Uppsala län	(2024,2029]	rcp45	0.794	0.063	0.192	0.350
Uppsala län	(2024,2029]	rcp85	0.845	0.063	0.192	0.366
Uppsala län	(2034,2039]	rcp45	0.857	0.063	0.192	0.371
Uppsala län	(2034,2039]	rcp85	0.844	0.063	0.192	0.366
Uppsala län	(2044,2049]	rcp45	0.828	0.063	0.192	0.361
Uppsala län	(2044,2049]	rcp85	0.892	0.063	0.192	0.382
Uppsala län	(2054,2059]	rcp45	0.856	0.063	0.192	0.370
Uppsala län	(2054,2059]	rcp85	0.904	0.063	0.192	0.386
Västerbottens län	(2024,2029]	rcp45	0.855	0.438	0.385	0.559
Västerbottens län	(2024,2029]	rcp85	0.888	0.438	0.385	0.570
Västerbottens län	(2034,2039]	rcp45	0.937	0.438	0.385	0.586
Västerbottens län	(2034,2039]	rcp85	0.924	0.438	0.385	0.582
Västerbottens län	(2044,2049]	rcp45	0.924	0.438	0.385	0.582
Västerbottens län	(2044,2049]	rcp85	0.941	0.438	0.385	0.588
Västerbottens län	(2054,2059]	rcp45	0.929	0.438	0.385	0.584
Västerbottens län	(2054,2059]	rcp85	0.948	0.438	0.385	0.590
Västernorrlands län	(2024,2029]	rcp45	0.435	0.563	0.423	0.474
Västernorrlands län	(2024,2029]	rcp85	0.718	0.563	0.423	0.568
Västernorrlands län	(2034,2039]	rcp45	0.533	0.563	0.423	0.506
Västernorrlands län	(2034,2039]	rcp85	0.770	0.563	0.423	0.585
Västernorrlands län	(2044,2049]	rcp45	0.436	0.563	0.423	0.474
Västernorrlands län	(2044,2049]	rcp85	0.644	0.563	0.423	0.543
Västernorrlands län	(2054,2059]	rcp45	0.529	0.563	0.423	0.505
Västernorrlands län	(2054,2059]	rcp85	0.535	0.563	0.423	0.507
Västra Götalands län	(2024,2029]	rcp45	0.691	0.063	0.385	0.379
Västra Götalands län	(2024,2029]	rcp85	0.708	0.063	0.385	0.385
Västra Götalands län	(2034,2039]	rcp45	0.865	0.063	0.385	0.437
Västra Götalands län	(2034,2039]	rcp85	0.797	0.063	0.385	0.415
Västra Götalands län	(2044,2049]	rcp45	0.890	0.063	0.385	0.446
Västra Götalands län	(2044,2049]	rcp85	0.869	0.063	0.385	0.439
Västra Götalands län	(2054,2059]	rcp45	0.870	0.063	0.385	0.439
Västra Götalands län	(2054,2059]	rcp85	0.896	0.063	0.385	0.448

Appendix A7

Table A7.1. *Species contribution to the flatfish species in the recreational fishery based on commercial species composition in the gillnets (GN) and longlines (LL) and only longlines (approximated to the most abundant species).*

Area	Flatfish species	Proportion GN and LL	Proportion only LL
North Baltic	-	-	-
Central Baltic	FLE	1.00	1.00
South Baltic	FLE	0.57	0.82
	PLE	0.19	0.05
	TUR	0.24	0.13
Öresund	FLE	0.43	NA
	PLE	0.57	NA
Kattegat	FLE		1.00
	PLE	0.44	
	SOL	0.37	
	TUR	0.19	
Skagerrak	PLE	1.00	0.74
	SOL		0.10
	WIT		0.16

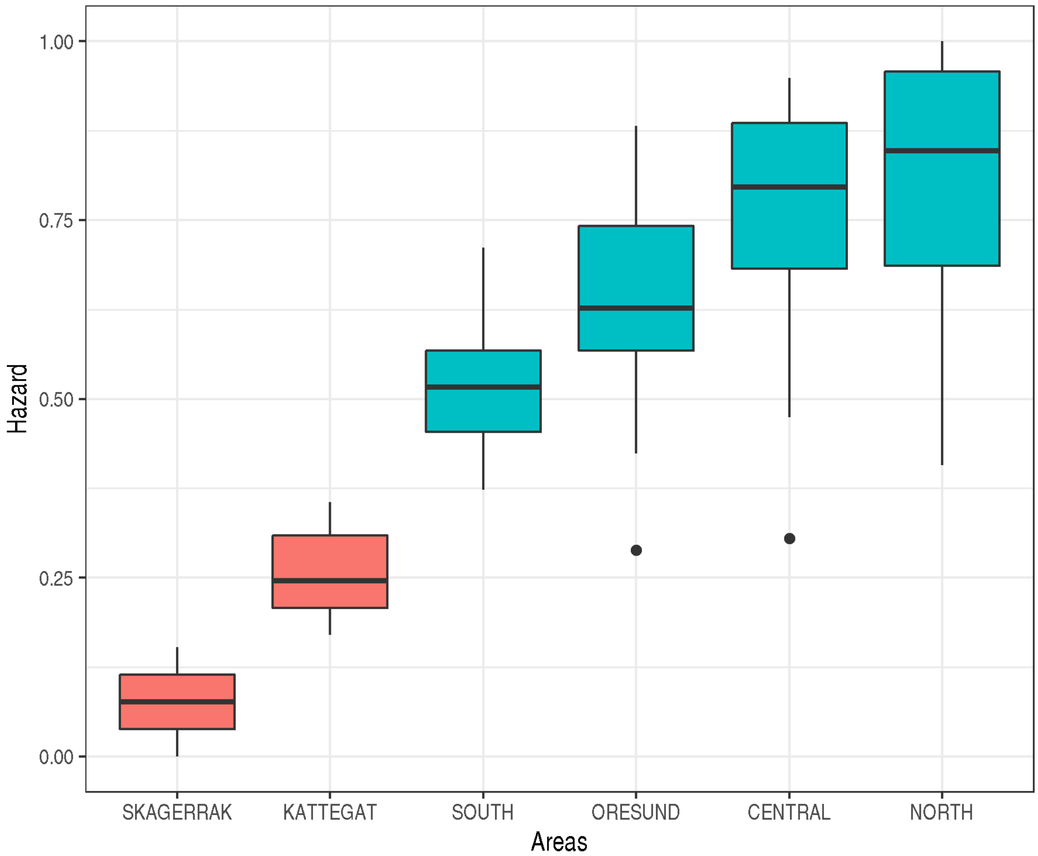

Figure A7.1. *Percentile rank of the hazard metric for the Swedish recreational fisheries across main geographical areas using the flatfish species disaggregation scheme based on the commercial longlines flatfish species composition. Colours separate the west waters (red) from the Öresund and Baltic Sea (blue).*