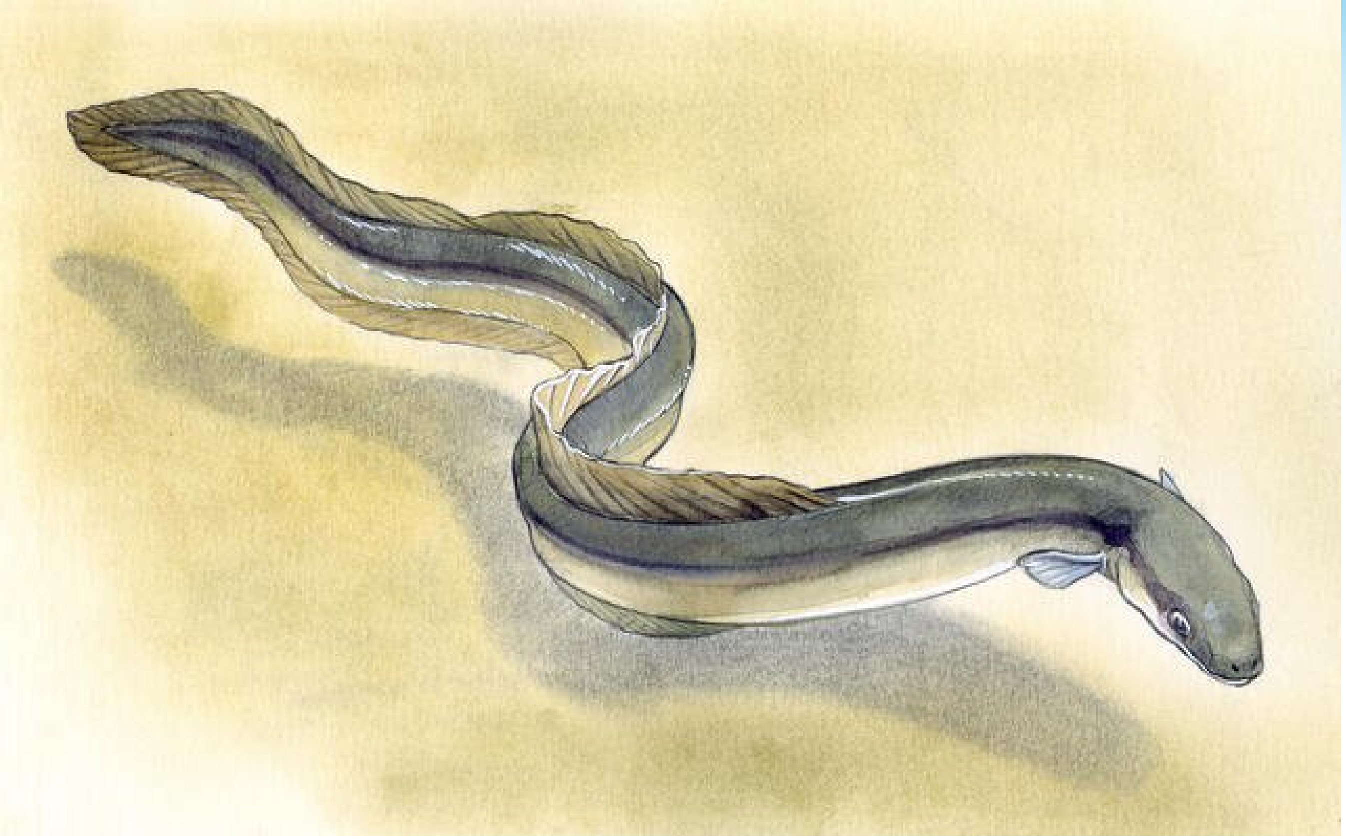


The challenge to anticipate the future of fish communities in warmer oceans and rivers: modelling approaches

Guillem Chust

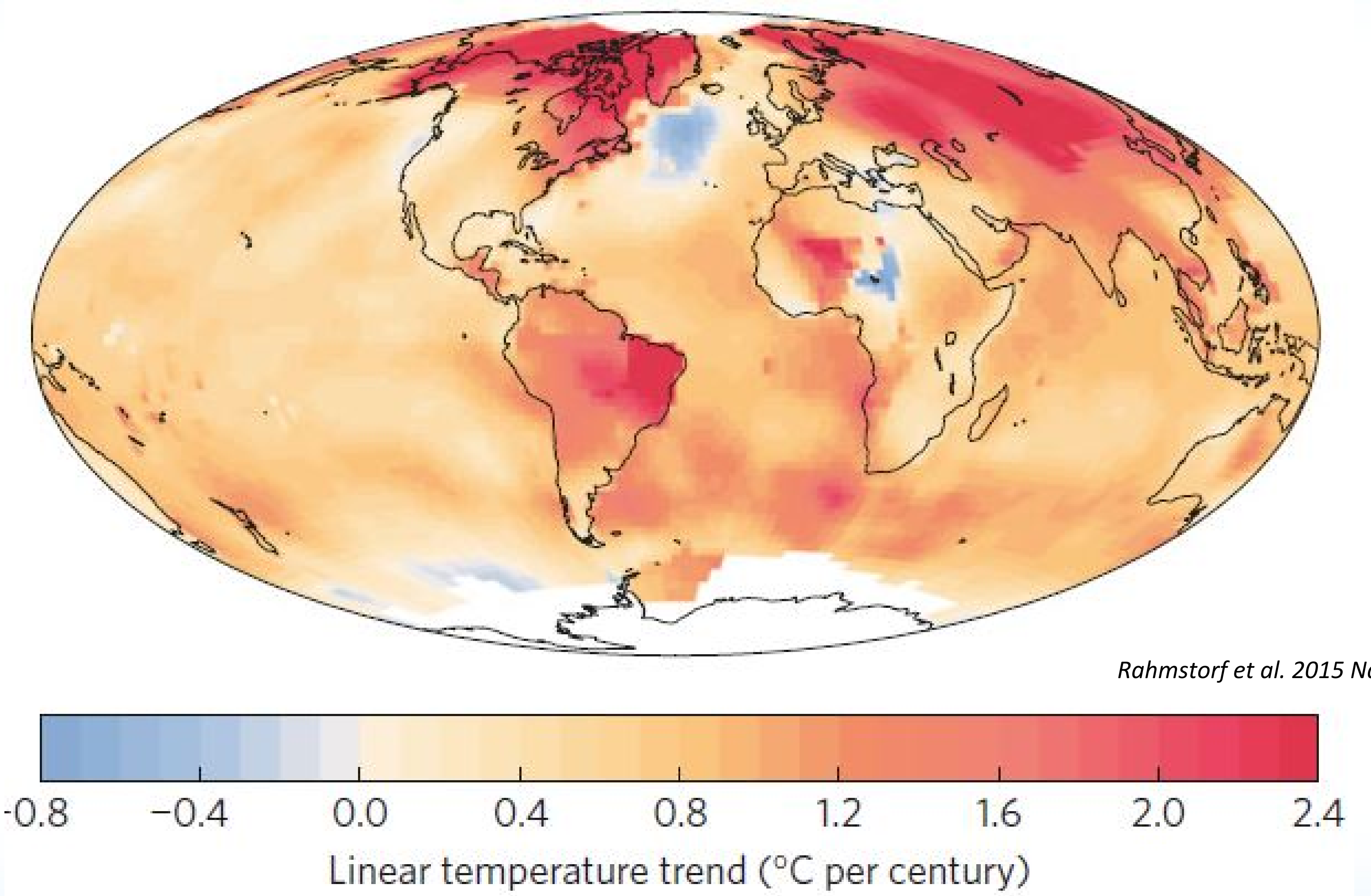
REVE Shad'EAUNA Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION DiadES

LOCAL AND GLOBAL INITIATIVES:

HOW SCIENCE SUPPORTS MANAGEMENT ACTIONS ON DIADROMOUS FISH

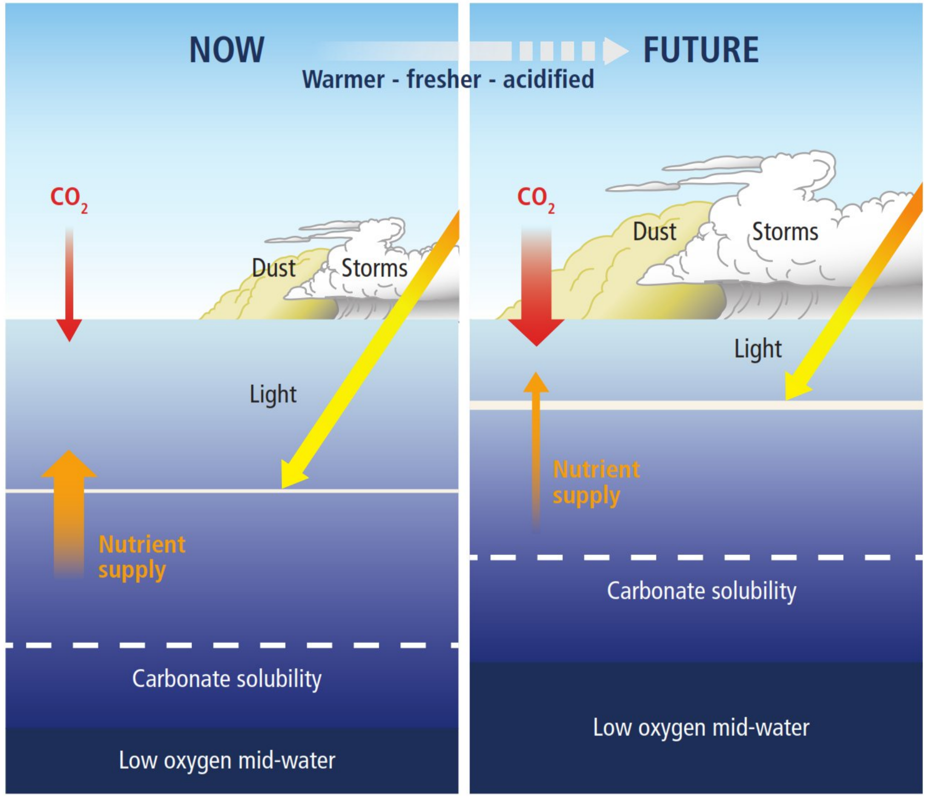
AZTI MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

Global trends of sea temperature

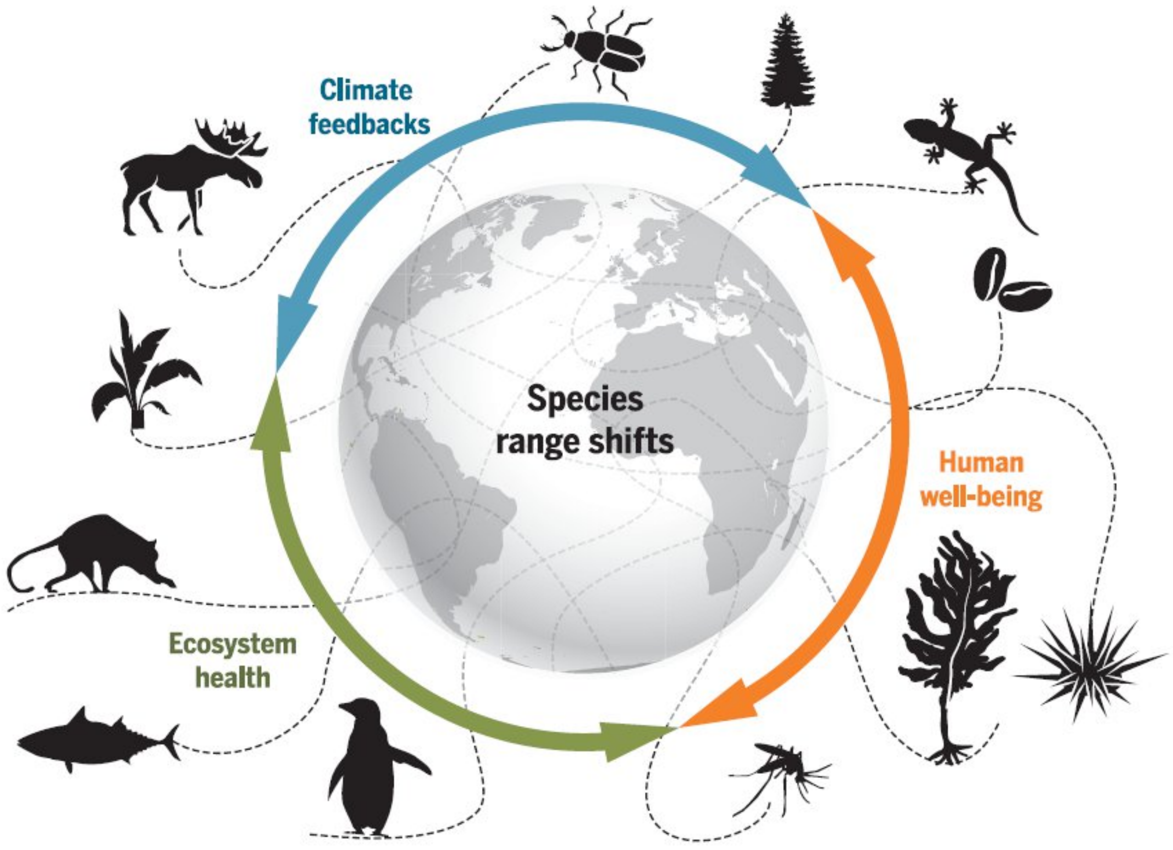


Rahmstorf et al. 2015 Nature Climate Change

How global warming will affect biodiversity and resources?



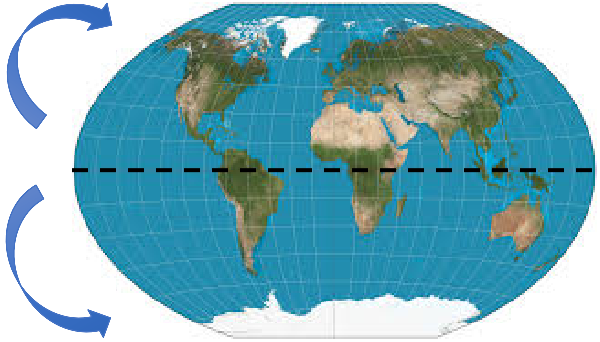
Global climate change is redistributing life on Earth



Pecl et al. 2017

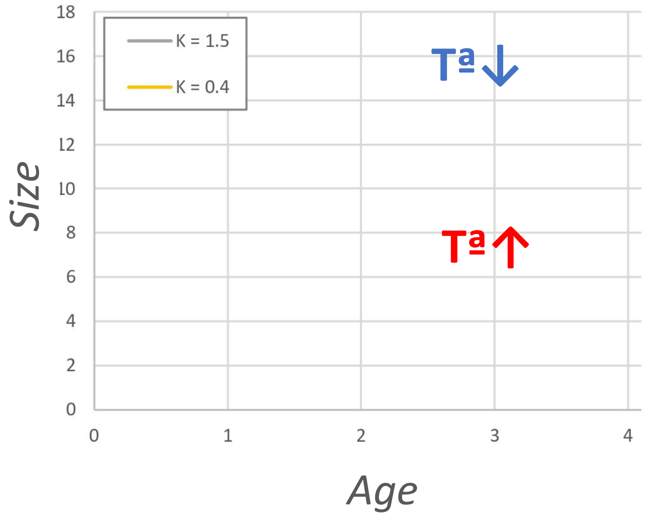
Universal ecological responses to global warming

Poleward shifts



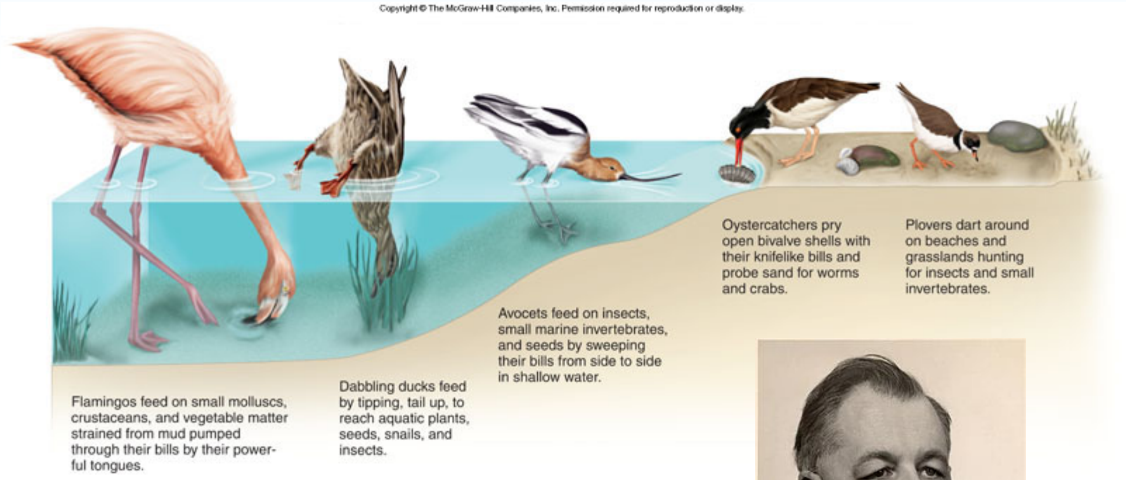
Seasonal shifts in life cycle

Size reduction



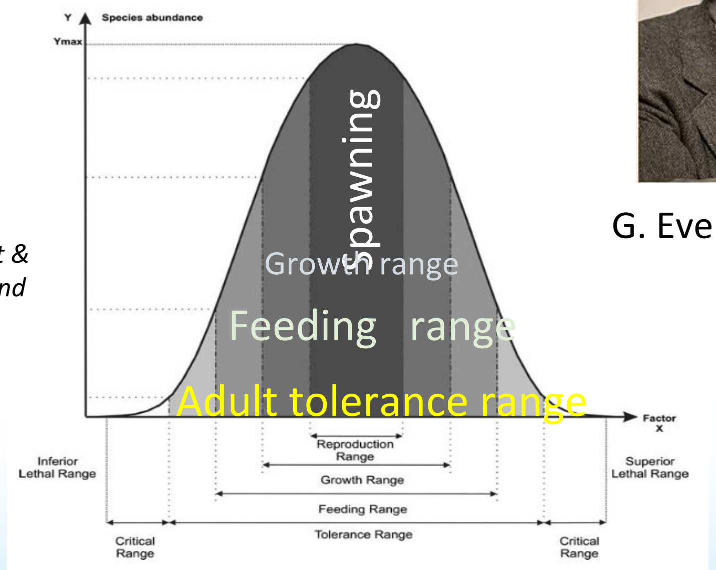
Daufresne et al. 2009

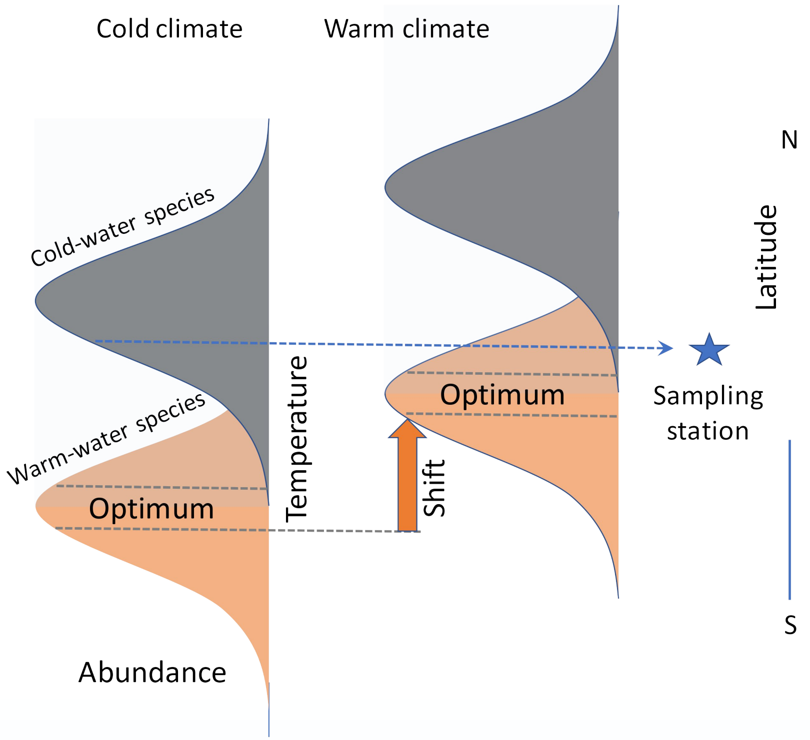
Tracking the species ecological niche



G. Evelyn Hutchinson

Helaouet & Beaugrand 2009





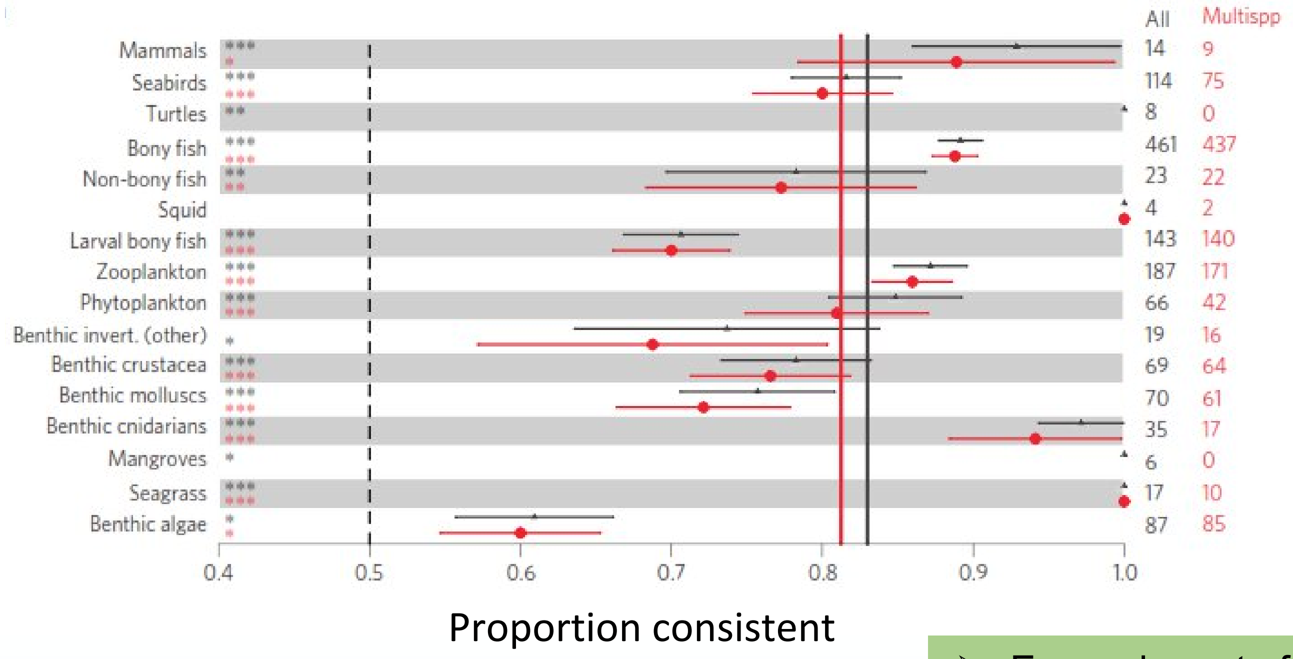
nature climate change

LETTERS

PUBLISHED ONLINE: 4 AUGUST 2013 | DOI: 10.1038/NCLIMATE1958

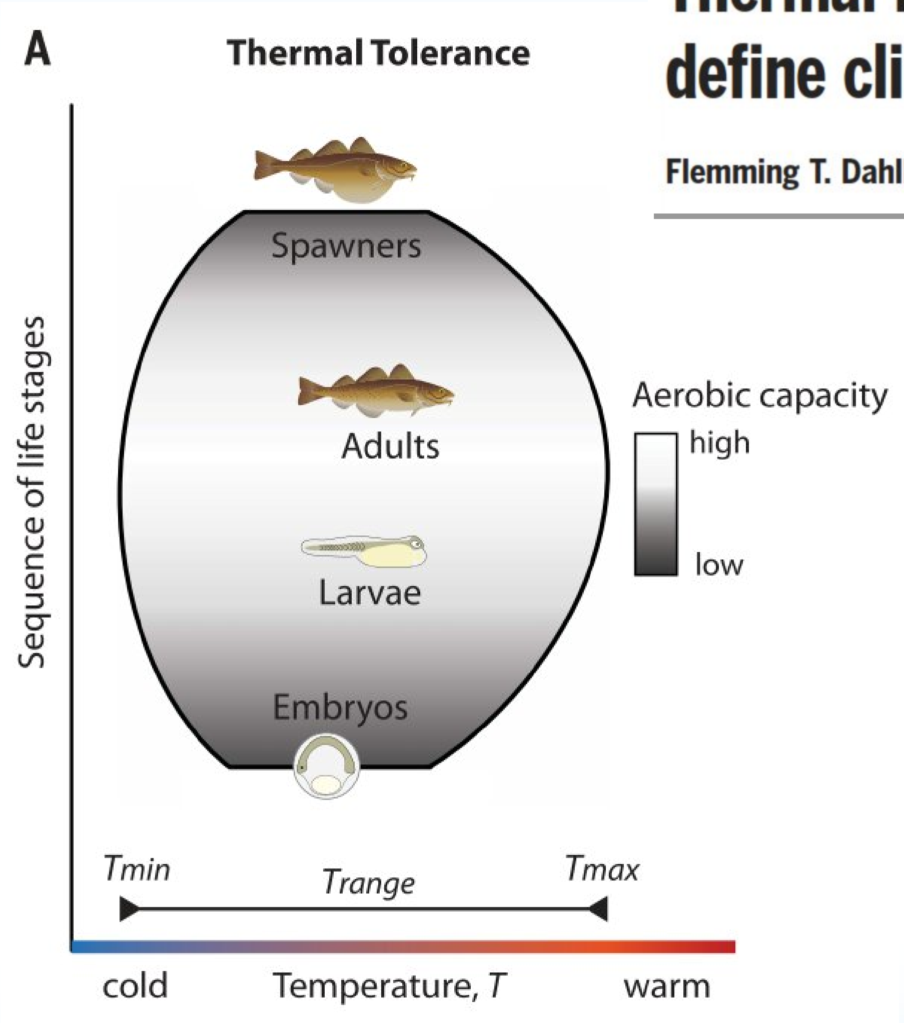
Global imprint of climate change on marine life

Elvira S. Poloczanska *et al.*†



81–83% (1,735) of all observations for distribution, phenology, community composition, abundance, demography and calcification across taxa and ocean basins were consistent with the expected impacts of climate change

- Expansion rate for marine species: 72 km / dec



Thermal bottlenecks in the life cycle define climate vulnerability of fish

Flemming T. Dahlke[1]*, Sylke Wohlrab[1,2], Martin Butzin[1], Hans-Otto Pörtner[1,3]*

- **Data**: observational, experimental, and phylogenetic data for 694 marine and freshwater fish species from all climate zones.
- **Conclusion**: Spawning adults and embryos consistently have narrower tolerance ranges than larvae and nonreproductive adults and are most vulnerable to climate warming.

Dahlke et al., Science 369,*65–70 (2020)*

The Marine Observatory of Climate Change of the Bay of Biscay

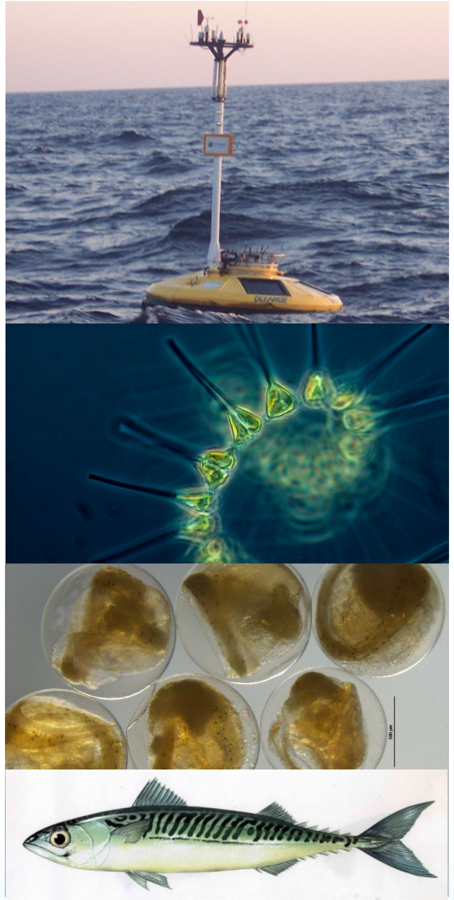
Climate Change Indicators

Marine physical-chemical indicators
1. Sea temperature
2. Salinity
3. Mixing and stratification layer
4. Oxygen
5. Nutrients
6. Mean sea level
7. Wave

Atmospheric indicators
8. Air temperature
9. Solar radiation and sunshine hours
10. Wind
11. Rainfall and river flows

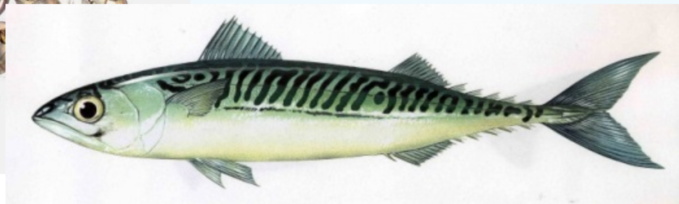
Coastal geomorphological indicators
13. Coastline
14. Beaches and sandy areas

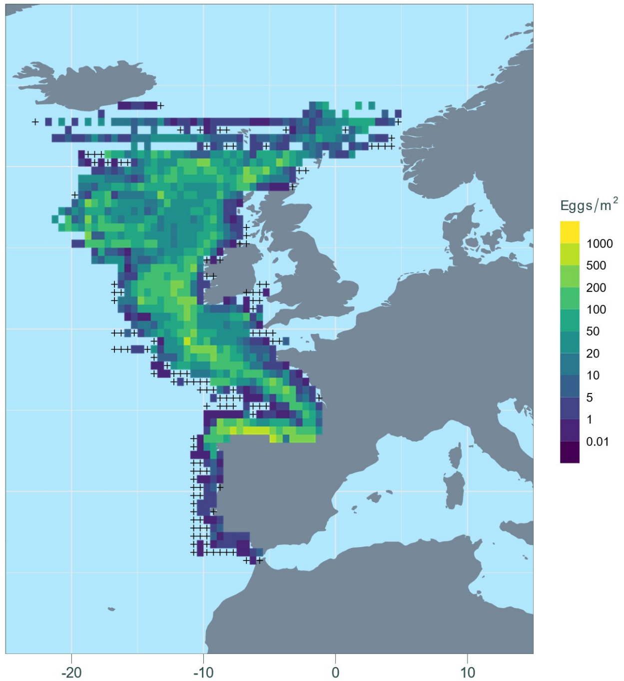
Marine biological and ecological indicators
15. Bacteria
16. Phytoplankton
17. Macroalgae
18. Benthic macroinvertebrates
19. Pelagic, demersal and diadromous fish

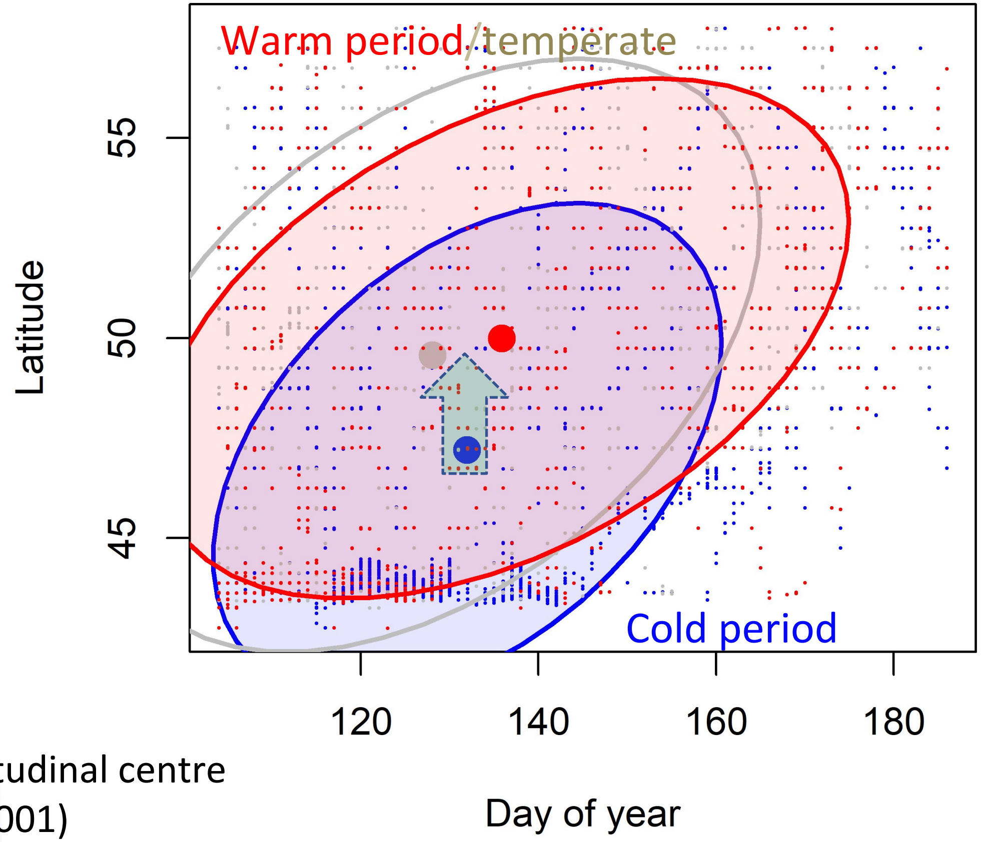


Chust et al. 2022 STOTEN

Poleward shift of the NE mackerel spawning

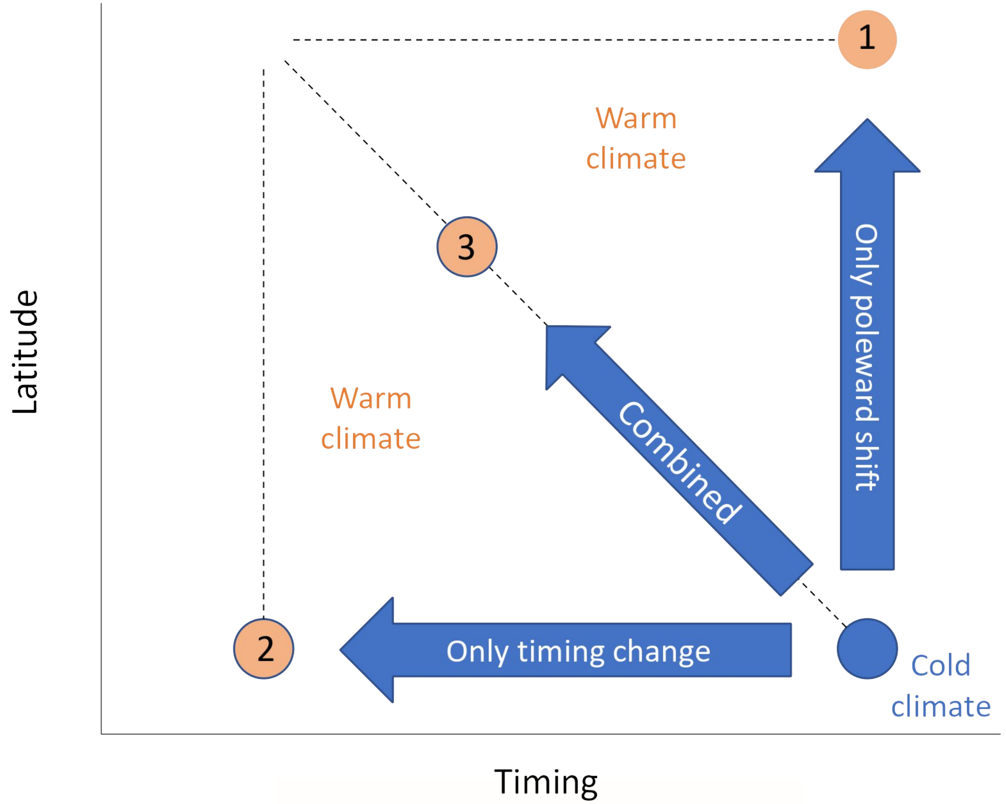


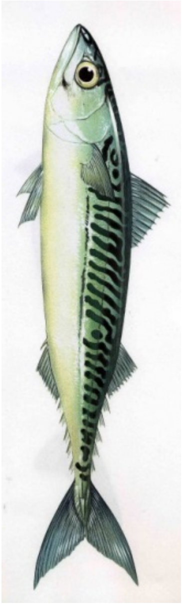




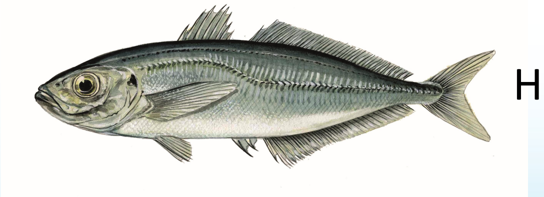
- From cold to warm period, the latitudinal centre of spawning shifted 311 km ($p<0.0001$)
- No phenology change

Potential acclimatization pathways



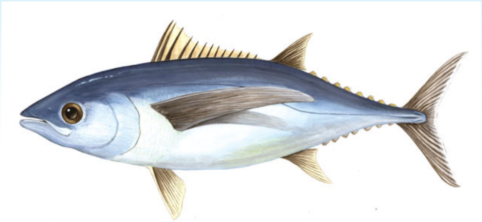


Atlantic mackerel

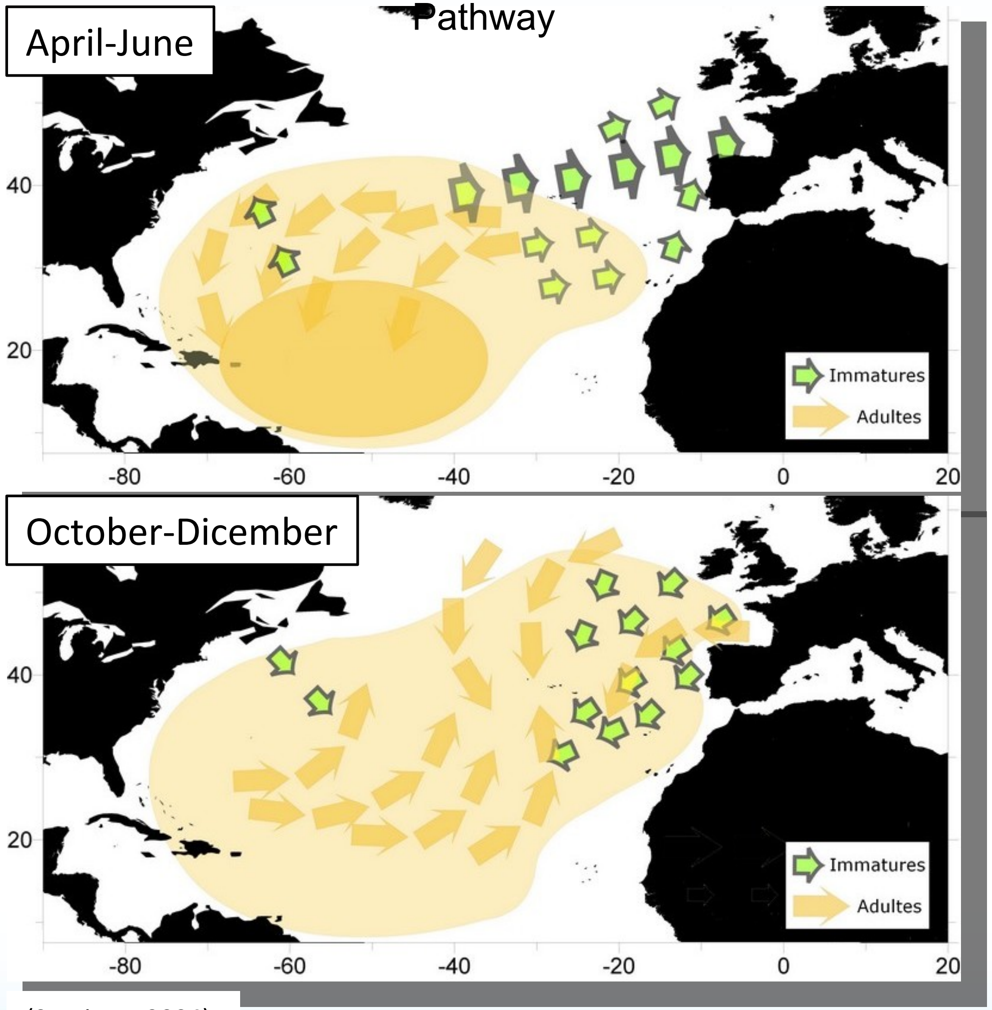


Horse mackerel

Albacore distribution variability and migration phenology



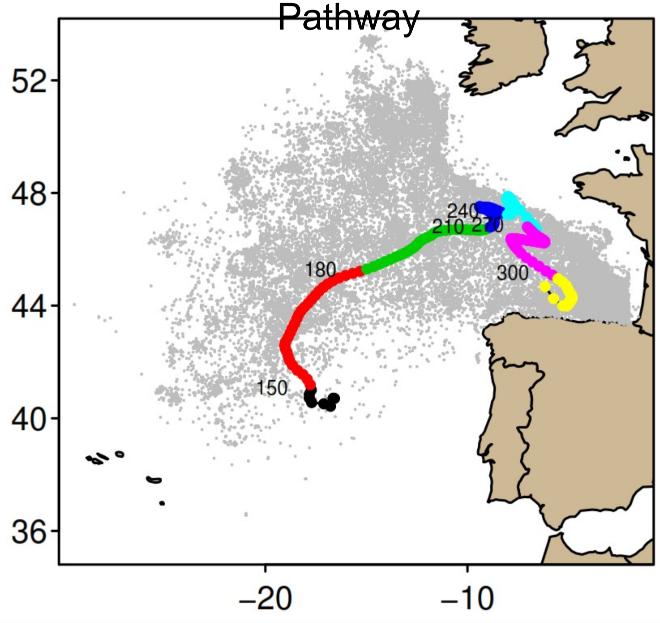
Seasonal Trophic Migration Pathway

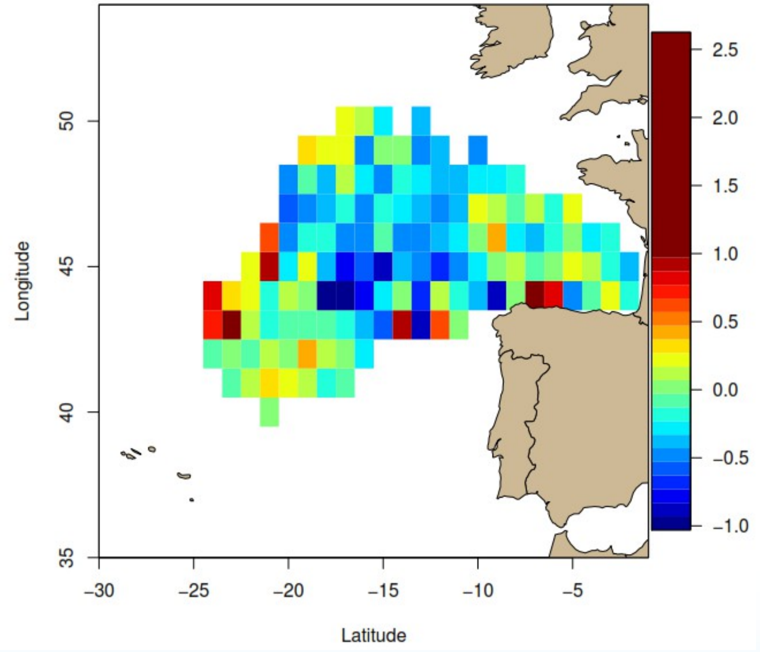


(Santiago, 2004)

- Earlier migration:
2.3 days/decade (1981–2017)

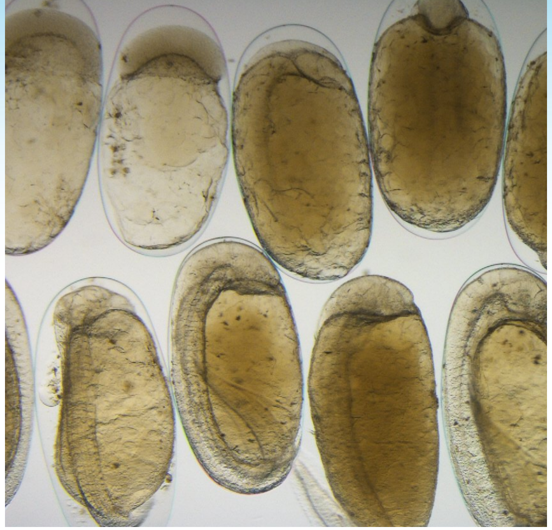
Seasonal Trophic Migration Pathway

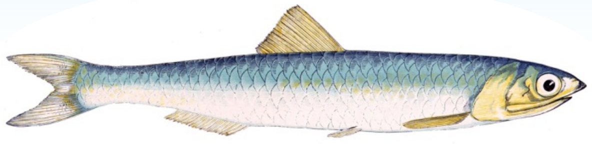


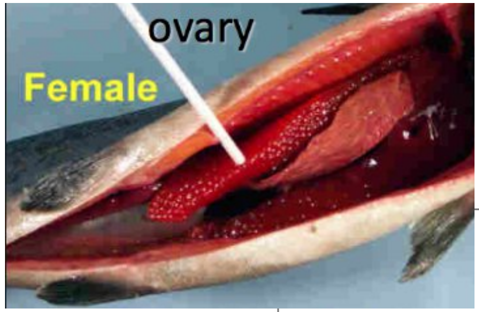


Chust et al. 2019. Fisheries Oceanography

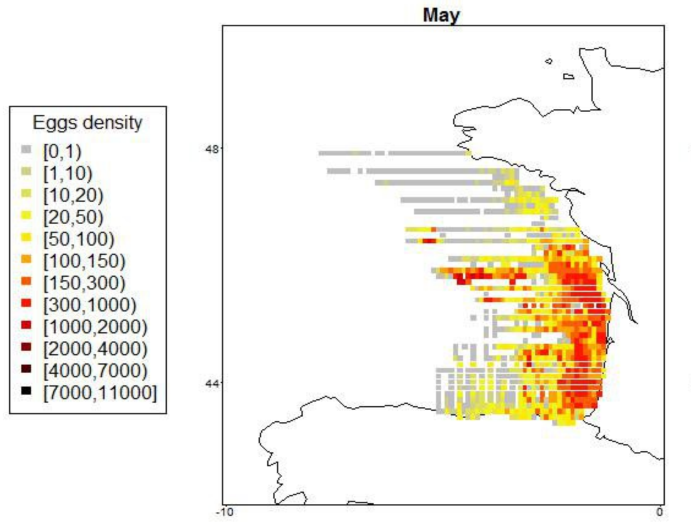
European Anchovy: spawning phenology







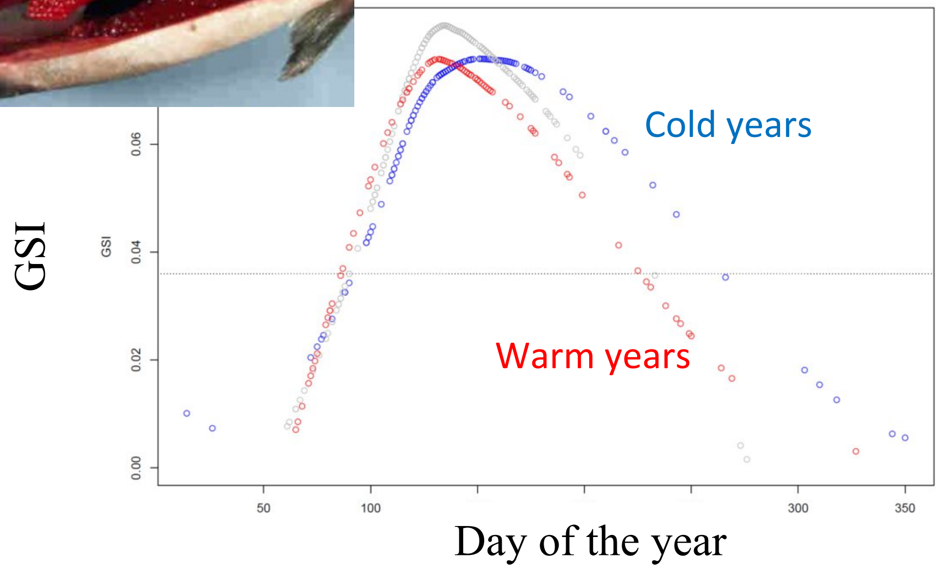
Spawning distribution



Erauskin-Extremiana et al. 2019 Deep Sea Research II

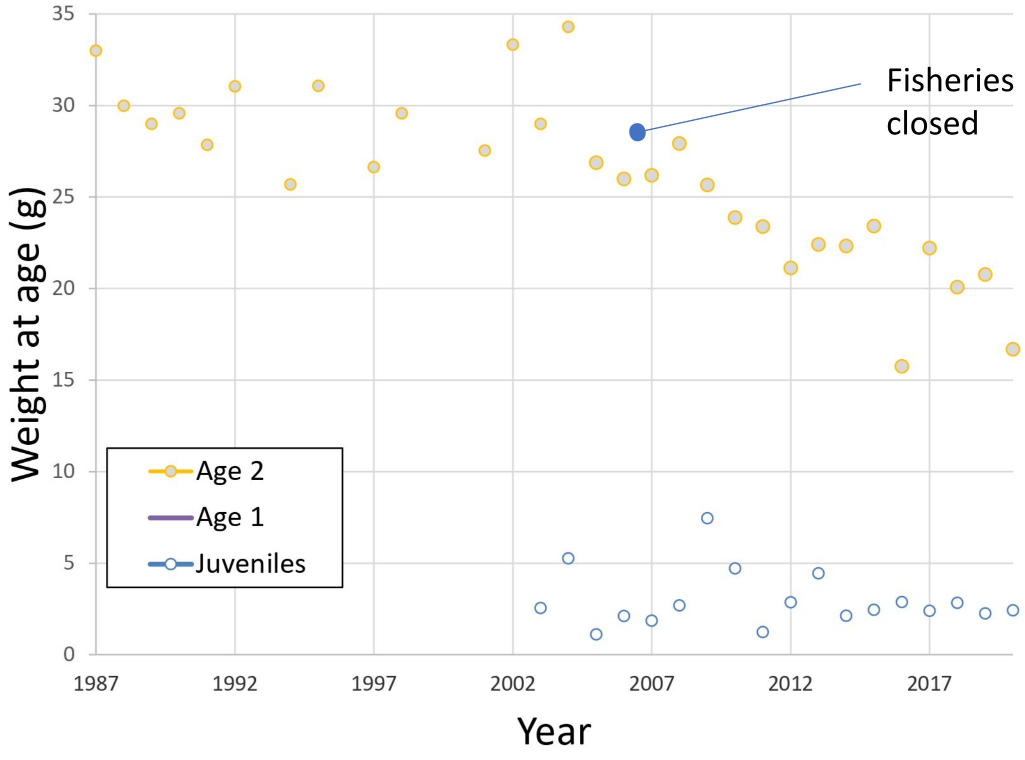
Spawning peak

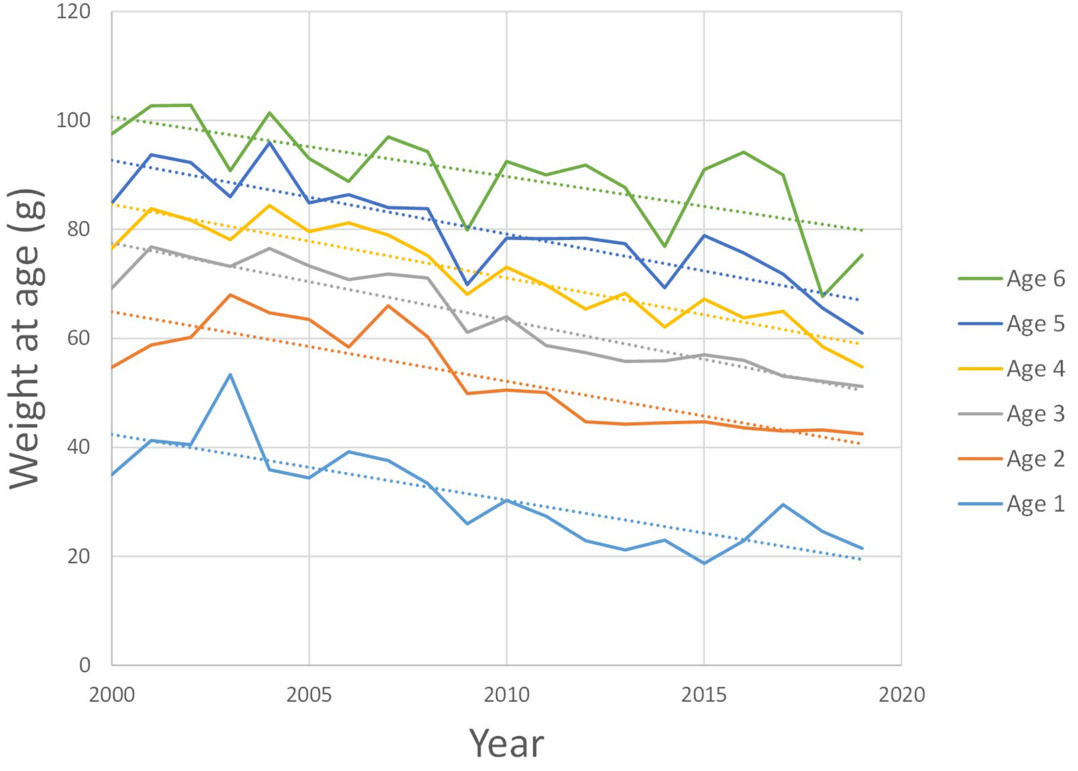
earlier 6 days/decade



Proyecto ANICHO (Gobierno Vasco)

Anchovy and sardine weight at age is declining



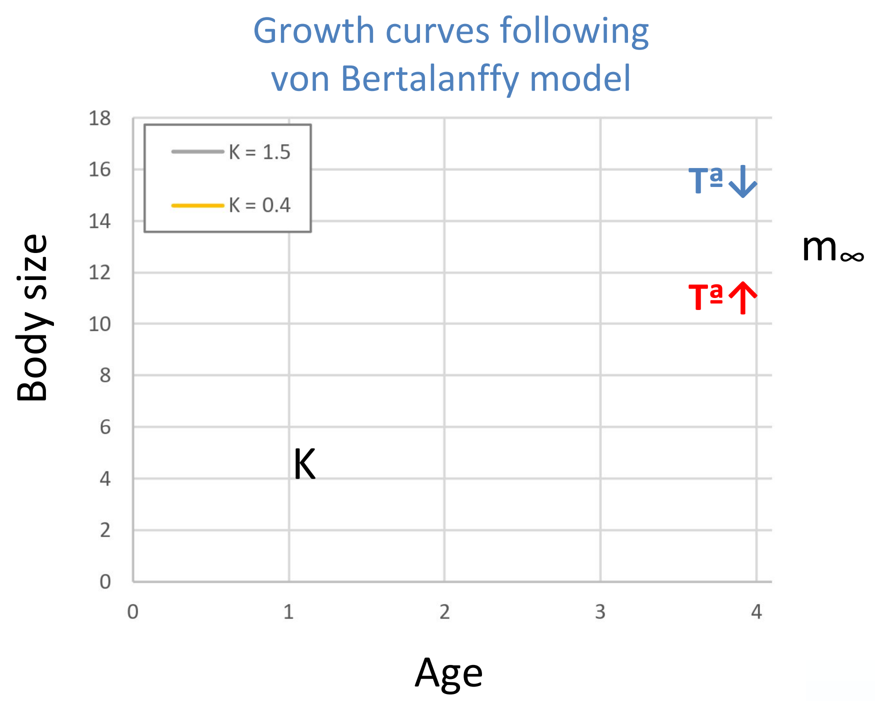


- In the last 5 years, the weight at ages 1 and 2 is 35% less than that of period 1987-2004

Chust et al. 2022 STOTEN

Body size and Growth response to warming

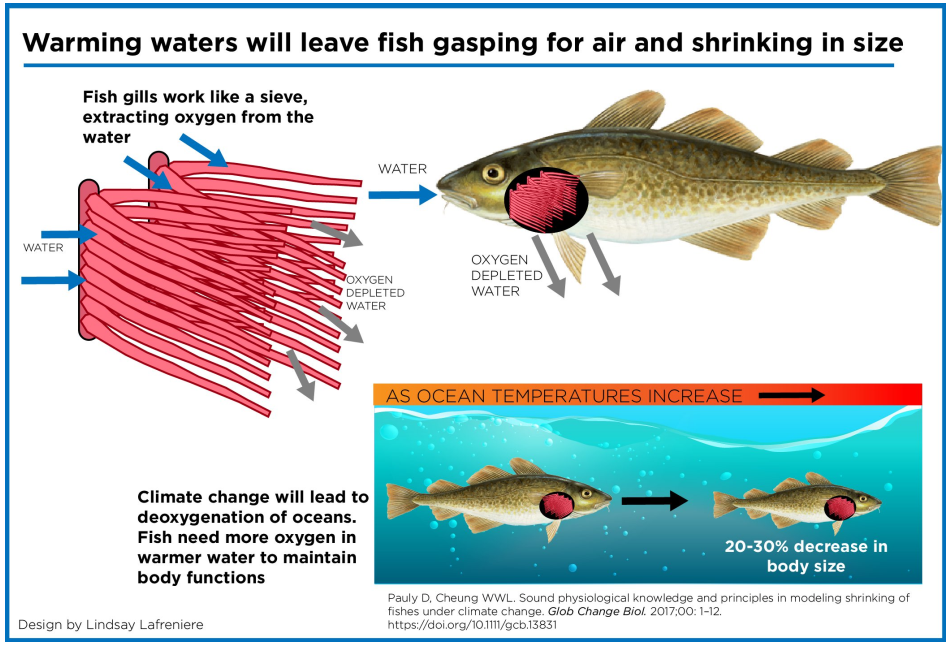
- Temperature increases initial growth but decreases adult body size (Atkinson, 1994, 1997)
- Fish size is decreasing due to climate change (Perry et al. 2005)



Why fish size shrinks with temperature?

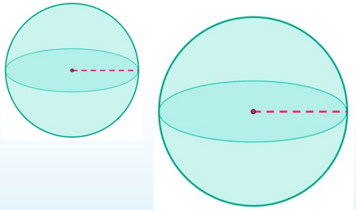
1. **Bergmann rule**

Oxygen supply to large fish size cannot be met by their gills, whose surface area cannot keep up with the oxygen demand by their 3D bodies



Volume $V(\text{esfera}) = \frac{4}{3}\pi R^3$

Surface $A = 4\,\pi\,R^2$



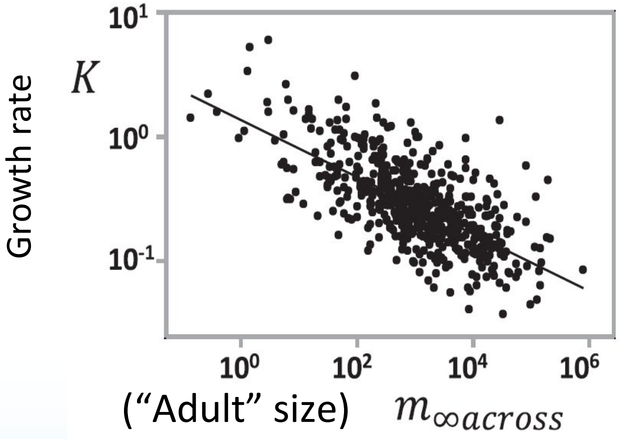
Pauly and Cheung 2017

2. **Adaptive response**, via phenotypic plasticity

Under favourable conditions, it is advantageous for the species to accelerate development leading early maturity and shorten the life cycle.

Atkinson (1994)
Audzijonyte et al. (2016)
Daufresne et al. (2009)

Body size is negatively related to growth in fishes (576 species)



Silby et al 2015 PNAS

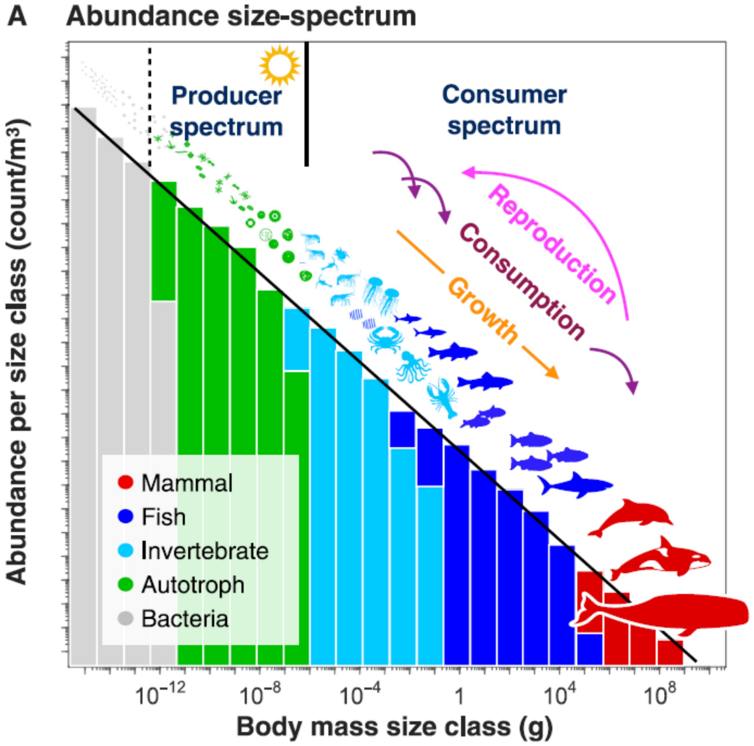
Expected impacts of future warming in fish size

20-30% less weight
(under CC scenarios)

…but more abundant (?)

Pauly and Cheung 2018

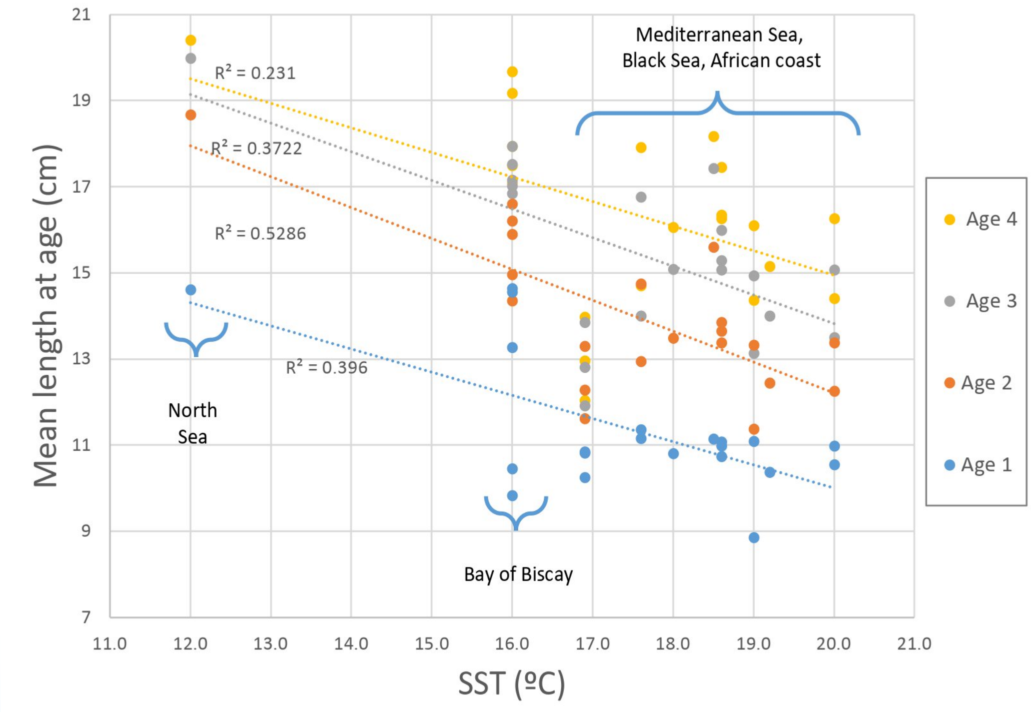
Size Spectra

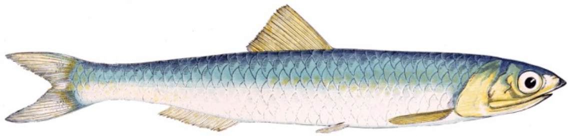


Heneghan et al 2019

Latitudinal gradients in the fish size

Length at age of different anchovy populations is smaller with region temperature (Source: Uriarte et al. 2016)



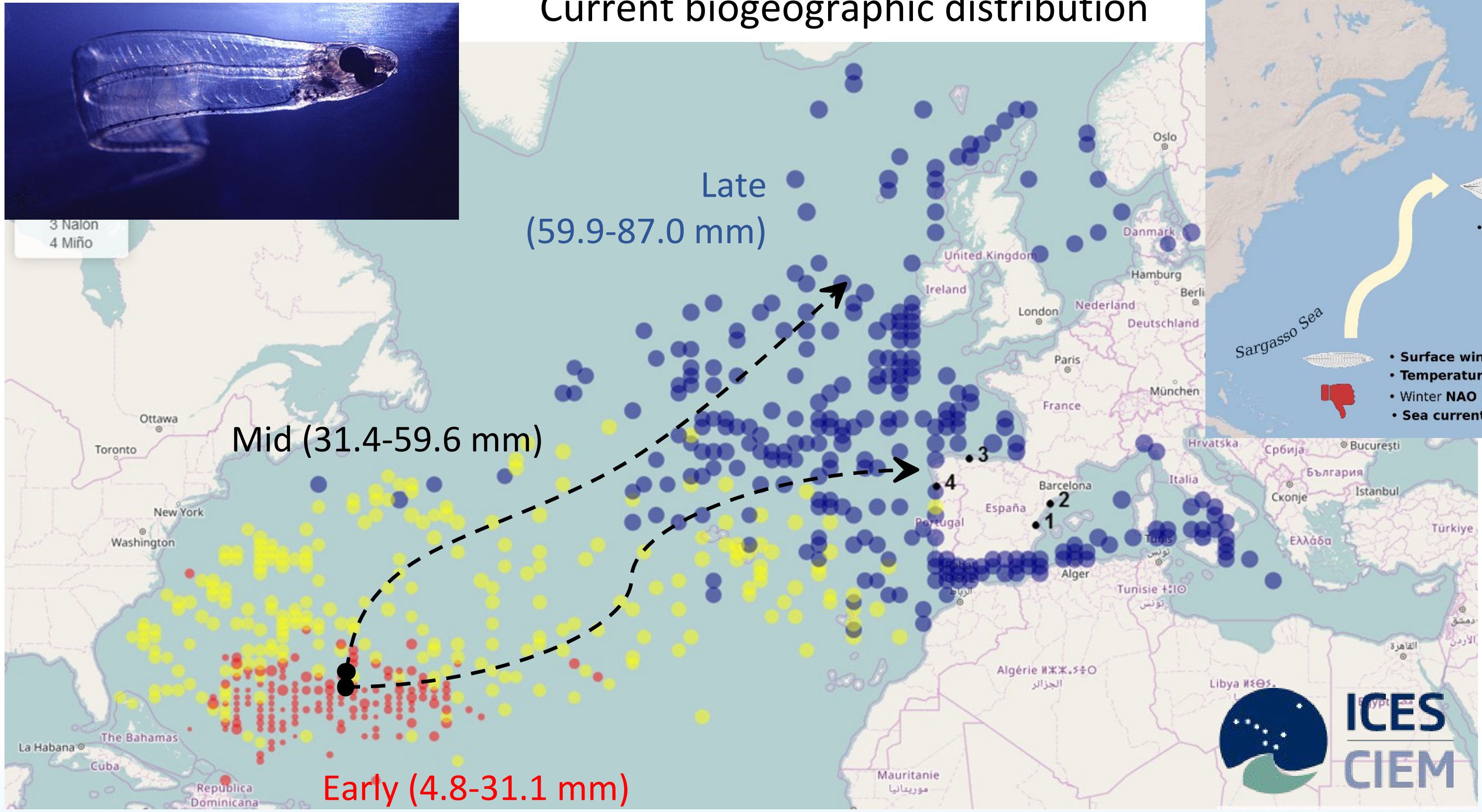


- Individuals in populations in northern (colder) seas are larger

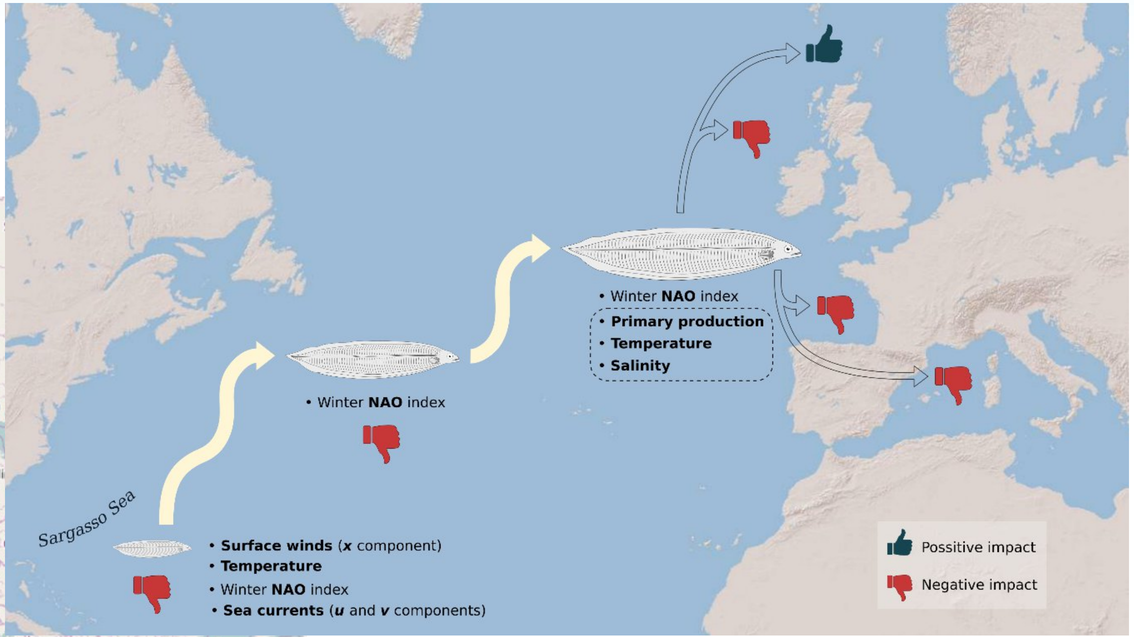
Proyecto ANICHO (Gobierno Vasco)

European eel larvae stage

Current biogeographic distribution



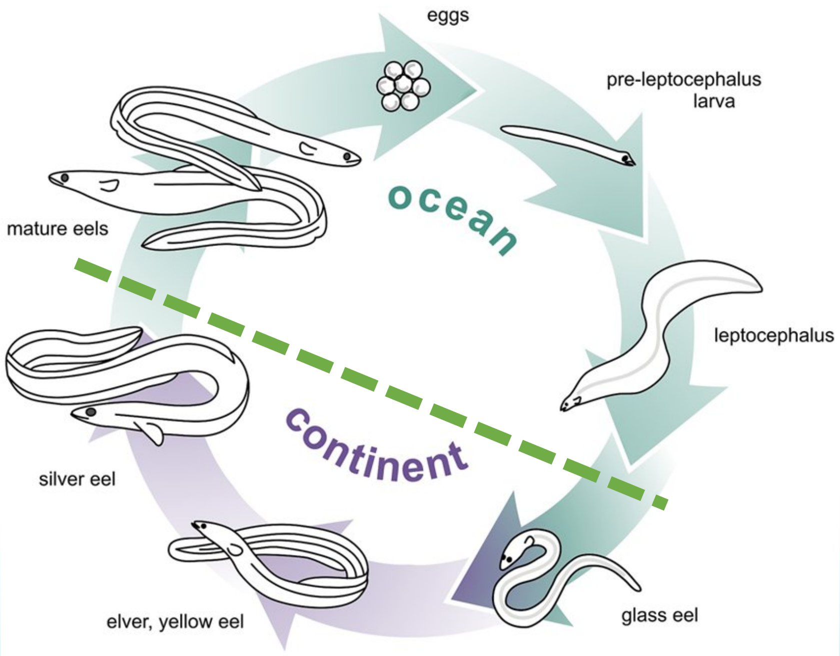
Projections



- Projected changes in NAO, sea temperature, currents and winds might negatively affect the *A. anguilla* recruitment in the Iberian Peninsula

Díaz et al. 2018 RIM

Diadromous species: Migrate between the ocean and freshwater to spawn and feed

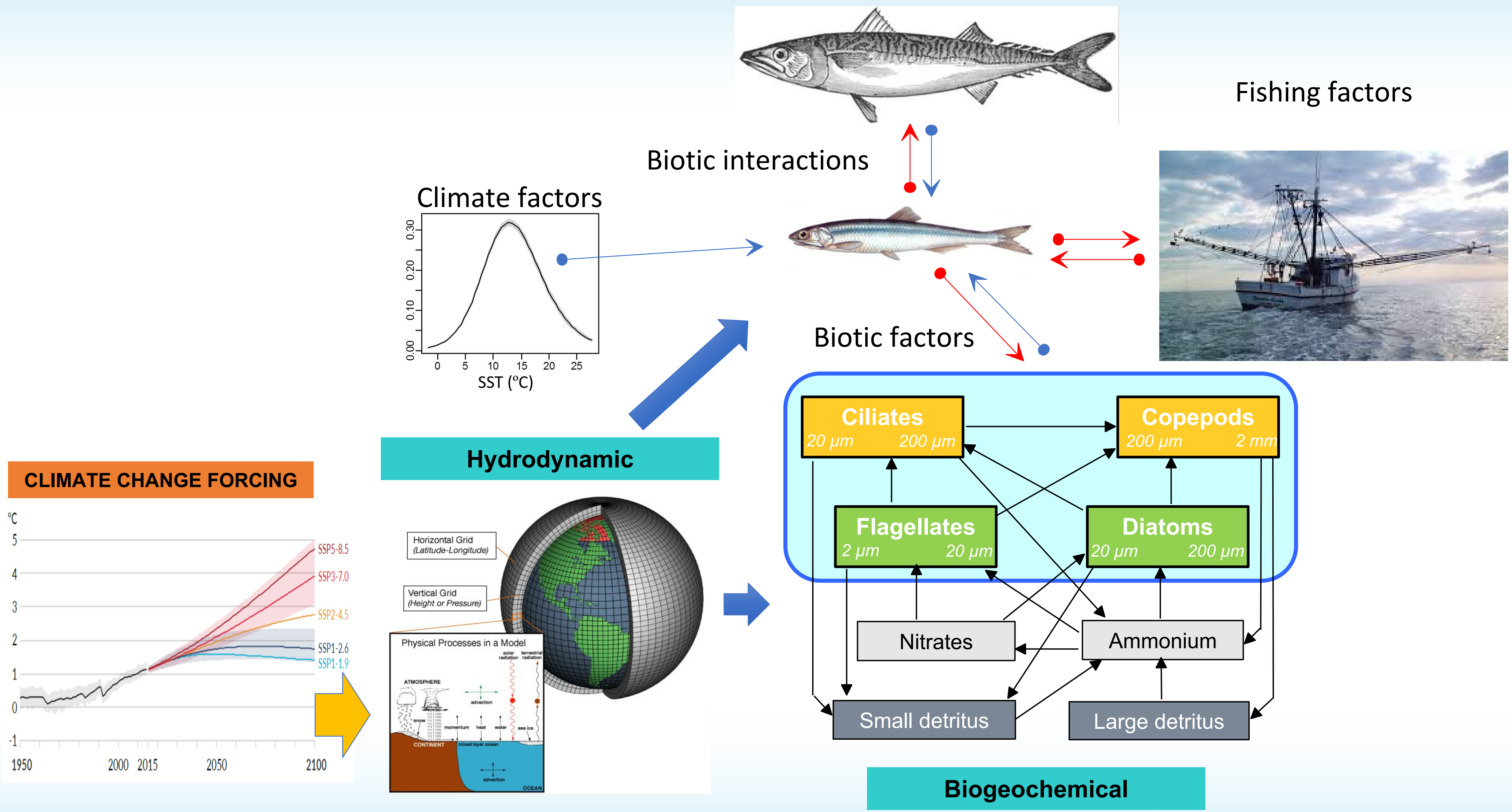


➢ Particularly vulnerable to CC

- Utilizing two habitats, so affected by changes in both
- Species with homing behavior for rivers such as most of anadromous have subpopulations with low connectivity that are prone to demographic stochasticity and inbreeding
- Allee effect: + relationship between population density and the per capita growth rate of a population
- Warming in land is stronger and more heterogeneous than in oceans, but oceans are more connected
    - Could lead to disconnect between the two habitats that could disrupt migration and affect population persistence
- Trend analysis of historical data in relation to CC are scarce

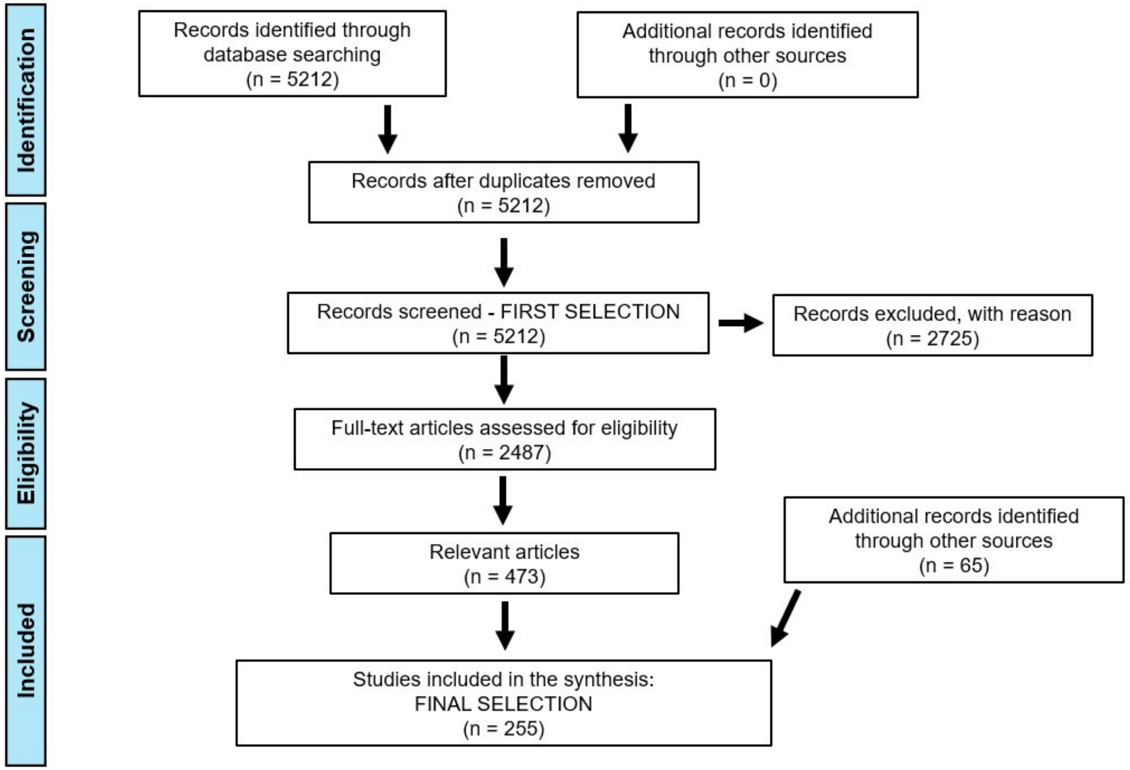
Henkel et al. (2015); Lin et al. (2017)

Approaches to evaluate future climate change impacts on fishes

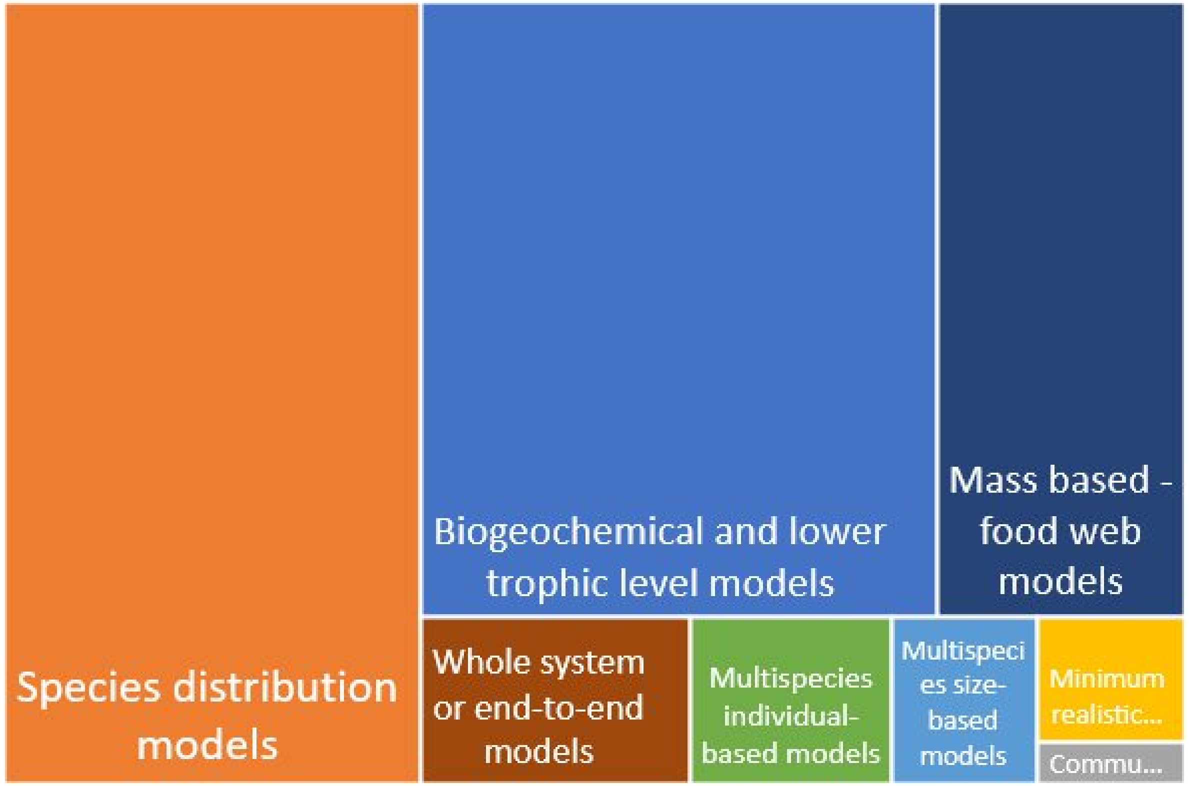


A panoply of biodiversity models

Systematic review



5212 papers

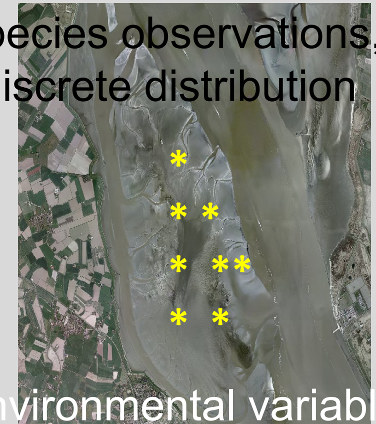


63 identified models

Marine Biodiversity Modelling RTD/2021/MV/10

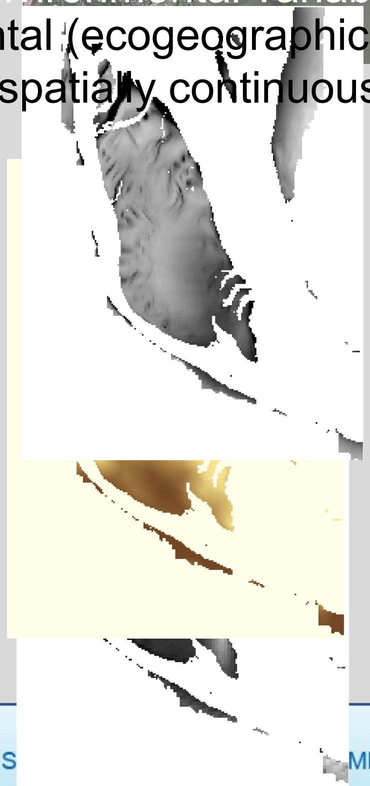
Habitat Species Modelling

Species observations, discrete distribution

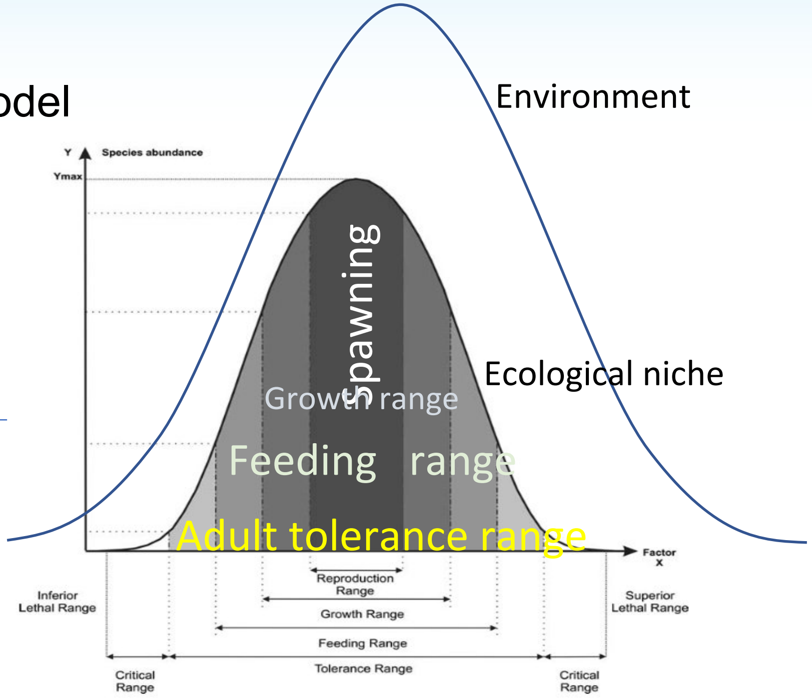


Environmental variables

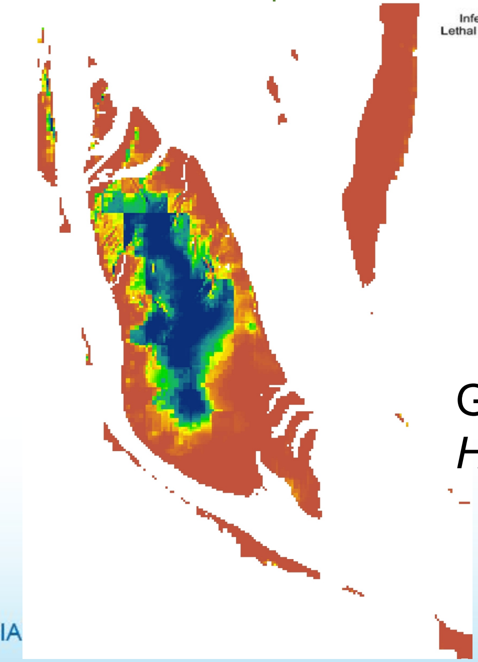
Environmental (ecogeographical) variables (spatially continuous)



Application of model techniques

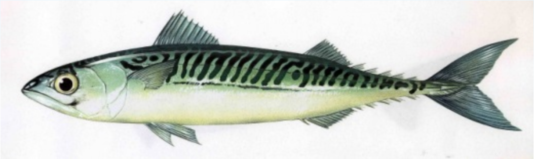


Shape-Constrained GAMs (Citores et al. 2020)

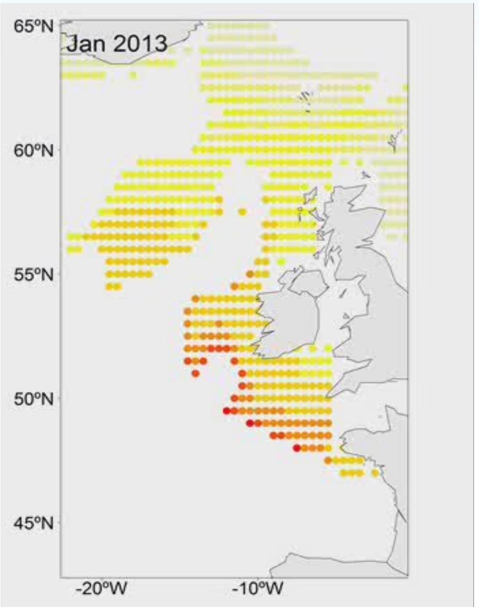


Geographical representation
Habitat Suitability Map

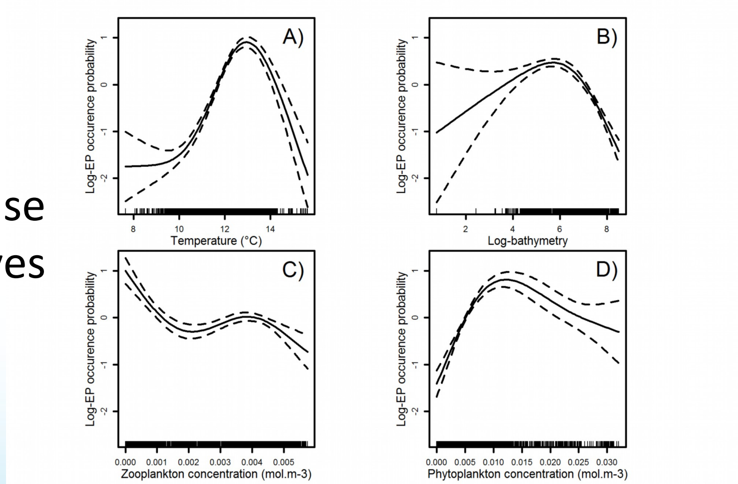
Future changes of the NE mackerel spawning distribution



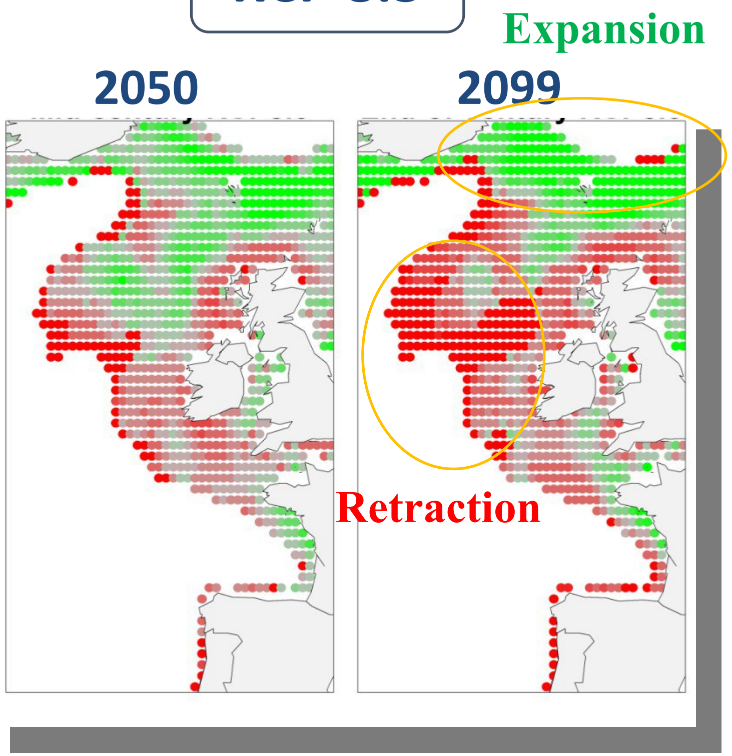
Niche-based model building



Response curves



RCP 8.5

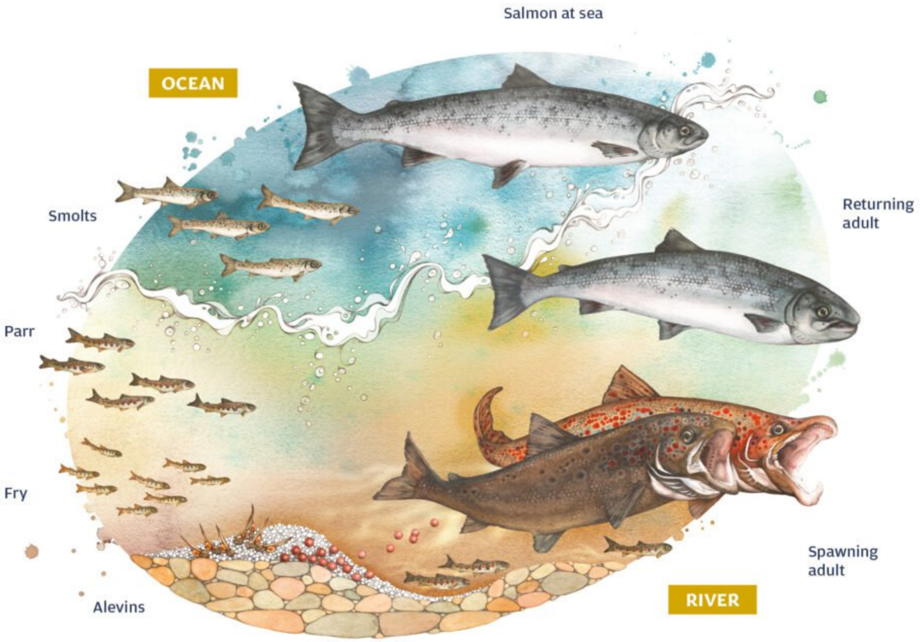


2050	2099
N. 44 km/dec	N. 41 km/dec
W. 8 km/dec	W. 15 km/dec

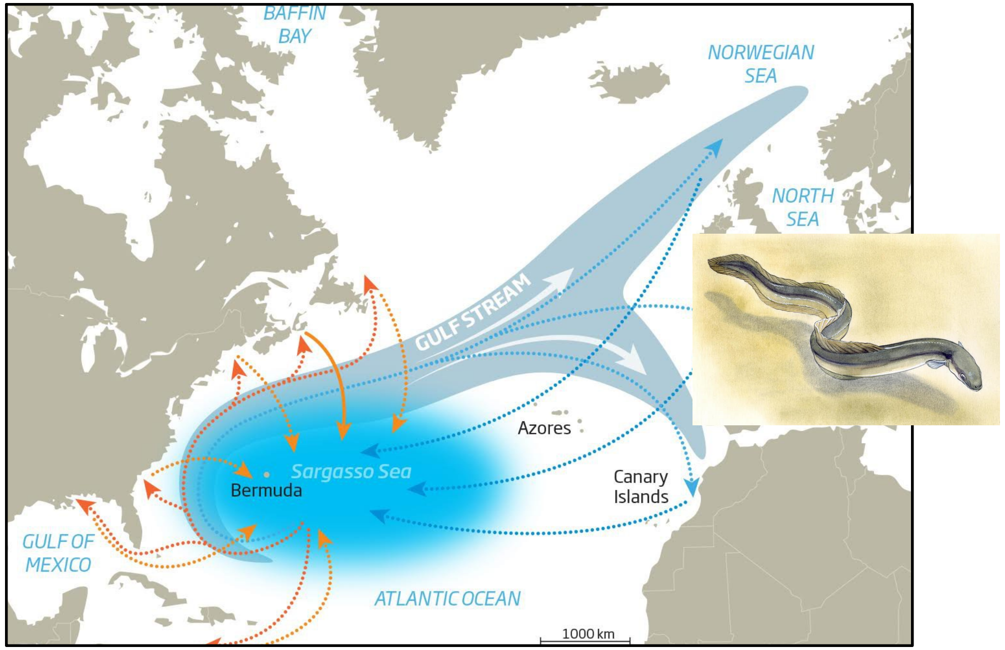
Bruge et al. 2016 Frontiers in Marine Science

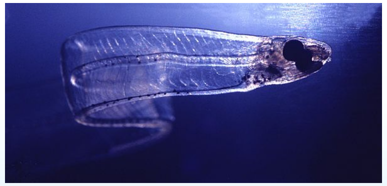
Species using distinct habitats: what to do?

Atlantic Salmon



European eel



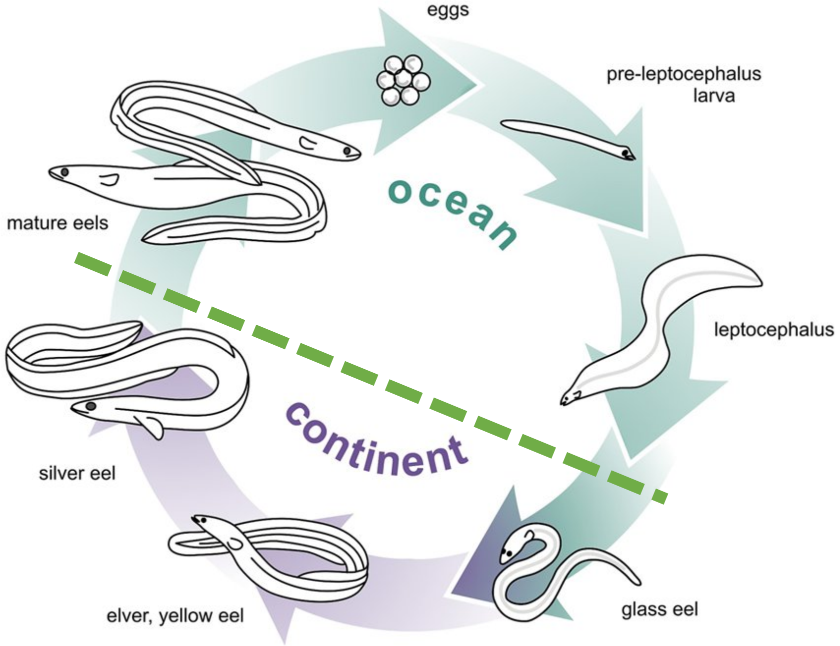


Marine mammals

Multi-state habitat models

Frans et al. (2018)

Diadromous species models

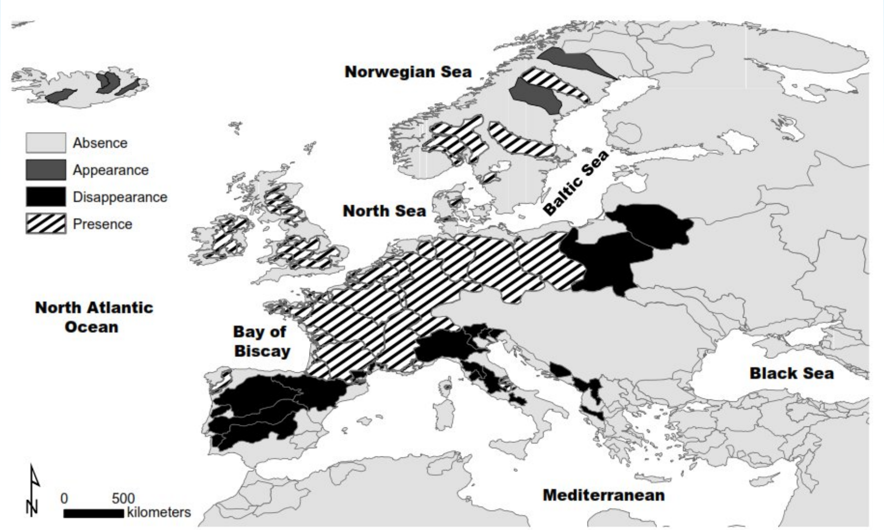


➢ Particularly complex to model

- Each life-cycle stage has specific physiological ranges and biotic interactions
- Each habitat have specific environmental characteristics (e.g. primary production for ocean, air temperature for rivers) with their specific projections (regional projection models are habitat specific in general; e.g. CORDEX for land)

Henkel et al. (2015); Lin et al. (2017)

Evolution of diadromous species models to evaluate CC



Previous works

Species distribution model:

- Lassalle et al. (2008, 2009, 2010)
- 23 diadromous species
- River habitats

Hybrid models
(Singer et al. 2018)

DIADES project

HyDiaD: Hybrid model combining dispersal, population dynamics, and multi-habitat suitability: included both the freshwater and oceanic environmental conditions

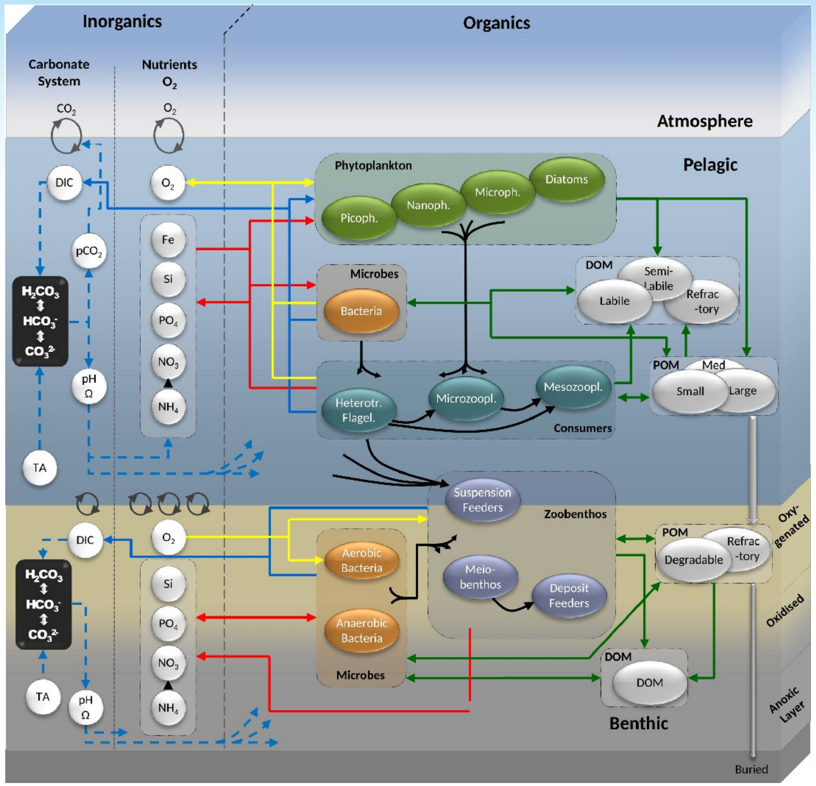
- **DIADES project** - Barber et al. (2022)
- Species: *Alosa alosa* and *A. Fallax*

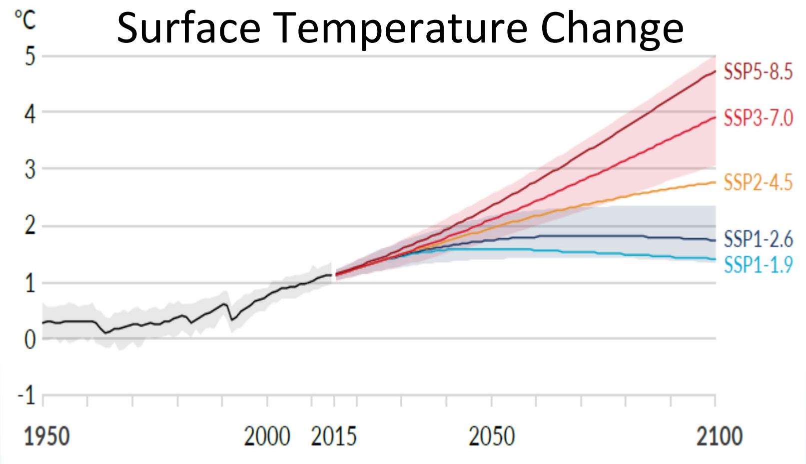
Future applications and improvements

- Applicable to other anadromous species
- Applicable with modifications to catadromous species
- To be Included: adaptive potential of species, phenotypic plasticity, and ecological processes such as competition and trophic relationships
- To implement shape-constrained GAMs to model habitat suitability according to ecological niche theory
- Eel model: need combination of larvae dispersal by currents with habitat suitability

Fish projections: main uncertainties and challenges

- ## When using complex models:
  - Model parametrization is problematic and large assumptions
  - Require greater computer processing
  - Model validation is often partial
  - Amplification of the warming signal through the food web
- ## Using simple models:
  - Lack of key processes
- ## Diadromous species models:
  - Lack of models that integrate the entire food web
  - Lack of models that couples both marine and freshwater systems
  - ➢ Diadromous could be a paradigmatic example of multi-habitat species models
- ## Model input forcings
  - Some variables are regionally uncertain (e.g. ocean primary production, river flow)
- ## GHGs Scenarios
  - Wide range of socio-economic pathways





Thanks for your attention!

Merci de votre attention!