Diadromous specie and marine-estuarine opportunists in the North-East Atlantic Ocean, including transitinal and upstream waterss

Storylines 16, 17, 18 & 19

Authors

Henrique Cabral
Chloé Dambrine
Hilaire Drouineau
Anaïs Janc
Patrick Lambert
Géraldine Lassalle
Mario Lepage
Jérémy Lobry
Maud Pierre
Eric Quinton
Benjamin Weigel

(Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement)

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 (Figure 1). 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.

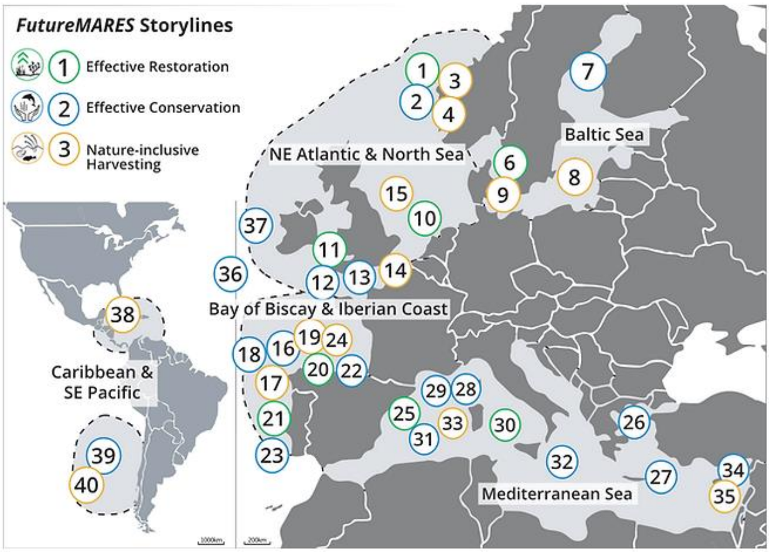


***Figure 1**: Overview of FutureMARES Storylines*

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

Diadromous species perform their life cycle between ocean and rivers with mandatory migrations between the two domains (McDowall 1988), and marine-estuarine opportunist (MEO) fish are species entering estuaries searching for nursery areas with high food availability, suitable environmental conditions for a rapid growth and refuge from predators (e.g. Lefcheck et al., 2019).

Migratory resources, especially the ones connecting land to sea, have a unique ecological function, contributing to the functioning of various systems in their lifetime. In terms of nutrient regulation, diadromous species bring nutrients of marine origin to rivers (e.g. decomposition of spawners' carcasses) and riverine nutrients to marine food webs (e.g. predation by carnivorous marine fishes and seabirds) (Poulet et al., 2022). Beyond their ecological role, diadromous species and marine-estuarine opportunists are also highly valuable for commercial and recreational fisheries, with crucial interconnections between domains for their production (e.g. Castelnaud et al., 2011, Le Pape et al., 2003). But most of all, their complex and unique life cycle make them charismatic and emblematic species of high cultural, almost spiritual value, difficult to monetarise (e.g. Liebich et al. 2018).

In the North-East Atlantic region, the species of main interest are shads (*Alosa alosa* and *A. fallax*), lampreys (*Petromyzon marinus* and *Lampetra fluviatilis*), salmon and sea trout (*Salmo salar* and *Salmo trutta trutta*), sturgeon (*Acipenser sturio*), eel (*Anguilla anguilla*), mullet (*Chelon ramada*) and smelt (*Osmerus eperlanus*) for diadromous species, while the common sole (*Solea solea*), plaice (*Pleuronectes platessa*), flounder (*Platichthys flesus*), meagre (*Argyrosomus regius*) and seabass (*Dicentrarchus labrax*) are key marine-estuarine opportunist (MEO) stocks (Figure 2). In the North Atlantic, diadromous species abundances have declined dramatically from original baselines (Limburg & Waldman, 2009, Wilson

& Veneranta, 2019). Marine-estuarine opportunists as many other North-East Atlantic stocks had suffered from overexploitation but now show signs of recovery following improved management of EU fisheries (Zimmermann & Werner, 2019).

In the North-east Atlantic Ocean, there are 550 inshore and offshore MPAs, but only 153 of these MPAs have a management plan and even less have specific actions for transient resources (Álvarez-Fernández et al., 2017). Nonetheless, preliminary modelling results tended to demonstrate that habitats favourable for diadromous species are more prevalent in MPAs than in adjacent waters (Sophie Elliott, MNHN, pers. comm.).

Figure 2: *Salt marshes and square net fishing in the Gironde estuary (south-west of France). Credit: Irstea/Cemagref*

Knowing the magnitude of the range-shift response of these functionally important species might be crucial to provide efficient adaptation to climate change for coastal and transitional waters and human-related activities, and thus long-term delivery of ecosystem services (Semmens et al., 2011). The information in this document should help inform key stakeholders such as the EU Fishery Ministry Council (e.g. quotas); NASCO (salmon); the French Biodiversity Agency (OFB) (marine, transitional waters); the French Ministry of Ecology (marine, transitional and upstream); the Fishery national committees (CNPMEM and CONAPPED) (marine, transitional and upstream respectively) with their regional offices; and the French Ministry of Agriculture (marine, transitional and upstream). At the local level: Water Agencies (marine, transitional and upstream); MPA boards (marine); and Territorial Councils (upstream).

Projected impacts of climate change

Species using the land-sea continuum across their life cycle have to face changes in continental, estuarine and marine environmental drivers carrying potentially contradictory and disconnected signals for fish species. “In freshwater environments, climate change has led to a reduction in annual river discharge (e.g., in large French rivers; Maire et al., 2019) and this trend is expected to intensify in the future (Dayon et al., 2018). Extreme events such as floods and droughts are expected to become more frequent, intense and unpredictable (Blöschl et al., 2017), along with an increase in mean water temperature of up to +1.6 °C (Bal et al., 2014; van Vliet et al., 2013).” [*Taken from Arevalo et al., 2020*]

The combined trends of increased water temperature, elevated salinity and sea level, and decreased precipitation and river flow are causing estuarine ecosystems to have more marine characteristics, particularly across southern Europe (Chaalali et al. 2013, Chevillot et al. 2016) (Figure 3). These trends are predicted to intensify in the future (Hallett et al., 2017).

In the marine domain, those changes converted into modifications in the spatial extent and dynamics of river plumes, affecting the physical, chemical and biological properties of coastal ecosystems (Gamito et al., 2016). Chust et al. (2021) provide a synthesis of the multiple occurring climate trends in the Bay of Biscay with changes in temperature (warming), mixed layer depth (deepening), and sea level (rise) that could interact with the species' marine phase. FutureMARES has made projections of physical and biogeochemical impacts of climate change in the marine and coastal region covered by this storyline, including three IPCC scenarios (SSP 126, SSP 245 and SSP 585 (for background see Deliverable Report 2.2) (Figure 4).

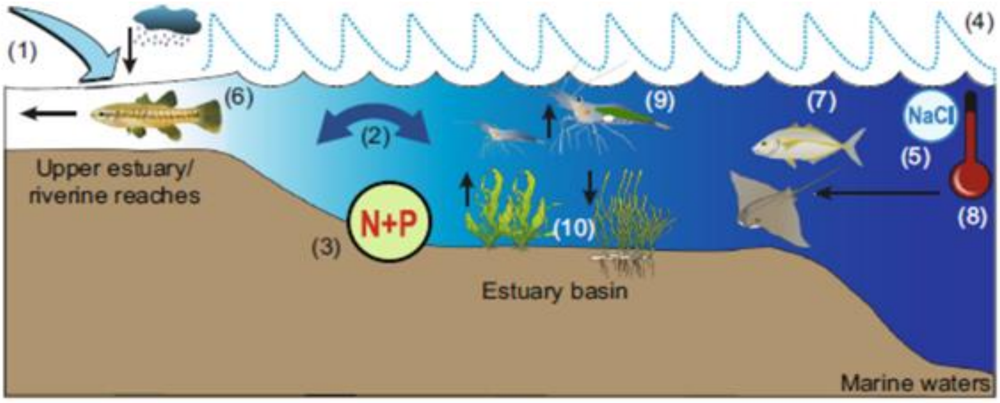
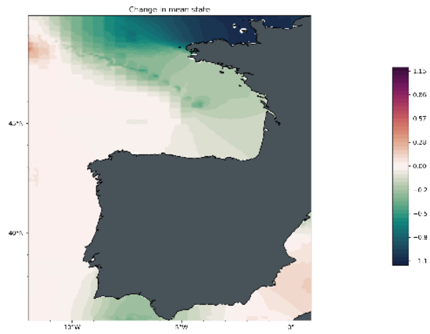
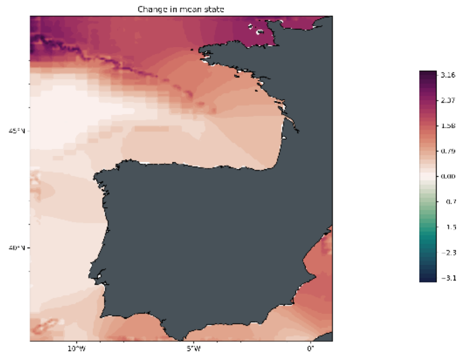


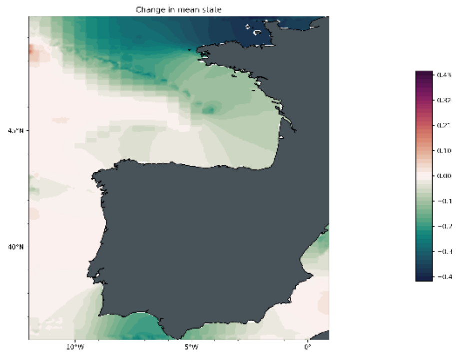
Figure 3: *Conceptual summary of predicted environmental and ecological impacts of climate change across estuaries in general (Hallett et al., 2017) (1) declining rainfall ➔(leads to) decreased freshwater flows ➔ (2) reduced riverine flushing of estuaries ➔ (3) increased retention and internal nutrient cycling. (4) Increased sea level and storm surge ➔ (5) enhanced marine influence and increased salinities ➔ (6) upstream contraction of freshwater species distributions and (7) expanded marine species distributions. (8) Increasing water temperatures ➔ (9) increased growth of ectotherms and (10) growth of macroalgae is favoured over seagrasses.*



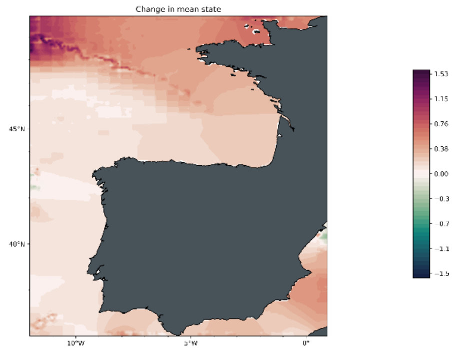
Salinity (in PSU) changes in the far future at seafloor under scenario SSP5-8.5



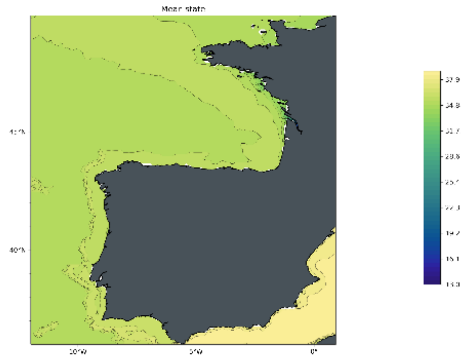
Potential Temperature (in degrees C) changes in the far future at seafloor under scenario SSP5-8.5



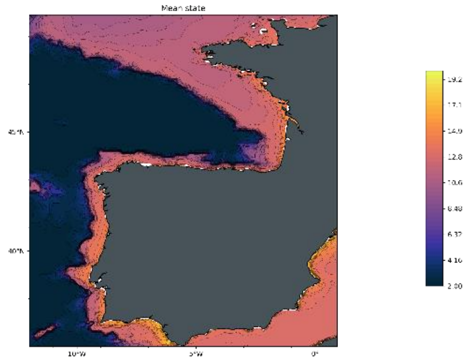
Salinity (in PSU) changes in the mid future at seafloor under scenario SSP5-8.5



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



Salinity (in PSU) at seafloor under present day conditions



Potential Temperature (in degrees C) at seafloor under present day conditions

Figure 4: *Climate projections for the Bay of Biscay 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

Credit: Momme Butenschön, CMCC.

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) (Figure 5). These scenarios were regionalised based on stakeholder perspectives (mostly INRAE scientists for this storyline) 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 5: *The three, broad scenarios that were regionalised to guide activities in FutureMARES. © FutureMARES project*

At the present time, a new EU biodiversity action plan of 30% of protected areas was launched and was adapted in a National (French) Protected Areas Strategy. France also has a National Plan in favour of Migratory Diadromous Species and a National Action Plan for Sturgeon in which some actions are devoted to the assessment of the amount of suitable habitats for *A. sturio* within the current/future MPA network. The management of MEO and diadromous species is currently regulated by the EU Common Fisheries Policy (CFP) and species management plan, including the Eel Management Plan (Eel Directive). Tourism, recreational fisheries, and other outdoor activities take place on a high level in the region and in relation with diadromous and MEO species, accompanied by heritage and traditional commercial fisheries around those species. The important cultural values of commercial fisheries is acknowledged.

In the future, in the GS scenario, marine habitat protection and conservation are in line with current policy but apply increased spatial protection (i.e. > 30% of MPAs, more areas with strong restrictions, e.g. generalized ban of fisheries, no offshore installations). This focus on protection leads to less coastal and marine tourism and more environmental protection. All diadromous species are fished at 0.8 MSY and a ban of most impacting fishing gears is in place. In contrast, the NE scenario comes with decreased levels of protection, for example by prioritizing local human communities' happiness and incomes and neglecting mitigation. Tourism areas might shrink due to climate change impacts, but strong initiatives will promote tourism locally. MSY is in place for all the species with artisanal and industrial fisheries. Under the WM scenario, protection is also decreased with a priority on economic activities to develop high-tech solutions to certain environmental issues. Touristic activities are decreased due to climate change impacts, and no investment occurs due to low return to the global economy. Industrial fisheries apply MSY for all species with a high demand for aquaculture. Small-scale fisheries diminish and there is a loss of traditional know-how in both the NE and WM scenarios, with these losses being most severe in the WM scenario.

FutureMARES research needs

Given the observed and projected impacts of climate change, managing stocks migrating over long distances and using multiple habitats across the land-sea continuum is a challenge (e.g. Danto, 2021; Ouellet et al., 2022) for which priority research needs were identified below:

- Improve knowledge on their distribution at sea, and along the land-sea continuum
- Assess their overall vulnerability to climate change based on their life-history traits as long as the vulnerability of essential habitats
- Evaluate the impacts of climate change in terms of spatial distributions
- Analyse the importance of connecting habitats in the specific range-shift responses
- Test various scenarios of NBS implementations for effective conservation and sustainable exploitation
- Provide first steps towards management measures considering their migratory nature

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

- **T1.1** CTI analysis applied to the Gironde estuary community and other estuaries across Europe
- **T1.2** CWM, RLQ and HMSC analyses running on the Gironde estuary community
- **T1.4** Regionalised scenarios were developed for the storyline

- **T2.3** Advance niche-based modelling to assess range-shift responses and their dependences to the consideration of multiple habitats in models for diadromous and marine-estuarine opportunist species
- **T5.1** Climate risk analyses (CRA) for marine-estuarine opportunist species and habitats
- **T6.1** Meta-analysis of locations of either climate change hotspots, brightspots or refugia for marine-estuarine opportunist species
- **T8.1** Engage relevant stakeholders on the benefits (and costs and trade-offs) of NBS implementation

2. Research conducted

- The fish community of the Gironde estuary across the last decades (T1.1 and 1.2)

Analysing the entire estuarine fish community overt time, we observed a significant increase of the CTI (Community Temperature Index) overt time, mainly through deborealisation (75%, Figure 6). The CTI change was estimated to 0.043 and the SST (Sea Surface Temperature) elevation to 0.015 (both trends being significant).

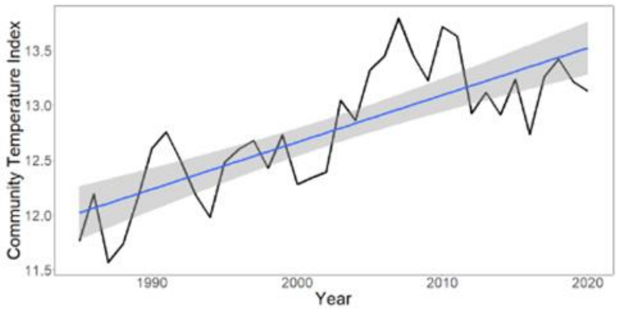


Figure 6: *Evolution of the CTI between 1985 and 2020 for the fish community of the Gironde estuary*

It seems that warming leads to a disappearance of the cold affinity fish species in the Gironde estuary. The seven species marked by a decrease in their abundance in the community were *Platichthys flesus (D)*, *Pomatoschistus minutus*, *Gasterosteus aculeatus*, *Alosa fallax (D)*, *Anguilla anguilla (D)*, and *Osmerus eperlanus (D)*. Thus, mainly diadromous fishes (D) suffer “deborealisation”. Indeed, warming plays a role in their disappearance but many other factors may exacerbate their decline as they share their lifecycle between sea and freshwater (e.g., pollution, habitat degradation).

As our fish community is a mix of marine and freshwater species, we wonder if a focus on the marine species would lead to the same trend. Indeed, maybe freshwater species could have been more sensitive to warming as they cannot “escape” from their habitat. Nonetheless, this hypothesis was not confirmed as removing the freshwater fish community (12 species) from our analysis led to the same trend: a significant CTI change of 0.04, 74% due to “deborealisation”.

Then, by investigating the community in terms of life-history traits, the main aim of our study was to compare traits over different sites along the estuarine longitudinal gradient in order to identify trait-environment patterns and potential environmental drivers of the community. Our results demonstrated a general pattern that could be related to the spatial dynamics of estuarine fish assemblages along the estuarine salinity gradient. Indeed, in our dataset, freshwater and diadromous fish, which were more abundant in upstream stations (low salinity, high turbidity), were mainly characterised by higher total length, maximum length and length at maturity, whereas the most abundant marine species associated with downstream sites (highest salinities) were mainly pelagic, zooplanktivorous and rather associated with fast life history traits. However, the estuarine environment is undergoing drastic changes mainly characterised by a 'marinisation of the environment' (mean salinity becoming higher with decreasing river flows). Thus, our results highlighted that fish assemblages would be more and more characterised by species with fast life history traits (fast growing and short-lived opportunistic marine pelagic species). This could lead to less resilient fish community or, at least, more fluctuating fish assemblages and thus very unstable estuarine foodwebs. However, estuaries are transitory essential habitats for most fish species. This means that the present results must be interpreted with caution as (1) most fish do not spend their entire life cycle in estuarine areas and (2) fish assemblages are highly transitory and fluctuating (at the seasonal scale, in relation with river flow).

- Changes in the distribution at sea for diadromous and MEO species (T2.3)

Various methods were used to assess the potential changes in species distribution at sea and connect changes in marine habitats with changes in continental habitats. The table below synthesized the main characteristics of the methods used with the papers that were published or in the process of being published.

Target species	Model	Main features (dynamic, spatial, species-based, size-structured)	Model output (biomass, abundance, P/A...)	Reference
Marine-estuarine opportunist fish species (European flounder, sea bass, common sole, plaice, Senegalese sole, and meagre)	Marine environment suitability distribution	Species-based	Marine environment suitability distribution in the form of probabilistic values and binary maps (P/A); resulting from the combination of a bioclimatic suitability distribution and a habitat suitability distribution	Janc et al., Under review

Diadromous of the Western Palearctic zone and marine-estuarine opportunist fish species, more particularly Allis shad and European flounder	Marine environment suitability distribution	Species-based	Marine Habitat suitability, P/A	Navarro et al., 2023
Diadromous species of the Western Palearctic zone, more particularly Allis shad, Twaite shad, Thin-lipped mullet, and European flounder	Marine and continental environment suitability distribution	Species-based	Probability of presence, P/A, management guidance options	Dambrine et al., 2023

Both for diadromous and MEO, technical choices were made to increase the ecological interpretation and realism of predictions under future climatic conditions. For example, for Allis shad and the European flounder, the “recurrence” approach was designed to include the main characteristics of the species life at sea (i.e. duration and biological processes taking place in this environment) into the definition of marine habitats (Navarro et al., 2023).

The main conclusion for the two diadromous species was that suitable habitat were mainly coastal and expected to experience minimal changes by mid-century, and the species may even benefit from new habitats at higher latitudes. However, the European flounder is likely to face greater challenges in the central part of its range by the end of the century, as potential spawning grounds may be threatened (Navarro et al., 2023). For MEO, including the European flounder again (the species guild remains unclear), a visible north-westward shift was predicted for all six species in our study area. However, the northward expansion was greater for ‘subtropical’ than for ‘sub-boreal’ species due to faster gravity centroid displacement shifts and faster margins shifts (Janc et al., Under review). For flounder, conclusions between the two papers converged on the decrease in the number of suitable areas at southern boundaries but not on the amplitude nor the location of lost suitable areas in coastal areas.

Also, in the scope of characterizing the marine habitat suitability for diadromous species, Dambrine and collaborators (2023) provided a concertation tool to managers and other stakeholders who might be interested on the topic of climate change impacts and land-sea continuum. This concertation tool takes the form of a decision tree comparing current population functionality with both continental and marine habitat suitability and does the same evaluation of habitat suitability coherency under future climatic conditions. Each branch of the tree leads to a management guidance to better integrate long-term issues and connectedness of suitable habitats into management practices.

- Climate vulnerability of MEO species (T5.1)

We conducted a climate risk assessment (CRA) for three species (i.e. European flounder, *Platichthys flesus*, the common sole, *Solea solea*, and the sea bass, *Dicentrarchus labrax*) while considering the effect of one nature-based solution (NBS) (i.e. conservation) and the action of nature-inclusive harvesting (NIH) on the systems under study. The assessment was conducted considering three scenarios of coupled emissions and shared social path (RCP/SSP scenarios) presented above and two time slices (2040 and 2080), each time under two circumstances (NBS/NIH on o NBS/NIH off).

NBS "Conservation" is having a positive mitigating effect (decreasing) on the risks for all scenarios and all time-slices and all taxa evaluated which is in accordance with the results for the other storylines on other groups. The NBS mitigation effects are mostly acting over on E (Exposure), S (Sensitivity) and AC (Adaptive capacity) for the bass and the sole and only on S for the flounder. The flounder was found to be the most at risk while bass and sole have a similar lower level.

NIH is having a positive mitigating effect (decreasing) for all scenarios and time-slices but only for flounder and sole. No effects are detected for sea bass. The NIH mitigation effects are only detectable for H (Hazard) in WM (World Market) in bass, S across all scenarios in flounder and E, S and AC across all scenarios in sole. The flounder is found to be the most at risk while bass and sole have similar lower levels.

- Resilience of MEO species to CC and MPA network coherency (T6.1)

A preliminary analysis of results showed that collectively MEO species seemed to be quite resilient to climate change, with quite extensive climate change refugia (climate-resilient). By the end of the century, consistently appearing refugia for this group of species covered a lot of the NW European shelf, with a large expansion from the mid-century plot. Hotspots identified in 2040-59 in SSP126 disappeared to become refugia by 2080-99. In the two higher emissions scenarios, the mid-century hotspots covered much less area, and the brightspots were more extensive.

On the suitability of the network of Marine Protected Areas (MPAs) for the conservation of MEO species, preliminary results tended towards the conclusion that understanding this network and the management measures and regulations implemented within it are hampered by the high number of MPAs, the diversity of categories, the coverage of certain sites by different MPAs, the very local management measures, and the lack of summary information on a wider scale.

- Stakeholder engagement (T8.1)

For the second half of the project, we mostly targeted other scientists working on climate change impacts on fish distribution and other ecological aspects. Three international events were identified: the ECSA conference (Spain) in September 2022, the joint SeaUnicorn - ICES workshop (Portugal) in May 2023 and the FSBI annual event (UK) in July 2023. A national event of the Association Française d'Halieutique (AFH) in June 2024 was also targeted.
For the end of 2024, we will inform the national authority in charge of the MPA network about the project results under Task 6.1.

Storyline Contact

Henrique Cabral (INRAE) - henrique.cabral@inrae.fr

Géraldine Lassalle (INRAE) – geraldine.lassalle@inrae.fr

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