Climate induced distribution shifts: The case of European small pelagic fishes

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Ocean warming

Annual reconstructed SST (1986 – 2005)
Averaged between 60°S and 60°N

- + 0.1 °C per decade

Annual projected SST (2000 - 2100)
(relative to 1986 – 2005)
- Up to + 4.5 °C in 2100

Consequences on the ocean :
- Salinity increase
- Stratification
- Changes in Primary Production

Smith et al. (2008)
IPCC (2014)
Species responses

The fundamental niche:
“Ensemble of environmental conditions in which a given population can live and reproduce”
- Measure of species fitness
- Maximised by the species

Response to environmental stress:
- Physiological adaptation
- Migration and range shift

Global consequences:
- Poleward migration
- Important species turnover
- Biological invasion amplification

Projected species turnover (by 2100)
Relative to 1986 - 2005
Small pelagic fishes

- Short lifespan species
- Important sensitivity to environmental stress
- Already observed responses

Ecological importance

- Central role in food webs
- Wasp – waist control
- Important natural mortality (constrained species)

Economical importance

- Landings > 1 Mt per year
- 50% of the Mediterranean catches are small pelagic fishes
- But large overfishing (> 2 FMSY) and risk of collapse

FAO (2016)
Aim of the study

Effect of climate change?
- On future environmental suitability
- On potential future range shifts

Modelling framework
- Species distribution models
- Coupled with IPCC General Circulation Models (GCM)
- Under several future emission scenarios (RCP)

Spatially explicit ensembles of future habitat suitability
Species distribution models

1) Biological data
- Species occurrence records
- Generated pseudo-absences

2) Environmental variables
- Current (1990-2017)
- Future (GCMs coupled with three RCP scenarios)

3) Projection (s)
- Current habitat suitability index
- Ensemble of future predictions

Ensemble modelling:
- Several statistical algorithms (Biomod2 and NPPEN) and five GCMs
- Uncertainty assessment
Data processing

A. Observations records:
   - Published data
   - Irrelevant data eliminated

B. Important geographical and environmental biases

C. Processing:
   - Environmental filtering
   - Convexhull (Getz and Wilmer, 2006)
   - Pseudo–absence selection

D. Calibration data:
   - Unbiased presences
   - Unbiased pseudo–absences
Model evaluation

**Prevalence**

\[
\text{nb presence} / (\text{nb presence} + \text{nb absence})
\]

- Pseudo – absences ≠ True absences

**Statistical evaluation**

- Prevalence independent metric
- Continuous Boyce Index (CBI) \(\text{Hirzel et al. (2005)}\)

**Response curves**

- Assessing ecological relevancy
- Discriminating multimodal or uniform responses

Based on theoretical ecology
No statistical framework
**Present distribution**
(1990 – 2017)

**Related uncertainty**
Standard deviation

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**Parameters:** mean SST + annual range of SST + Salinity

- **High suitability:** greater North Sea, Celtic Sea and Bay of Biscay
- **Medium to high suitability:** north-western Mediterranean Sea
- Significant model convergence in the highly suitable areas (low SD)
Sardina pilchardus

Future potential distribution (RCP 8.5) (2090 – 2099)

Difference relative to present

- Norwegian Sea, Danish coasts, Iceland and Faroe islands
- Mediterranean Sea, Bay of Biscay, western Ireland

- Northward distribution shift
- Near to local extinction in the south-western Mediterranean basin
- Less impacted in the Adriatic Sea and the Gulf of Lion
Present distribution (1990 – 2017)

Related uncertainty

Parameters: mean SST + annual range of SST

- **High suitability:** Mediterranean Sea
- **Medium to high suitability:** Bay of Biscay, north-western Africa
- Significant model convergence in the highly suitable areas (low SD)
Boops boops

Future potential distribution (RCP 8.5) (2090 – 2099)

- Adriatic Sea, Black Sea, English Channel
- North-western Africa, Celtic Sea

- Northward distribution shift
- Near to local extinction in the Celtic Sea
- No impact in the Mediterranean Sea
Future of small pelagic fishes

- Decrease of the environmental suitability in the Mediterranean Sea
- Extension of temperate-to-cold species in the Norwegian Sea
North-eastward distribution shift

Distribution centroid evolution in Europe
(relative to 1990-2017)

- North-eastward distribution shift
- Range shift gradually increasing from RCP2.6 to RCP8.5
- Eastward shift corresponding the Black and Baltic Seas
Importance of temperature(s)

Physiology
- Thermal optimum and tolerance
- Directly affects physiological performances
- Critical life stages (larval development, reproduction)

Which temperature?
- Mean temperature
- Temperature variability

Species distribution
- Discriminate a diversity of water bodies
- Improve distribution accuracy
- Less type I error

Annual range ≈ Seasonality
Monthly variance ≈ Short term climatic events
Consequences and limitations

**Shifting stocks**
- From an Exclusive Economic Zone (EEZ) to another
- Adaptation of local fisheries?
- Complexity of fisheries management \( \text{Gaines et al. (2018)} \)

**Environmental pressure**
- Altering species fitness
- Consequences on spawning stock biomass
- Forecasting recruitment under climate change

**Limitations**
- Biomass and biological interactions not considered
- Local scale factors
- Consequences on ecosystems and food-webs?
Ecosystemic approach

The Ecopath model:
- Mass balanced food-web model
- Carbon flow in the food-web
- Ecosystem health indicators

From habitat suitability to biomass:
- Same evolution through time (Chaalali et al. 2016)
- Regression models (GLM, GAM, MARS...)
- Bayesian framework

Objectives:
- Assessing cascading effects of distribution shifts
- Ecosystem resilience
- Food-web restructuration
- Harvesting capacity
Thank you

References:


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