Basin-wide sea turtle conservation in the Mediterranean Sea

Storyline 32

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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.

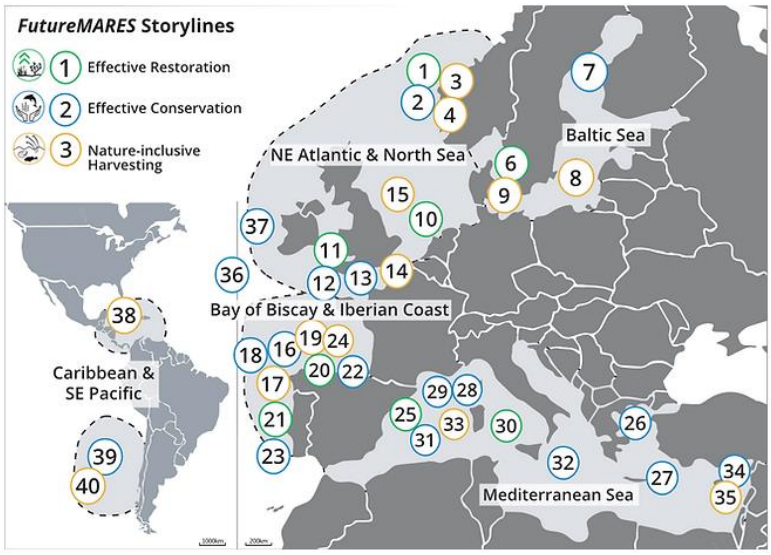


***Figure 1**: Overview of FutureMARES Storylines*

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).

Regional Storyline Context

The accelerated pace of contemporary climate change and the increased degradation of their habitats raise serious concerns on their persistence (Fuentes, et al. 2011; Cuevas et al. 2019). Sea turtles are highly mobile organisms, with their life cycle taking place in a variety of habitats. Adult individuals take long migration trips from foraging areas to nesting grounds, where females lay their nests in the sandy shores (Hays& Scott 2013, Schofield et al. 2010). This charismatic species has even distinct foraging areas for different life history stages. Thus, connections among ecosystems along different realms are critical for their persistence (Mazor et al. 2016). In addition, as ectothermic animals, their entire life cycle is closely related to climatic conditions (Poloczanska et al. 2009). All these features require conservation planning across broad spatial scales, with the potential measures implying the commitment of many nations.

Sea turtles, iconic representatives of marine biodiversity, are also considered as:

a) an umbrella species, whose protection could ensure the conservation of several species, even under changing climatic conditions (Fish & Drews 2009)

b) ecological indicators while they could reflect alterations at various environmental parameters and respond to climatic differences both in the air and sea (Aguirre & Lutz 2004)

c) keystone species as top-level consumers feeding on large quantities of marine invertebrates (Coleman & Williams 2002)

d) flagship species with hundreds of organisations and volunteers being involved in conservation actions.

The Mediterranean hosts a distinct population of loggerhead sea turtles (*Caretta caretta*), with specific demographic and genetic features, which is subjected to multiple human-related pressures (Wallace et al. 2011, Wallace et al. 2010). In addition, the Mediterranean loggerheads are considered to be adapted to the discrete climatic characteristics of the basin (Almpanidou et al. 2017), exhibiting some level of resilience to climate change (Fuentes et al. 2013). The loggerhead sea turtles are priority species in the European Union (EU) and listed in Annexes II and IV of the Habitat Directive 92/43/EEC, also being protected by several international agreements (e.g. Bern Convention, Bonn Convention, CITES etc.). Mediterranean loggerheads are considered as Least Concern by the IUCN, even though the global population is classified as Vulnerable. However, we shouldn't be complacent as their conservation status is attributable to long-term systematic efforts (Mazaris et al. 2017), highlighting the need for strengthening their protection.

Protection at multiple levels is essential and conservation measures should consider the different life stages of loggerheads and their vulnerability due to altered conditions at the various habitats that use to fulfil their needs (Casale et al. 2018). Given the nature of the species, several challenges arise in the application of systematic conservation planning under climate change but also in the establishment of proposed measures for migratory species.

The information in this document should help inform key stakeholders such as the National Natural Environment & Climate Change Agency, the Ministry of Environment and Energy,

municipalities responsible for coastal zone planning, industrial actors in tourism and fishing and NGOs involved in restoration and conservation activities.

Figure 2: Adult and hatching loggerheads turtles in Zakynthos nesting rookery, Western Greece. Credit: Charis Dimitriadis, Antonios Mazaris

Projected impacts of climate change

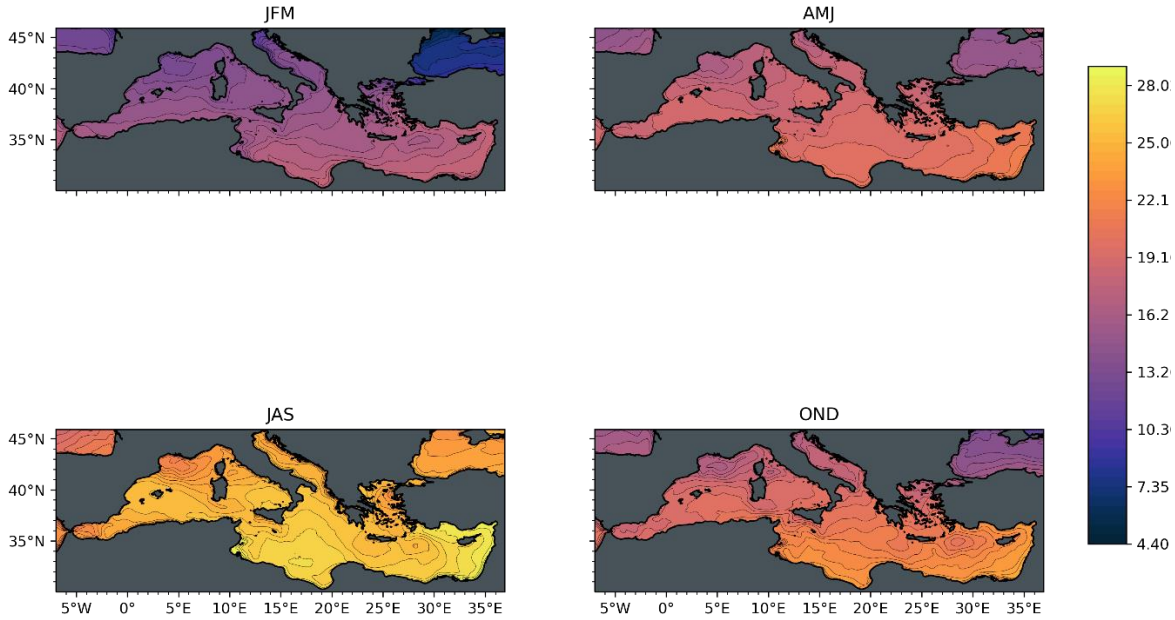
The Mediterranean region represents a climate change hotspot, with future projections revealing temperatures increases at a higher rate compared to the global average (Lionello & Scarascia 2018). Towards the end of the 21st century, the intensity and the severity of marine heatwaves are going to be increased by 4 and 42 times, respectively, with at least one long-lasting event being predicted every year, up to three months longer (Darmaraki et al. 2019). Therefore, it becomes apparent that climate change impacts pose serious and multi-faceted challenges to the conservation of marine biodiversity.

Climate change is a key component that alters biological and behavioural features but also the conditions of the sites inhabited by sea turtles, with all these aspects affecting species viability (Poloczanska et al. 2009). The altered climatic conditions have a profound impact on breeding ecology of sea turtles, increasing the risk of female-skewed sex ratios of offspring, reduced hatching success and abnormal embryonic development due to raising beach temperatures (Fuentes & Porter 2013, Laloë et al. 2017). Potential differentiations on the suitability of nesting sites have been also proposed (Witt et al. 2010), with an increase in thermally suitable nesting sites at higher latitudes [e.g. in the Western Mediterranean (Maffucci et al. 2016)]; or a risk for nesting grounds closer to the equator to approach upper thermal limits (Pike 2014). Given that range shifts of sea turtles nesting habitat have been already observed at local scales (Reece et al. 2013), there is a need to explore potential future suitability of nesting sites at a regional level.

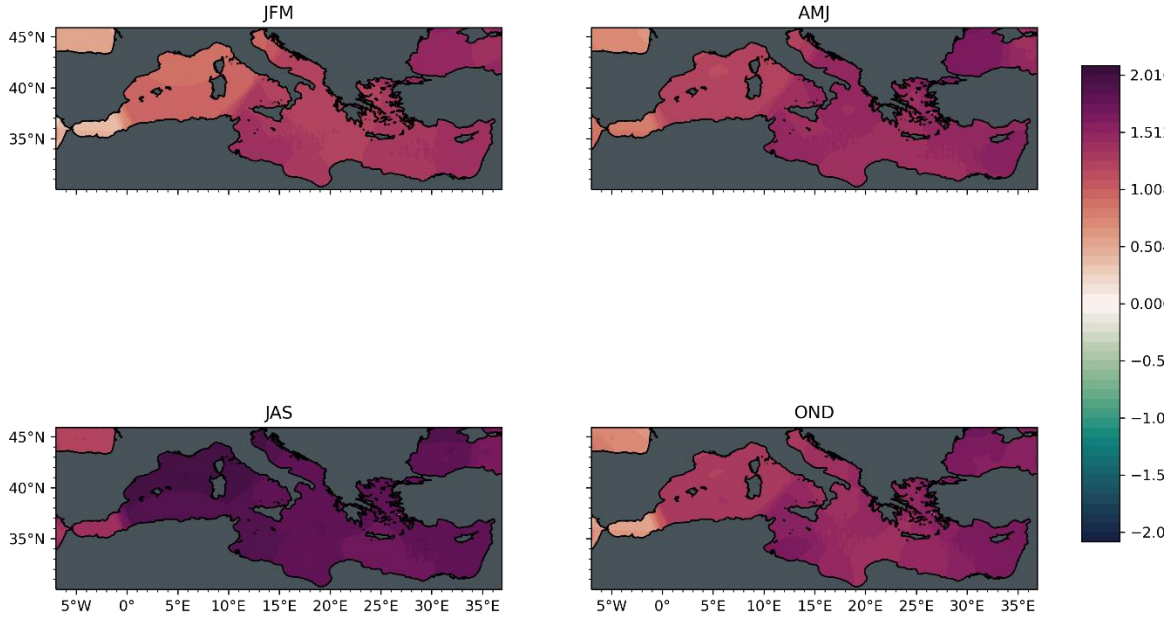
Considering that sea turtles spend most of their life within the marine realm, it is crucial to have a comprehensive view on their potential vulnerability in the marine environment, under climate change. Variability of ocean temperature could influence reproductive output [e.g. determining inter-nesting intervals (Hamann et al. 2013)], but also foraging activities [e.g. altering primary productivity, prey distribution (Poloczanska et al. 2009)]. In the Mediterranean Sea, where sea turtles experience lower water temperature compared to the tropics, increased temperatures could affect behavioural mechanisms and activities at different life-cycle stages. For example, rising temperature could reduce the length of winter dormancy (Hochscheid et al. 2007), extend the foraging period (Witt et al. 2010), and improve nesting conditions, but reduce post-

hatchling survival (Maffucci et al. 2016). In addition, the increased temperatures could lead to higher metabolic rates of sea turtles (Marn et al. 2017), impeding them to use energy reserves slowly and survive the long periods of fasting related to long distance migration (Hays et al. 2014). Raising water temperatures could also lead to intense stress because of the increase of pathogens and toxic phytoplankton (Milton & Lutz 2003).

It becomes apparent that for sea turtles with multi-realm, complex life cycles a better comprehension of the consequences of climate change at the different life stages represents a key challenge to guide management decisions and mitigation investments. The comparison of different scenarios on the future distribution of the Mediterranean loggerheads is also vital so as to identify and prioritise important areas for conservation, alleviating the uncertainty which is inherent to model projections.



Potential Temperature (in degrees C) changes in the mid future
at 5m depth under scenario SSP5-8.5



Potential Temperature (in degrees C) at 5m depth under present day conditions

Figure 3: *Climate projections for the Mediterranean Sea and surrounds. 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 developed policy-relevant scenarios with stakeholders across the world. These scenarios are based on commonly used IPCC frameworks including SSPs and RCPs.

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

In the present time the, Mediterranean sub-population of loggerhead sea turtles is listed as Least Concern by the IUCN, provided that conservation efforts are maintained. However, the species continues to face significant threats from anthropogenic pressures, including habitat loss due to coastal development, pollution, bycatch, and the impacts of climate change. Recent evidence suggests that nesting populations are increasingly being observed in the central and eastern parts of the basin, indicating an expansion from their traditional eastern distribution.

Despite protection under various European Directives and international conventions, such as the Bern, Bonn, and Barcelona Conventions, there is a lack of common monitoring and reporting practices. Additionally, inconsistencies in assessment methods persist due to the absence of standardized approaches for evaluating the five criteria (four primary and one secondary) of the Marine Strategy Framework Directive (MSFD) under the "Reptiles" species group of Descriptor 1 (D1).

Given the migratory nature of loggerhead sea turtles and the evidence of redistributive patterns in nesting and foraging areas within the region, it is apparent that international conservation efforts are more critical than ever. Enhanced cooperation and standardized assessment protocols are essential to effectively monitor and protect these populations. Ensuring the implementation of common indicators and consistent methodologies across countries will improve the ability to assess the conservation status of sea turtles accurately and respond appropriately to emerging threats.

In the future, under the GS scenario, the future of sea turtles in the Mediterranean looks increasingly positive. With a global shift towards sustainable development and improved management of marine ecosystems, critical habitats for sea turtles, such as nesting beaches and foraging grounds, are likely to be better protected. Reduced coastal development and pollution will lead to healthier marine environments, crucial for the survival of sea turtles. Educational and health investments will raise awareness and engagement in conservation efforts, directly benefiting sea turtle protection initiatives. As societies prioritize human well-being and environmental sustainability, there will be a stronger focus on reducing bycatch and mitigating the impacts of climate change on marine species. Lower resource and energy intensity will also decrease threats to both coastal and marine habitats. Overall, the collective commitment to sustainability and reduced inequality will foster a more supportive environment for sea turtles in the Mediterranean, promoting their recovery and long-term resilience.

Under the NS scenario, the outlook for sea turtles in the Mediterranean is concerning. Resurgent nationalism, regional conflicts, and a focus on domestic issues lead to fragmented and inconsistent protection measures for critical sea turtle habitats. Policies prioritizing national and regional security overshadow environmental conservation initiatives, compromising broader development goals essential for marine conservation. Declining investments in education and technology impede the progress of innovative conservation strategies and public awareness campaigns, which are vital for protecting sea turtles. Slow economic development and material-intensive consumption patterns exacerbate environmental degradation, increasing coastal development and pollution that threaten nesting and foraging habitats. Without substantial changes in policy and international cooperation, sea turtle conservation efforts will likely be severely compromised, leading to a decline in sub-population numbers.

Under a scenario of WM, sea turtles in the Mediterranean face a mixed future. Technological progress and investments in education and health support conservation efforts, but the exploitation of fossil fuels and resource-intensive lifestyles increase environmental pressures. While local issues like air pollution are managed, broader ecological challenges persist, threatening sea turtle habitats. Balancing economic growth with sustainable practices and international cooperation is crucial for their survival.

FutureMARES research needs

Given the role of marine megafauna in ecosystem functioning, we need to quantify the species vulnerability to climate change. There is also an existing gap of information on critical sea turtle

areas and on how future conservation planning should include climate change impacts. Our main research questions and objectives are to: 1) Identify tipping points for climate change on species behaviour and phenology, as for foraging activities, reproduction and migration, 2) Improve current knowledge on distribution and habitat use and their possible alterations by climate change, 3) Investigate possible links between habitat suitability and prey distributions, by developing and applying innovating process-based modelling, 4) Develop metrics on climatic stability, identify climatic refugia and assess the vulnerability of critical habitats, 5) Incorporate climate change in conservation planning and develop a 3D based Systematic Conservation Planning framework, 6) Identify areas of potential conflict between the conservation needs and human activities and detect hotspots of risk.

The outputs of the storyline provide information on how and where the expected impacts will be more severe. They also provide management guidelines for conservation managers, but also stakeholders representing other human activities (e.g. fisheries, tourism) that are connected to marine biodiversity of the Mediterranean region.

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

- Task 1.1 – Assess all available monitoring data on species distribution, occurrences and habitats for sea turtles
- Task 1.4 – Regionalise scenarios for use in storyline
- Task 2.3 – Identify hotspots of persistent climate change and regions that can serve as climatic refugia in the Mediterranean Sea
- Task 4.1 – Modelling the future distribution of potential habitats for sea turtles in the Mediterranean Sea
- Task 4.2 – Modelling of present and future distributions of sea turtles in the Mediterranean Sea
- Task 4.4 – Use of the outcomes of food-web models as input in process-based modelling
- Task 5.1 – Climate risk assessment for Caretta in the Mediterranean Sea
- Task 6.1 – Provide maps of climate readiness in current and future important sea turtle areas in the Mediterranean Sea
- Task 6.2 – Assessment of the potential socio-economic benefits of the proposed important sea turtle areas
- WP7 – Co-development of the storyline with relevant policy makers
- Task 8.1 – Dissemination of the results to national and regional stakeholders, and the international scientific community
- Task 8.2 – Engage relevant stakeholders on the benefits (and costs and trade-offs) of establishing the proposed important sea turtle areas in the Mediterranean Sea

Figure 5: Monitoring sea turtles on the sea. Credit: Mazaris research Group

Figure 6: Protection cages of sea turtle nest in Zakynthos Island, Western Greece. © National Marine Park Zakynthos

2. Research conducted

We focused on quantifying and projecting possible climate change impacts on highly migratory marine megafauna. The development, testing and application of spatially explicit methods was conducted, concerning species distributions, movement, energy budgets, and connectivity. The research aimed to contribute to the conservation challenges posed by climate change, emphasizing the importance of delineating the spatial distribution of at-risk species and their interactions with critical and dynamic habitats across different stages of their life history.

We explored the use of alternative types of data, tools, and monitoring protocols to deliver critical information for delineating the spatial distribution of marine megafauna. We also employed different modeling approaches, including statistical distribution models, novel mechanistic models and systematic conservation planning approaches to examine habitat use and potential climate-driven changes in distribution and provide adapted conservation guidelines.

2.1 Projected shifts in sea turtles foraging habitats

Future projections for loggerhead sea turtles showed that several important foraging areas for both juveniles and adults are expected to maintain their climatic suitability in the future. However, our findings indicated a possible westward shift in part of the foraging areas of loggerhead sea turtles in the future (Chatzimentor et al. 2021).

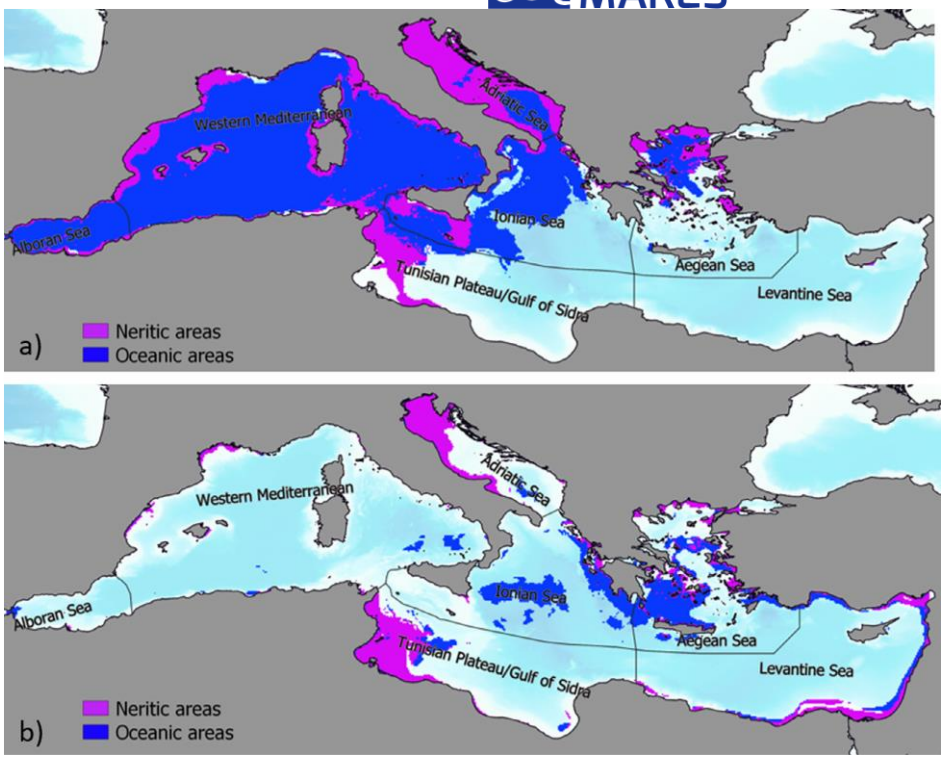


Figure 7: The projected distribution of foraging grounds of (a) juvenile and (b) adult loggerhead sea turtles, Caretta caretta , under present (1991–2020) climatic conditions across the Mediterranean Sea. Neritic grounds are colored in purple, while oceanic ones are colored in blue. Marine ecoregions are delineated by black lines.

2.2 3D climatically suitable foraging areas of loggerhead sea turtles under climate change

The above findings were validated when using depth-specific climatic data obtained from the FutureMARES project, at three distinct depth levels (5m, 25m, and bottom temperatures) of the Mediterranean Sea. Critical foraging areas for both juvenile and adult loggerhead sea turtles predominated in the central (North Adriatic Sea, Tunisian plateau) and the western Mediterranean Sea (Balearic Islands, Gulf of Lions) across all depth layers. Projections indicated a westward shift in climatically suitable areas for adult turtles, whereas crucial 3D climatically suitable foraging zones for juveniles were projected in the Adriatic Sea (Chatzimentor et al. in press).

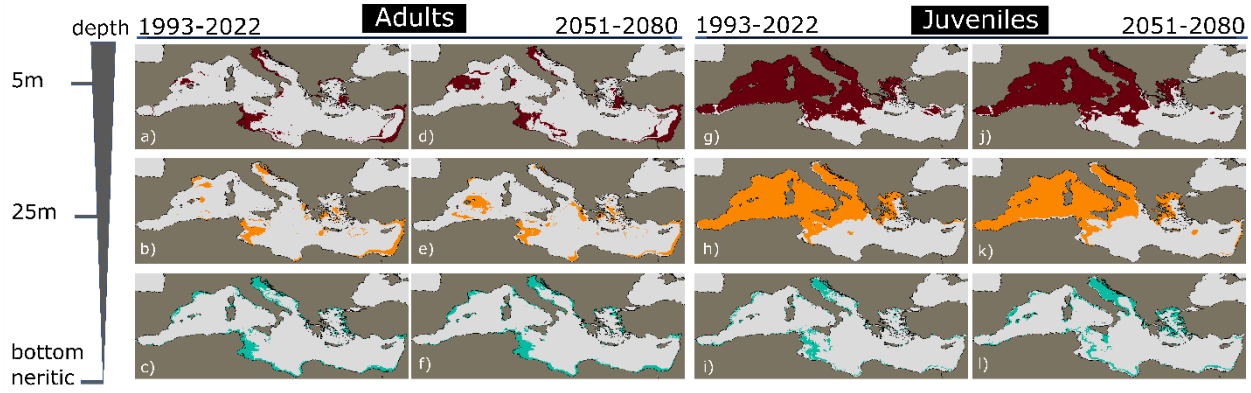


Figure 8: Potential distribution of climatically suitable foraging areas for 5m, 25m and neritic bottom habitats for adult (a-f) and juvenile (g-l) loggerhead sea turtles under present and future conditions in the Mediterranean Sea.

A general potential decrease in climatic suitability was projected for the southeast habitat range edges of the species, which aligns with climate change induced shifts in abundance, raising concerns about the potential reduction in juvenile abundances in these areas.

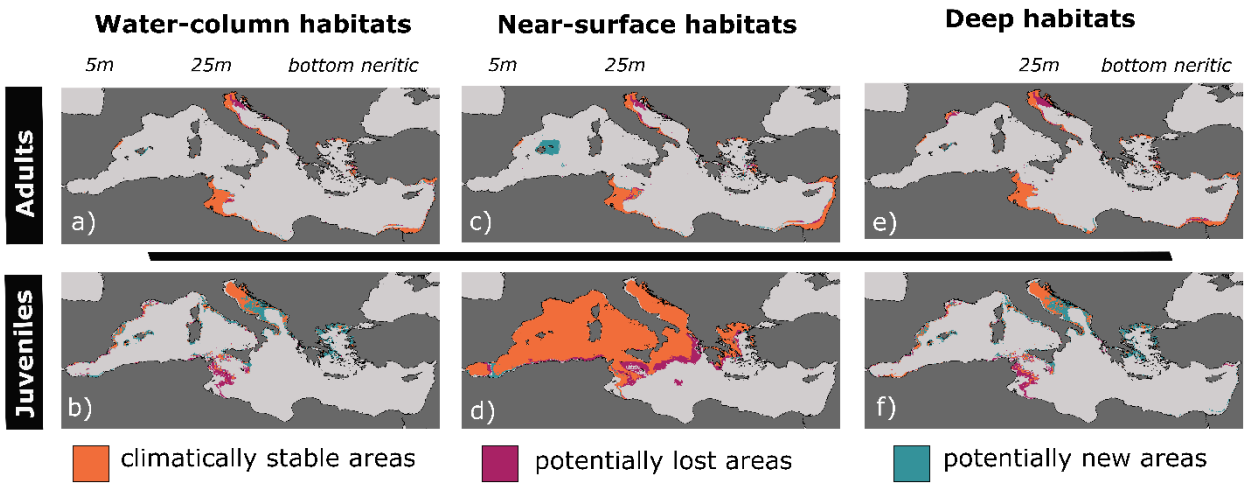


Figure 9: Potential distribution of climatically suitable 3D water-column, near-surface and deep habitats for adults (a,c,e) and juveniles (b,d,f). Climatically stable areas are indicated in orange, areas that will potentially loss or gain their climatic suitability in the future are indicated in magenta or blue respectively.

2.3 The impact of climate change on ocean currents and its potential consequences to the migration routes of sea turtles

We spatially delineated optimal routes, in form of paths and corridors that minimize exposure to sea currents for loggerhead sea turtles. The analyses revealed that the species do not explicitly take advantage of ocean currents to facilitate long distance migrations and reduce energetic demands. The modifications in sea currents patterns due to climate change are expected to minimally alter the species migration routes in the future. Incorporating connectivity assessments, such as this work, to conservation planning approaches is crucial for future conservation design under climate change (Petsas et al. 2023).

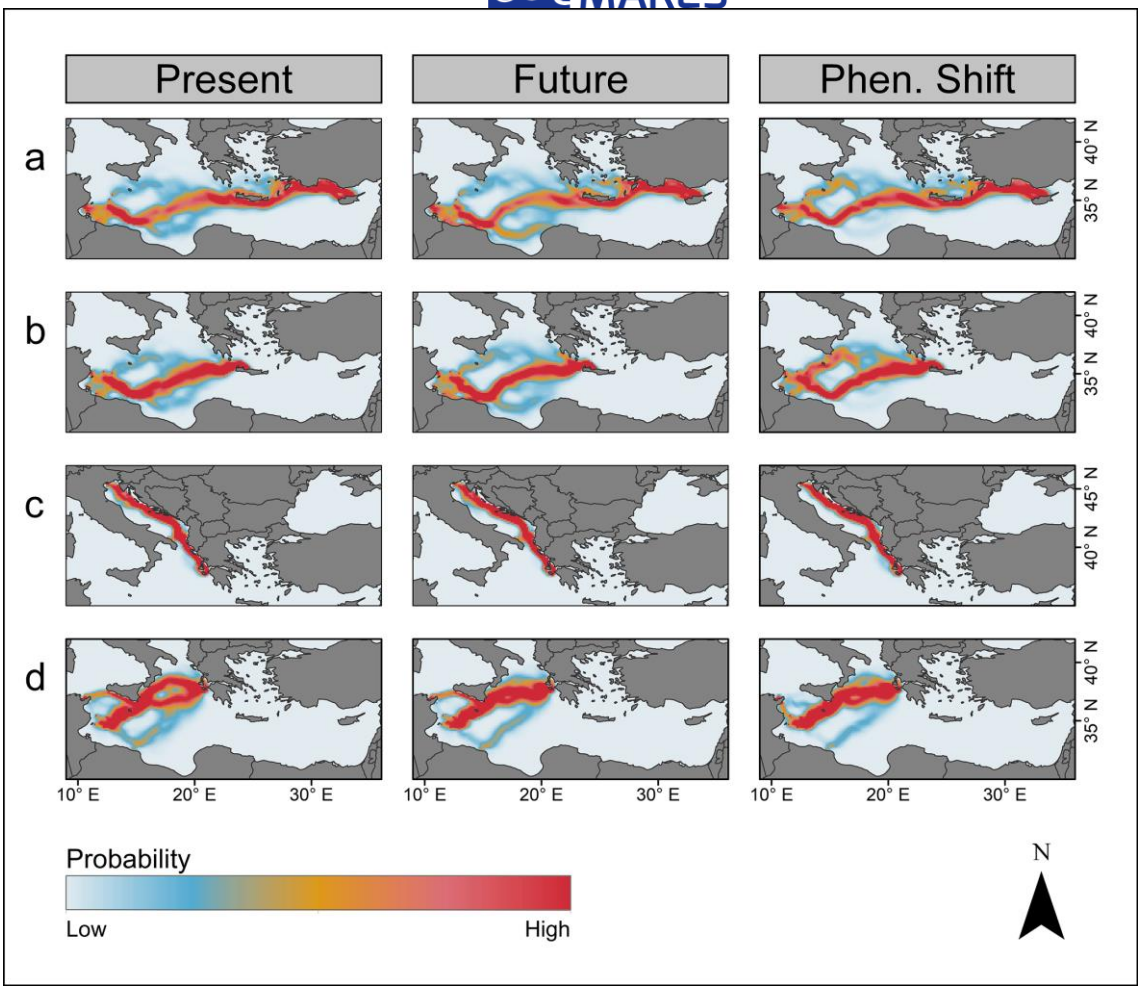


Figure 10: Optimal corridors derived from randomized shortest path (RSP) algorithm for three different climatic conditions. Each row corresponds to a pair of foraging –breeding areas. Cell values indicate probability that an individual traversing between the areas passes through it.

2.4 • Mechanistic models as an accurate tool of species distribution modelling

We developed and applied innovative modelling approaches which incorporate process-based information of sea turtles in evaluating population dynamic responses to climate change. High complexity mechanistic models provide novel insights in species distributions modelling under climate change.

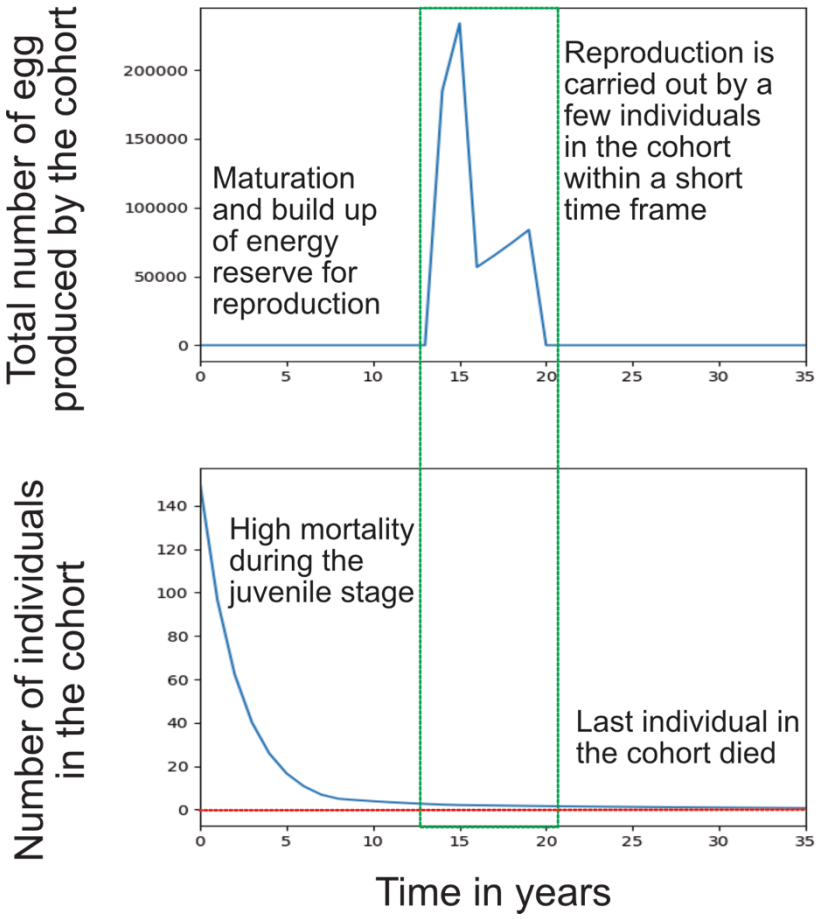


Figure 11 Example outputs from the DEB and Pop model. The top graph shows the egg production for one cohort as the years passed and the individuals within it mature. The bottom graph shows the size of the cohort, from the initial recruit to the last individual. The green box shows the reproductive output for this cohort, and how many individuals actually make it to this period. The various text highlight different phases for the cohort dynamics.

2.5 Holistic spatial conservation planning under climate change

We conducted a systematic conservation planning analysis to delineate critical areas for the loggerhead sea turtles both on land and in the sea in the Mediterranean basin. We considered different stages of the species life cycle (juveniles and adults), significant breeding and foraging habitats, and cumulative pressure indices to provide a holistic and long-term planning, including climate change impacts. Climate niche modeling was conducted for the projection of current and future distributions of nesting beaches in the Mediterranean Sea. We further considered the suitable foraging areas for juveniles and adults at three distinct depth levels (see section 2.2). A cost layer was further generated for both coastal and marine realms by considering a number of alternative human activity layers. This cost layer was used to incorporate considerations into planning, helping to identify areas where conservation efforts can achieve the greatest impact at the lowest cost.

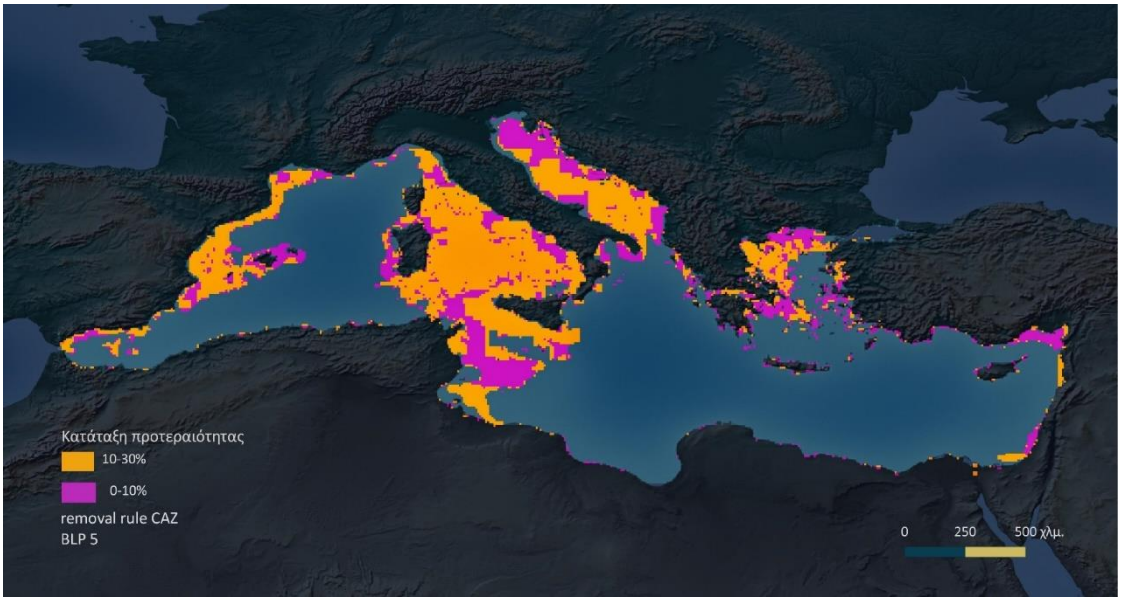


Figure 12: Priority areas for the conservation of loggerhead sea turtles in the Mediterranean Sea. Very high priority areas are highlighted in purple, while high priority areas are indicated in orange.

Alternative prioritization analyses, with different parameterizations, were run in Zonation to determine high-value areas for the species, covering the 10% and the 30% of the total area. The prioritization solutions exhibited similar patterns, revealing a coherent network of high (30%) and very high (10%) priority conservation areas. While this analysis confirmed known habitats used by the species throughout the basin (like the Greek coasts), it also highlighted new critical areas for the species (e.g., the Tyrrhenian Sea). Our results can be used to support the network of marine protected areas in the Mediterranean Sea and guide targeted policy development for the species (Mazaris et al. 2023).

Storyline Contact

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