End-to-end projections for 21st century sardine and sardinella population dynamics in the Canary Upwelling System

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INTRODUCTION

Small pelagic fish play a key ecological role by linking plankton to top predators, and account for about half of the global marine fish catch. These stocks are most abundant in **Eastern Boundary Upwelling Systems** **EBUS** Fig. 1), with the **Canary Current Upwelling System** (CCUS, Fig. 2), off northwest Africa, standing as one of the most productive and ecologically significant. Within this system, the dominant species, **round sardinella** (*Sardinella aurita*) and **European sardine** (*Sardina pilchardus*), represent a critical socio-economic resource for the **Senegalese-Mauritanian region** (Fig. 3), accounting for ~450,000 tonnes of annual commercial landings (Braham et al., 2014).

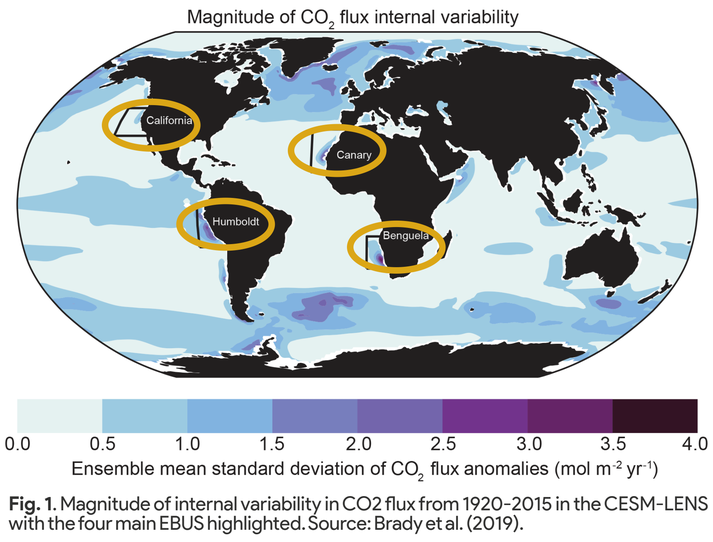


Fig. 1. Magnitude of internal variability in CO2 flux from 1920-2015 in the CESM-LENS with the four main EBUS highlighted. Source: Brady et al. (2019).

Fig. 3. Artisanal fishing landing site in Senegal (A, ©Hellio & Van Ingen) and women processing sardinella in Guet N'Dar, Saint-Louis, Senegal (B,©Hamedine Kane).

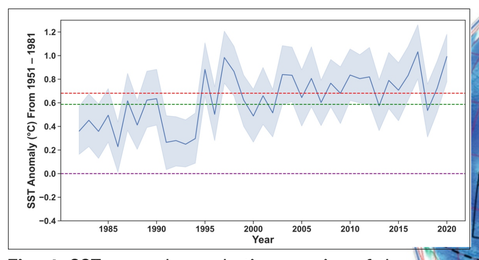


Fig. 4. SST anomaly yearly times series of the CCUS from the baseline period 1951–1981. Source: Mills et al. (2024).

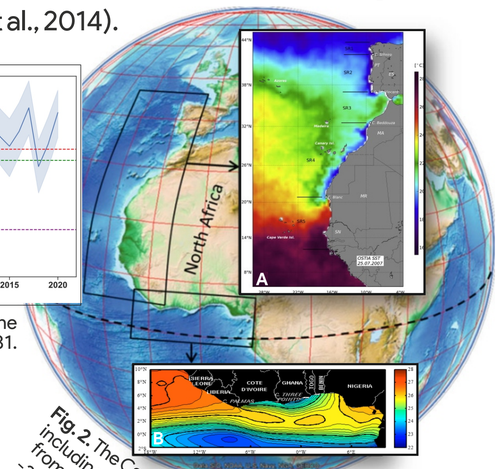


Fig. 2. The Canary current upwelling system including image sources of mean SST (2007, A) from Aristegui et al. (2009), and mean SST (1982 -2010, B) from Toualy et al. (2012). Adapted from: Käempf & Chapman (2016).

Recent studies of the CCUS suggest that the interplay between changes in sea temperature (see Fig. 4) and in food availability will affect the abundance and distribution of small pelagic fish in north-west Africa. However, the ways in which climate change can propagate through the physical environment and lower trophic levels to affect sardine and round sardinella at a population level are not yet well understood.

MOTIVATION...

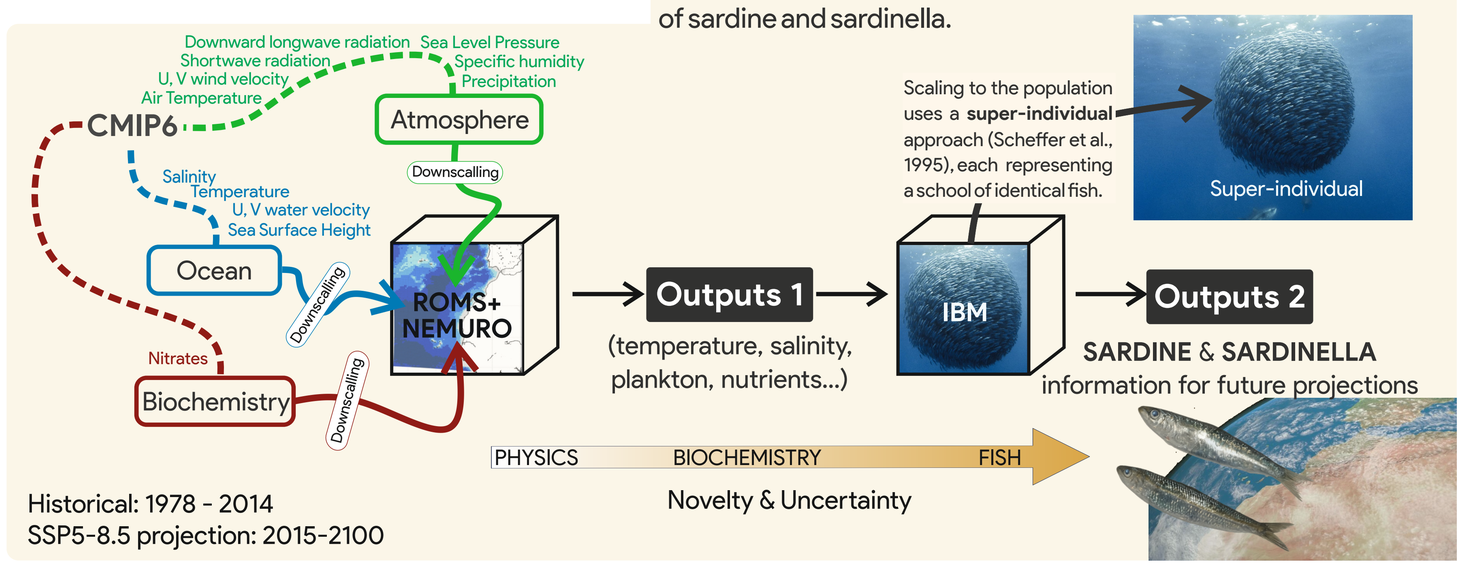
Exploring the underlying physical and biological processes driving changes in sardine and round sardinella abundance and distribution is critical for anticipating 21st-century ecosystem dynamics. While anthropogenic warming will undoubtedly play an important role, climate projections combined with full life-cycle individual-based models can shed light on the relative extent to which future environmental conditions will affect population dynamics of these species.

...AND GOALS

1. To determine **how environmental drivers** from 1978–2100 projections (historical and SSP5-8.5) **impact the distribution and abundance** of simulated round sardinella and sardine in northwest Africa.
2. To explore the possible **influence of other drivers** exhibiting more subtle responses to climate change, such as the intensity of coastal upwelling and the prey availability (Fiechter et al., 2021).
3. To investigate how the projected amplification of globally dominant modes (e.g., ENSO) under a warmer climate may drive potential **teleconnections between global climate and local round sardinella and sardine** population biomass (López-Parages et al. 2020).

DATA AND METHODS

The numerical framework is an existing approach used to study sardine and anchovy variability in the CCUS (Sánchez-Garrido et al., 2019). The end-to-end ecosystem model combines a primitive-equation **ocean circulation model** (i.e. ROMS), a **lower trophic model** for nutrient, phytoplankton and zooplankton (i.e. NEMURO), and an **individual-based model** (IBM) for the population dynamics of sardine and sardinella.



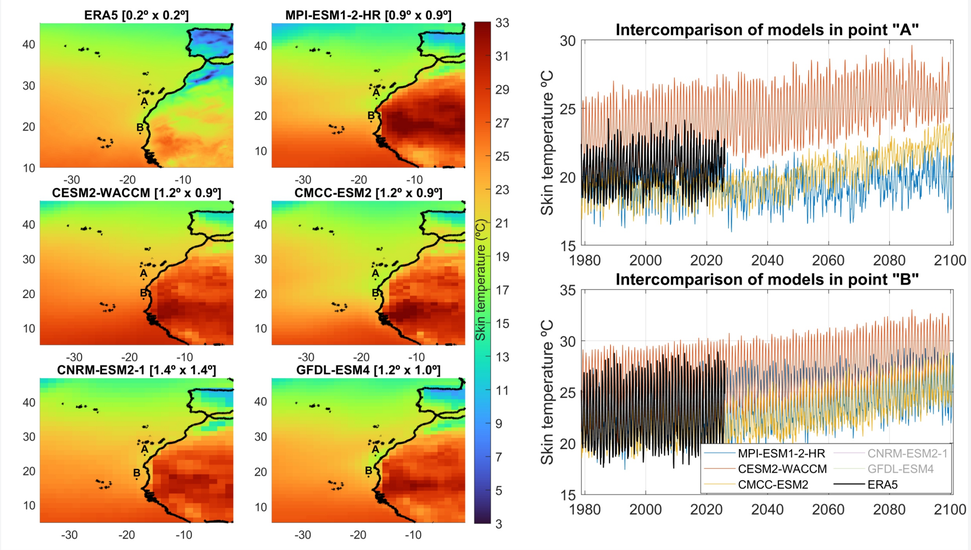


Fig. 5. Left panels: Spatial averages of skin temperature (ºC) for the Canary Upwelling System from ERA5 and five ESMs (names and resolutions in headers). Right panels: Time series evolution at map locations A and B for historical period (1978–2014) and projection (2015–2100). ERA5 reanalysis period is also displayed.

ONGOING WORK

Future projections of sardine and sardinella are simulated using three representative Earth System Models (ESMs, Fig. 5) from the CMIP6 ensemble: **MPI-ESM1-2-HR** (Müller et al., 2018), **CESM2-WACCM** (Danabasoglu et al., 2020) and **CMCC-ESM2** (Lovato et al., 2022). These models cover a wide range of physical and biogeochemical uncertainties, from low warming and increased production (MPI-ESM1-2-HR) to high warming and decreased production (CESM2-WACCM).

$$DELTA_{1978-2100} = ESM_{1978-2100} - ESM_{CLIM,\ 1978-2008}$$

$$ESM'_{1978-2100} = REAN_{CLIM,1978-2008} + REAN_{HF,1978-2008} + DELTA_{1978-2100}$$

To reduce the biases exhibited in the ESMs' historical simulations, we apply a 'time-varying delta' bias-correction method to the models' output prior to downscaling, following the approach of Pozo Buil (2021).

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SIMILAR APPROACHES IN OTHER EBUS

A similar analysis of the end-to-end model projections developed for sardines in the California Current System (CCS) (Fiechter et al., 2021) evaluates the total annual biomass of the species from each downscaled solution (Fig. 6) and the spatial distribution of juvenile and adult abundance. Maps of suitable thermal and feeding habitats are also produced, based on estimated species preferences (Fig. 7).

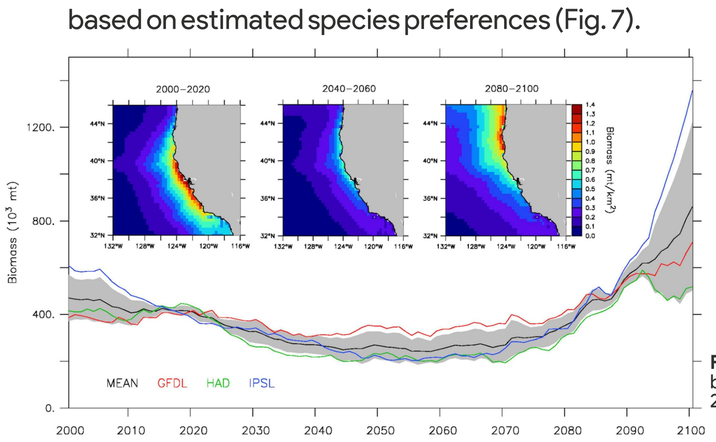

Fig. 7. Projected sardine spawning stock biomass for 2000–2100, along with mean spatial biomass distribution (metric tons per km^2) for 2000–2020 (left), 2040–2060 (center), and 2080–2100. Adapted from Fiechter et al. (2021).

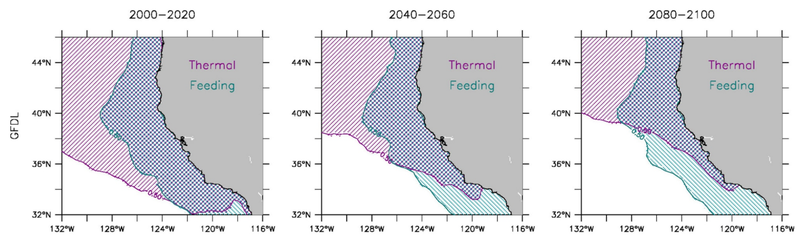

Fig. 6. Feeding and thermal habitat suitability for adult sardines in the CCS during 2000–2020 (left), 2040–2060 (center), and 2080–2100 (right) from GFDL solution. Adapted from Fiechter et al. (2021).

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