A reduction of fishing effort and spatial management actions are needed to successfully recover small pelagic fish in the Mediterranean Sea under climate change

Coupling modelling techniques to predict future scenarios and alternative management options for small pelagic species in the NW Mediterranean Sea

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Introduction and aims

During the last years small pelagic fish species (SPF), such as **European sardine** (*Sardina pilchardus*) and **European anchovy** (*Engraulis encrasicolus*), have experienced **changes in their abundance, biomass and spatial distribution** in the Northwestern Mediterranean Sea (Figure 1). Different hypotheses try to explain these changes, such as:

1. An increase in **fishing impact**;
2. Changes in **environmental conditions**;
3. The recent **recovery** of some **pelagic predators** such as Bluefin tuna (*Thunnus thynnus*);
4. Inter-specific **competition for food** with the expanding round sardinella (*Sardinella aurita*).

We aimed to (1) quantify the past and present ecological and socio-economic consequences of changes in SPF population distributions on iconic predator species, their fisheries and ecosystem dynamics, and (2) identify robust future management options to achieve resilient SPF populations in order to ensure healthy populations of small pelagic fish and sustainable exploitation under climate change.

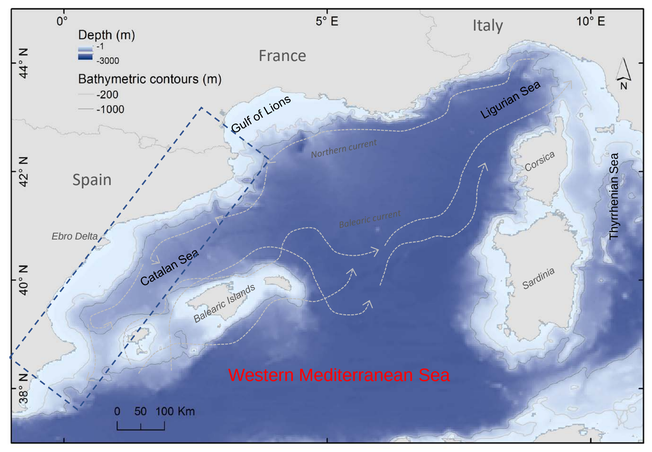

Figure 1. Study area (dashed line).

After a notable effort to collect and integrate available biological and ecological data of SPF, their predators and their fisheries, we undertook a series of statistical and mechanistic spatial-temporal modelling analyses (Figure 2).

- We tested **hypotheses of change** through spatial Redundancy (RDA) and qualitative modelling, and explored environmental effects from a temporal perspective through Random Forests (RFs).
- We **spatially predicted the distribution** of SPF species and their annual changes with Species Distribution Models (SDM, such as Boosted Regression Trees (BRTs) and Bayesian Spatial-Temporal Models (B-STMs)).
- We defined **plausible future environmental and management scenarios** to predict species biomasses, distributions and the impacts of predators, fisheries and the ecosystem using a multi-modelling platform (Figure 2).
- We linked results of the various SDM, updated Stock Assessments and Dynamic Energy Budget (DEB) models with a **spatial-temporal Ecopath with Ecosim (EwE) food-web model** (Figure 3). Models were driven with IPCC-projected environmental variables, and alternative management scenarios.

Multi-modelling platform

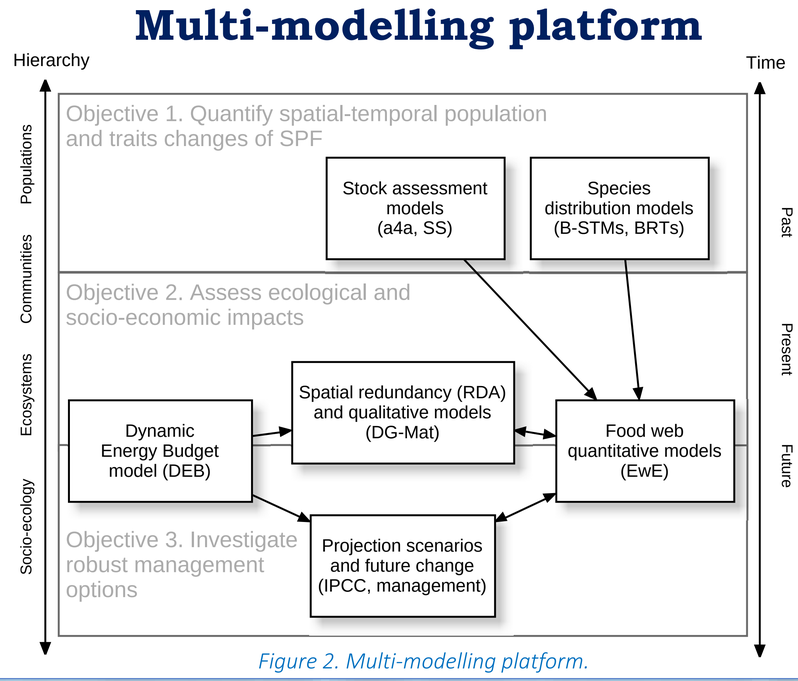

Figure 2. Multi-modelling platform.

Results

- Forecasts indicate that **both species will likely undergo a reduction in their distribution ranges due to environmental unfavourable conditions** (most relevant for sardine).

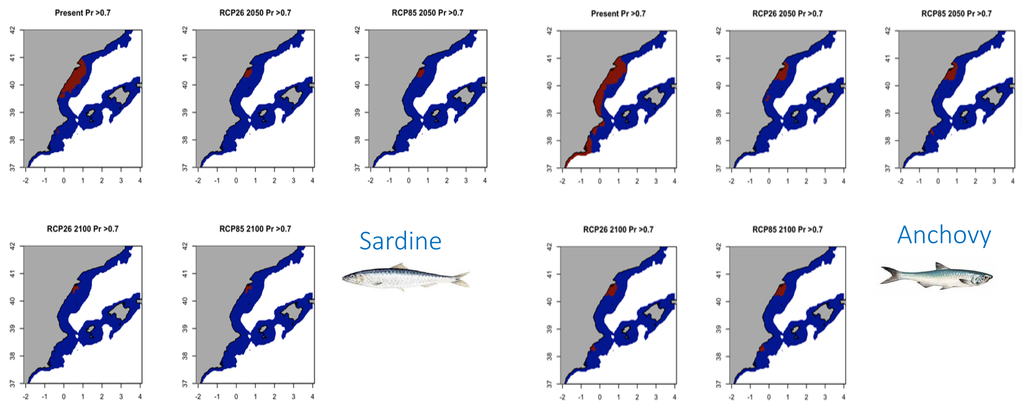

Figure 4. Predictions of the SDMs. Red areas have a probability of occurrence >0.70.

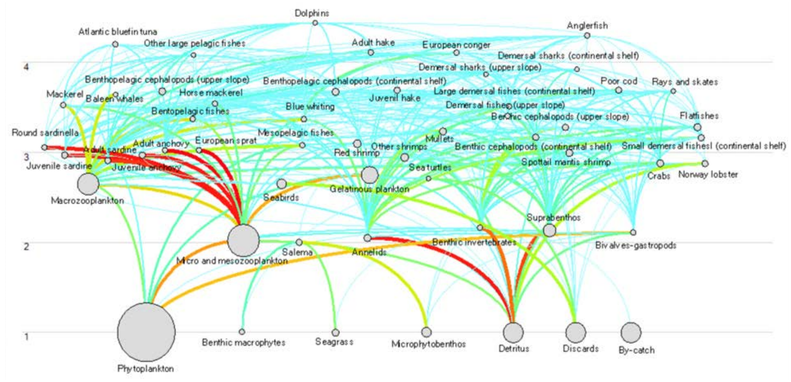

Figure 3. Food web representation of the EwE model of the NW Mediterranean.

- The deltas of the Rhone (France) and Ebro (Spain) emerge as potential "**future climate refuges**", and became our focus areas for management (Figure 4).
- **Scenarios of alternative management** highlighted that **a general reduction of fishing mortality** for anchovy and sardine (up to 50% of the historical status quo) could contribute to a successful recovery of both species, with positive impacts on predators and fisheries.
- The **establishment of a MPA** in coastal waters with restrictions to purse seine and bottom trawling could partially compensate the negative historical fishing impacts.