Climate change and bioinvasion impacts on reef & canopy-forming macroalgae and shelf fisheries catchin the southeast Mediterranean Sea

Storylines 34 & 35

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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 regional context

The Levantine basin is the easternmost ecoregion in the Mediterranean. Within the Levantine basin, the south-eastern Mediterranean (SEM) corner, represents the trailing-edge of distribution of native Atlanto-Mediterranean and endemic Mediterranean species where they are exposed to the most extreme temperature and salinity conditions in this marginal sea. Many of the species that occur in the western Mediterranean or even in the northeast (e.g., the Aegean Sea) do not occur in the SEM. This means that the native biodiversity is generally lower in the SEM. There are also very few species that are known to be endemic only to the SEM (Coll et al. 2010), among them is the canopy-forming brown algae Gongolaria rayssiae (formerly Cystoseria rayssiae) (Mulas et al. 2020). The coastal areas (coastline and shallow shelf) are mainly sandy in the south and rocky in the north.

Figure 1: A vermetid reef in north Israel; a unique and endangered ecosystem. Credit: Gil Rilov

The SEM is a hotspot for ocean warming and bioinvasions of non-indigenous species (NIS), mostly of tropical origin (Coll et al. 2010, Edelist et al. 2013, Rilov et al. 2018, Rilov et al. 2019a). Coastal waters are warming ca. four times faster than the global average, temperatures have increased by 2-3 degrees over the last three decades and hundreds of alien species have invaded in the past century and a half while dozens of native species populations have collapse or completely disappeared (Rilov 2016). Marine heatwave index analysis shows that currently the entire summer period in the SEM region can be considered as one continuous and strong heatwave that has been intensifying over the past decade (unpublished data). Invasions rates have also been accelerating in the past few decades, assumingly at least partly because of warming. There is also an increase in the synoptic systems that create extreme desiccation events in the rocky intertidal ecosystem (Zamir et al. 2018).

Figure 2: Documenting an algal beaching after a strong desiccation event on the Israeli shore. Credit: Gil Rilov

Furthermore, sea level rise is severe threat to the regional intertidal ecosystems because of the small tidal range and the topographic structure of the rocky intertidal zone in the region. Most of this zone is composed of flat vermetid reefs found in the low shore level, and they will permanently drown with only a small increase in sea level (Rilov et al. 2021). This biodiversity on this zone is highly seasonal, dynamic and is experiencing strong ecological shift, some may

be partly related to climate change (Rilov et al. 2020). On top of these global stressors, there is also a strong influence of overfishing by different sectors (Rilov et al. 2018). Other human impacts may include increase in the number and volume of desalination plants, a gradual increase in marine aquaculture (fish in cages, and macroalgae on land) and oil pollution threats, as was recently demonstrated in an extensive tar pollution event from a passing offshore tanker in February 2021.

There is growing evidence that populations of dozens of non-harvested native species have already collapsed in the past several decades on the Israeli coast (Rilov 2016). For one (sea urchin, Paracentrotus lividus) we have experimental evidence that warming may have been the main driver (Yeruham et al. 2015), while competition with invasive rabbitfish for food has probably also contributed to its extirpation (Yeruham et al. 2019). The combination of warming and bioinvasions results in major reshaping of coastal benthic communities as well as fisheries stocks, and undoubtedly changes ecosystem functions and possibly services.

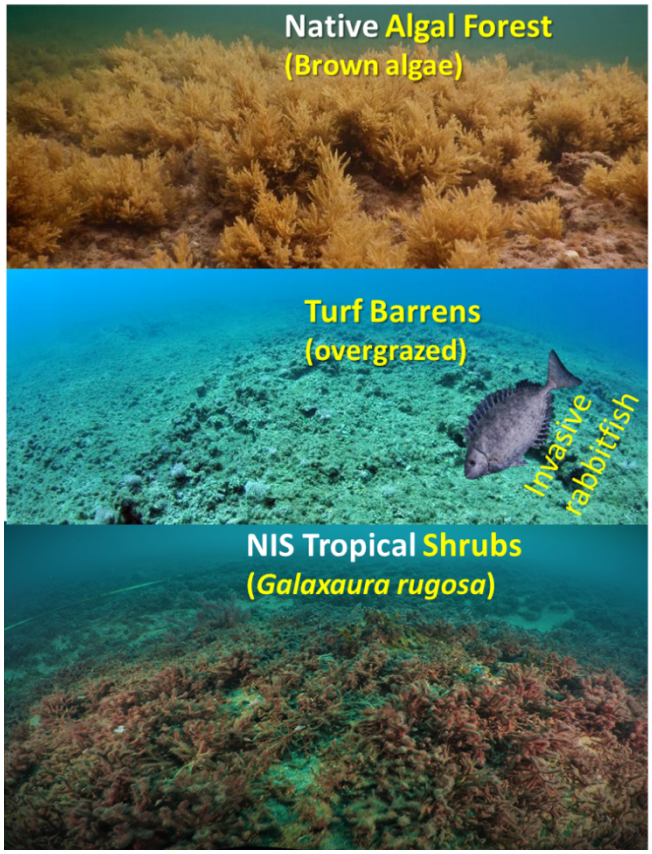


Figure 3: Current status of Levant reefs. Small and patchy native brown algal forests, domination of turf barrens and rapid takeover of NIS tropical macroalgae. Credit: Gil Rilov

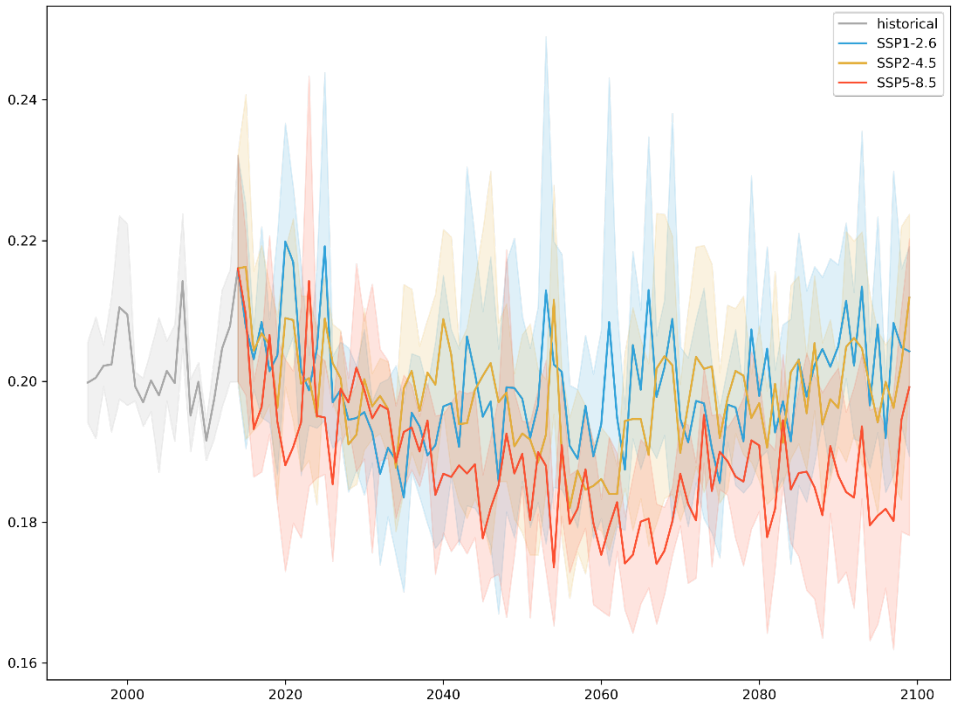
A decade of surveys indicated that intertidal and shallow reefs communities, as well as trawl catch composition, have been heavily transformed from their original ecological state and will probably continue to do so (Rilov et al. 2019b). Overfishing has dwindled populations of predators and native assemblages of herbivores and fish are, in many places, dominated by alien species such as the mollusk assemblage (Rilov 2016). Macrophyte communities are dominated by turf “barrens” (probably caused by rabbitfish overgrazing) and, in many areas, there is an increasing cover of alien macroalgae, while native habitat-forming brown macroalgae, which are known to be a major reef component in the Mediterranean Sea with multiple functional roles, have very low cover, are very patchy (Rilov et al. 2018) and are also highly seasonal (collapse in early summer) (Mulas et al, under review).

In the region, functional MPAs (NBS2-conservation) do maintain greater fish communities and predator biomass but alien species are a major component inside these reserves (Rilov et al. 2018, Frid et al. 2021). Preliminary data indicates that, inside a well-functioning MPA, the macrophyte community is more diverse (although dominated by alien species) and possibly with higher biomass than in areas outside the reserve thus benthic functions may be more intact in the MPA. The question then rises, what is the role of MPAs in an area where local biodiversity is rapidly shifting by warming and bioinvasions (NBS2). Fishery catch is also becoming more and more dominated by invaders (a process facilitated by warming), some are commercially important and some become a hazard (Edelist et al. 2013). This shift appears to be driven mostly be warming water and less by competition with NIS or overfishing (Givan et al. 2018). The question then rises how should NIS be treated in the context of sustainable harvesting (NIH).

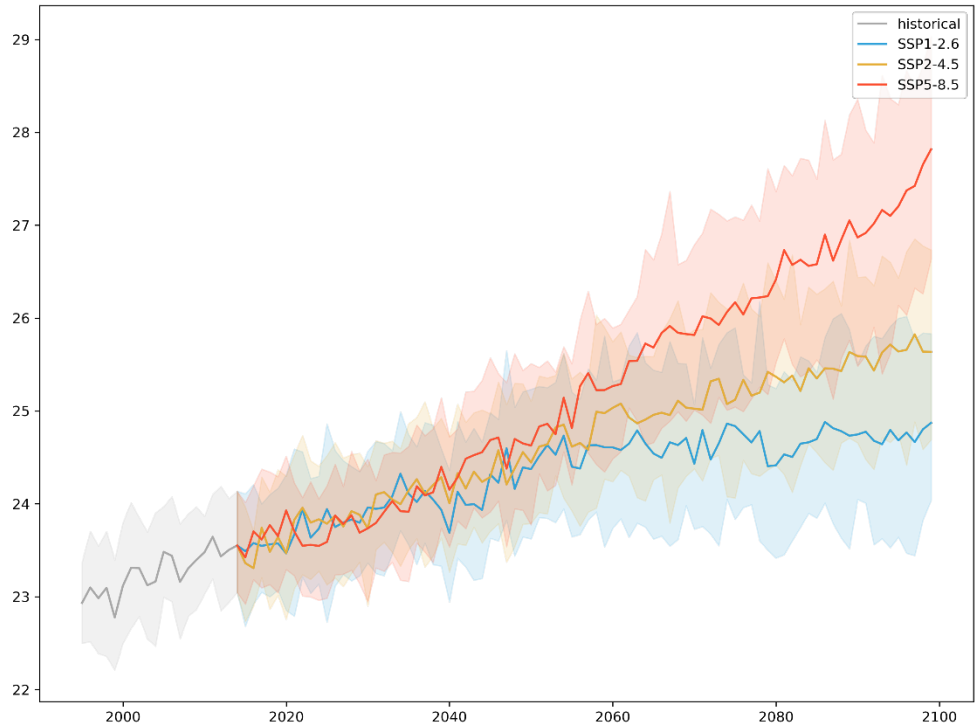
Projected impacts of climate change

There are currently no regional projections for ocean warming, acidification, extreme events or sea level rise, and climate change research (e.g., in experimental planning) relies on global projections. Therefore, models and experimental design still rely on global projections.

Initial single species and assemblages' experiments on benthic species indicate that most native species will become increasingly vulnerable and with higher risk of regional extirpation as temperature will continue to rise while most tropical aliens will be more resilient.



Chlorophyll (in mg m-3) at 5m depth



Potential Temperature (in degrees C) at 5m depth

Figure 4: Mediterranean sea climate projections. The figures were produced using trend preserving statistical downscaling (Lange, 2019) of a multi-model ensemble Earth System Model historical simulations and future projections from the CMIP6 archive trained on reanalysis datasets from the Copernicus Marine Environment Monitoring Service.

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

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

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

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 three NBS examined in this program (effective restoration, effective conservation, sustainable seafood harvesting):

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

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

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

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

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

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

Figure 5: Representation of three, broad scenarios to be regionalised to guide activities such as model simulations in FutureMARES project. Credit: FutureMARES

FutureMARES research needs

Regional physical and biogeochemical projections of climate change impacts are needed at spatial scales relevant for assessing biological impacts in offshore and rocky intertidal habitats.

Information on the risk to climate change impacts of dominant or important habitat forming native and invasive macrophytes as well as species key for fisheries is needed.

Knowledge is needed to compare the functional traits and the relative contribution of different shallow reef macrophyte communities (native, invasive, turf) to habitat provisioning (benthic biodiversity) and carbon uptake to understand if alien macroalgae can replace some of the functions and services lost with the reduction of native macroalgae by warming and invasive consumers (i.e. rabbitfish). Furthermore, an assessment is needed in the shift in biological traits and functions of NIS in fisheries catches.

More information is needed to understand if MPAs reduce the presence or the impacts of NIS on reef communities, or in fact enhance them. Specifically, we need to understand if MPAs can provide protection from overgrazing by invasive rabbitfish on habitat-forming macrophytes

- or whether, in fact, the protection offered by MPAs exacerbate the impacts of rabbitfish overgrazing. Potential mechanisms of control of rabbitfish (e.g. selective fishing) to remove the pressure of native habitat-forming macrophytes and increase their prevalence need to be explored.

A specific habitat of interest for conservation are vermetid reefs. More research is needed to understand what sea level rise will due to intertidal macrophyte communities on these reefs, as they are expected to expose them to greater grazing pressure by rabbitfish.

Finally, we need to understand if some key reef species have the potential to adapt to marine heatwaves.

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

- **T1.1**: Retrieve available environmental data, species composition data along with long-term (1990-2019) fisheries data for the Israeli coast;
- **T1.2** Compilation of published data about abundance and traits (including information on the thermal limits) of selected endemic and NIS fish and invertebrate species characteristic and their distribution in relation to depth, impacts of fishing pressure to assess shifts in community temperature index and biological traits due to bioinvasions and ocean warming;
- **T2.1** Testing in-situ vs. SST data and marine heat wave (MHW) trends for the southeast Levant;
- **T2.2** Perform a biological traits analysis (BTA) on the data for historical and new (non-native) fish species;
- **T3.1** Examine ocean warming risk to native & NIS macrophytes (seasonal metabolic variation, thermal performance curves) to understand resilience to MHW of native (e.g, Gongolaria and Sargassum) vs. NIS (e.g, Galaxaura Lobophora) macrophytes, and explore the seasonal dynamics of the macrophyte community and metabolism and the potential contribution of these habitats to Blue Carbon;
- **T3.2** Conduct mesocosm experiments to explore adaptation potential to MHWs (macrophyte and key invertebrates);
- **T4.1** Develop species distribution models (SDMs) for several native and NIS macrophytes;
- **T4.2** Compilation of GIS layers about distribution of charismatic species, such as marine mammals, seabirds and turtles, in the WMB;
- **T4.4** Develop a foodweb ECOSIM/ECOPATH model for reefs and use this to test scenarios of interaction between MPAs, NISs and fishing;
- **T5.1** Climate Risk Assessment at species and functional group level;
- **T5.2** Climate Risk Assessment of the ecosystem services level of the WMS;
- **T6.1** Mapping of MPAs, climate change and competing sectors along the Israeli coast for effective use of NBS in marine spatial planning;
- **T7.1 & 7.2** Engagement with policy makers at national, regional or EU level, and international level (IPCC, IPBES, through FishMIP collaboration);
- **T8.1** Engage stakeholders to regionalise scenarios and provide other input on project activities in NBS2 (MPAs) and NIH (future sustainable fishing)

Storyline Contact

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