NE Atlantic & North Sea - Nature-based Solutions along the Norwegian Coast: Inter-relationships among kelp and sea urchins

Storylines 1, 2, 3

NBS 1 EFFECTIVE RESTORATION

NBS 2 EFFECTIVE CONSERVATION

NIH NATURE-INCLUSIVE HARVESTING

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FutureMARES

Introduction

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

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

NBS/NIH regional context

Blue Forest Ecosystems (BFE) in Norway have been promoted as potentially powerful NBS/NIH (Nature-inclusive Harvesting). They provide a wide array of services and offer opportunities to mitigate and adapt to climate change (Frigstad et al. 2021, Portner et al. 2021). They are likely a significant carbon sink (Filbee-Dexter et al. 2019), and the ongoing recovery of kelp in previously sea urchin grazed areas in northern-Norway linked to climate change and shifts in range expansions of urchin predators. This provides a golden opportunity to study management actions needed to promote and maintain these BFE services in different climate settings. The kelp *Laminaria hypoborea* (Fig 1) is a brown seaweed that forms the primary canopy of subtidal kelp forests and is the most widely distributed kelp species in the Northeast Atlantic, extending from Portugal in the South to Russia and Svalbard in the North. It covers approx. 8000 km^2 along Norways coasts (Gunderson et al. 2021) where it is found as far east as Oslo Fjord (Nyhagen et al. 2017). These coastal macroalgal ecosystems provide a wide array of biodiversity and ecosystem services, support coastal fisheries and larger ecosystem functions.

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Regime shifts and fluctuations are underway between opportunistic and invasive seaweeds as well as the interplay between urchin grazing, crab and fish populations, climate and environmental change and macroalgal distribution. Stressors are a complex interplay between exogenic (e.g. climate change, invasives) and endogenic (e.g. harvesting, eutrophication, hydrological control, land-use derived material). *Laminaria hypoborea* is recovering after years of excessive pressure, starting in the 1970s, from Urchin grazing in southern to mid-Norway leading to urchin barrens (Rinde et al. 2014). Since the 1980´s, *S. droebachiensis* has retreated northwards along the Norwegian coast to 67N (Rinde et al. 2017) although populations are still found in some Norwegian fjords (Nyhagen et al. 2017). Following an explosive increase in population in Southern and mid-Norway due to reductions in fish predation.

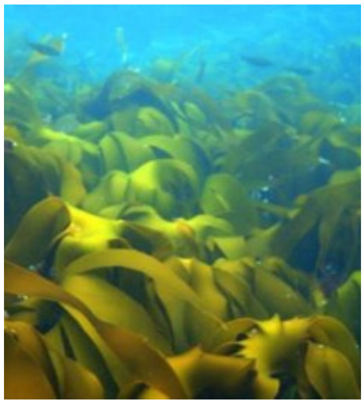

Figure 1: A thriving tangle kelp ecosystem © Eli Rinde

Services provided by these ecosystems include:

- Regulating services: carbon sequestration, water quality improvement, ocean acidification buffering
- Provisioning Services: coastal fisheries, sea food and relevant products from aquaculture, fertiliser, agar, pharmaceuticals
- Cultural services: coastal and marine tourism (fishing, diving), culture heritage, sense of place, aesthetic values, educational values
- Supporting services: biodiversity, fuelling adjacent habitats

This Storyline examines the interplay between climate change, terrestrial nutrient control and deliberate urchin management in restoring kelp ecosystems (NBS1). The goal is to identify optimum conservation areas for kelp ecosystems (NBS2) and evaluate the deliberate management of urchin grazers on these systems to promote their sustainability. Finally, sustainable harvesting opportunities (NIH) for both kelp and sea-urchins are explored.

Projected impacts of climate change

Kelp ecosystems are anticipated to be directly sensitive to warming, ocean acidification, coastal darkening, and nutrient supply, including eutrophication. These processes will directly affect kelp species as well as on their grazers resulting in non-intuitive, ecosystems responses. Our initial study will evaluate the temperature control on the distributions of tangle kelp and green urchins. Temperature projections for three different kelps systems along coastal Norway are shown in Figure 2. *L. hypoborea* has been estimated to occupy habitat space within temperature ranges from -1.4 to 18 (winter) and 21.2 (summer); salinity minimum of 6.6 and max ice depth of 0.6m (Assis et al. 2017).

The critical upper limit for the normal development of *S. droebachiensis* larvae is 10°C (Stephens 1972). This temperature also corresponds to the optimal for gonad development and growth (Siikavuopio et al. 2006, 2012). Ocean acidification negatively affects many aspects of the urchin life cycle including larval survival and settlement success (Dupont et al. 2013) and composite growth and development endpoint has been established at pH 7.75 (Bednarsek et al. 2021; and references within).

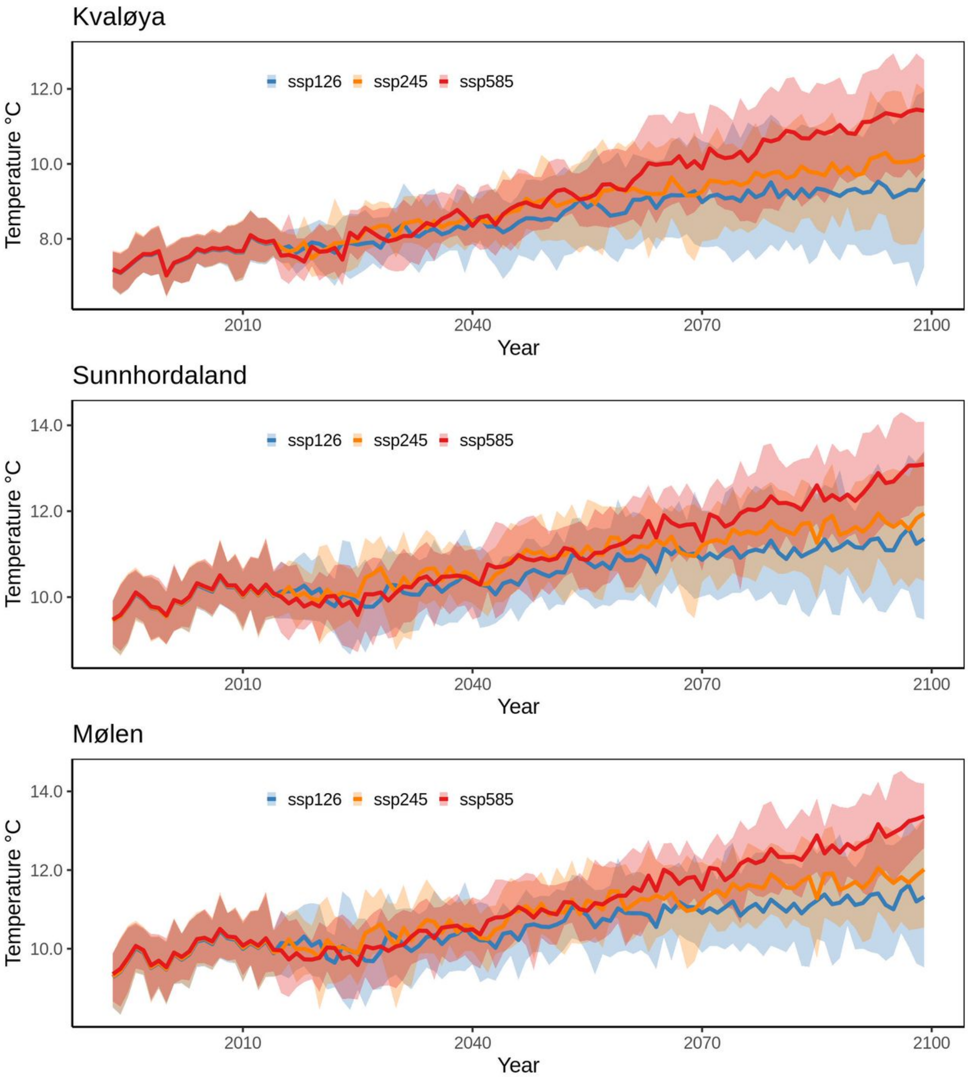

Figure 2: Surface seawater temperature projections for kelp systems in northern Kvaløya (SL1 Kelp reforestation and SL3 Urchin harvesting), mid-Norway Sunnhordaland (SL3 Kelp Harvesting) and southern Norway Mølen (SL2 Kelp ecosystem protection).

Scenarios describing future society and economy

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

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

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

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

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

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

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

Figure 3: Representation of three, broad scenarios to be regionalised to guide activities such as model simulations in FutureMARES project. © FutureMARES project

FutureMARES research needs

A transparent process towards rebuilding marine life is required to accelerate policy development and co-create conservation science around NBS/NIH. To ensure international transparency and comparability, we will ensure that the project It is unclear if the present regulatory and policy framework is suitable to facilitate appropriate actions to maximise blue forest ecosystem services (BFE) under projected climate change. There is a need for a more proactive adoption and more intense efforts to conserve, restore and sustainably harvest BFEs. Restoration is an emerging management strategy to reverse loss of kelp forests. However, measures and efforts needed to achieve successful outcome and to maintain restored kelp are not well understood in transitional areas with respect to climate change. There is a pressing requirement to understand how BFE structure and functioning in Norway are changing due to climate change and endogenic pressures in order to facilitate informed management practices. The sensitivity of single species and functions to climate drivers is often a good, initial guide to evaluate potential future BFE distributions. Climate change vulnerability, alone, may not be sufficient to identify optimal solutions for BFE and a more complex ecosystem approach will enable sensitivity studies to multiple stressors, regulation and industrial activity. There is a need to advise management practices to best reduce susceptibility and/or enhance resilience of BFEs and their services to climate change.

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

- **T1.1** Collect distribution and habitat data for kelp and sea urchins;
- **T1.2** Analyse the biological traits of kelp ecosystems and their associated species;
- **T1.4** Regionalise FutureMARES PESTLE scenarios based on engagement of stakeholders;
- **T2.1** Extract hindcast and projection data from CMIP6 archive and downscaling models to understand climate threats to Norwegian coastal help ecosystems;
- **T2.3** Identify hotspots and refugia for Kelp, Urchins and Crabs along Norwegian Coast
- **T3.1** Examine the impact of nutrients and ocean darkening on ecosystem structure and function by performing mesocosm experiments;
- **T3.2** Collect local specimens of model species for others for common garden / latitudinal comparisons of kelp physiology and climate responses
- **T4.1** Develop a kelp module for Norwegian Coast to make climate projections of shifts in distribution;
- **T4.4** Develop kelp-urchin benthic ecosystem module for Norwegian Coast to perform projections of restoration / sustainable harvesting scenarios;
- **T5.1** Perform climate risk assessment using biological traits informed by expert knowledge of the species and ecosystem
- **T5.2** Analyse ecosystem service supply and examine risks under climate scenarios;
- **T5.3** Perform Socioecological climate risk assessments
- **T6.1** Produce climate readiness maps
- **T6.2** Analyse community-based adaptation opportunities
- **T6.3** Bayesian belief setup and analysis to identify opportunities and challenges for NBS/NIH in relation to management strategies for climate-ready regulatory and industrial investments
- **T7.1/8.1** Communicate FutureMARES results to Norwegian Environmental Ministries and local stakeholders including engagement activities for T5.1 & T1.4

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References

Assis J, Araújo MB, Serrão EA (2017) Projected climate changes threaten ancient refugia of kelp forests in the North Atlantic. Glob Chang Biol. 24(1): e55-e66. doi: 10.1111/gcb.13818.

Bednaršek N, et al. (2021) Synthesis of Thresholds of Ocean Acidification Impacts on Decapods. Front. Mar. Sci. 8:651102. doi: 10.3389/fmars.2021.651102

Dupont, S, et al. (2013) Long-term and trans-life-cycle effects of exposure to ocean acidification in the green sea urchin Strongylocentrotus droebachiensis . Mar Biol 160:1835–1843. https://doi.org/10.1007/s00227-012-1921-x

Filbee-Dexter K, et al. (2019) Carbon export is facilitated by sea urchins transforming kelp detritus. Oecologia. https://doi.org/10.1007/s00442-019-04571-1.

Frigstad et al. (2021) Blue Carbon – climate adaptation, CO_2 uptake and sequestration of carbon in Nordic blueforests, TEMANord 2020: 541. Results from the Nordic Blue Carbon Project. 2020:541.

Gundersen H, et al. (2021) Variation in Population Structure and Standing Stocks of Kelp Along Multiple Environmental Gradients and Implications for Ecosystem Services. Front. Mar. Sci. 8:578629. doi: 10.3389/fmars.2021.578629

Nyhagen FO, Hartvig C, Norderhaug KM (2018) Will altered climate affect a discrete population of the sea urchin Strongylocentrotus droebachiensis? Journal of Sea Research. ISSN 1385-1101. 132, p. 24–34. doi: 10.1016/j.seares.2017.12.001.

Portner O, et al. (2021) IPBES-IPCC Co-Sponsored Workshop Report on Biodiversity and Climate Change. Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change; IPBES secretariat, Bonn, Germany.

Rinde E, et al. (2014) The influence of physical factors on kelp and sea urchin distribution in previously and still grazed areas in the NE Atlantic. PLOS ONE. ISSN 1932-6203. 9(6). doi: 10.1371/journal.pone.0100222.

Siikavuopio SI, Christiansen JS & T Dale (2006) Effects of temperature and season on gonad growth and feed intake in the green sea urchin (*Strongylocentrotus droebachiensis*). Aquaculture 255(1-4):389-394.

Siikavuopio SI, et al. (2012) Effects of size and temperature on growthg and feed conversion of juvenilegreen sea urchin (*Strongylocentrotus droebachiensis*). Aquaculture 354-355: 27-30.

Stephens RE (1972) Studies on the development of the sea urchin Strongylocentrotus droebachiensis. I. Ecology and normal development. Biological Bulletin 142:132–144.