Sustainable Harvesting in the NE Atlantic & North Sea: Atlantic salmon in Hardangerfjord

Storyline 4

NIH NATURE-INCLUSIVE HARVESTING

Future MARES

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Introduction to FutureMARES

The EU Horizon project FutureMARES (2020-2024) was designed to develop science-based advice on viable actions and strategies to safeguard biodiversity and ecosystem functions to maximise natural capital and its delivery of services from marine and transitional ecosystems in a future climate. The program investigates effective habitat restoration, conservation strategies and sustainable harvesting at locations across a broad range of European and other marine and transitional systems. The restoration of habitat-forming species (plants or animals) and habitat conservation (e.g. marine protected areas, MPAs) represent two nature-based solutions (NBS) defined by the EU as "resource efficient actions inspired or supported by nature to simultaneously provide environmental, social and economic benefits that help to build resilience to change". A third action that will interact with these two NBS and have positive effects on marine biodiversity is nature-inclusive harvesting (NIH) such as the sustainable farming of plants and animals at the base of marine food webs and ecosystem-based management practices for traditional (artisanal) and commercial fisheries.

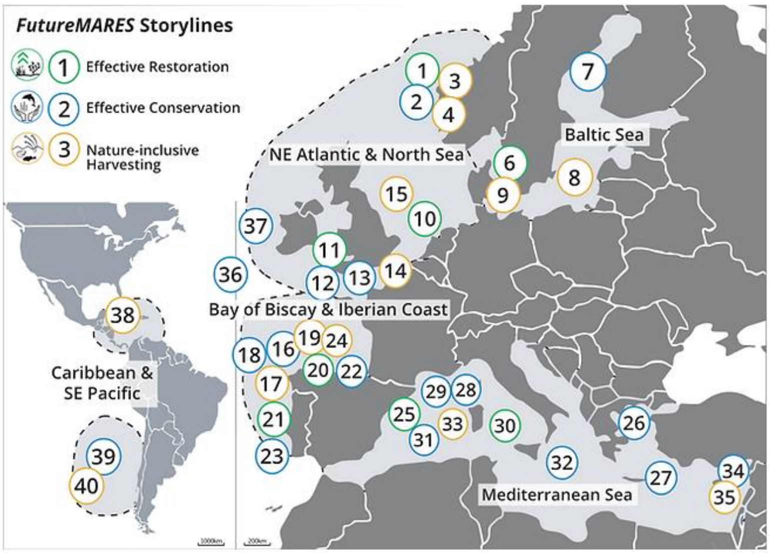

***Figure 1**: Overview of FutureMARES Storylines*

FutureMARES was designed to:

- advance the state-of-the-art forecasting capability for species of high conservation value,
- explore new and less carbon intensive aquaculture production methods,
- perform modelling analyses geared towards informing the development of climate-smart marine spatial planning approaches, and
- provide an assessment of ecosystem services based on scenarios of climate change and the implementation of NBS and NIH.

This document provides a summary of activities conducted in FutureMARES in a specific area on specific NBS and/or NIH. The activities are multi-disciplinary and

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

NBS Regional Context

Atlantic salmon (*Salmo salar*) (**Figure *2***) is a mainstay of the Norwegian coastal economy. Wild salmon stocks have traditionally been a source of food and tourism. Farmed salmon in Norwegian Fjords (**Figure 3**) has grown rapidly to be worth more than NOK 70 billion in 2020 with planned capacity more than doubling since 2018 (Kontali, 20121). Wild and most farmed salmon are susceptible to modifications in ocean climate. The focus of this study will be to characterise climate thresholds on individuals with a focus on temperature. The study will evaluate viability of present populations and farm location. For wild salmon this will include an evaluation of oceanic changes representing present distributions and for future migratory trajectories. For farmed stocks, the Storyline will focus on Hardangerfjord where climate impacts will be studied in relation to the optimum farm placements in a changing climate and also on the interplay between aquaculture activity and the carrying capacity of the fjord. Climate opportunities for farming in Northern Norway will also be evaluated. Climate challenges to the migration of wild salmon will be studied in Hardangerfjord and the coastal waters at the mouth of Hardangerfjord.

The information in this document should help inform key stakeholders such as the Norwegian Directorate of Fisheries, the Norwegian Environment Agency and municipalities responsible for coastal zone planning. This vulnerability analysis will also inform future risk and opportunity analyses for investments and protection of Atlantic salmon aquaculture.

***Figure 2**: Atlantic salmon. © ourspecies.com*

Figure 3: Salmon farm in Western Norway. © Intrafish

Projected impacts of climate change

The temperature tolerance of adult fish is high, between -0,9 - 23 °C (e.g. **Figure 4**) (Dalkhe et al., 2020; Calado et al., 2021). Nevertheless, wild salmon are most commonly reported in temperatures between -8 to 16 °C and Salmon from northern fjords have been shown to prefer temperatures for feeding migration between 1.6 and 8.4 °C (Strøm et al., 2019). Salmon have been shown in aquaculture systems to have a sustainability limit of 22-24 C (Barton, 1996). The temperature sensitivity of migrating smolt is much higher and optimum temperature range between 9-15 °C (Calado et al., 2021) and young salmon have a preference range of 8-12 °C (Holm et al., 2004; Sheehan et al., 2012).

FutureMARES has made projections of physical and biogeochemical impacts of climate change in the region including three IPCC scenarios (SSP126, SSP 245 and SSP 585 (for background see hyperlink to report). This includes surface temperature development at the mouth of the Hardangerfjord, Western Norway (see **Figure 5**). Initial analysis of the climate model projections indicate that there will be small to moderate temperature risk to smolt and adult salmon. However, these are monthly averaged values and do not represent shorter timescale warming events. This will be part of the future studies in this project where regional climate models will be used.

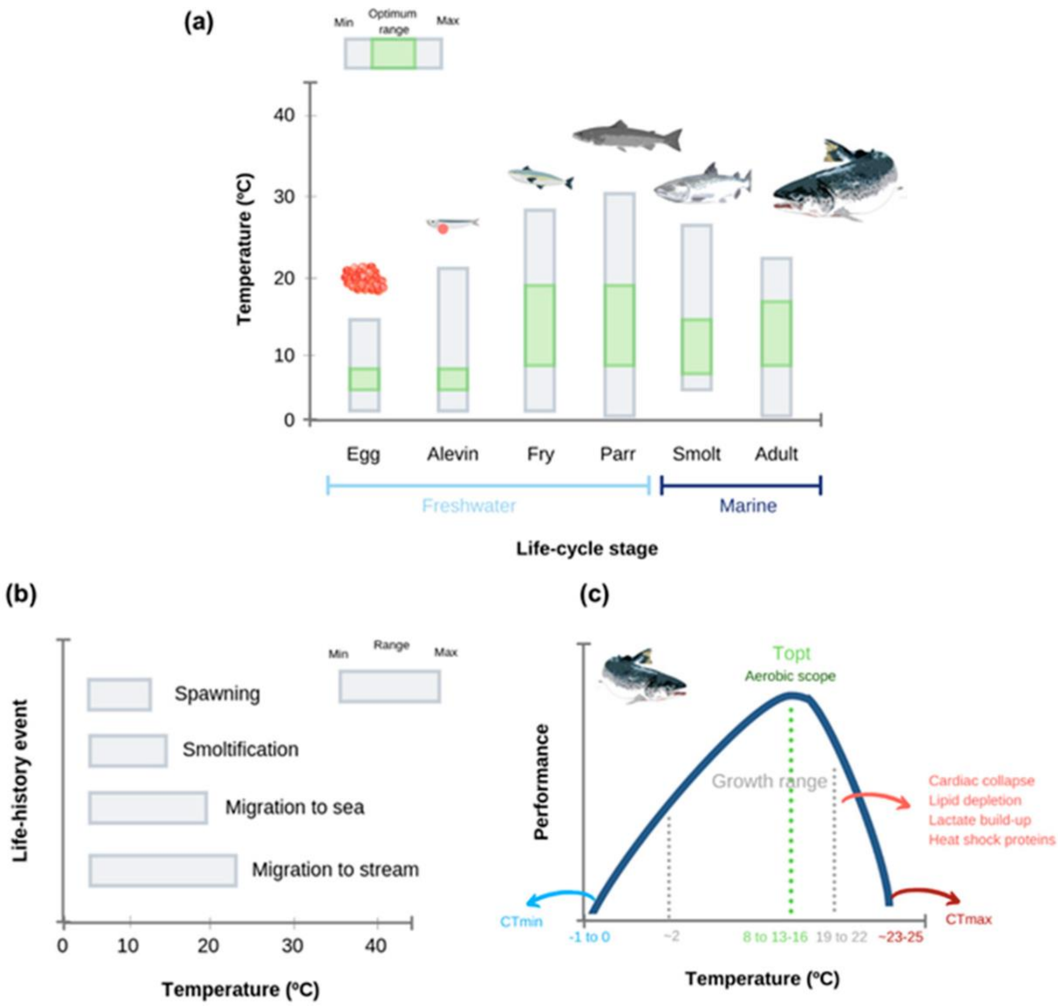

Figure 4: *Thermal biology of Atlantic salmon (a) Thermal windows estimated along different life stages; (b) thermal windows for life-history events; and (c) hypothetical thermal performance curve for adult Atlantic salmon. (Calado et al., 2021)*

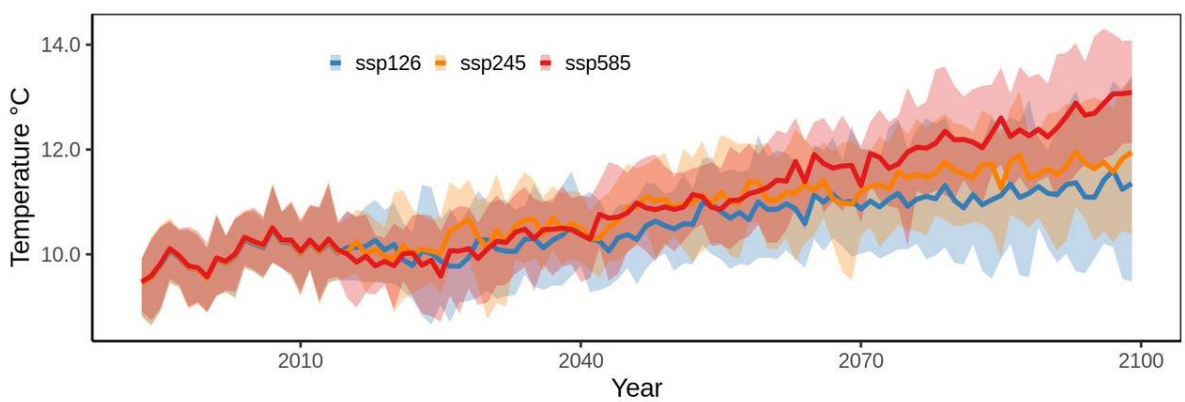

Figure 5: *Surface ocean warming projections at the mouth of the Hardangerfjord, Western Norway*

Scenarios describing future society and economy

FutureMARES developed three policy-relevant scenarios for NBS and NIH based on commonly used IPCC frameworks (for more details see hyperlink). These scenarios were regionalised based on stakeholder perspectives to guide activities such as model simulations and risk assessments.

(GS) Global Sustainability (SSP126) - Low challenges to mitigation and adaptation. The world shifts gradually but pervasively to a more sustainable path, emphasising inclusive development that respects perceived environmental boundaries. Management of the global commons slowly improves, investments in educational and health accelerate lower birth and death rates, and the emphasis on economic growth shifts to an emphasis on human well-being.

(NE) National Enterprise (SSP385) - High challenges to mitigation and adaptation. A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to focus on domestic or regional issues. Policies shift over time to be oriented more on national and regional security. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development.

(WM) World Markets (SSP585) - High challenges to mitigation, low challenges to adaptation. The world increasingly believes in competitive markets, innovation and participatory societies to produce rapid technological progress and train and educate people for sustainable development. The push for economic and social development is coupled with exploiting abundant fossil fuel resources and adopting resource and energy intensive lifestyles around the world.

Figure 6*: The three, broad scenarios that were regionalised to guide activities in FutureMARES. © FutureMARES project.*

In the present time, Atlantic salmon investment and operations have been done in environments where wild salmon have been shown proliferate and safely within windows of habitat opportunity. Farming practices have been mostly done without concerns for climate change. However, the habitat limits have been recognised due to lack of investment in Southern and far northern Norway. Licenses are given with small regard to the carrying capacity of supporting systems regarding feedbacks on climate indicators, such as ocean acidification, salinity and oxygen concentrations. In the future, salmon farming will have to take these factors into account for climate change challenges and opportunities and to support NiH, and thus reducing activities that exacibate stressors on the aquaculture practice and the supporting environment.

Under all future scenarios, there is seen reductions in suitable conditions of surface sea waters in the summer months with southern Norway becoming inhospitable for salmon in Southern Norway by ca. 2030. By the end of the century, most of the coastal regions will have unsuitable surface habitat by the end of the century under the Global markets ssp585 scenario. Under the National enterprise scenario, the presently highly productive salmon farming regions and wild salmon migration pathways of the western fjords may experience unsuitable habitats by as early as 2040. Even in the conservative Global sustainability scenario, ssp126, large regions of western Norway will be impacted.

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

It is imperative to understand how current investment strategies in salmon farming are consistent with projections of climate change and sustainable ecosystem management. It is also crucial for the planning of sustainable production to identify future opportunities for industrial migration under climate change. Similarly, climate change will affect the migration routes and feeding areas of wild salmon and there is need to provide early warning of potential barriers to migration due to ocean warming.

FutureMARES research

- **T1.1** Collect distribution data of salmon aquaculture activity in coastal Norway and assemble environmental data
- **T2.3** Identify climate change challenges and opportunities in relation to salmon farming in Norway. Analyses barriers for migration of wild salmon.

2. Research conducted

2.1 Ecological Knowledge

We have collated data on the distribution of Atlantic salmon (Salmo salar) and corresponding environmental variables. In instances where direct environmental data were not directly observed or sampled, latitude, longitude, date, time and depth information served as proxies for the acquisition of data pertaining to temperature, salinity, and oxygen. These acquired sea surface datasets (5m depth) were subjected to rigorous analysis aimed at delineating the ecological niche for salmon, as well as identifying optimal thermal conditions for prospective habitat assessments and refugia evaluations. Our research endeavours have successfully delineated areas where habitat alterations may lead to consequential losses in suitable habitats for salmon with combined habitat index (CHI), a combination of temperature thresholds and aerobic growth index (AGI, Clarke et al. (2021)).

The historical state of habitat for salmon illustrates that, in general, there is suitability (positive CHI) along the entire Norwegian coast, with an increase in habitat suitability from south to north and from winter and spring to summer and autumn (**Figure 7**). Optimum conditions are found mostly in the north in spring and in the south in winter, whilst the summer months in the southern and mid-Norway exhibit the least favourable conditions.

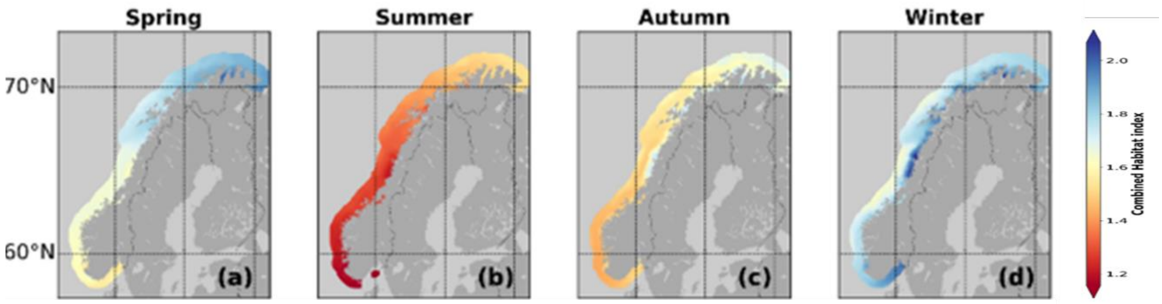

Figure 7: *The historical distribution of suitable habitat (CHI > 0) for Atlantic Salmon at 5m for the baseline time period (1993-2012) along Norwegian coast under three different climate scenarios.*

2.2 Projections of future biological effects

Under all future scenarios, there is seen reductions in suitable conditions of surface sea waters in the summer months with southern Norway becoming inhospitable for salmon in Southern Norway by ca. 2030 (**Figure 8**). By the end of the century, most of the coastal regions will have unsuitable surface habitat by the end of the century under the Global markets ssp585 scenario. Around 35,000 km^2 suitable habitat will be lost by the end of this century (**Figure 9**). Under the National enterprise scenario, the presently highly productive salmon farming regions and wild salmon migration pathways of the western fjords may experience unsuitable habitats by as early as 2040. Even in the conservative Global sustainability scenario, ssp126, large regions of western Norway will be impacted.

All the above analysis are based on sea surface environmental variables at a water depth of 5m. However, when we applied a deeper layer of 25m to the model, no suitable habitat loss could be observed (figure not shown).

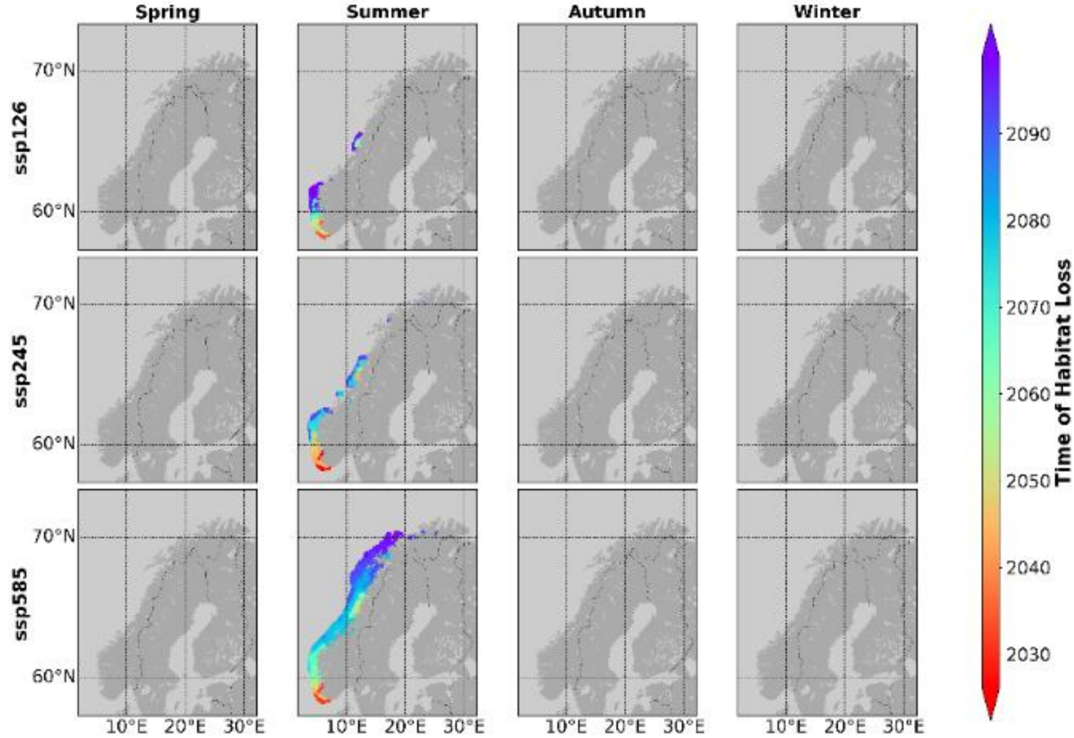

Figure 8: *The spatial distribution of the time of suitable habitat loss (ToL) for Atlantic Salmon compared with baseline period under three different climate scenarios.*

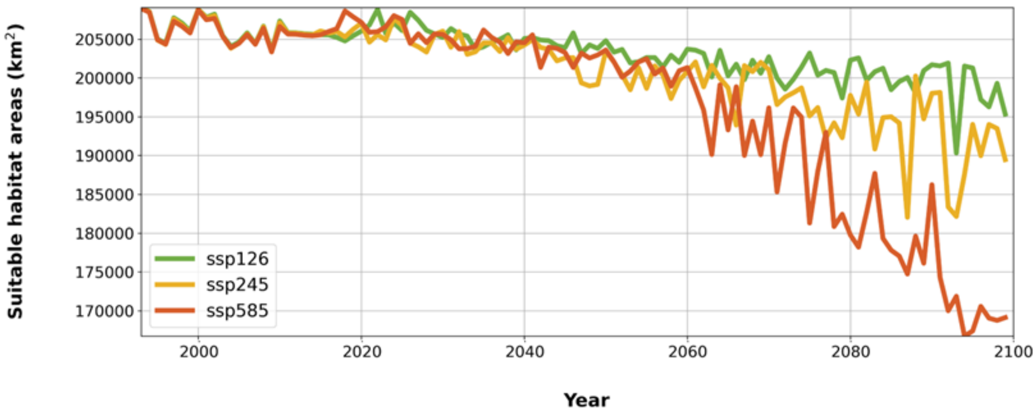

Figure 9: *Evolution of suitable habitat area (km^2) for salmon for the Norwegian coast formeans for years compared to the baseline period 1993-2012 under the three climate scenarios (ssp126, ssp245, ssp585).*

3.1 Social-ecological vulnerability

From a wild salmon perspective, this study highlights that the habitat space for salmon will become constricted. Although salmon will be able to operate in deeper waters, away from the inhospitable surface ocean, the projected changes in ocean conditions to enable passage and feeding may impact on salmon behaviour and population success. Regarding salmon farming, it will constrict some farm operations, demanding that the fish be kept at greater depths and also modifying the threshold for oxygen demand related to stocking and feeding operations, both have a large local effect on AGI due to increases in oxygen consumption. New opportunities for farmin will become available in northern regions. However, it is essential that licenses and practices are such that operations do not esacerbate climate change indicators, limiting both farmin operations and the carrying capacity of the supporting fjords and coastal systems

Storyline Contact

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