a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA

# Projecting climate change impacts on global marine fisheries


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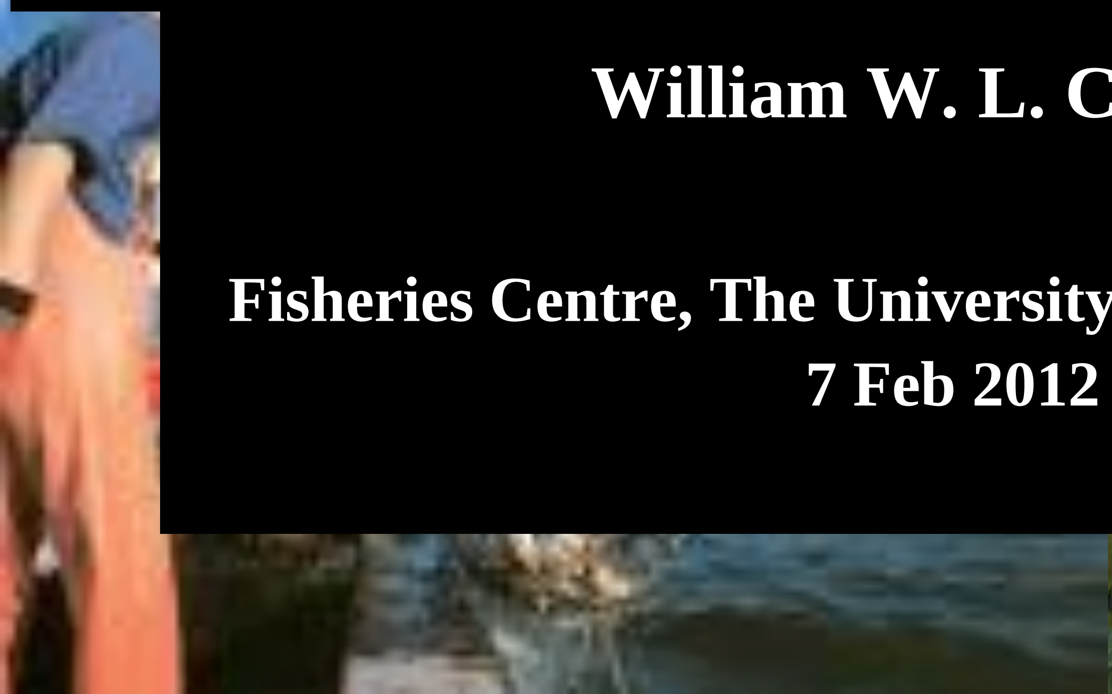
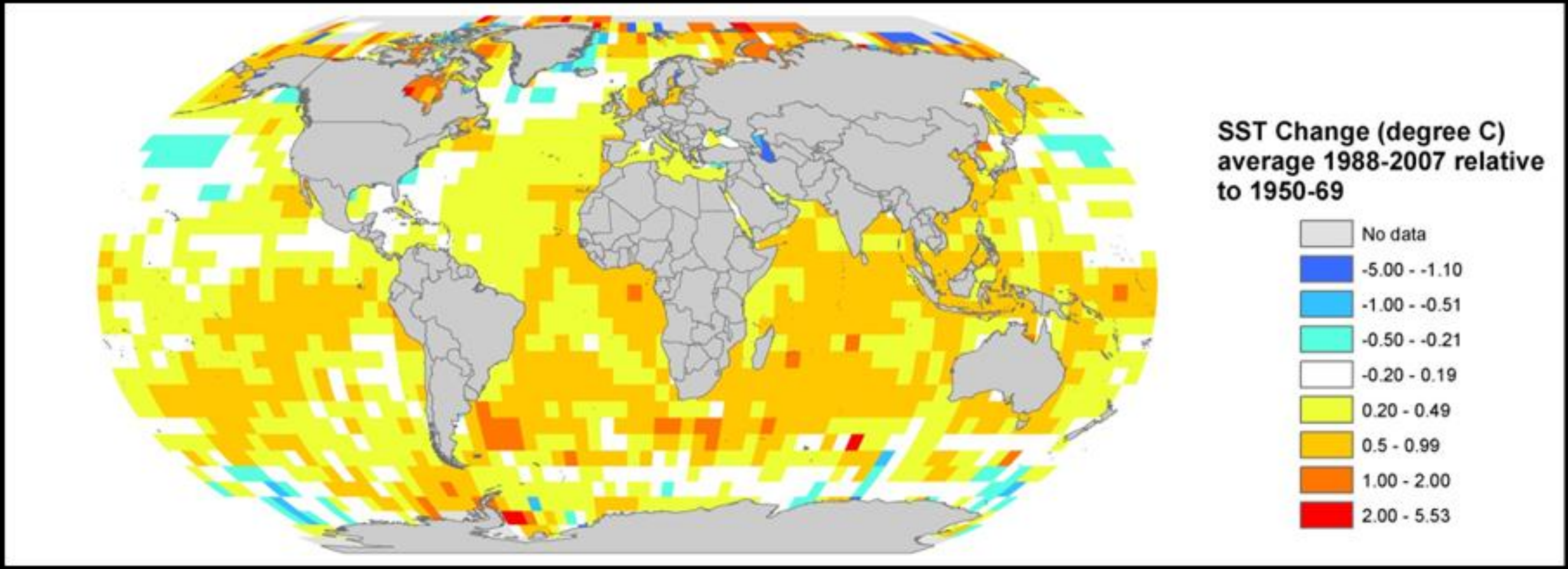
**7 Feb 2012**



# Human impacts on marine ecosystems

# Climate change, ocean warming and acidification



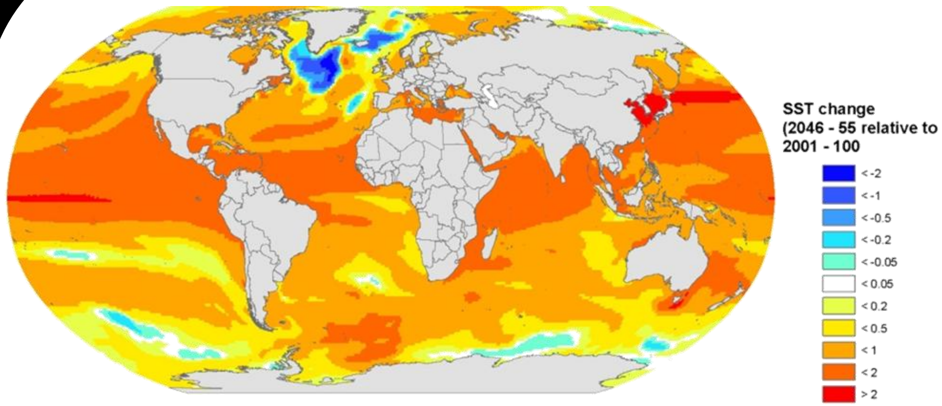

**The ocean has become:**

- **warmer** (an increase in average temperature of 0.2°C at the top 300 m of the ocean between the 1950s and1990s);
- with **less sea-ice** (summer Arctic sea ice extent is decreasing at 7.4% per decade);
- **more acidic**;
- **less oxygenated** in some area, **higher sea level**, **changes in primary productivity**.

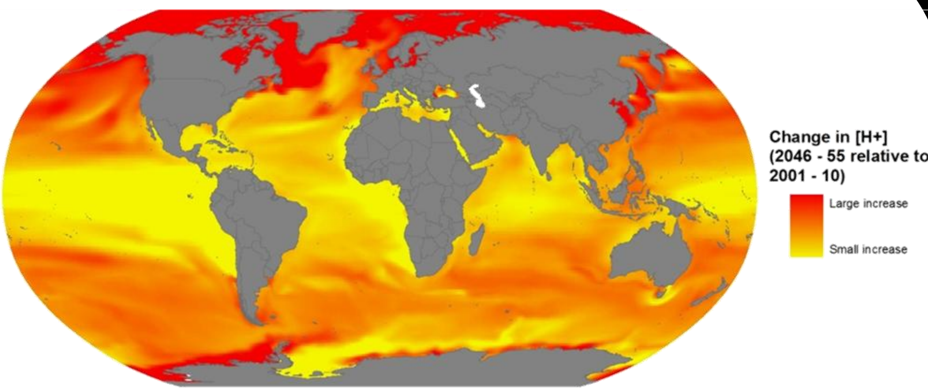
# Future changes in ocean conditions

## Scenario: SRES A1B

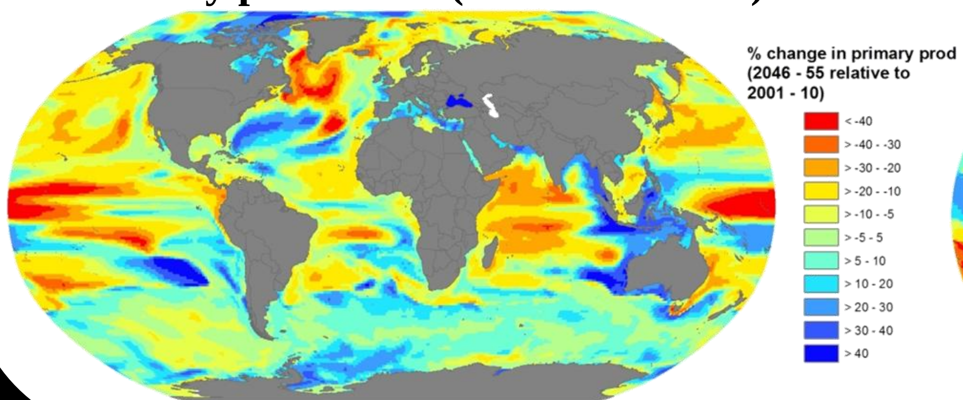
### Sea surface temperature



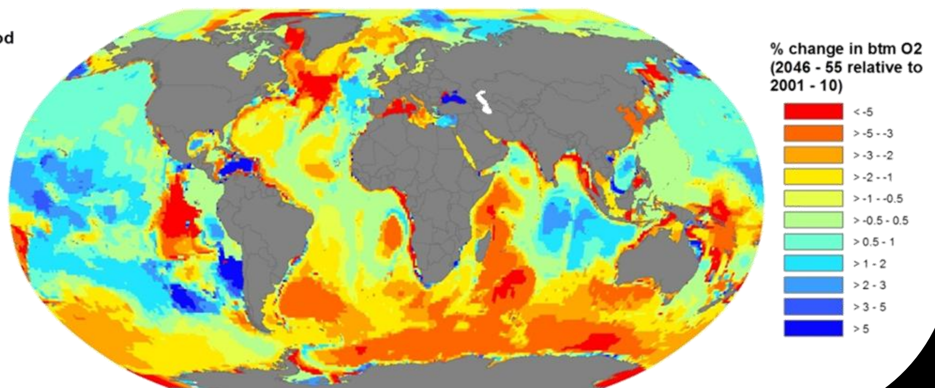

### Acidity




### Primary production (available to fish)

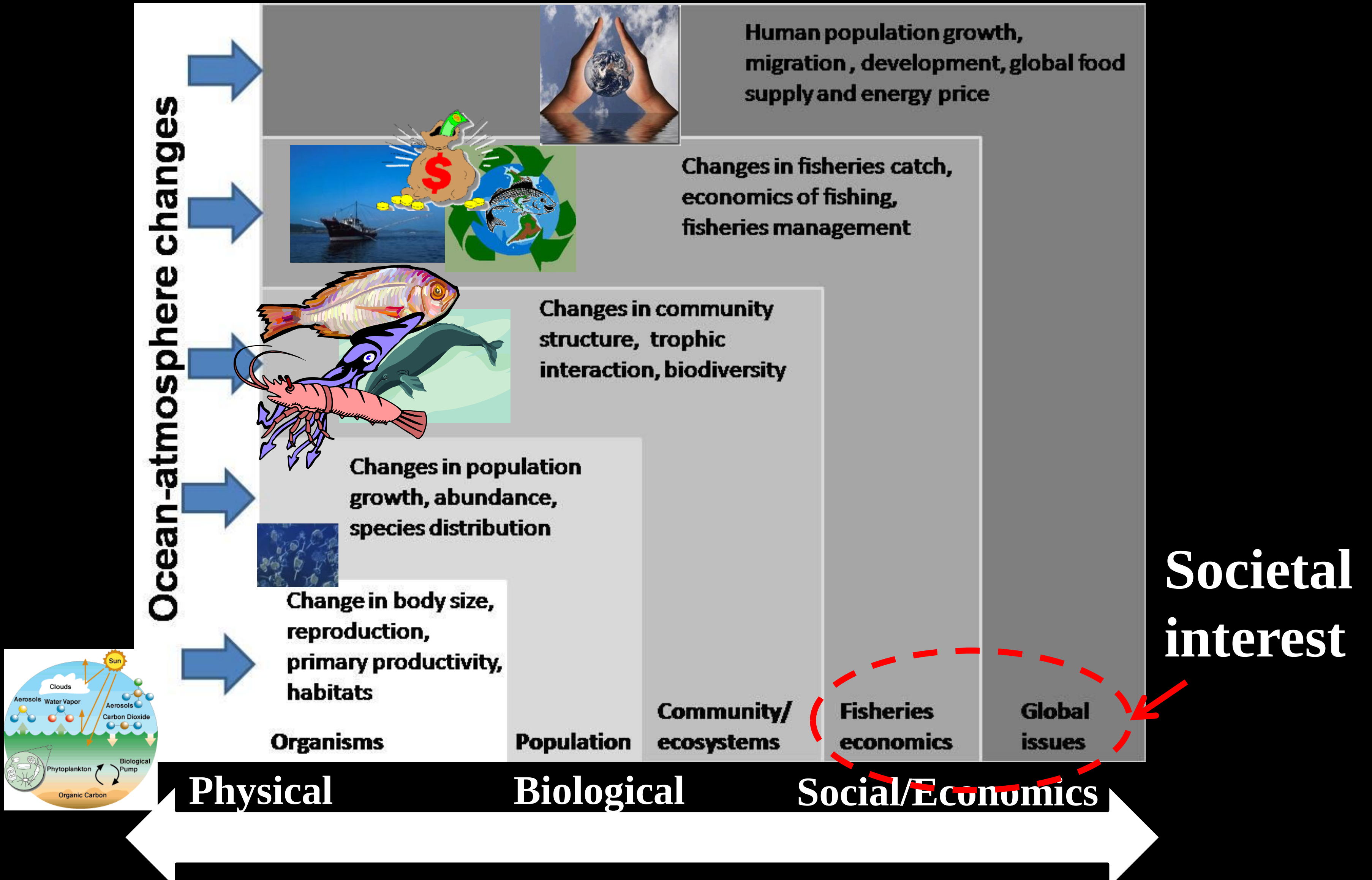



### Oxygen content (sea bottom)




**Source: NOAA/GFDL Earth System Model (TOPAZ)**

# Climate change effects in the ocean




From: Sumaila, Cheung, Lam, Pauly, Herrick (2011) Nature Climate Change

# Research program

- **Goal:**

  **Assesses the biophysical and socio-economic vulnerabilities and impacts of marine climate change, and identifies mitigation and adaptation options.**

# Outline

- Key theories and hypotheses;

- Impacts of climate change on marine biodiversity:

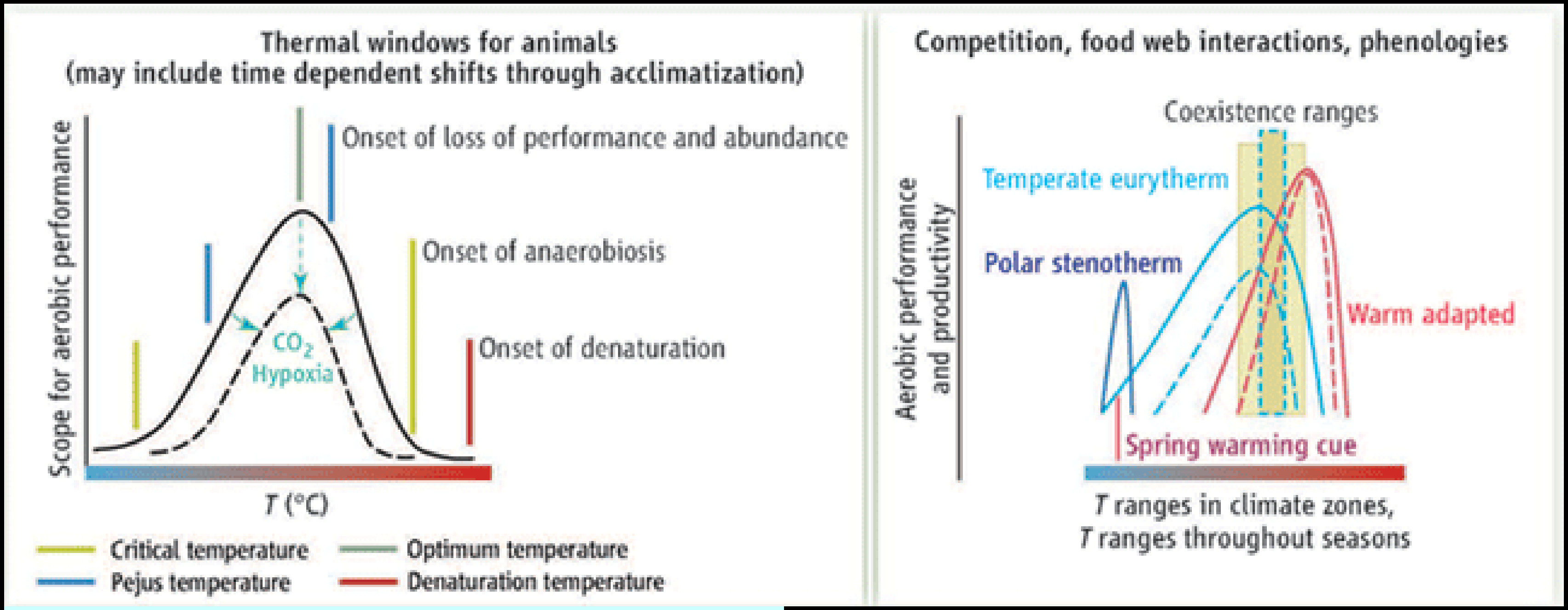
- Impacts of climate change on fisheries

- Future research direction.

# Outline

- Key theories and hypotheses;
- Impacts of climate change on marine biodiversity:
- Impacts of climate change on fisheries
- Future research direction.

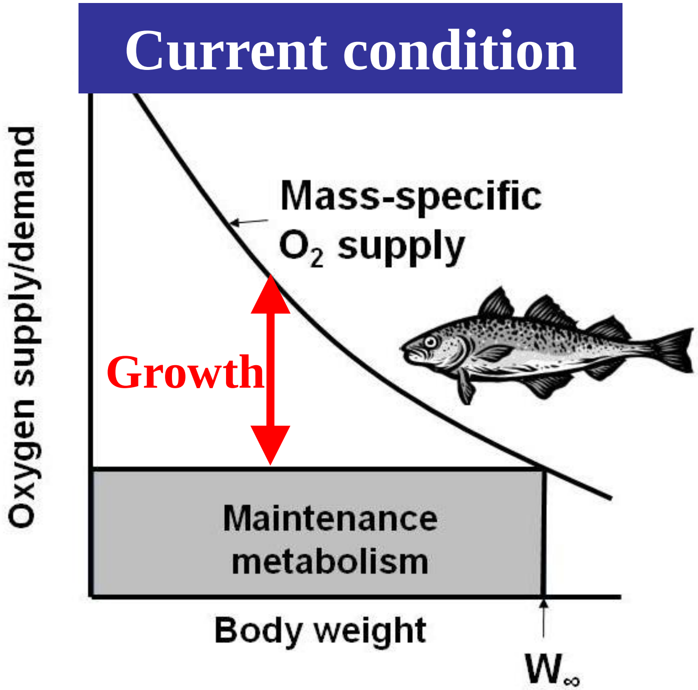
# Oxygen- and capacity- limited thermal tolerance

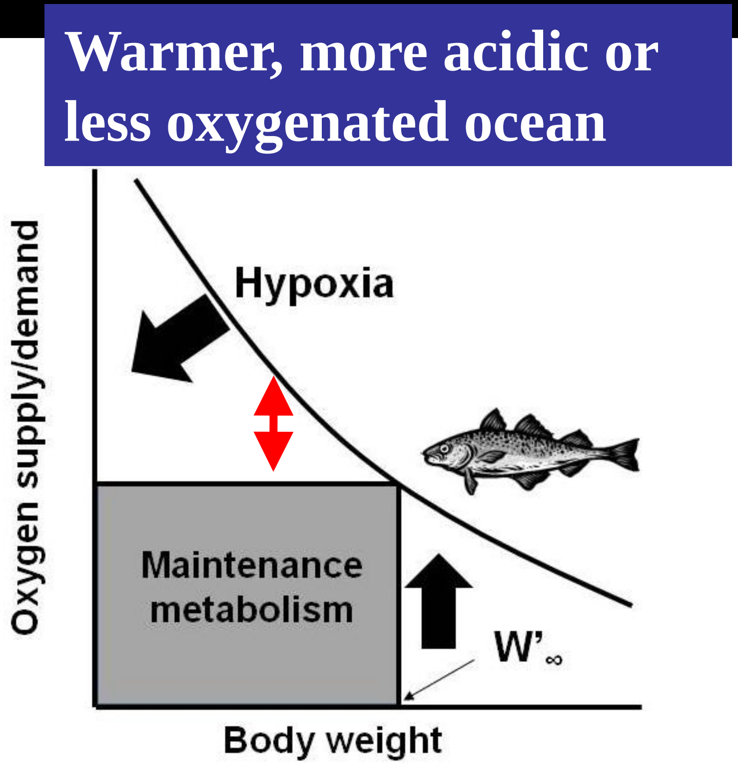



From: Pörtner & Farrell (2008) Science

- Environment stresses such as acidification or hypoxia reduce aerobic scope.

# Metabolic and life history theories



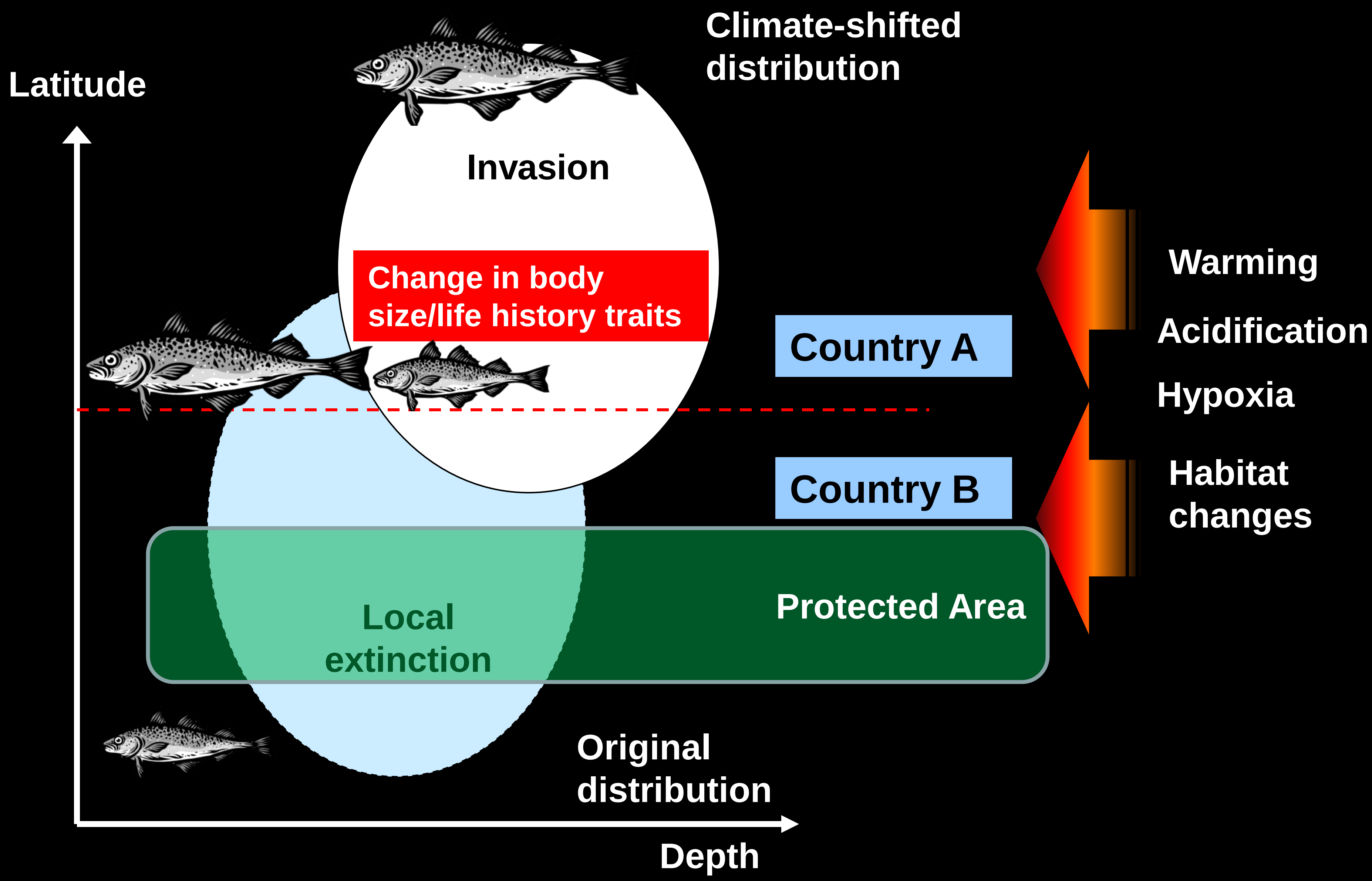

- **Linking aerobic scope and growth function;**
- **Effects on natural mortality, maturity, fecundity and recruitment.**

**Source: Pauly (2010); Cheung, Dunne, Sarmiento, Pauly (2011)**

# Ecological-niche theory

- **Predicts that animals distribute themselves to maximize their growth performance.**

# Hypothesis of climate change impacts on fish and fisheries



# Outline

- Key theories and hypotheses;

- Impacts of climate change on marine biodiversity:

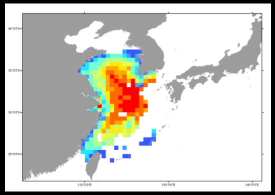
- Impacts of climate change on fisheries

- Future research direction.

# Interdisciplinary approaches to model impacts of global change

Global climate/ocean changes projections

Dynamic Bioclimate Envelope Model (DBEM)



Species composition

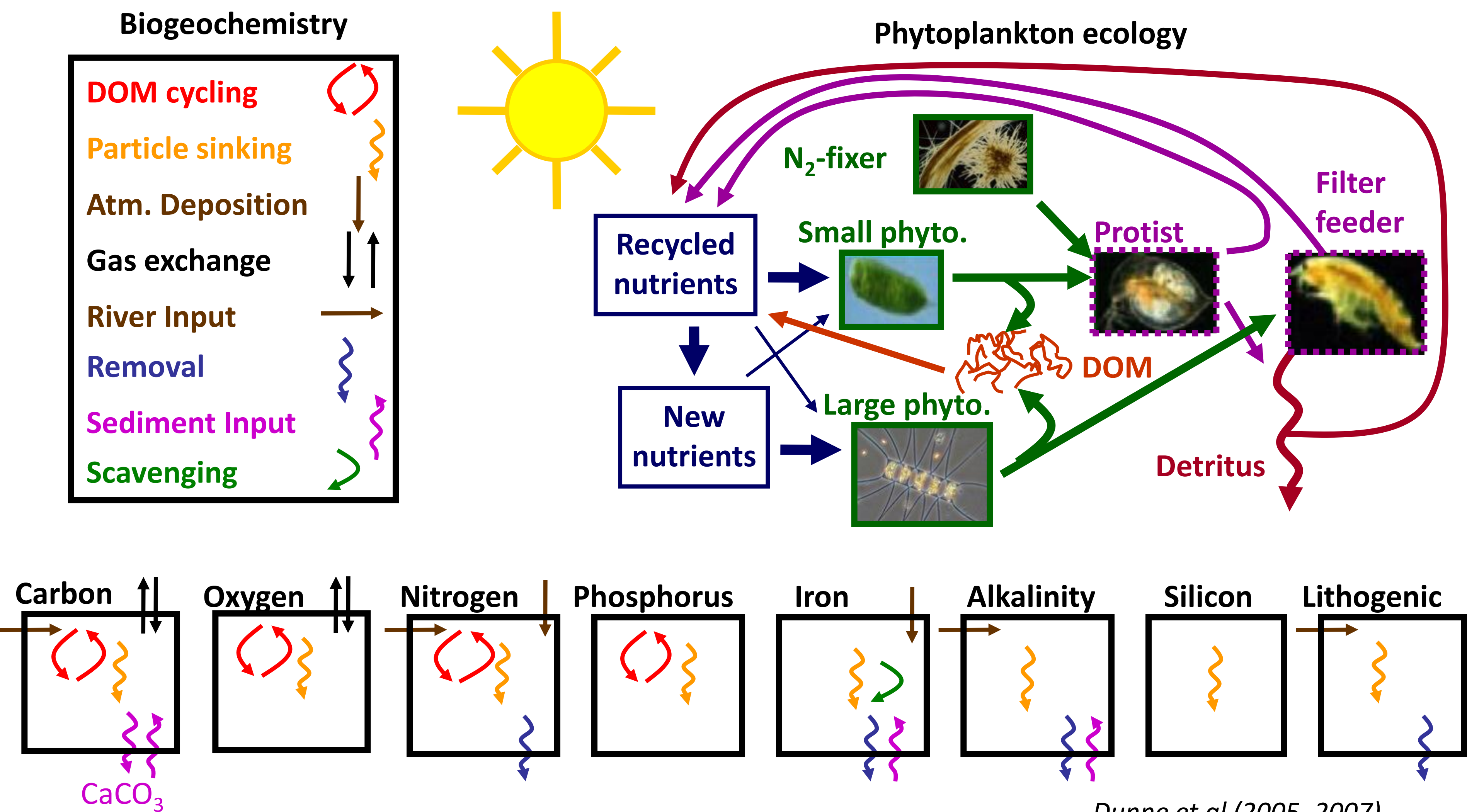
Body size and relative abundance

Maximum catch potential

# Dynamic bioclimatic envelope model

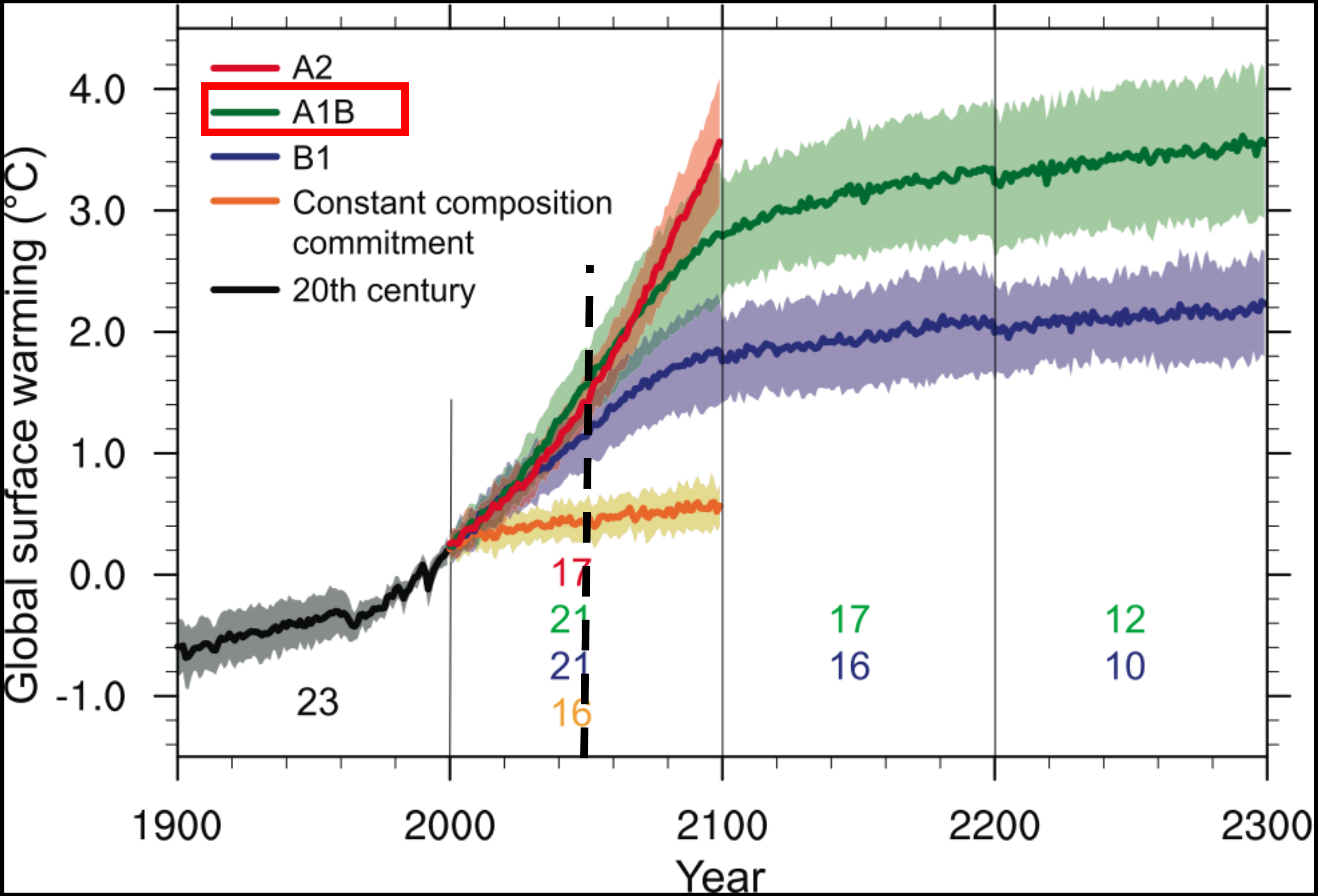
- Current (1980-2000) species distributions, life history and habitat preferences as initial conditions;
- Link to spatial-temporal size-structured population dynamic model;
- Recruitment, larval transport, adult movement, individual and population growth, and carrying capacity are dependent on environmental conditions;
- Explicit ecophysiology component;
- 30’ x 30’ grid of global ocean.

# Modelling biogeochemical loop (e.g. GFDL TOPAZ)

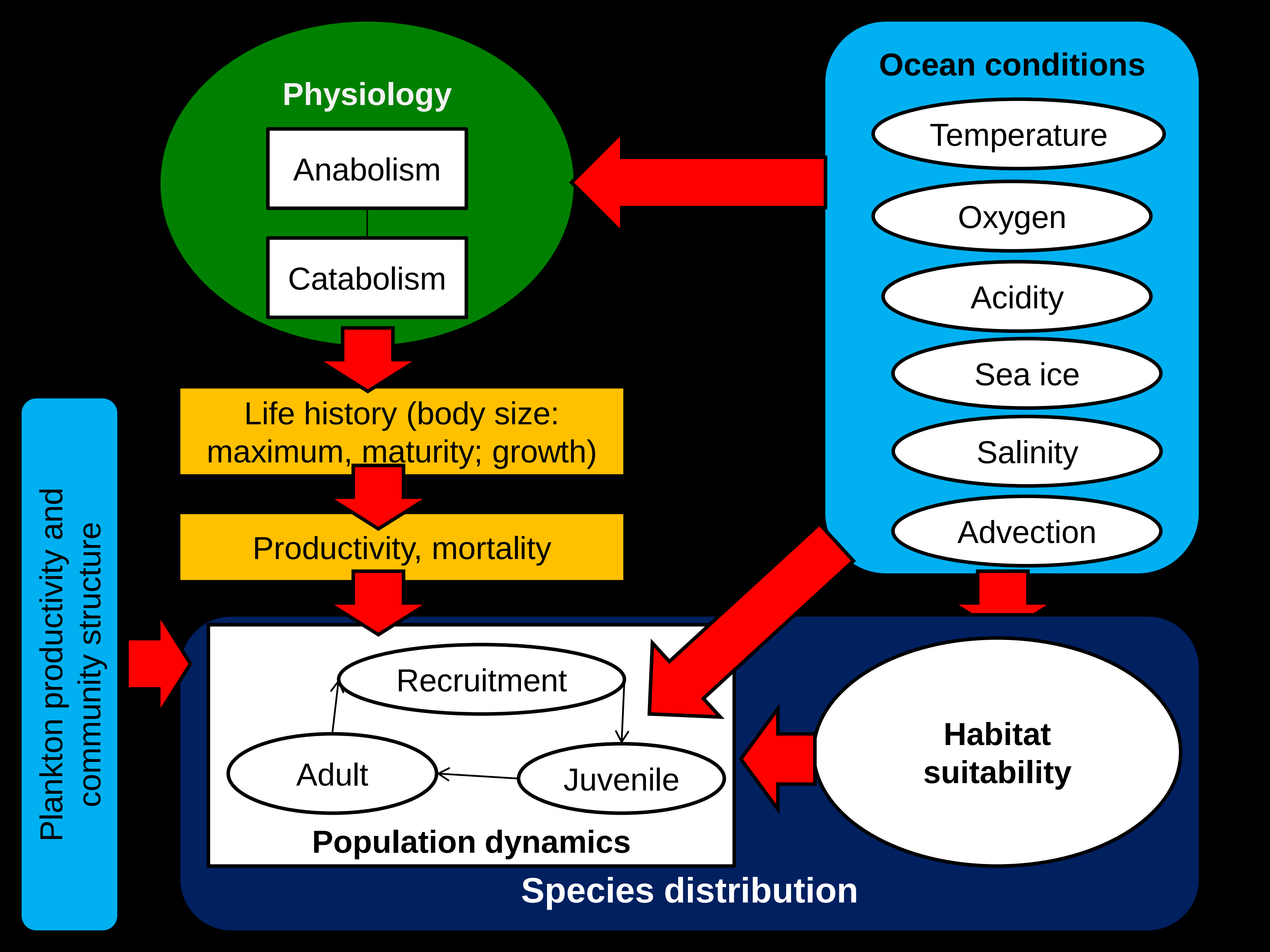



*Dunne et al (2005, 2007)*

# Climate change scenarios



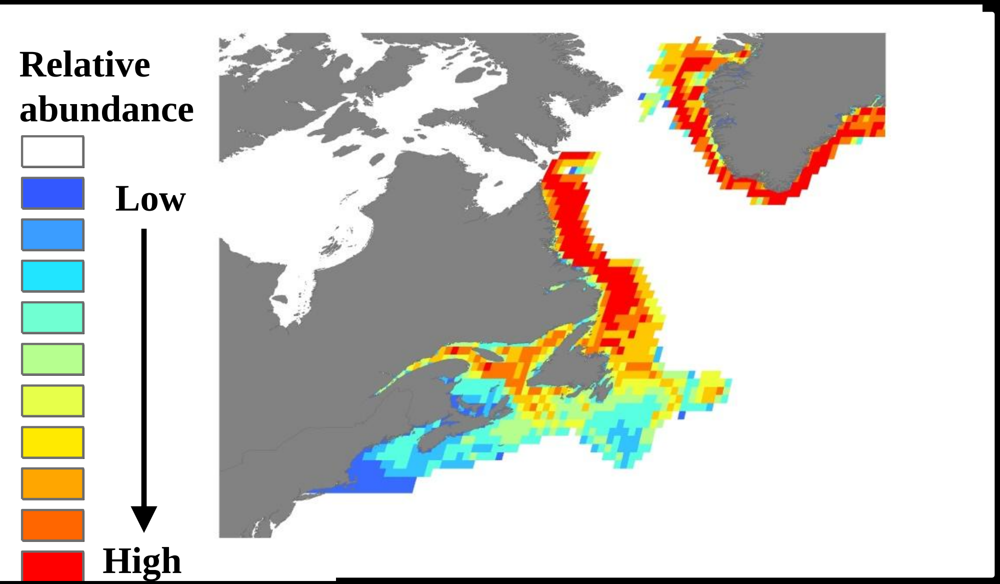

**Source: IPCC 2007**

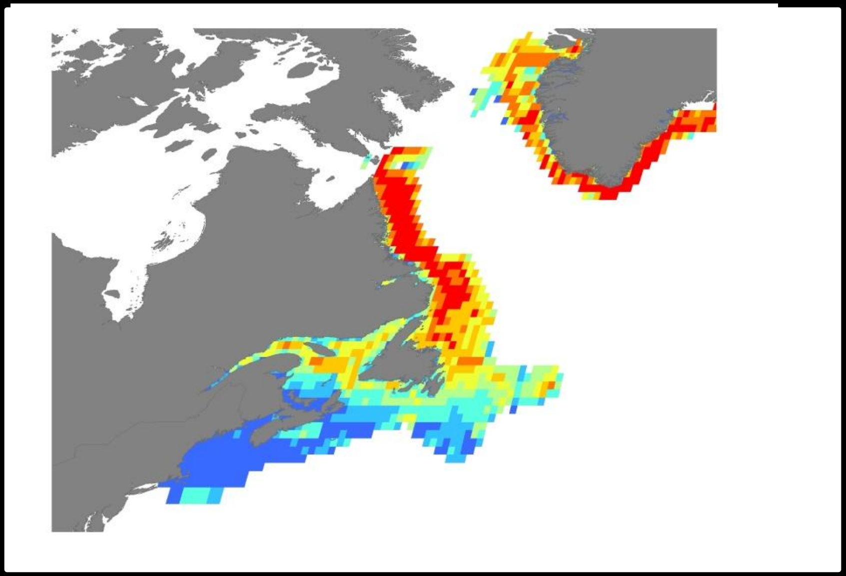


Physiology
Anabolism
Catabolism
Ocean conditions
Temperature
Oxygen
Acidity
Sea ice
Salinity
Advection
Life history (body size: maximum, maturity; growth)
Productivity, mortality
Plankton productivity and community structure
Recruitment
Adult
Juvenile
Population dynamics
Habitat suitability
Species distribution

# Example: Atlantic cod (*Gadus morhua*)

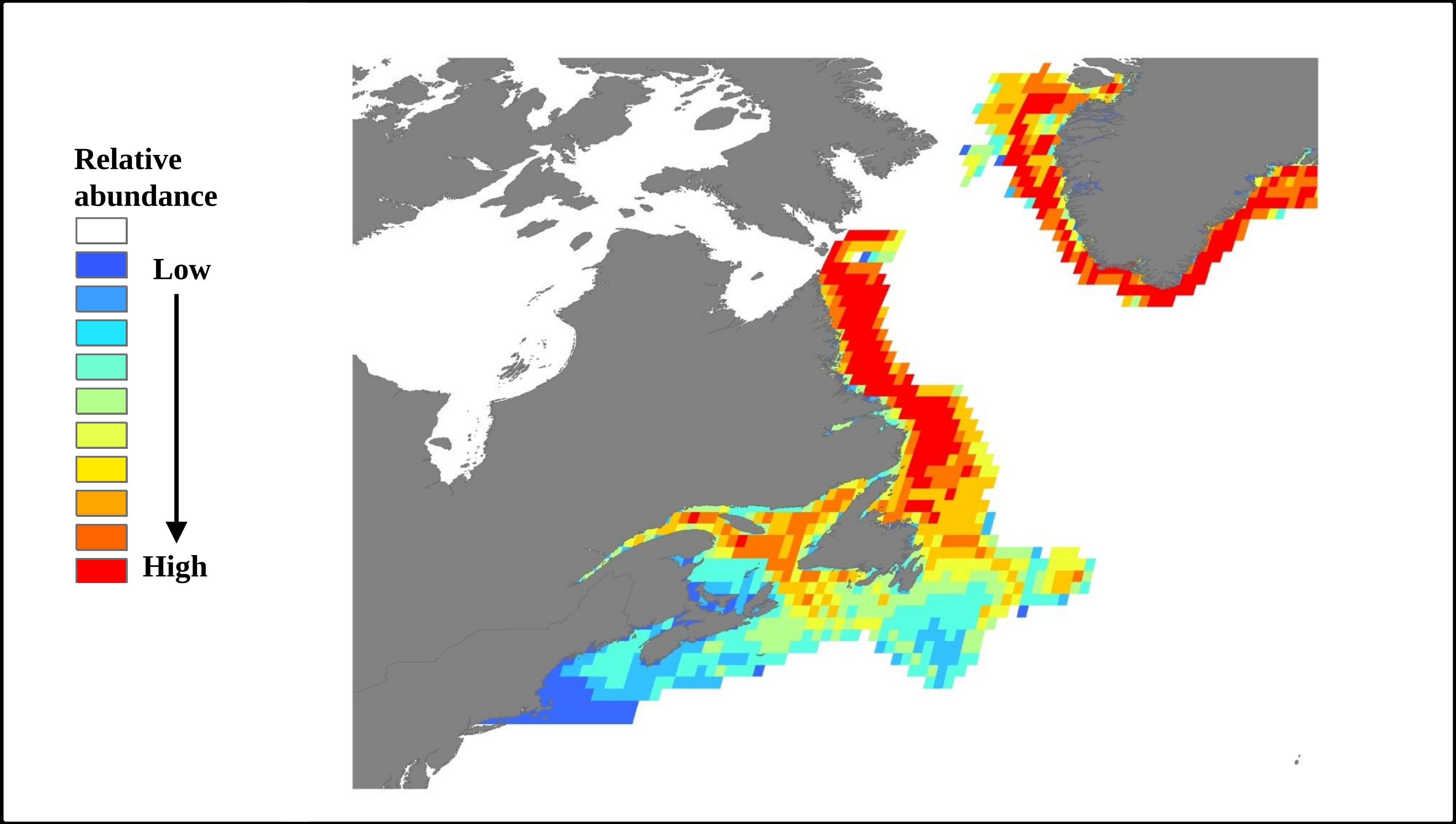
**Original (static) distribution** | **Distribution after 50 years**



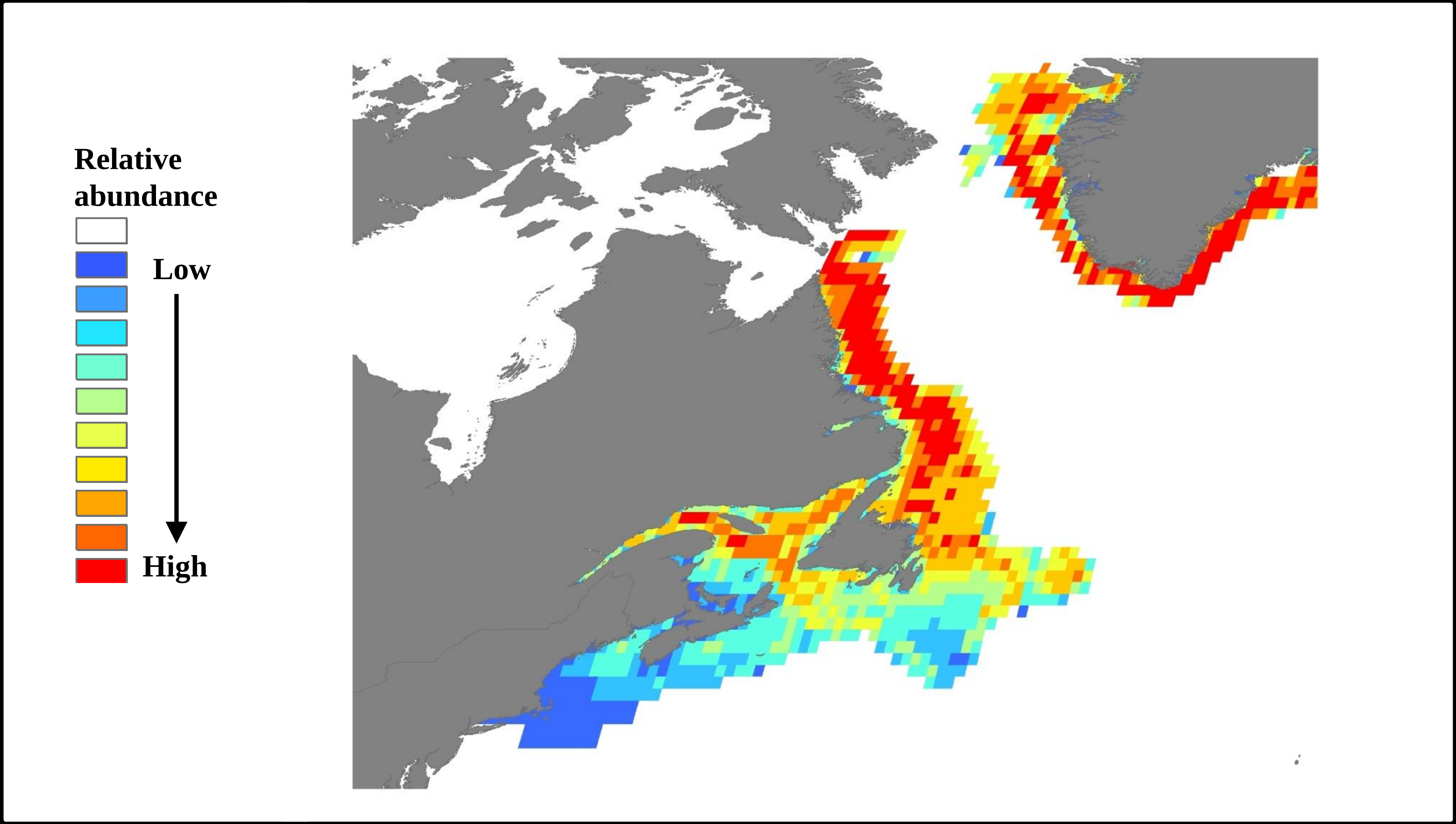
# Atlantic cod

**Year 2001**



# Atlantic cod

## Year 2005



# Atlantic cod

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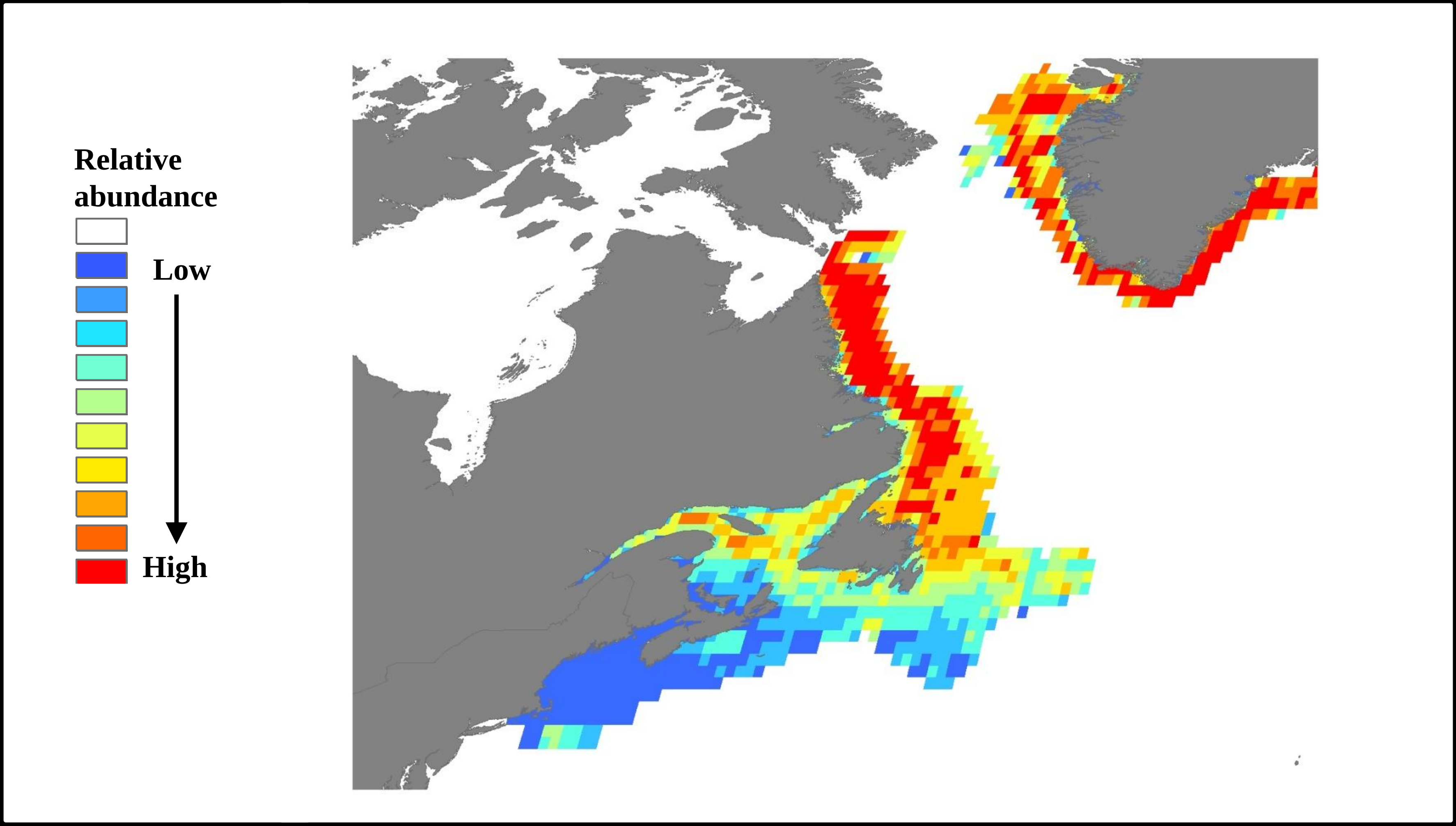
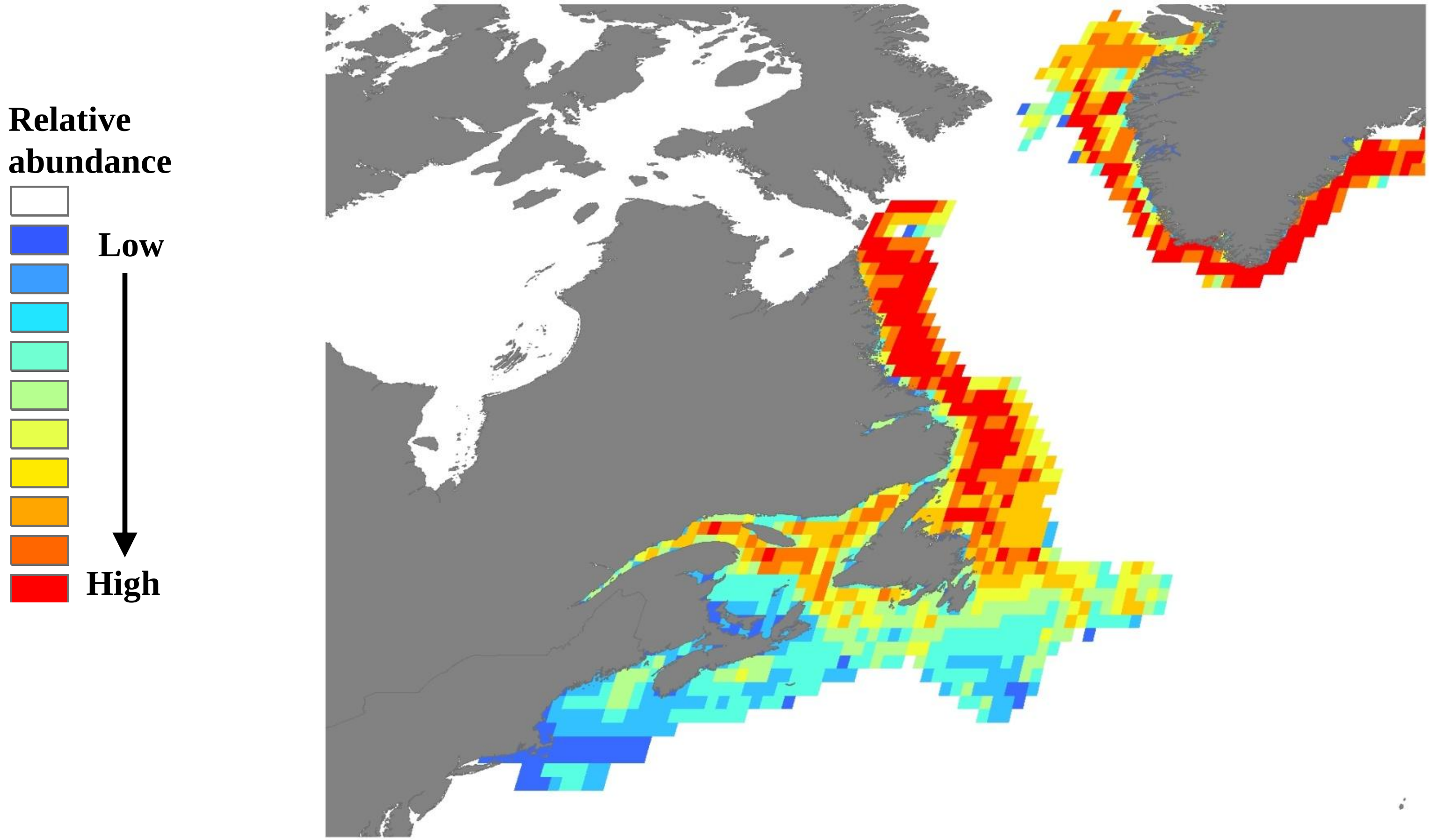


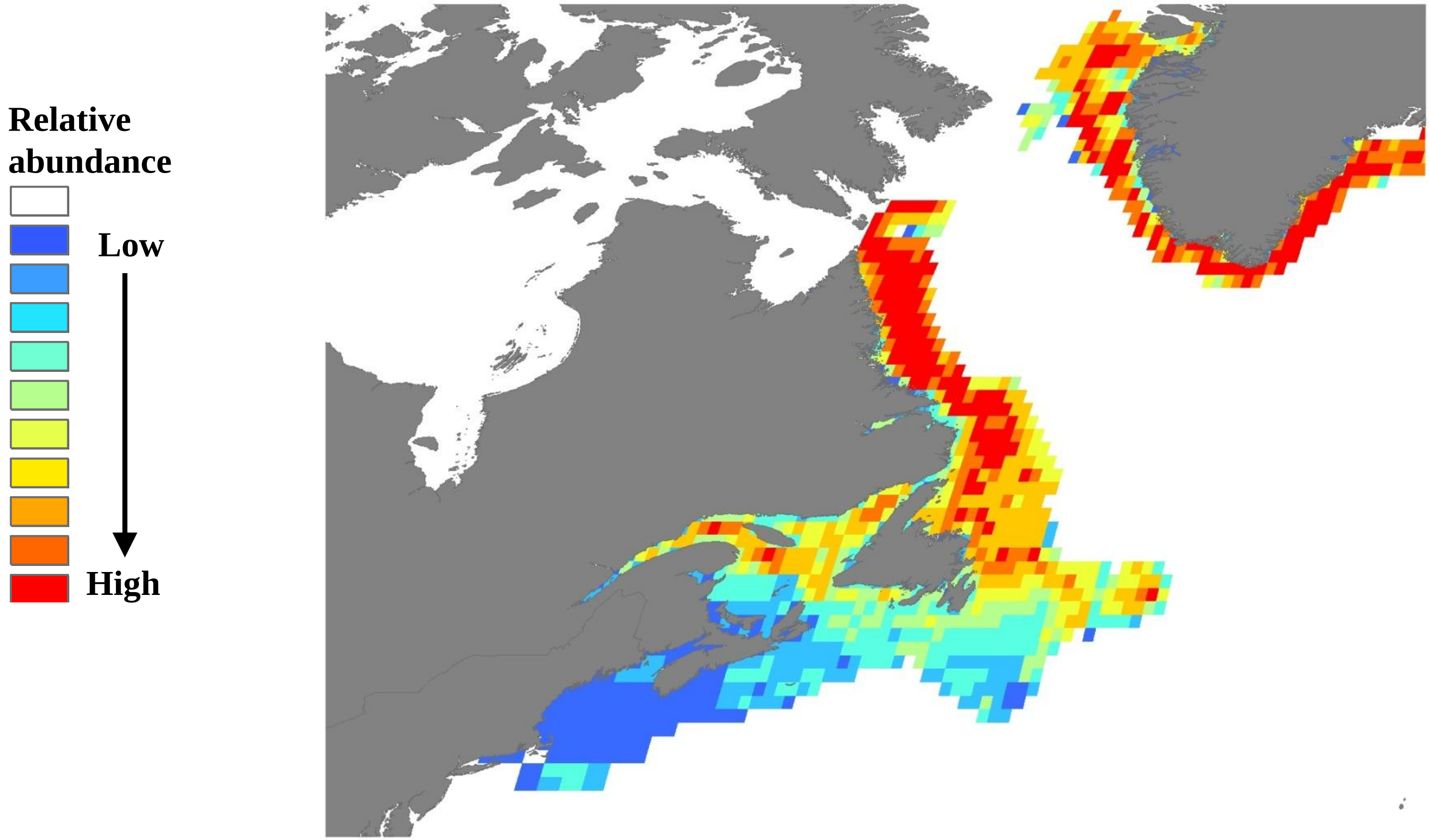
# Atlantic cod

**Year 2020**



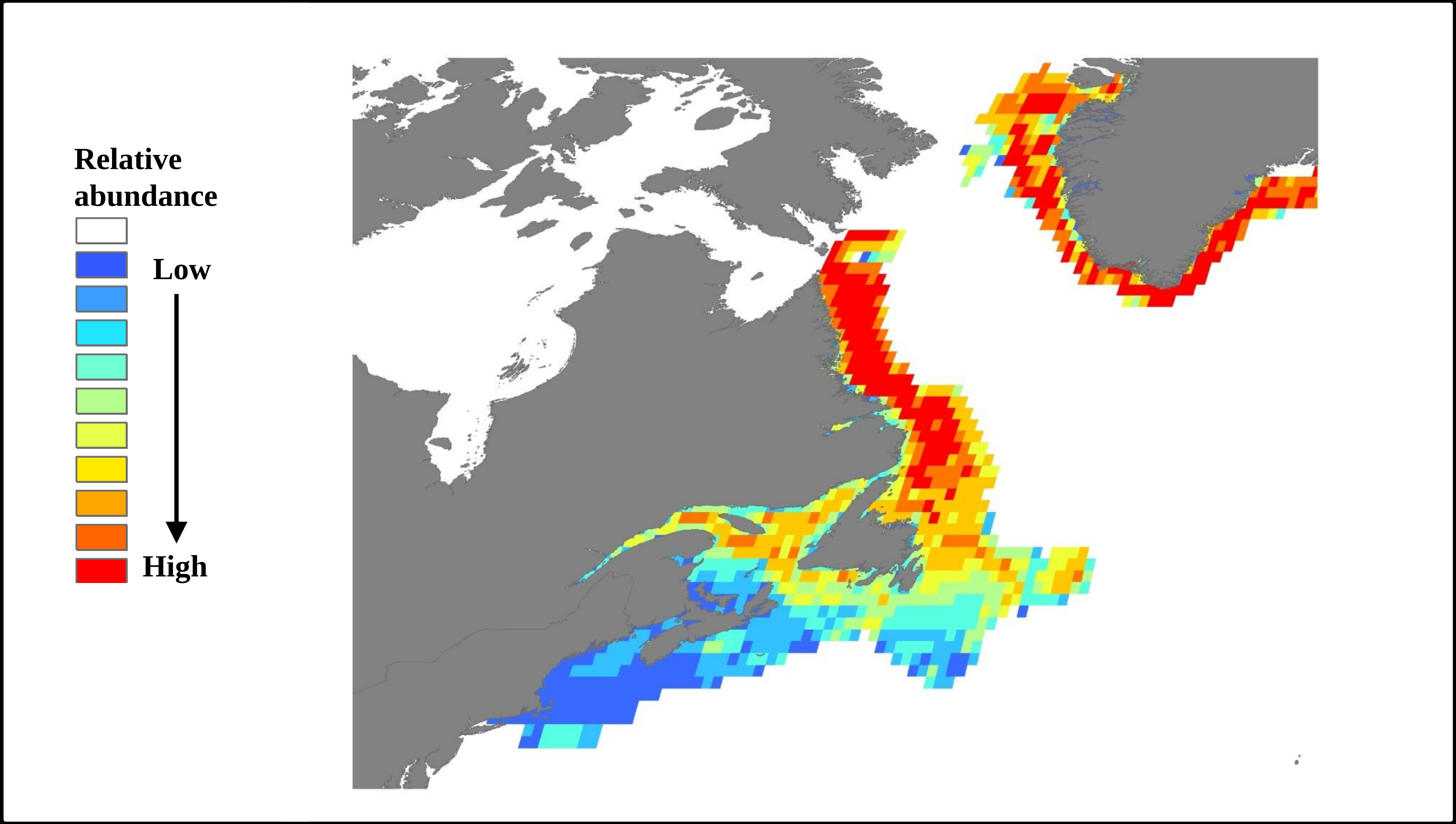
# Atlantic cod

Year 2030



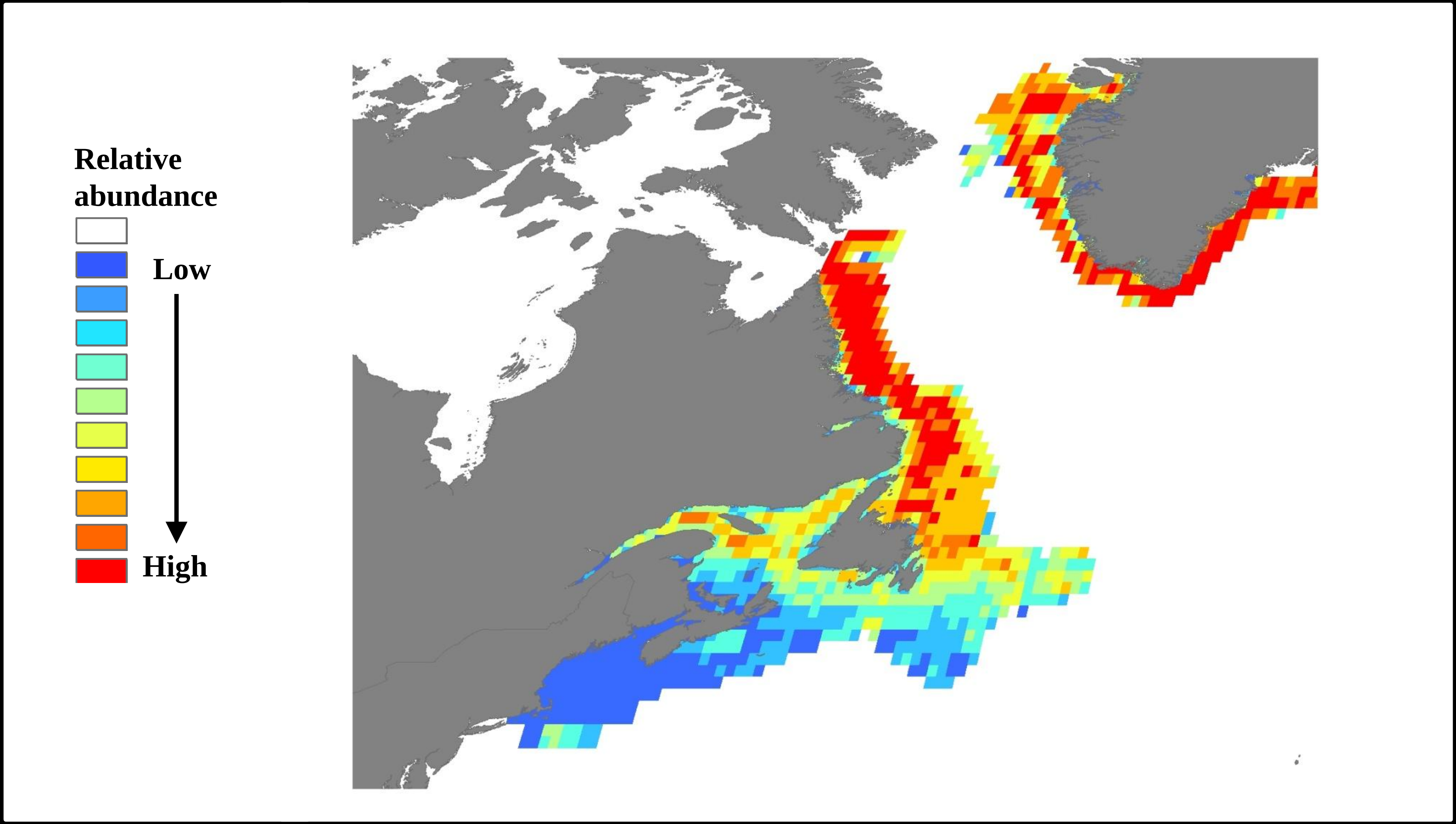
# Atlantic cod

**Year 2040**



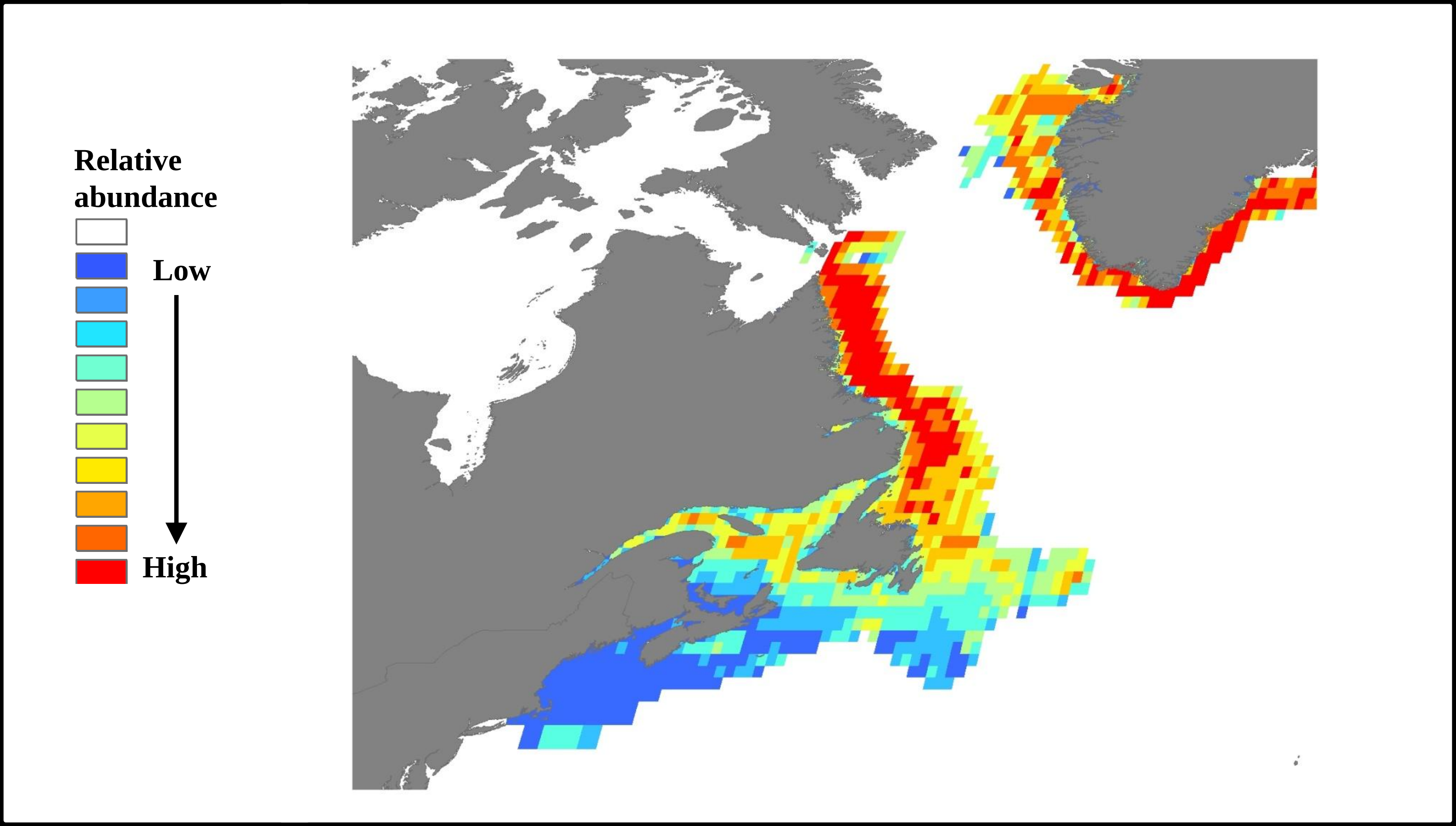
# Atlantic cod

**Year 2050**



# Atlantic cod

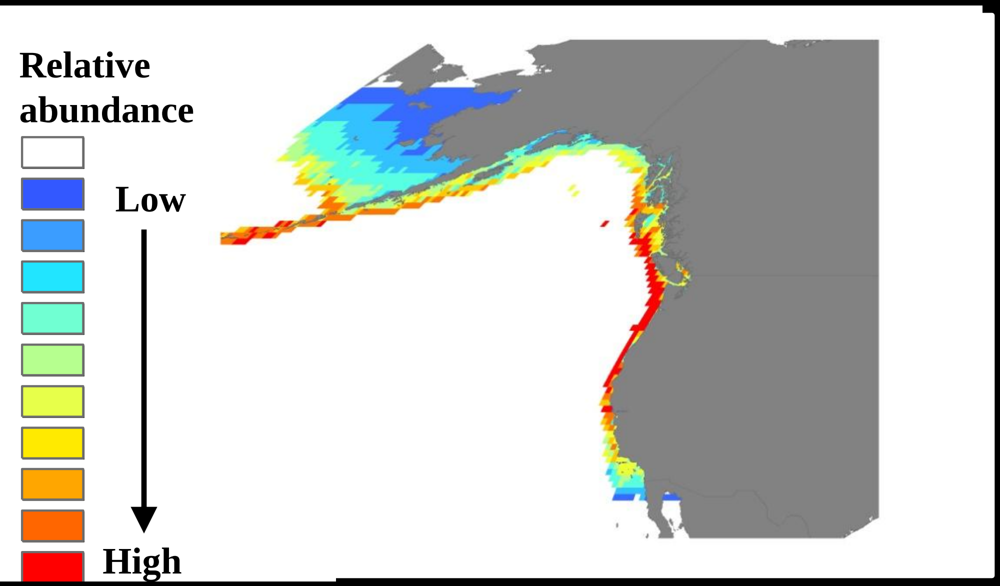
**Year 2060**

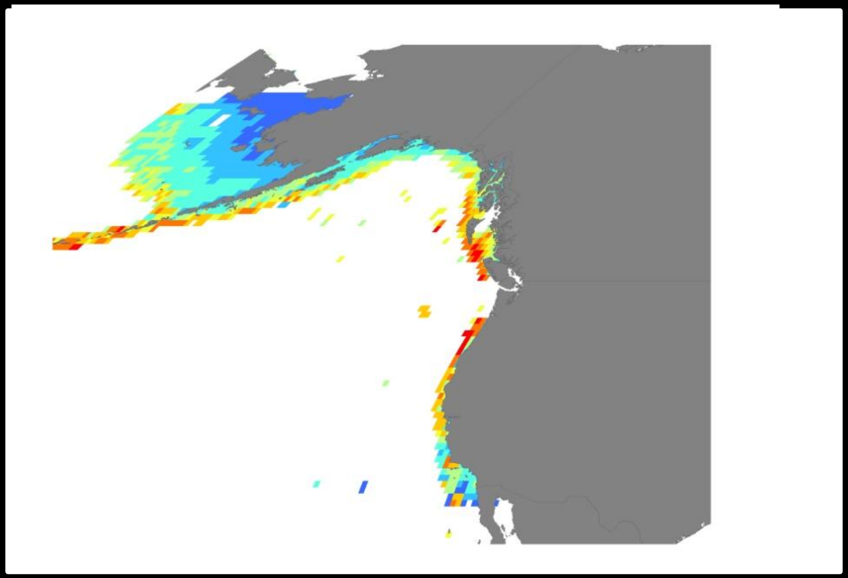


# Example: Pacific Halibut (*Hippoglossus stenolepis*)

**Original (static) distribution**

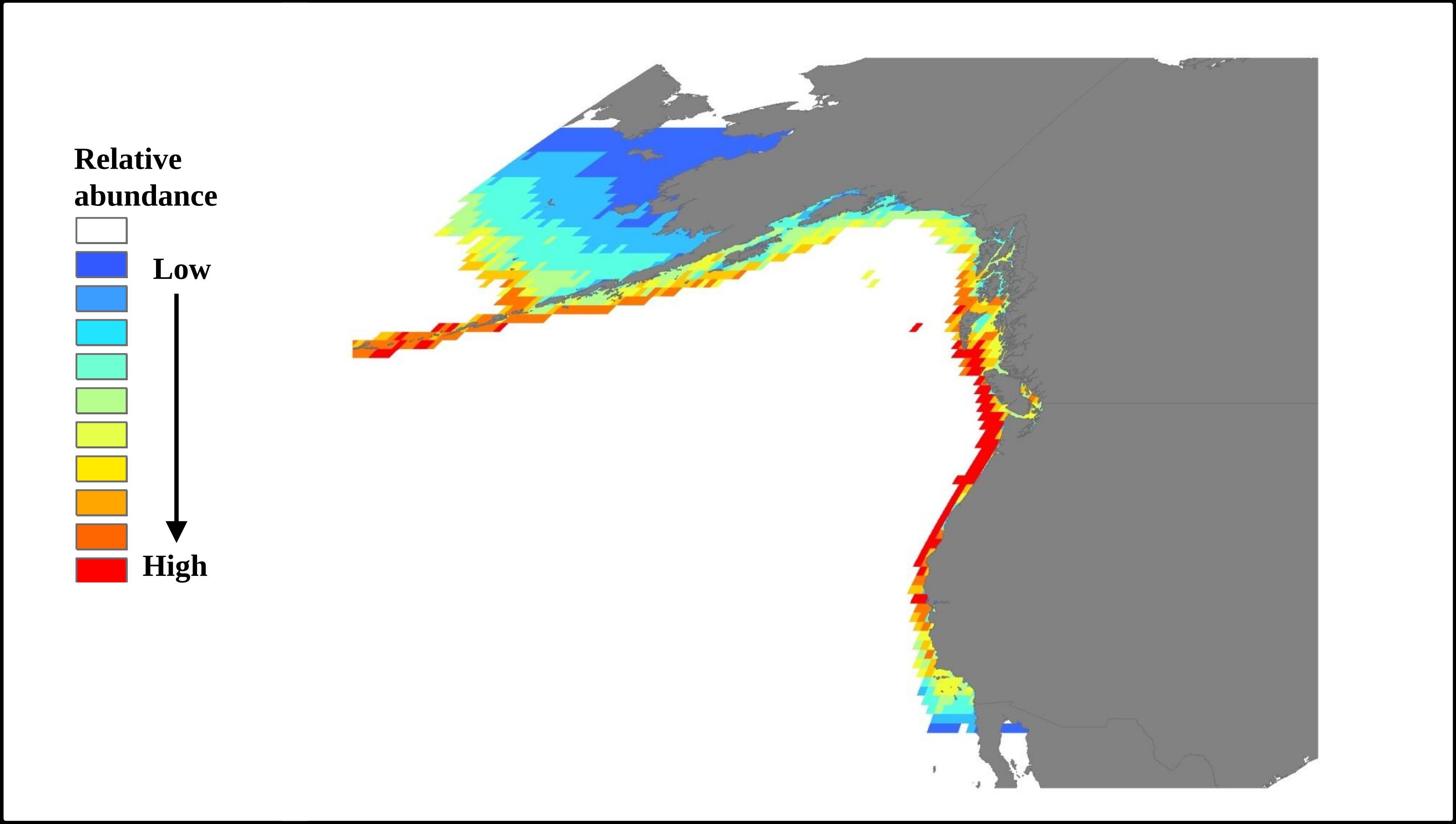
**Distribution after 50 years**



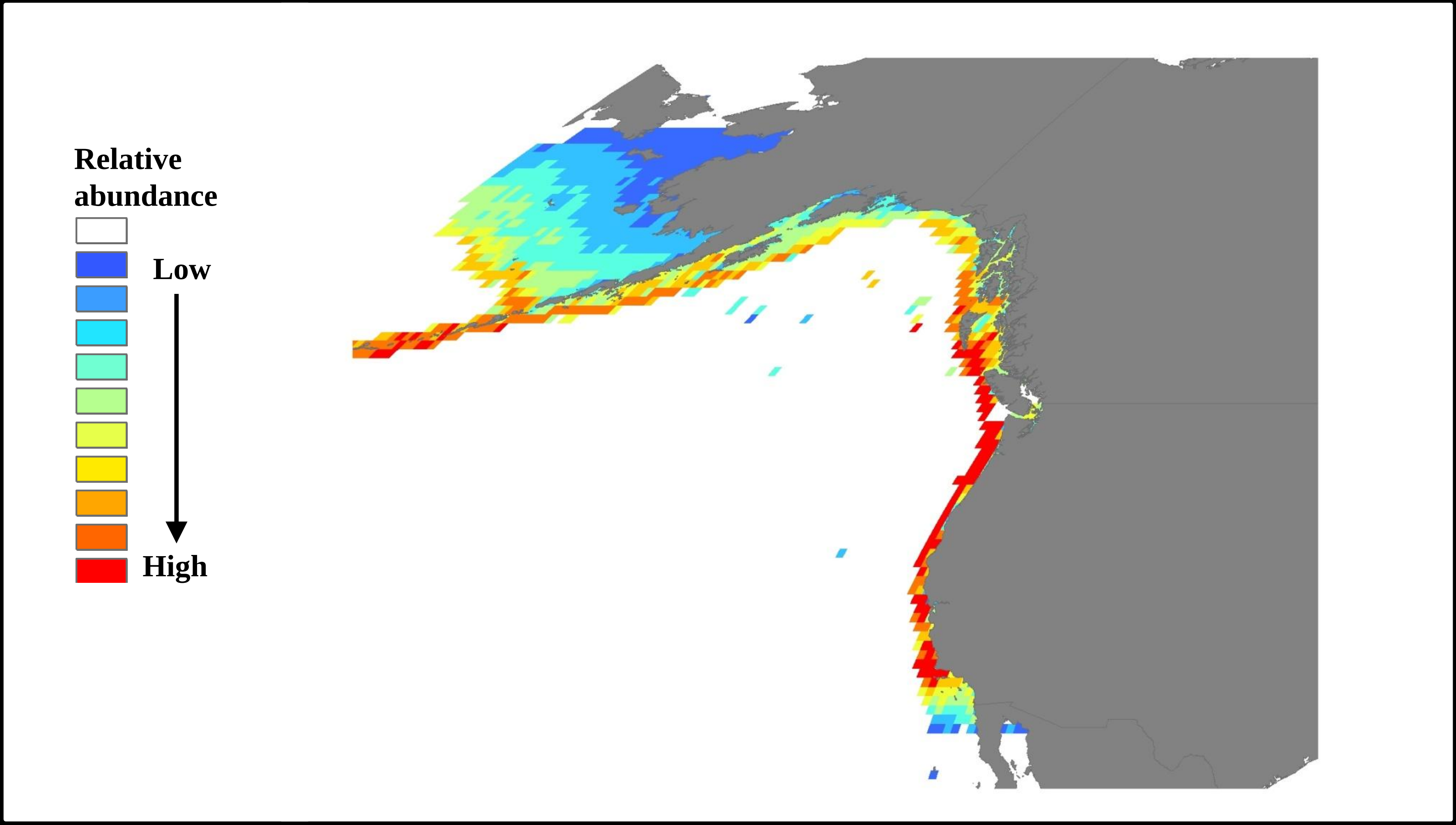
# Pacific Halibut

**Year 2001**



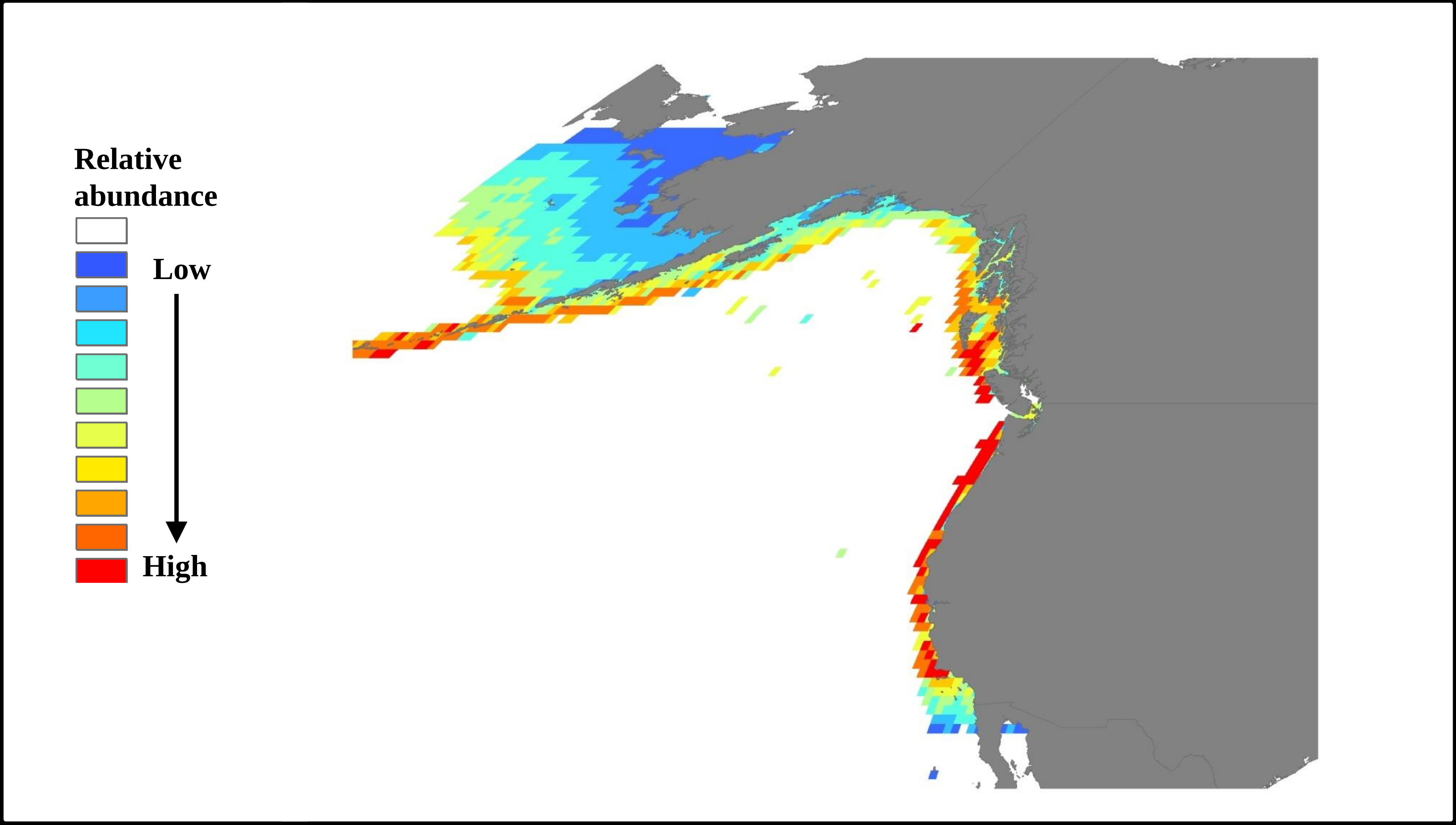
# Pacific Halibut

**Year 2005**



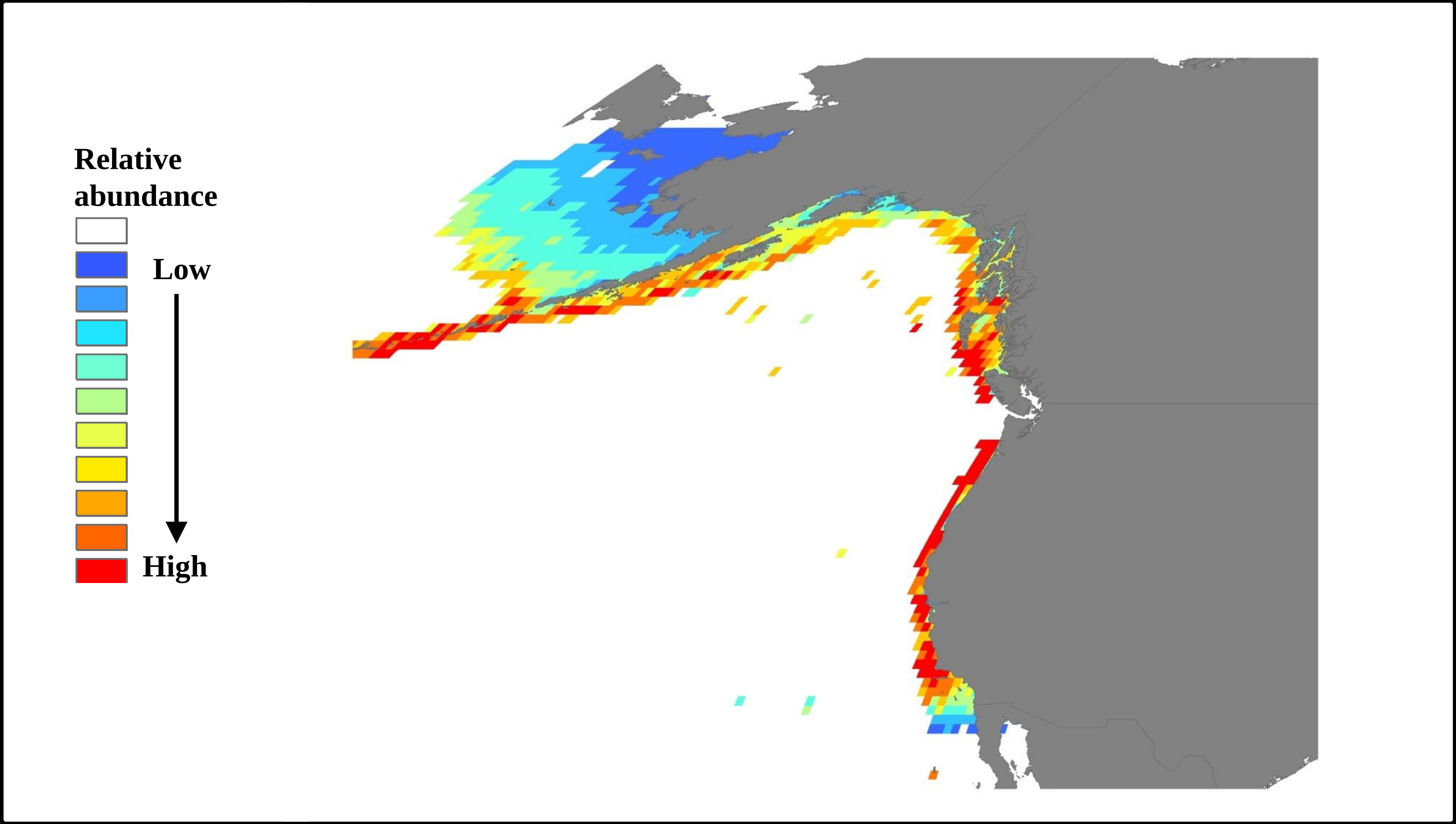
# Pacific Halibut

**Year 2010**



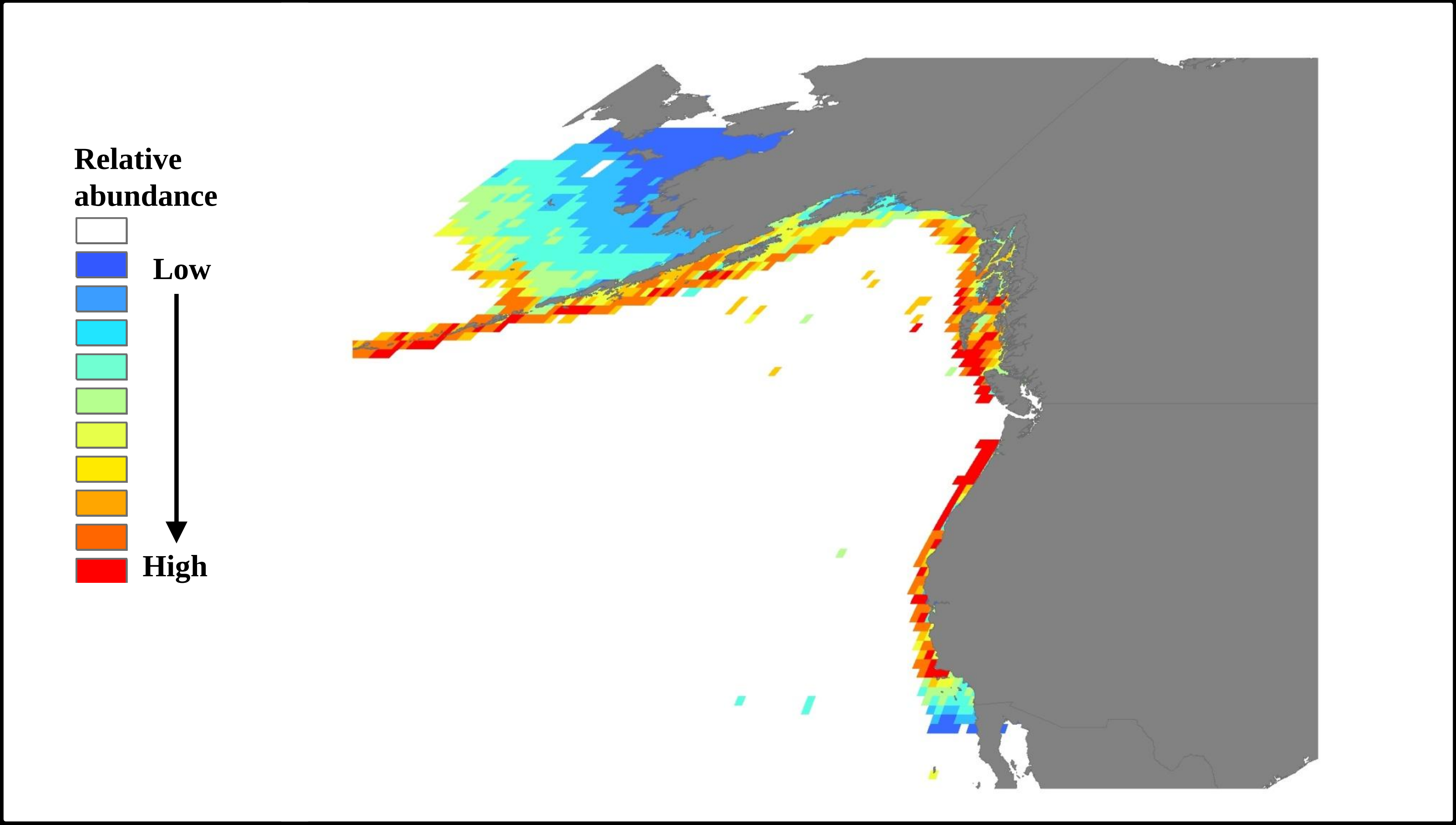
# Pacific Halibut

**Year 2020**



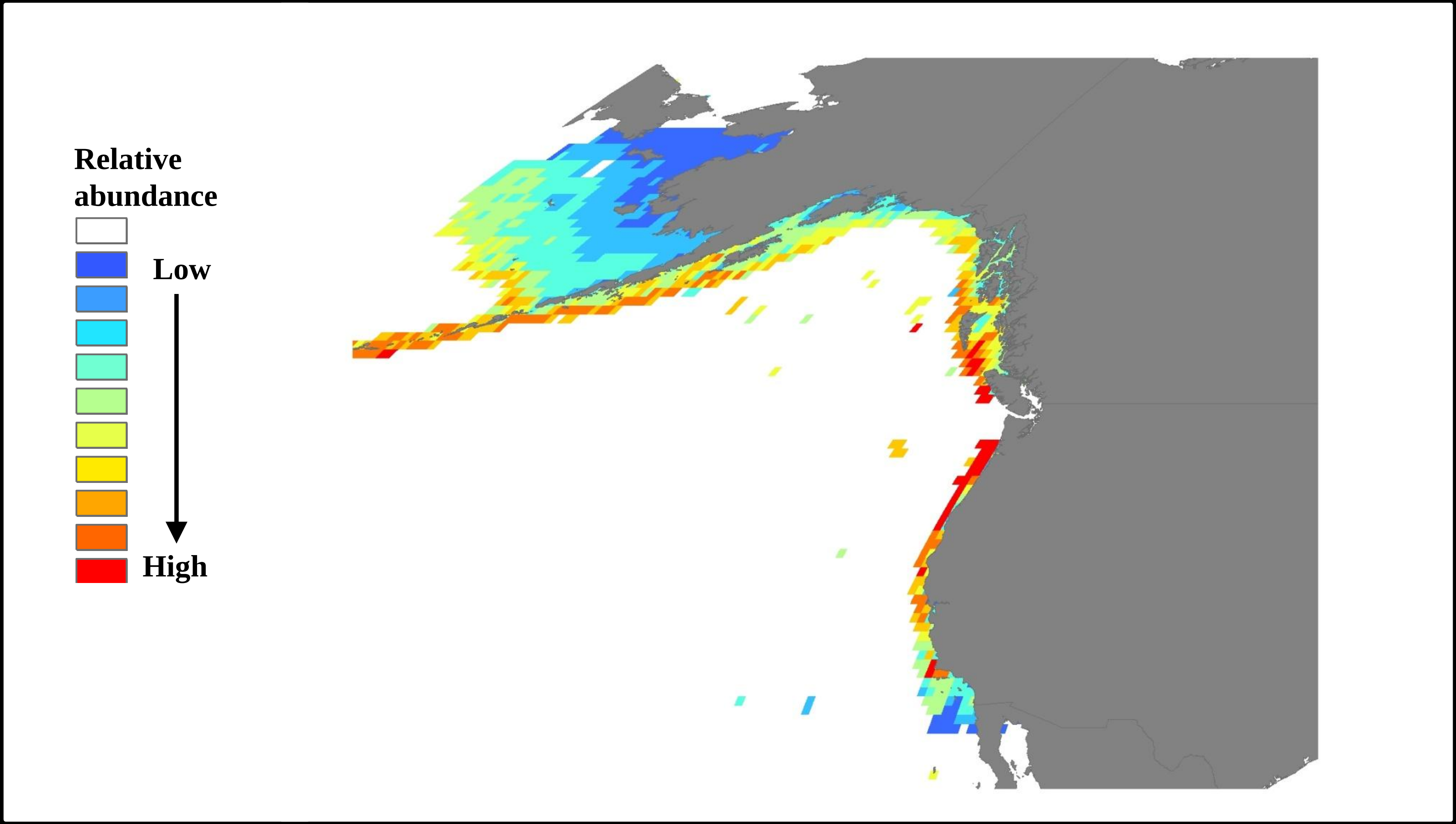
# Pacific Halibut

Year 2030



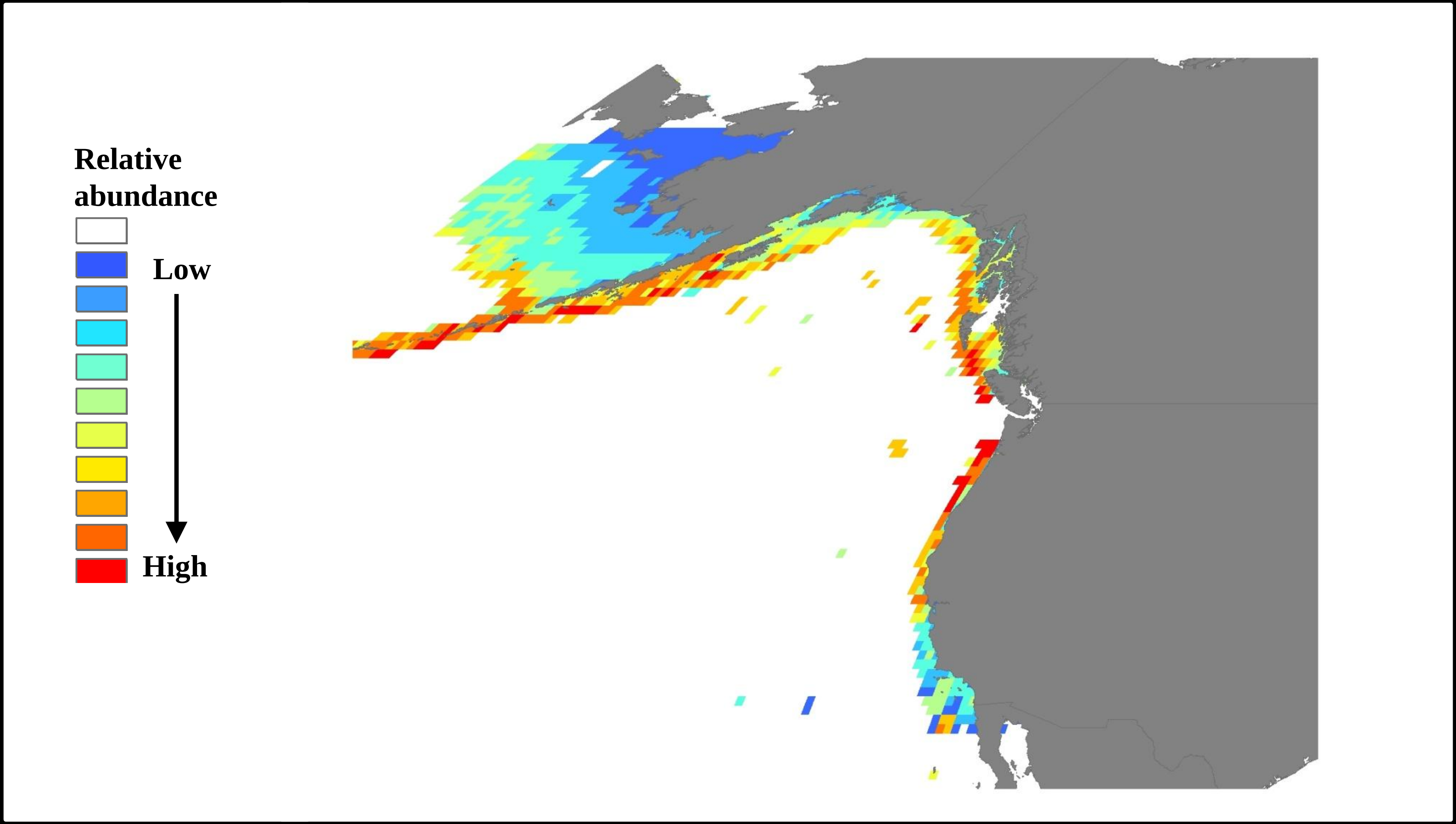
# Pacific Halibut

Year 2040



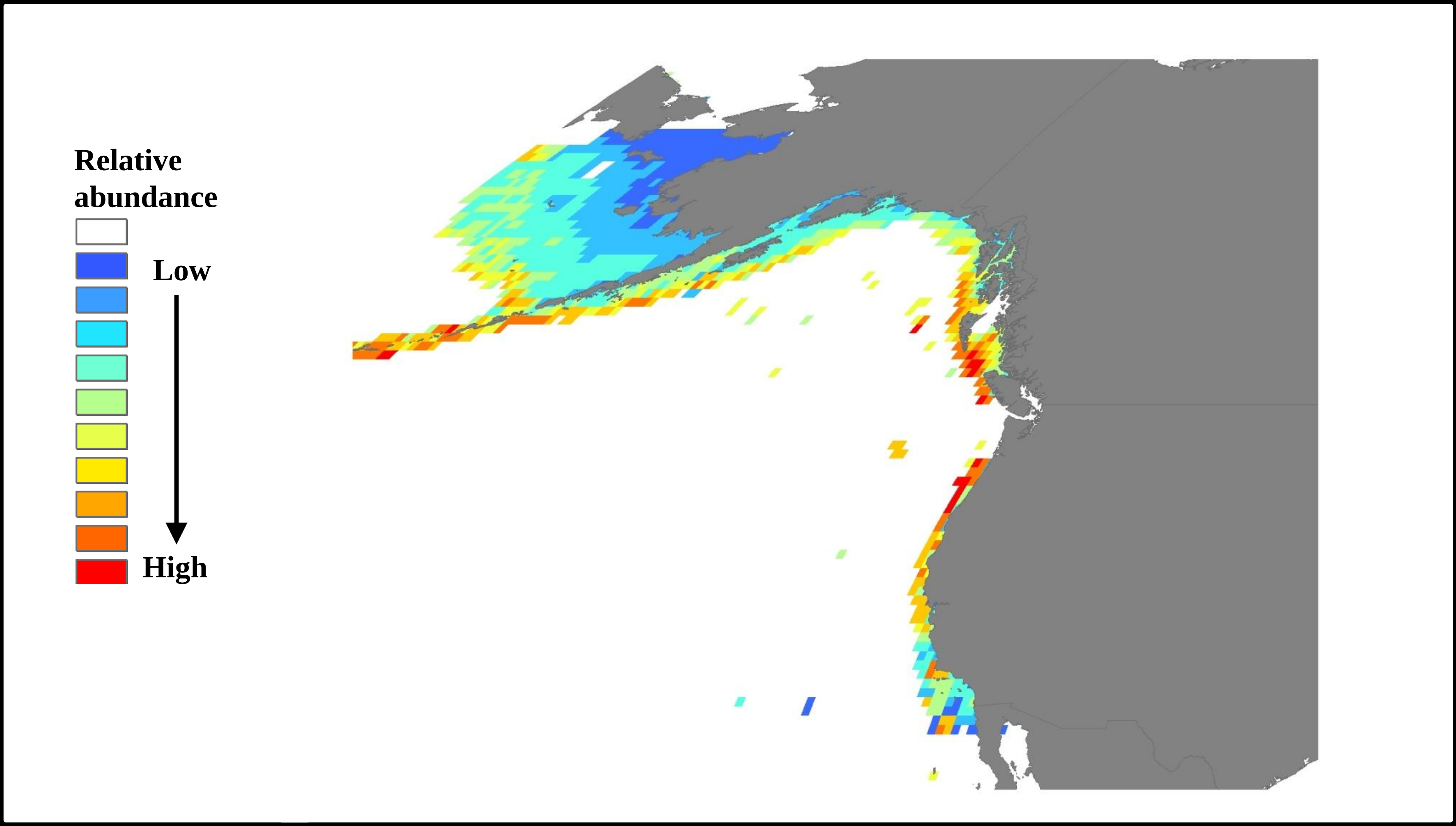
# Pacific Halibut

Year 2050

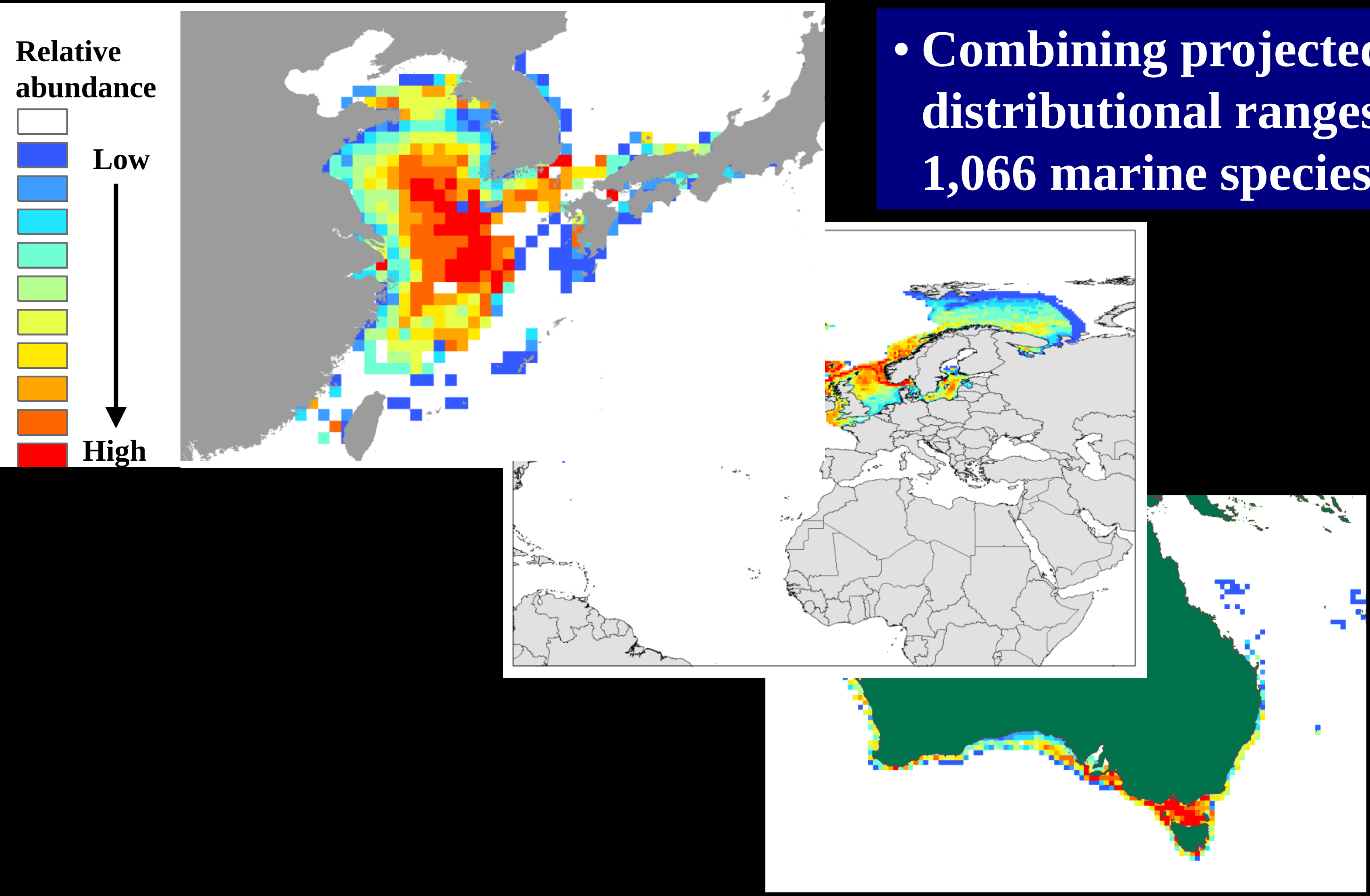


# Pacific Halibut

Year 2060



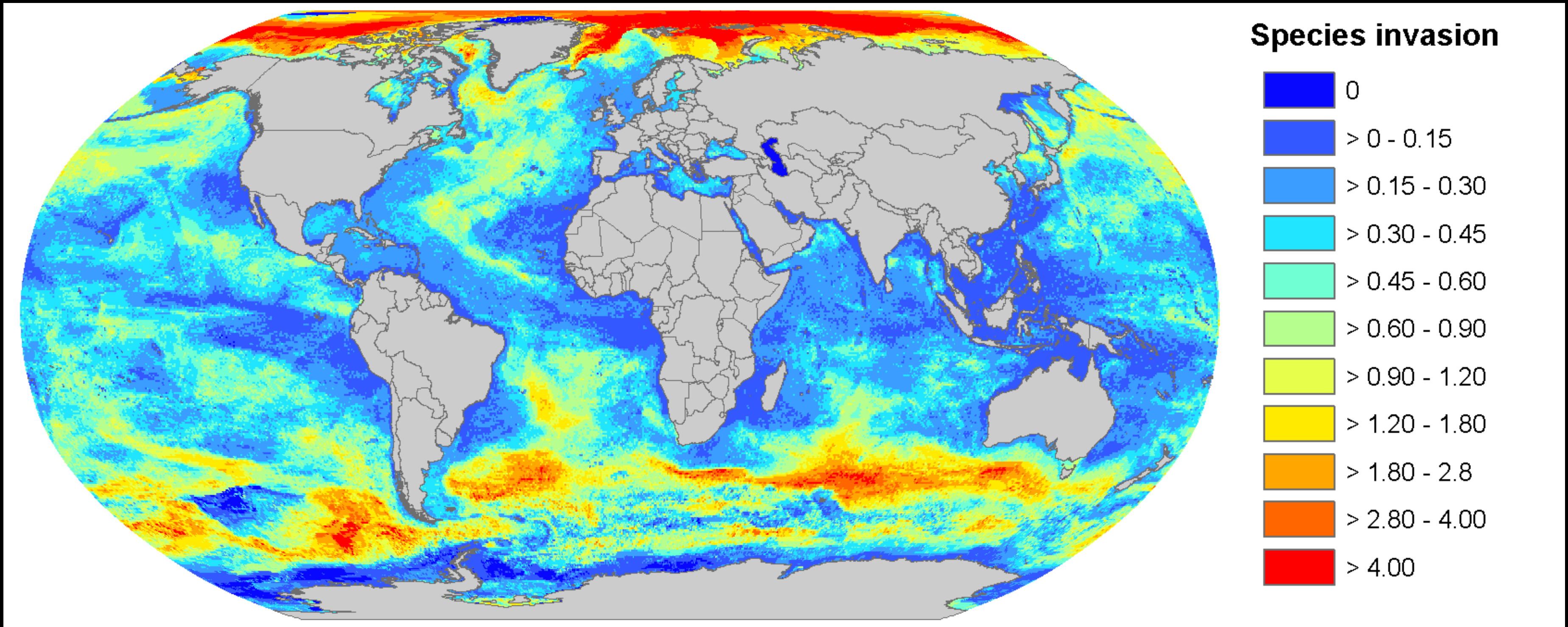
# Predicting climate change impacts on marine biodiversity




- **Combining projected distributional ranges of 1,066 marine species.**

# Intensity of species invasion by 2050

**Scenario: SRES A1B**

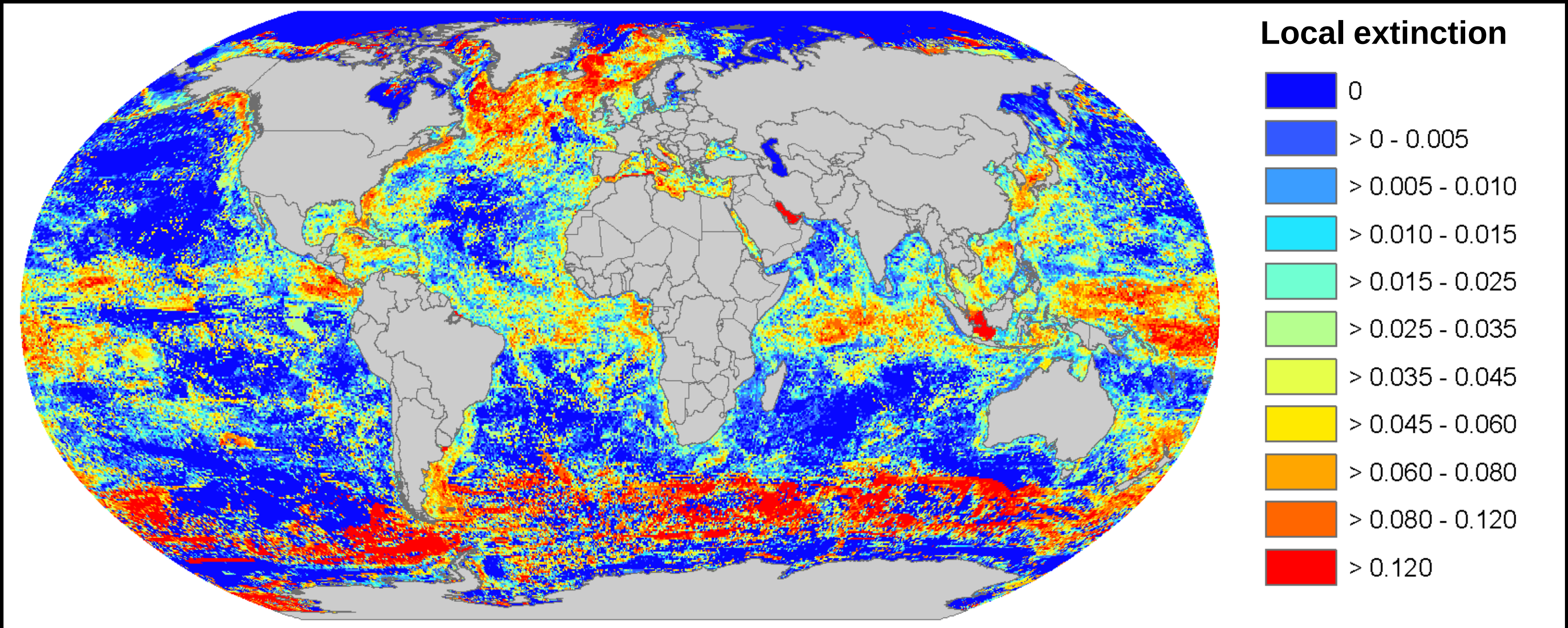



- **High rate of species invasion in Arctic and Southern Oceans.**

**Source: Cheung, Lam, Kearney, Sarmiento, Watson and Pauly (2009) Fish and Fisheries**

# Intensity of local extinction by 2050

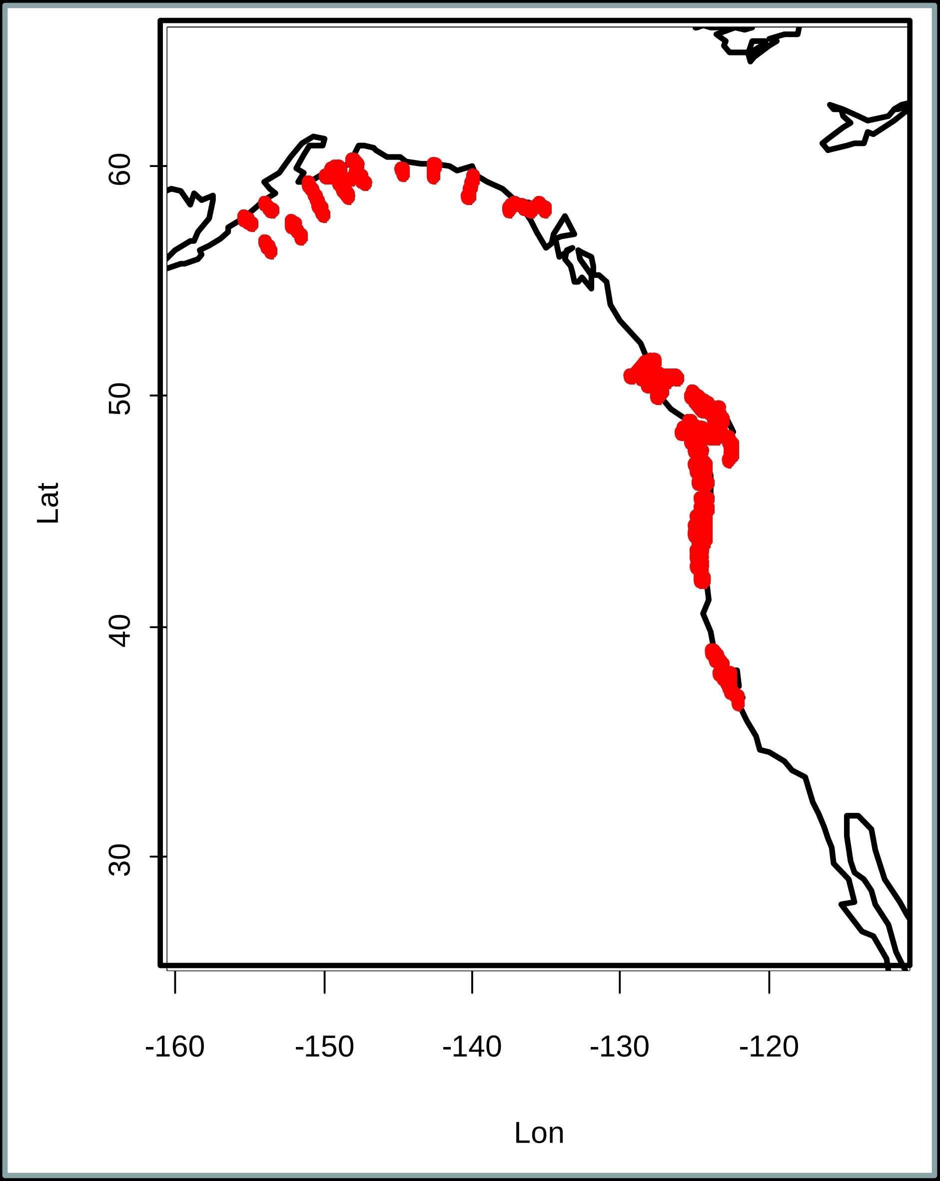
**Scenario: SRES A1B**




- **Some marine species are projected to move away from the tropics and the southern boundary of semi-enclosed seas (e.g. the Mediterranean Sea);**
- **This leads to high rate of local extinction in these regions.**

**Source: Cheung, Lam, Kearney, Sarmiento, Watson and Pauly (2009) Fish and Fisheries**

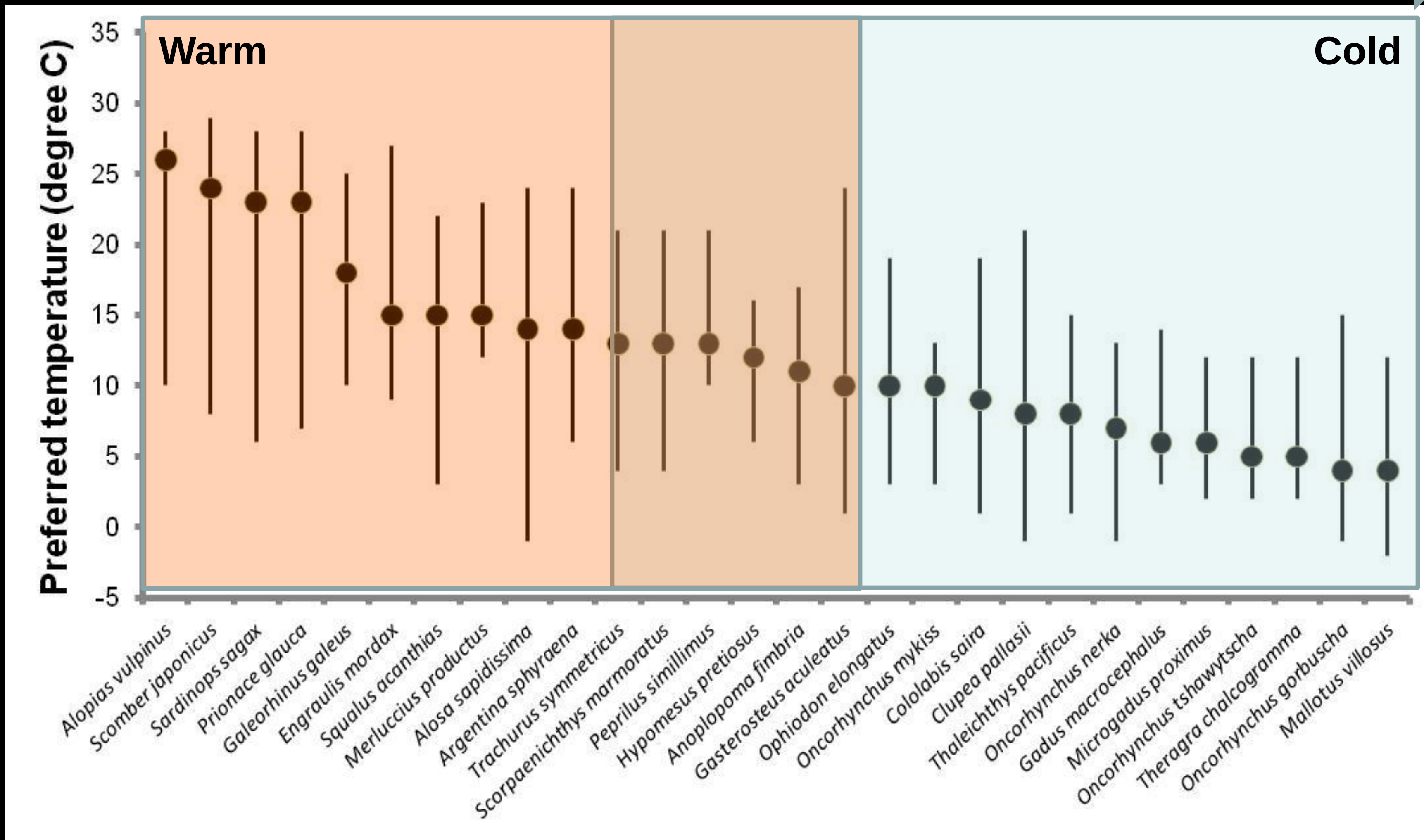
# Regional analysis



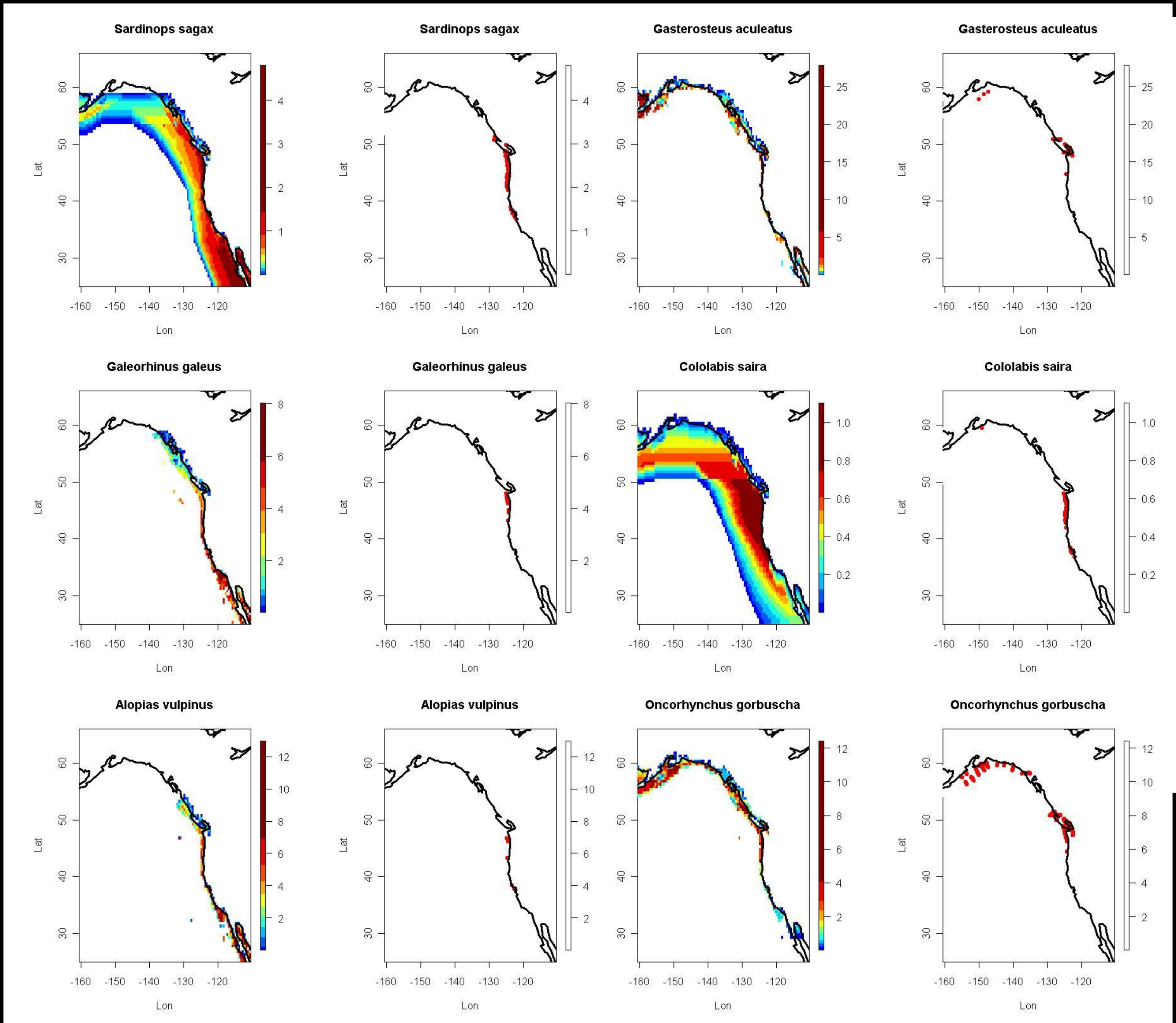

**Research questions:**

- How would species in NE Pacific coast response to climate change in terms of distribution range?
- What are the expected changes in community structure to be in future research survey?

# Temperature Preference Profile



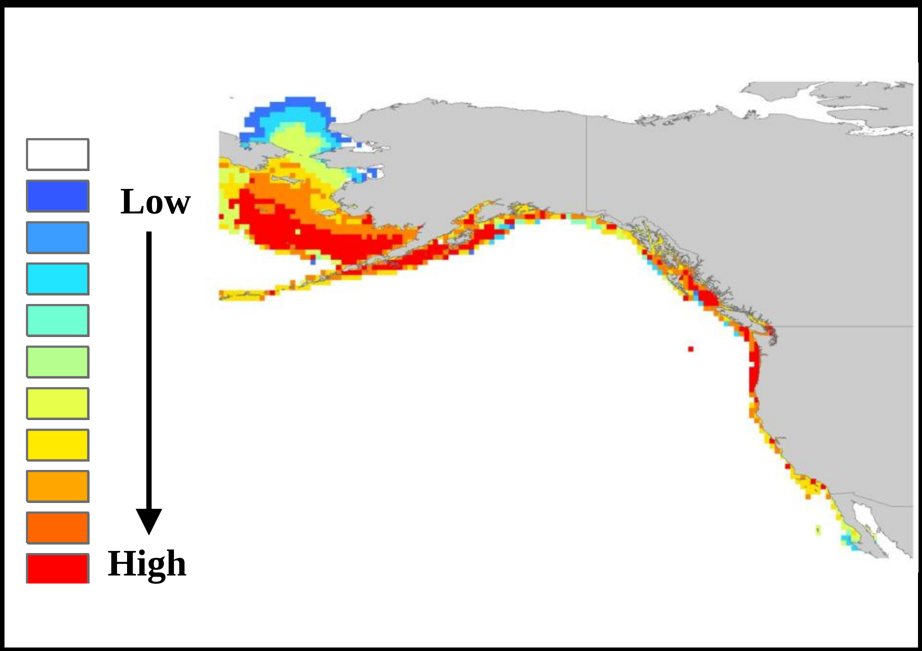
# Comparing prediction distributions with observations




- Comparing with presence data from pelagic trawl survey along the coast (N =30);
- Observed species richness at sampling stations is significantly correlated with model prediction ($p<0.01$).

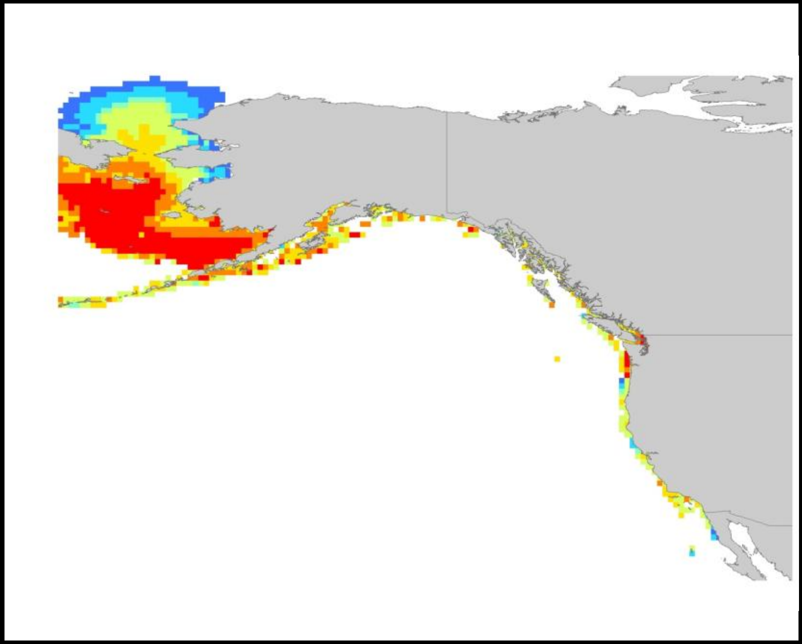
# Chinook salmon

## Original (static) distribution




## Distribution after 50 years

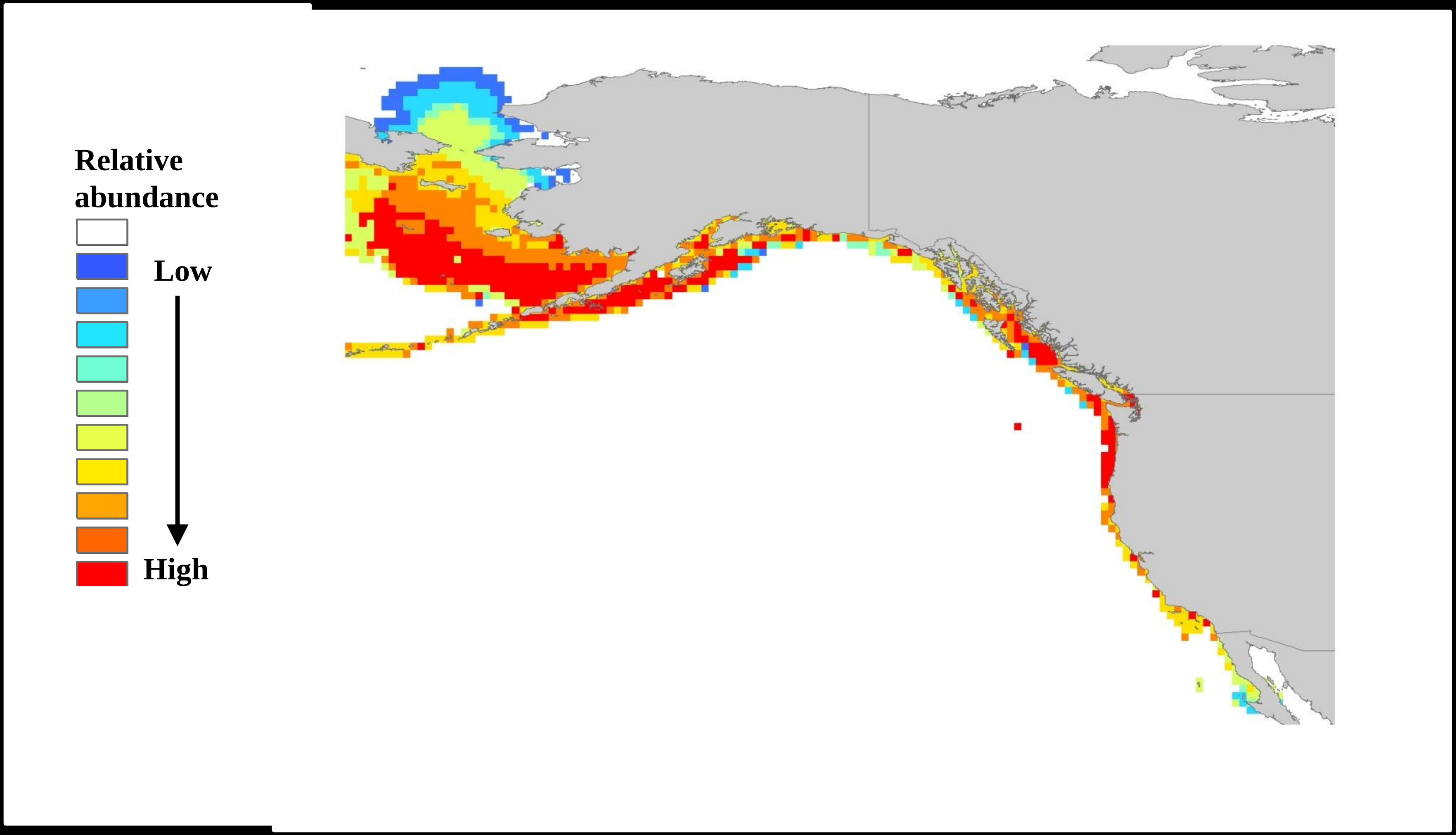
**(Climate projection from NOAA/GFDL CM 2.1)**



# Chinook salmon

**Year 2005**

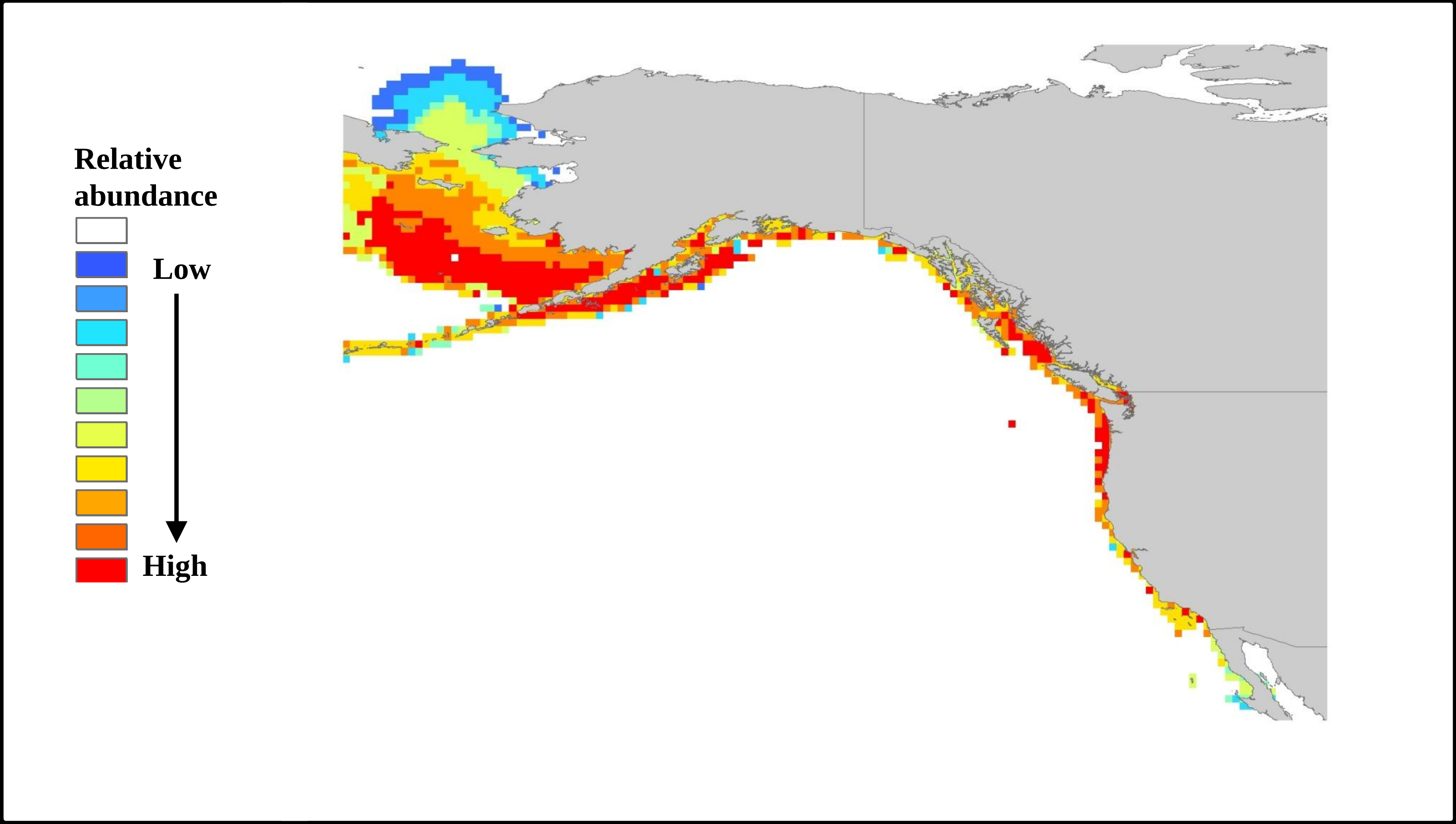
- NOAA/GFDL (SRES A1B)



# Chinook salmon

**Year 2010**

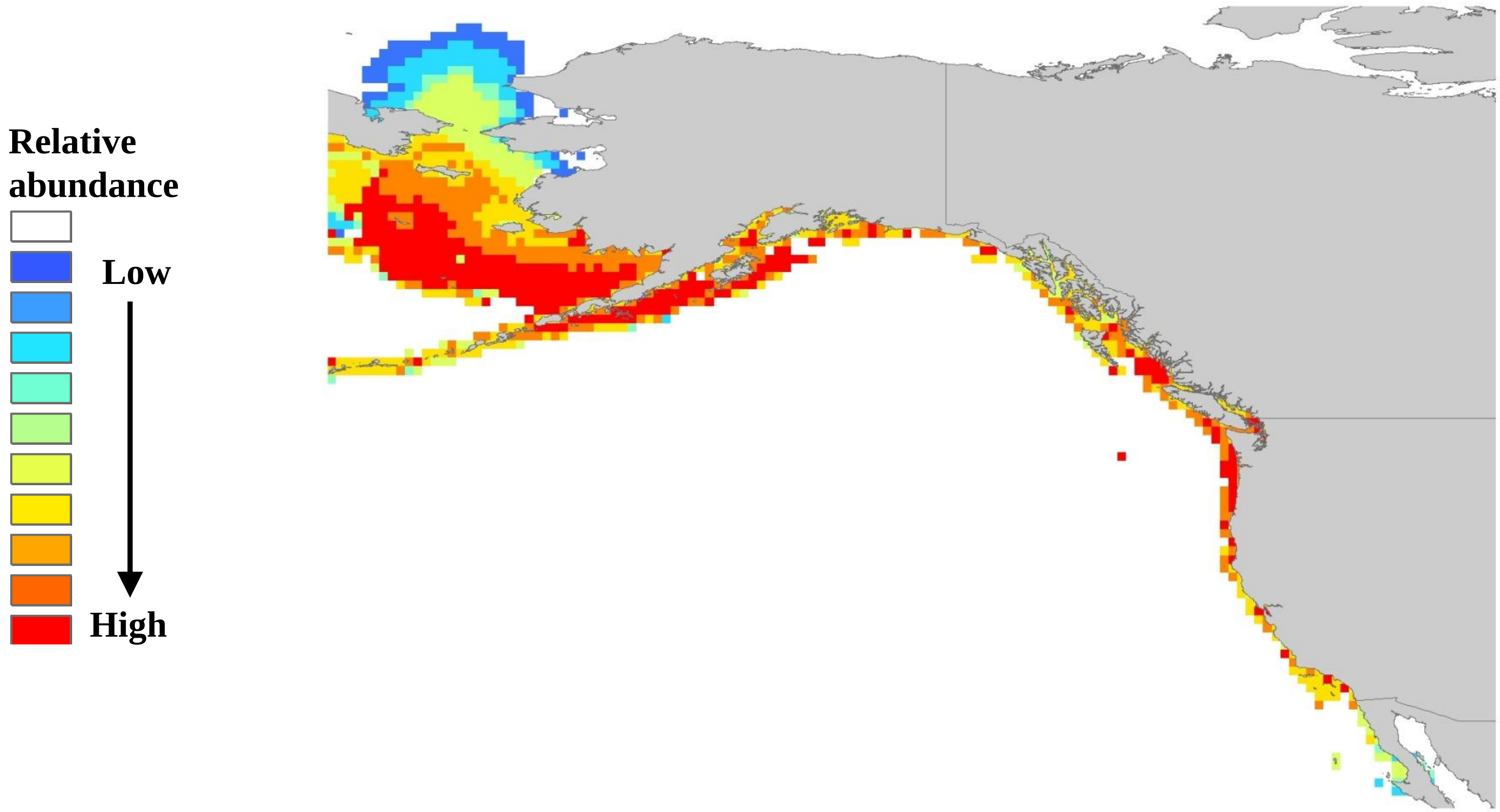
- **NOAA/GFDL (SRES A1B)**



# Chinook salmon

**Year 2015**

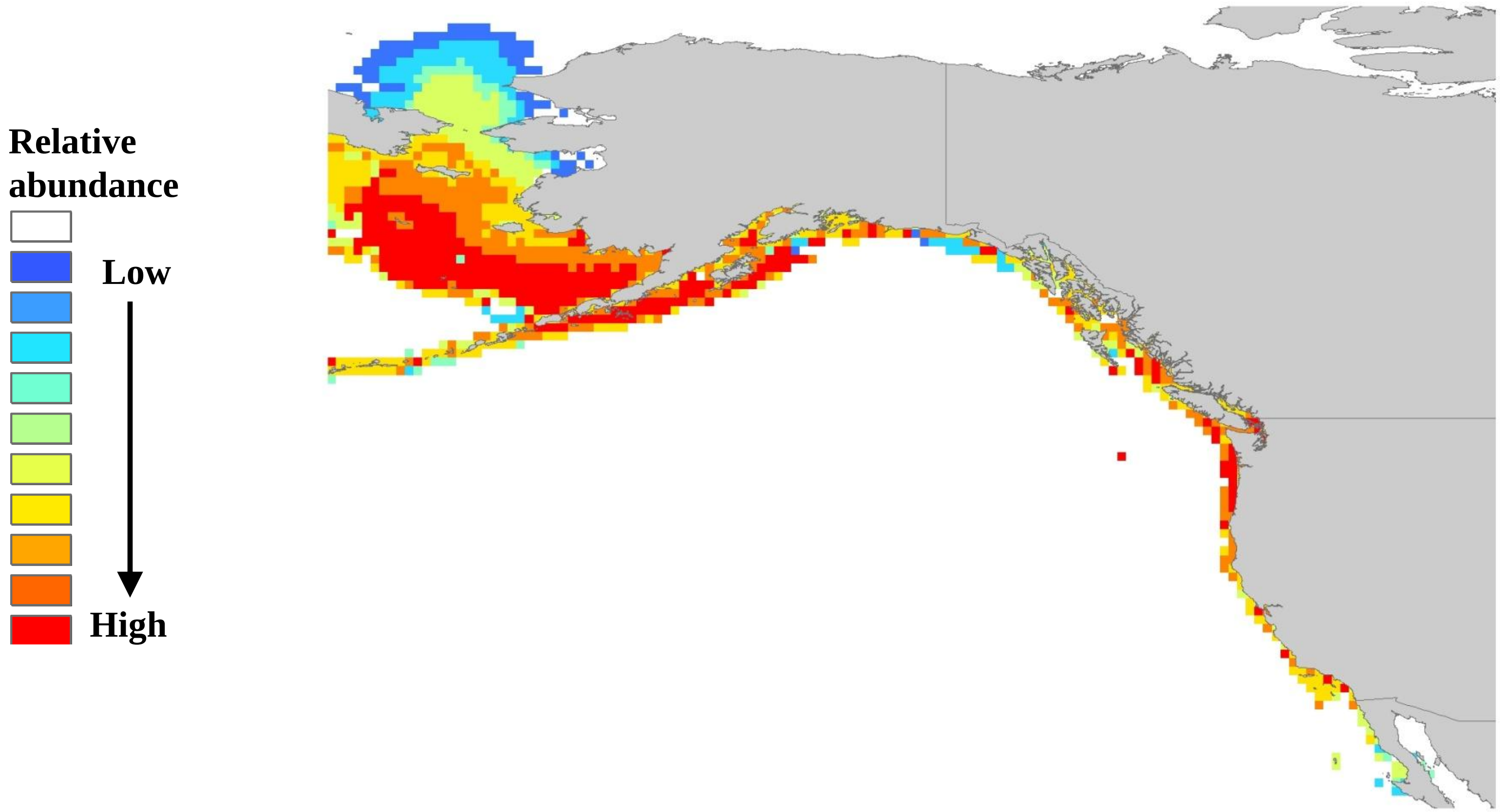
- **NOAA/GFDL (SRES A1B)**



# Chinook salmon

**Year 2020**

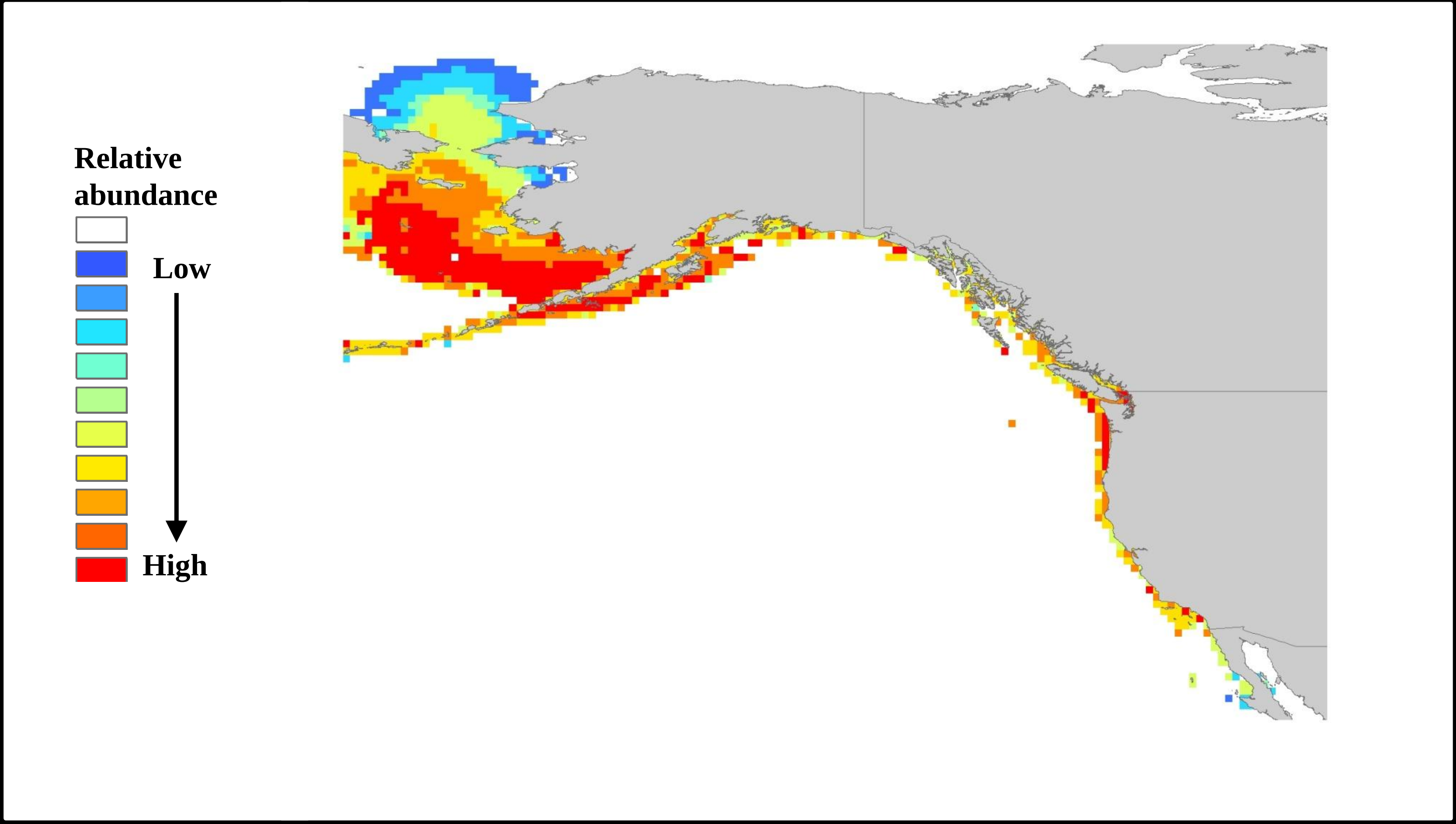
- **NOAA/GFDL (SRES A1B)**



# Chinook salmon

**Year 2025**

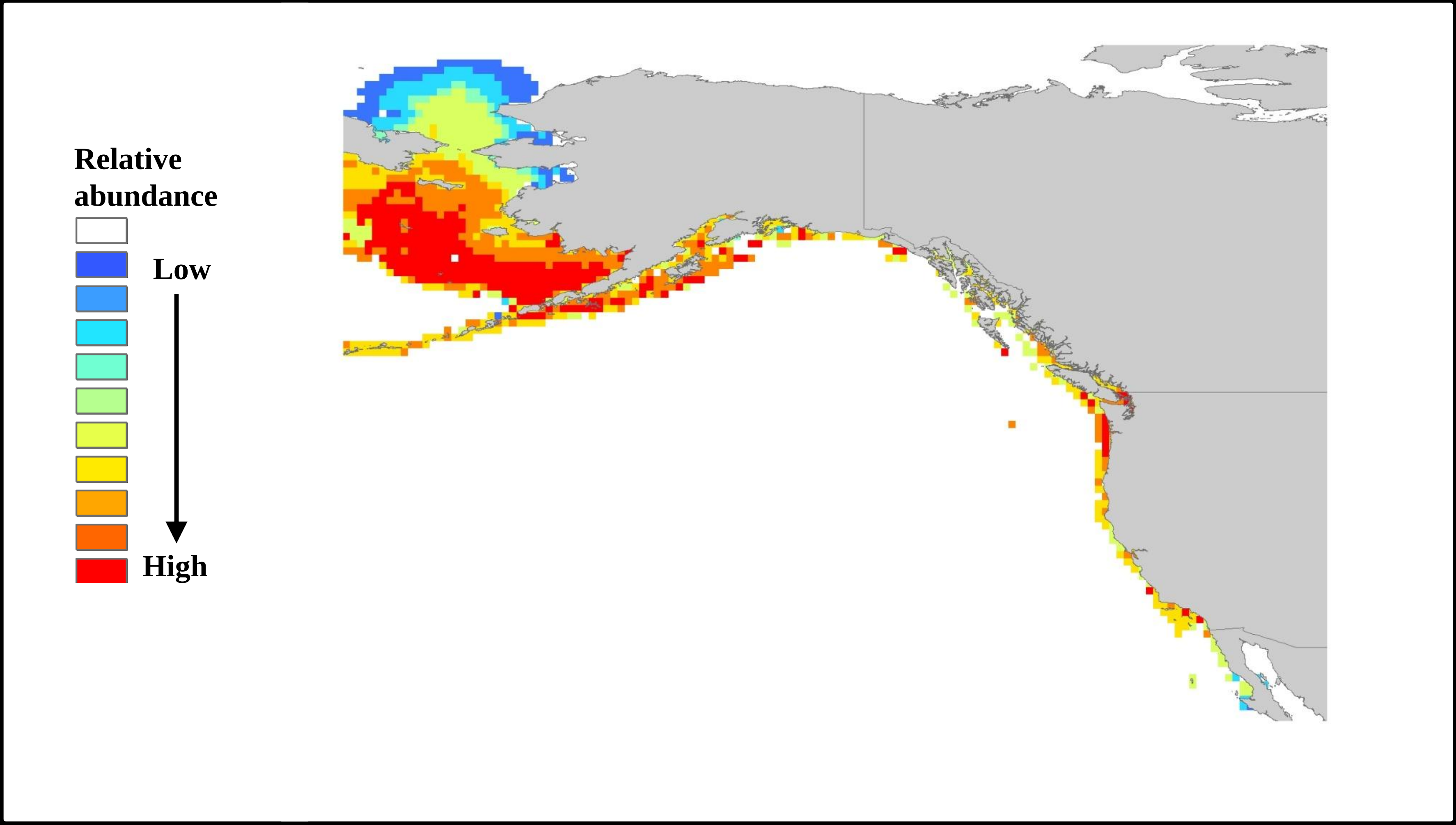
- **NOAA/GFDL (SRES A1B)**



# Chinook salmon

Year 2030

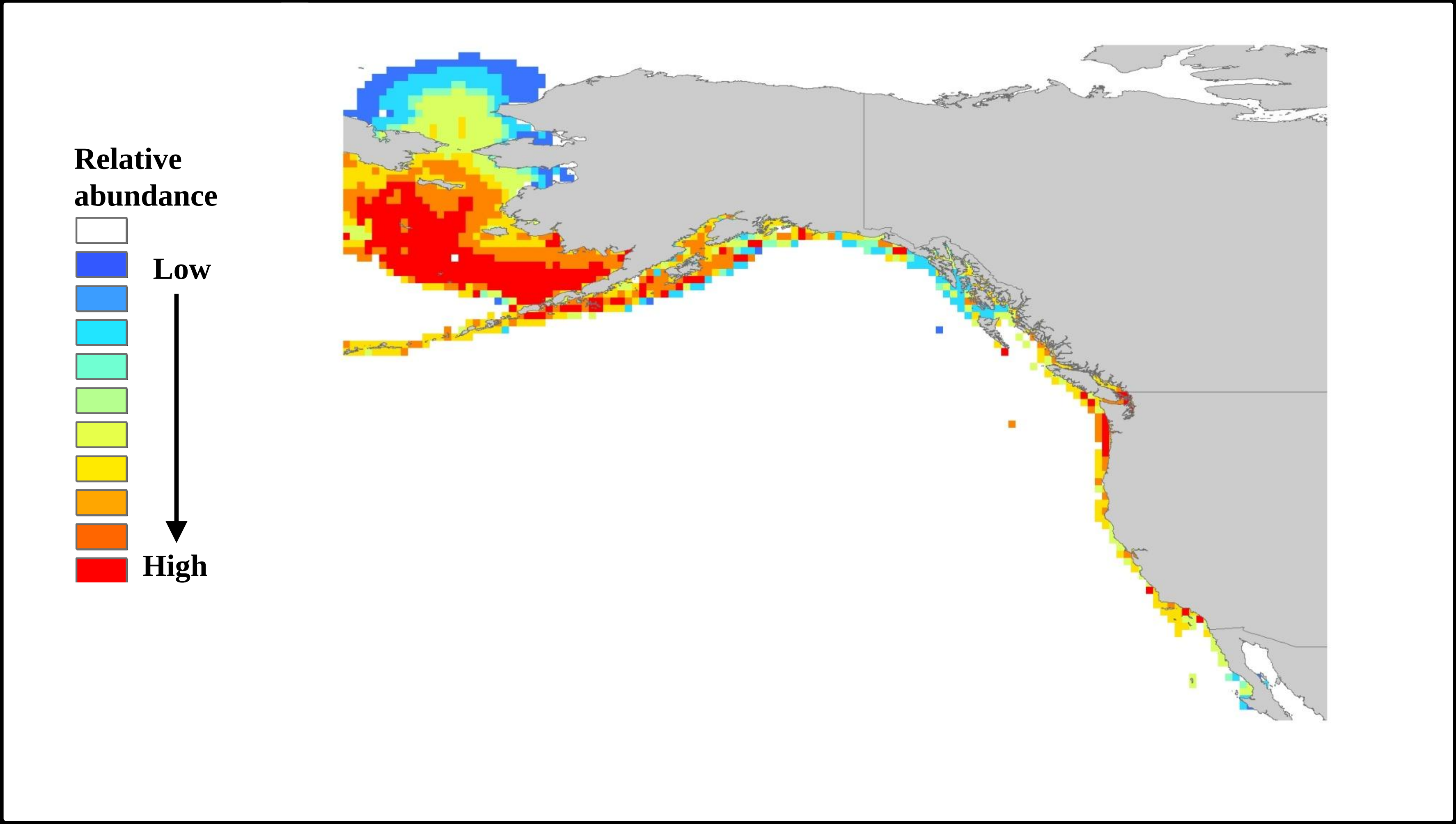
• NOAA/GFDL (SRES A1B)



# Chinook salmon

**Year 2035**

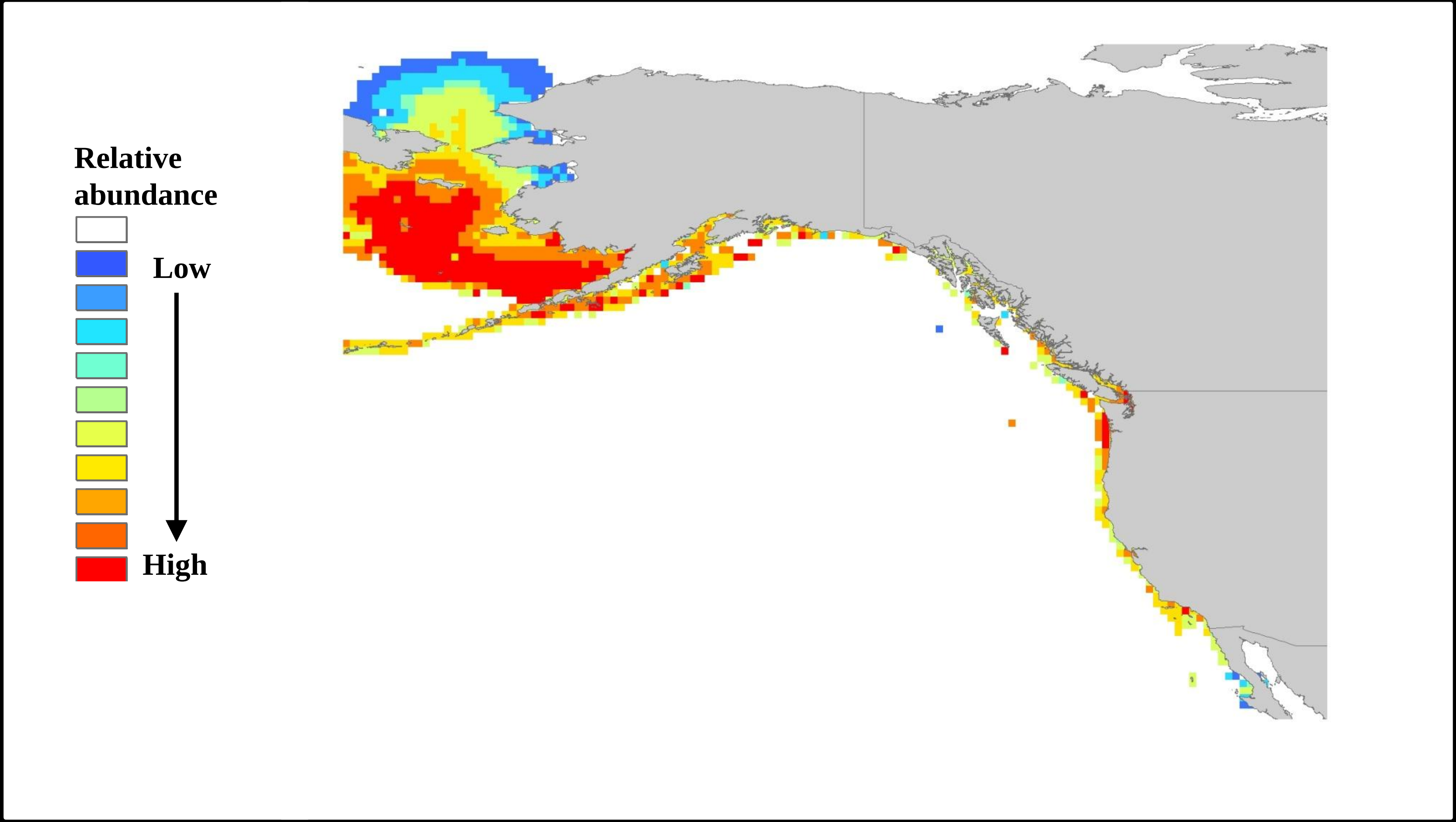
- **NOAA/GFDL (SRES A1B)**



# Chinook salmon

**Year 2040**

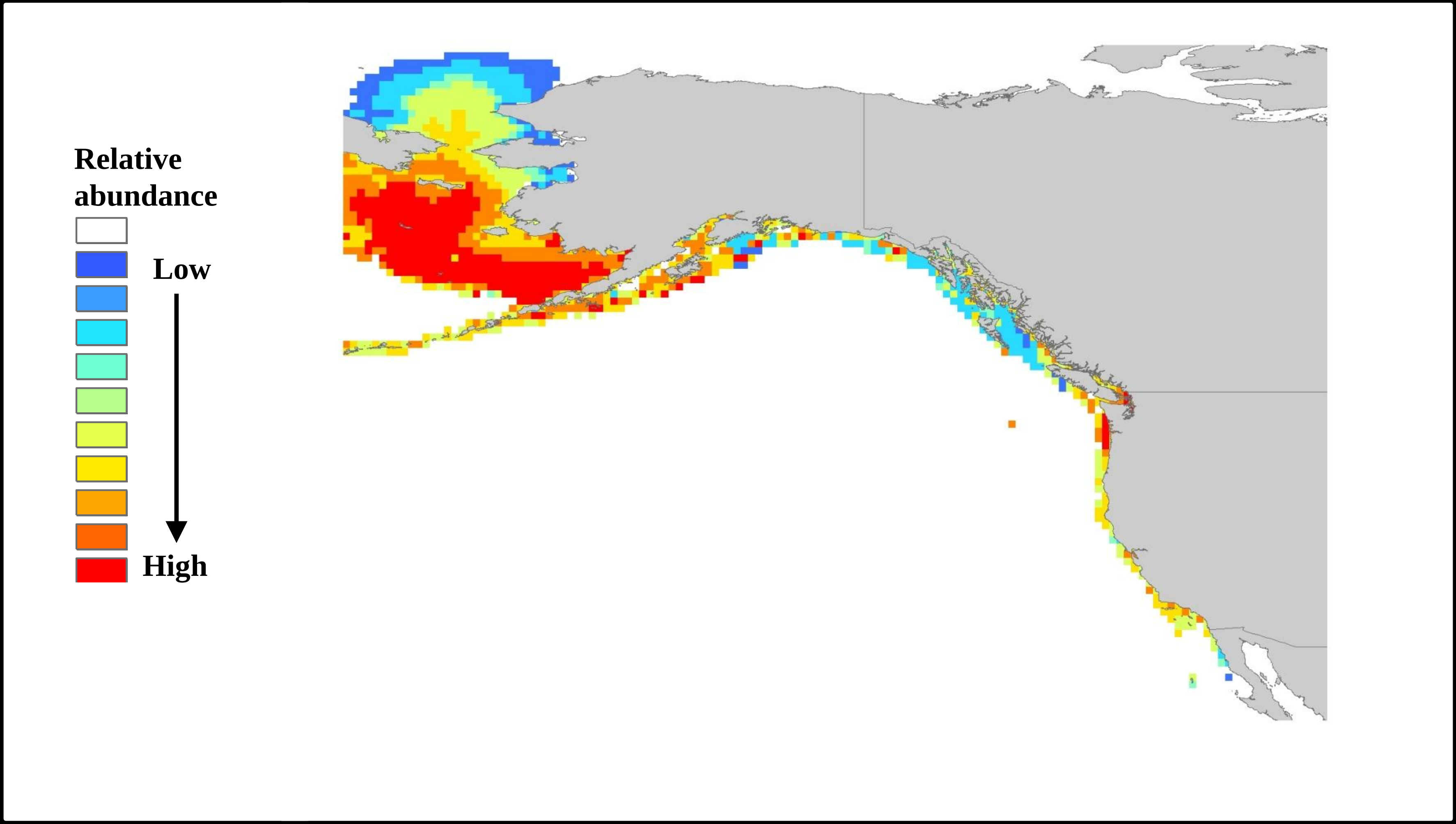
- NOAA/GFDL (SRES A1B)



# Chinook salmon

**Year 2045**

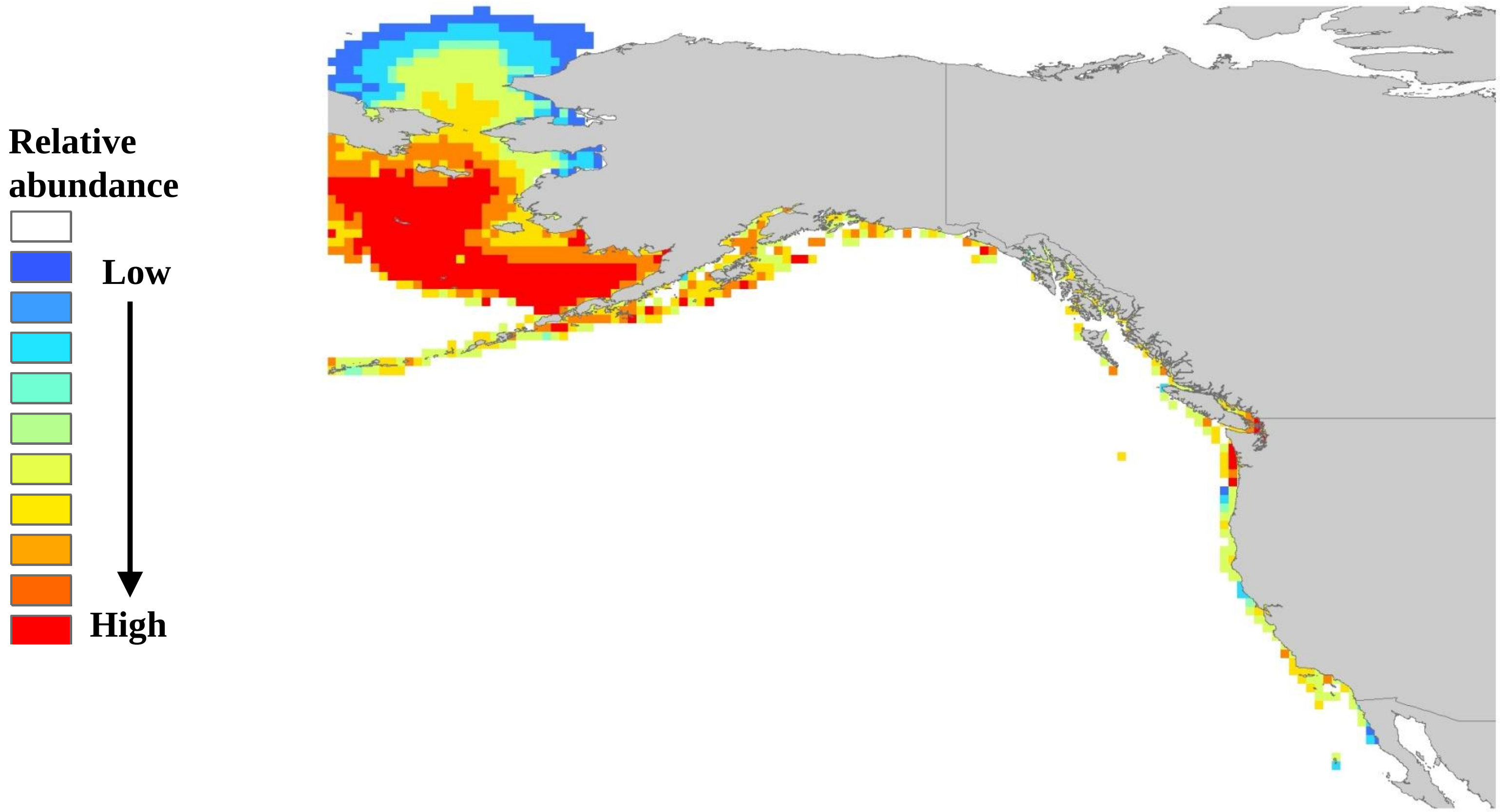
- NOAA/GFDL (SRES A1B)



# Chinook salmon

**Year 2050**

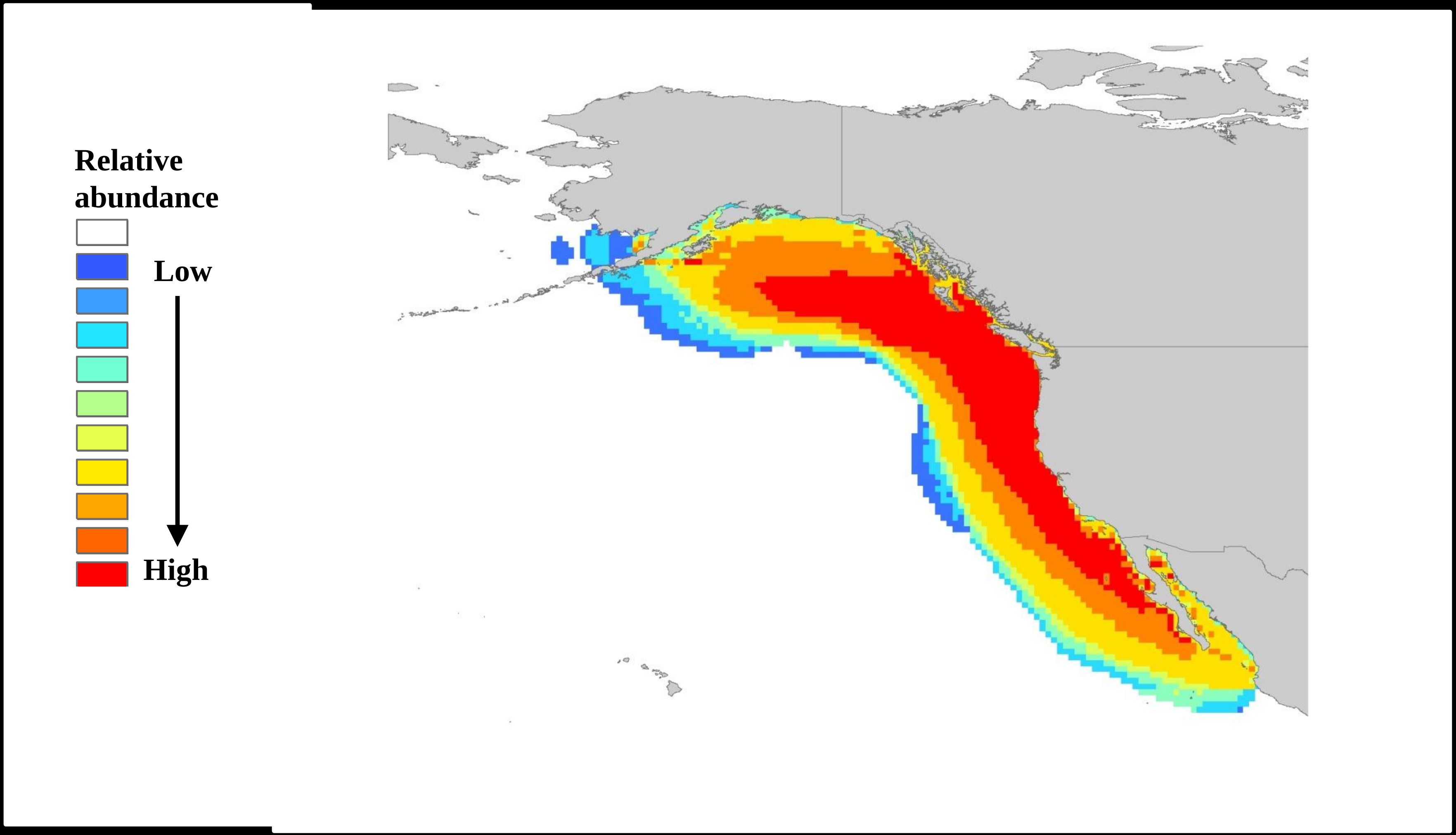
- **NOAA/GFDL (SRES A1B)**



# Pacific jack mackerel

Year 2005

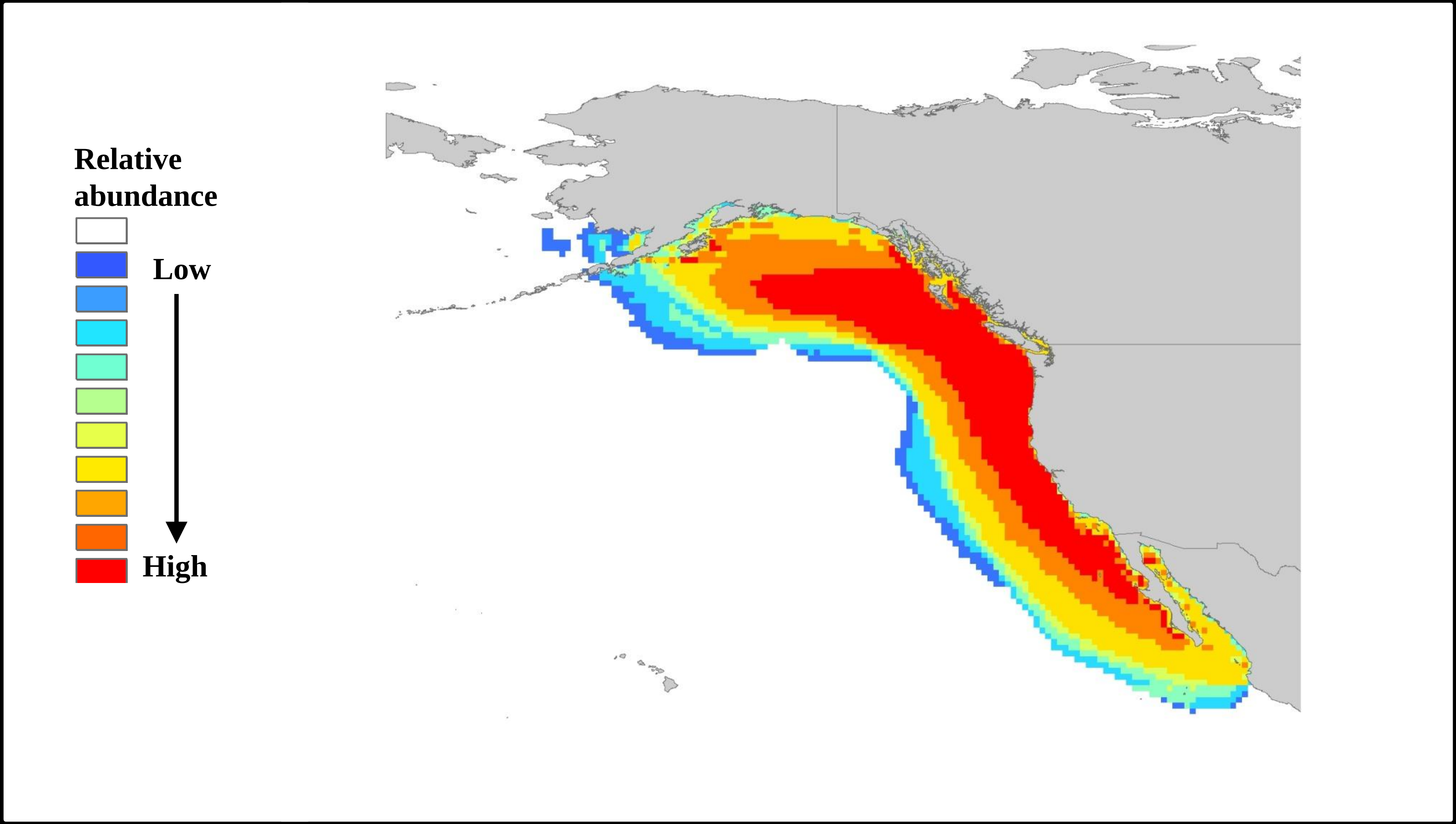
- NOAA/GFDL (SRES A1B)



# Pacific jack mackerel

**Year 2010**

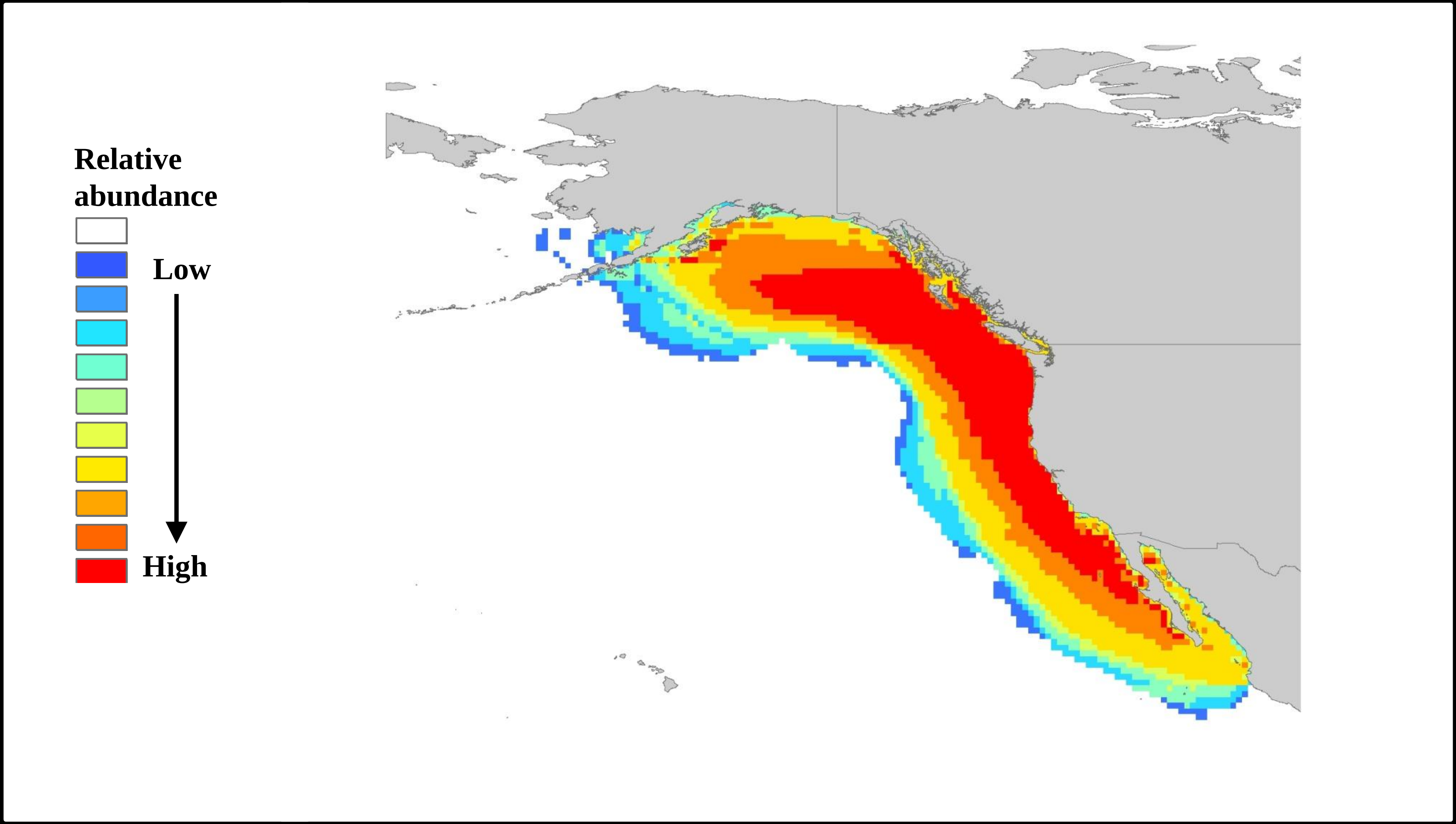
- NOAA/GFDL (SRES A1B)



# Pacific jack mackerel

**Year 2015**

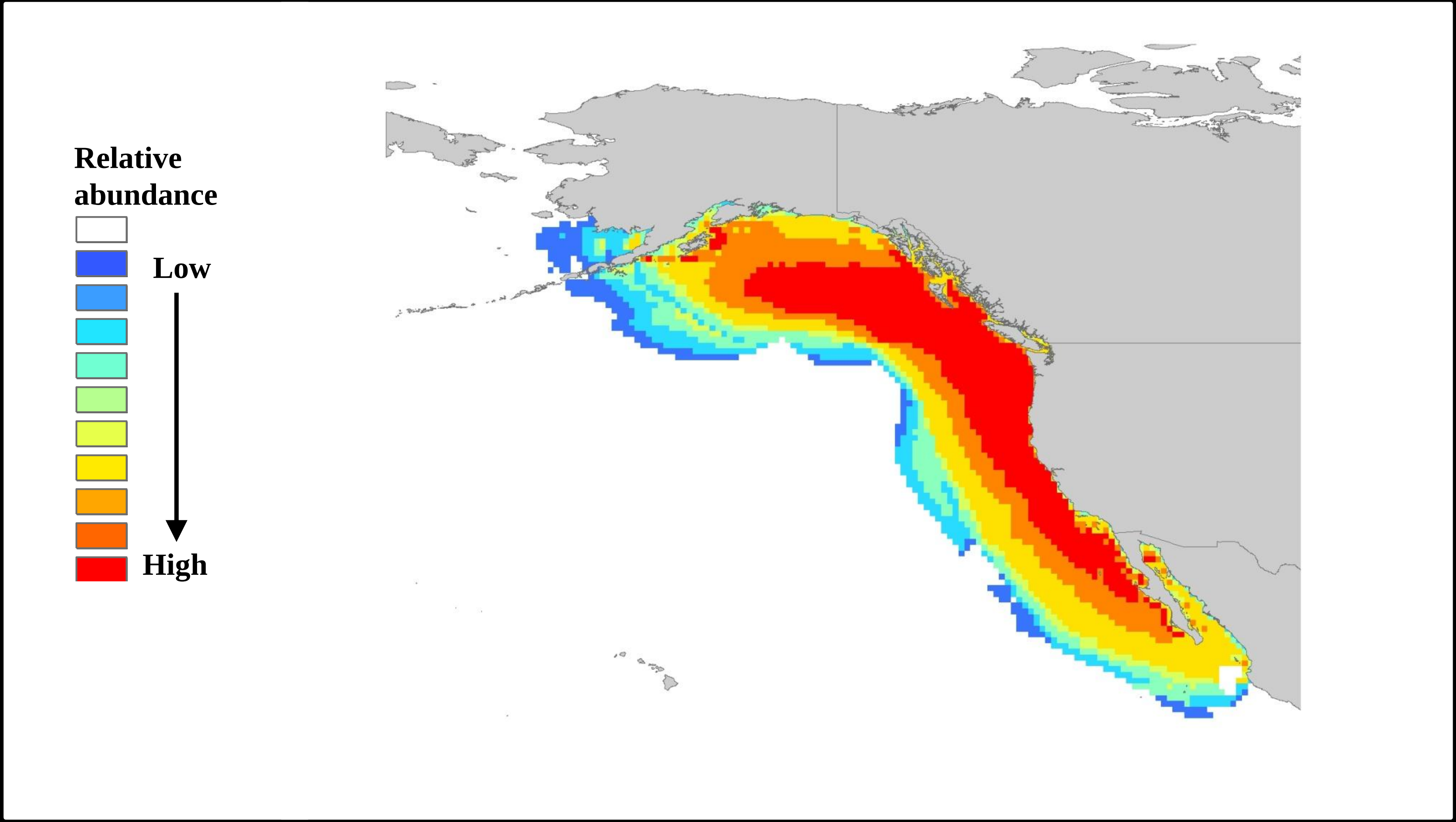
- **NOAA/GFDL (SRES A1B)**



# Pacific jack mackerel

**Year 2020**

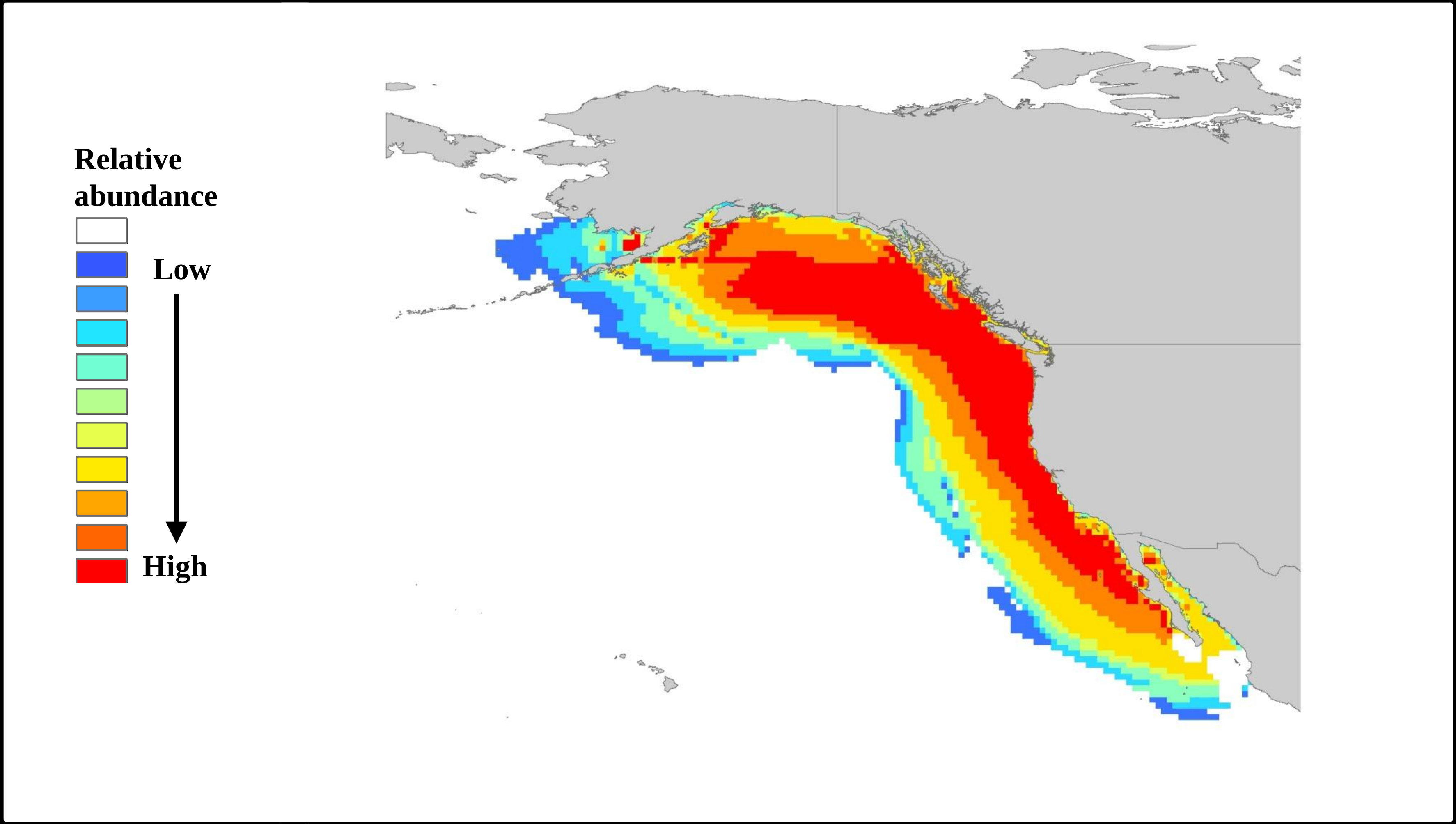
- **NOAA/GFDL (SRES A1B)**



# Pacific jack mackerel

Year 2025

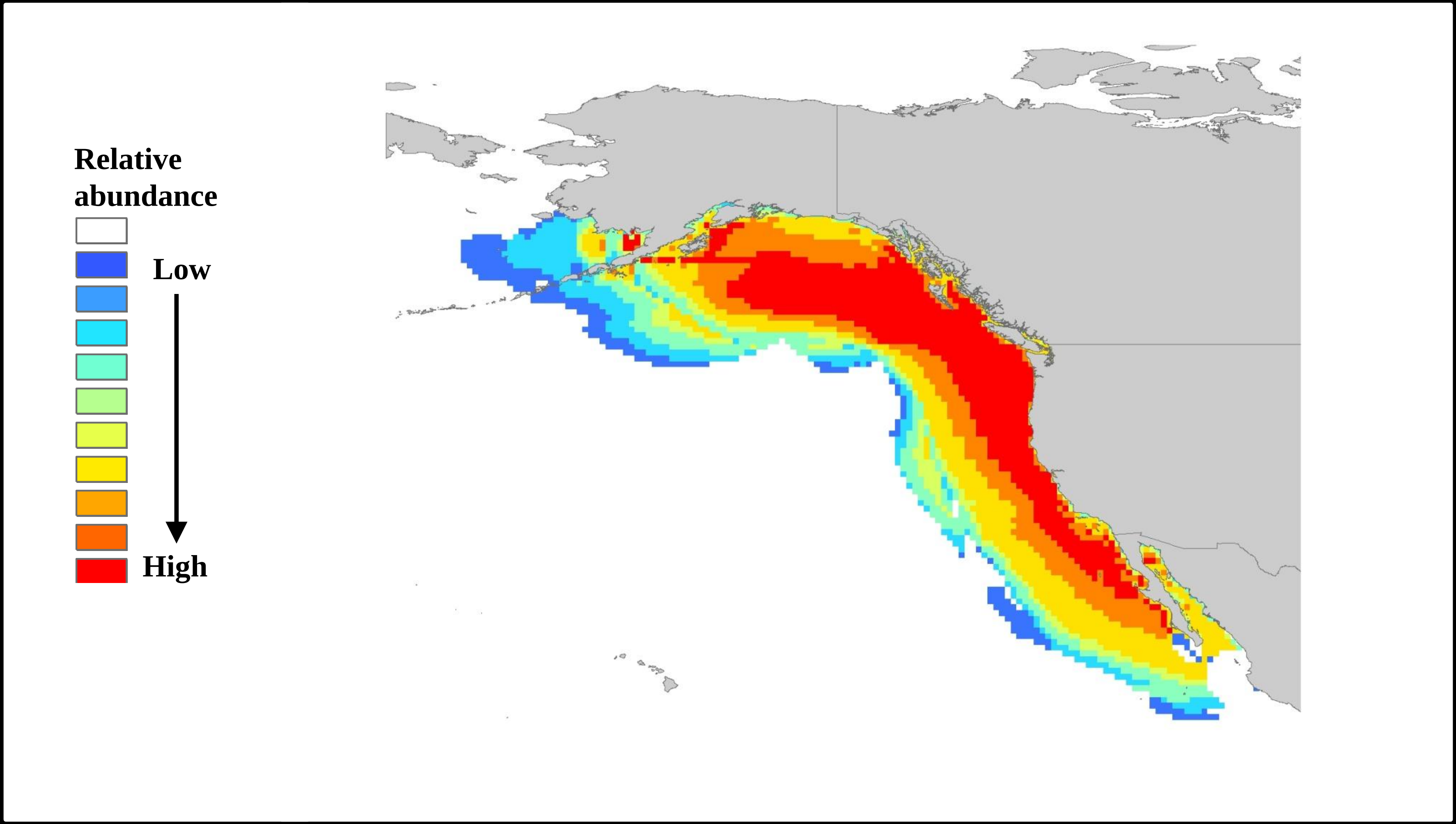
- NOAA/GFDL (SRES A1B)



# Pacific jack mackerel

**Year 2030**

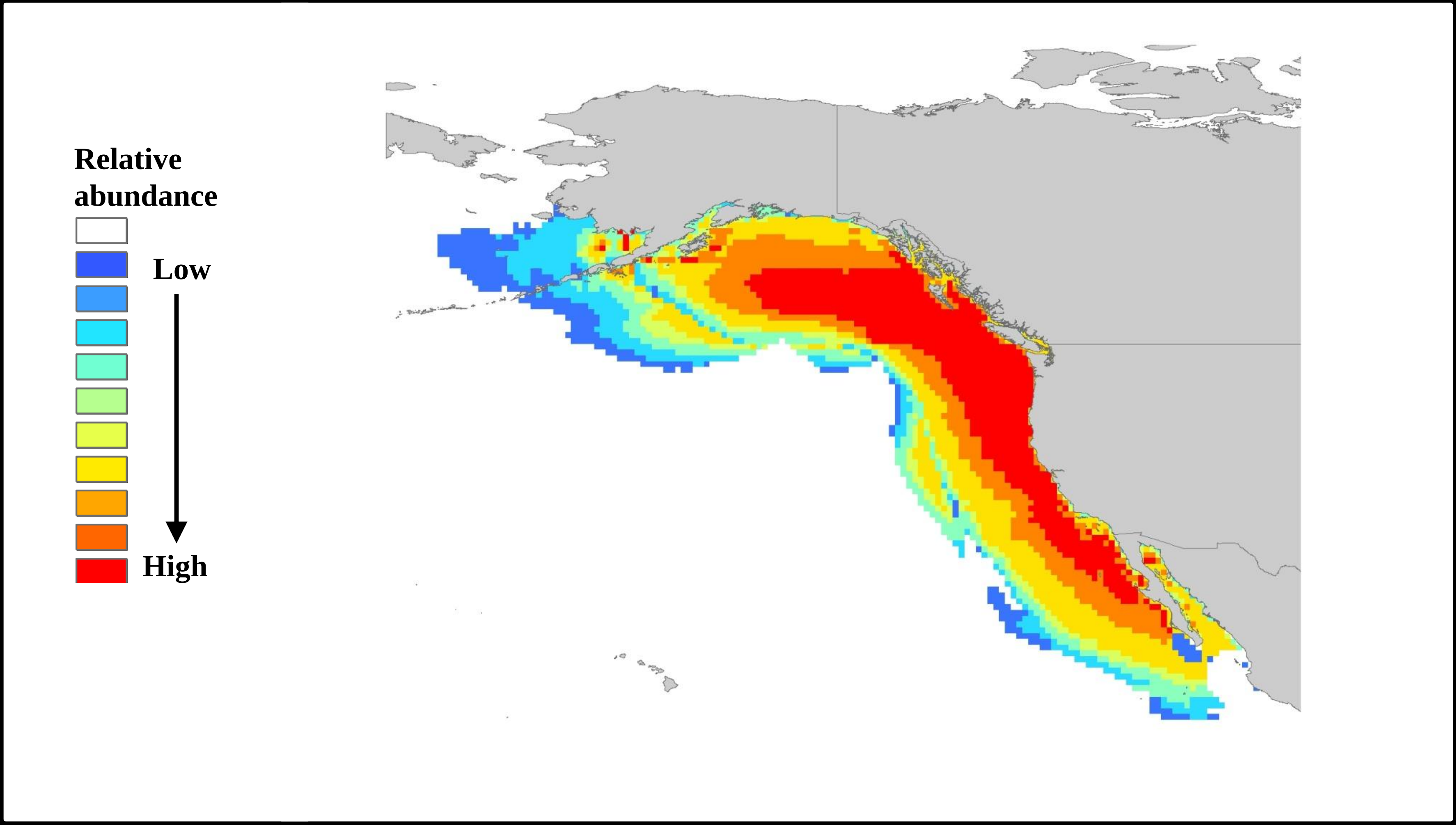
- **NOAA/GFDL (SRES A1B)**



# Pacific jack mackerel

**Year 2035**

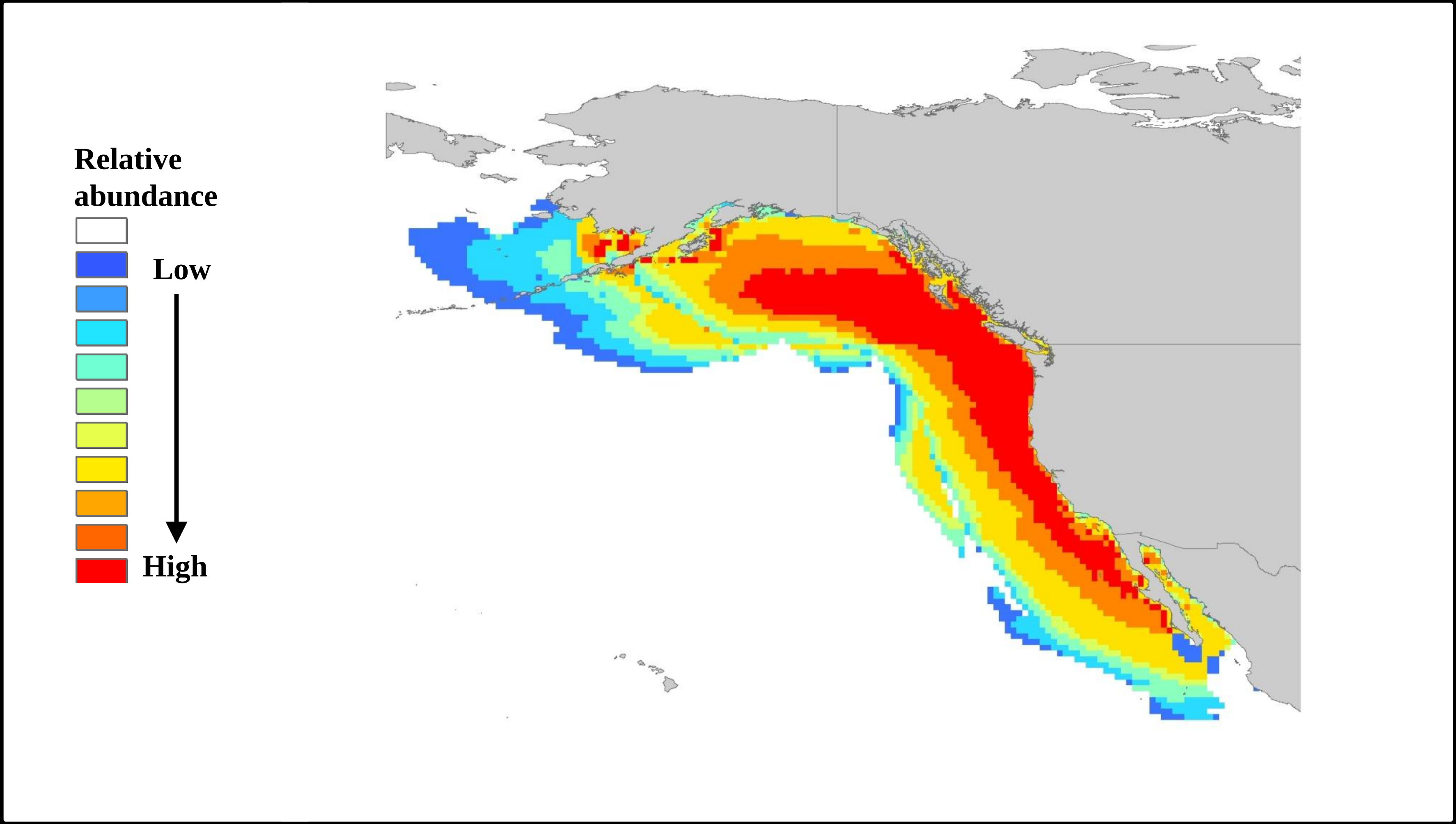
- **NOAA/GFDL (SRES A1B)**



# Pacific jack mackerel

**Year 2040**

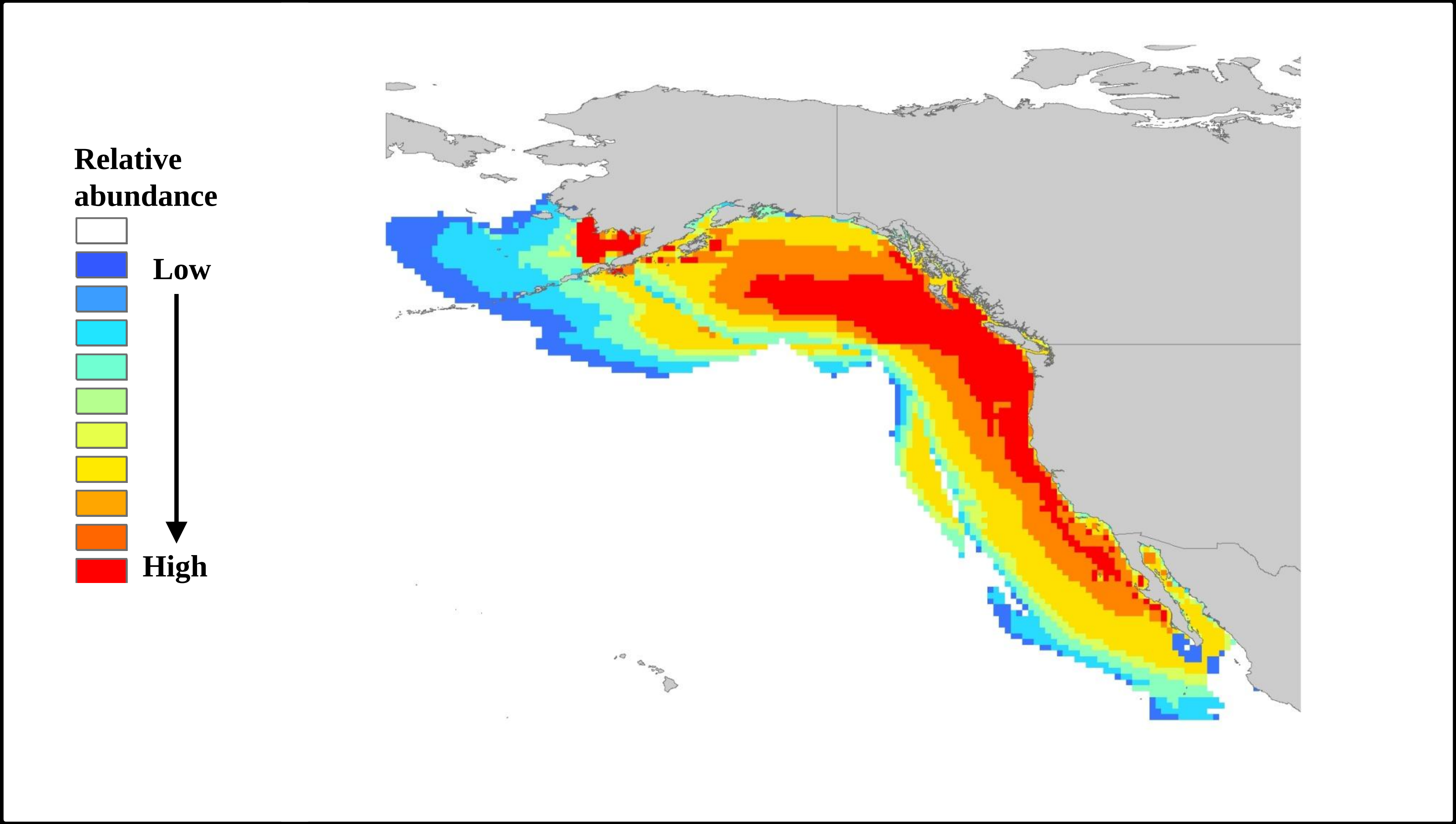
- NOAA/GFDL (SRES A1B)



# Pacific jack mackerel

**Year 2045**

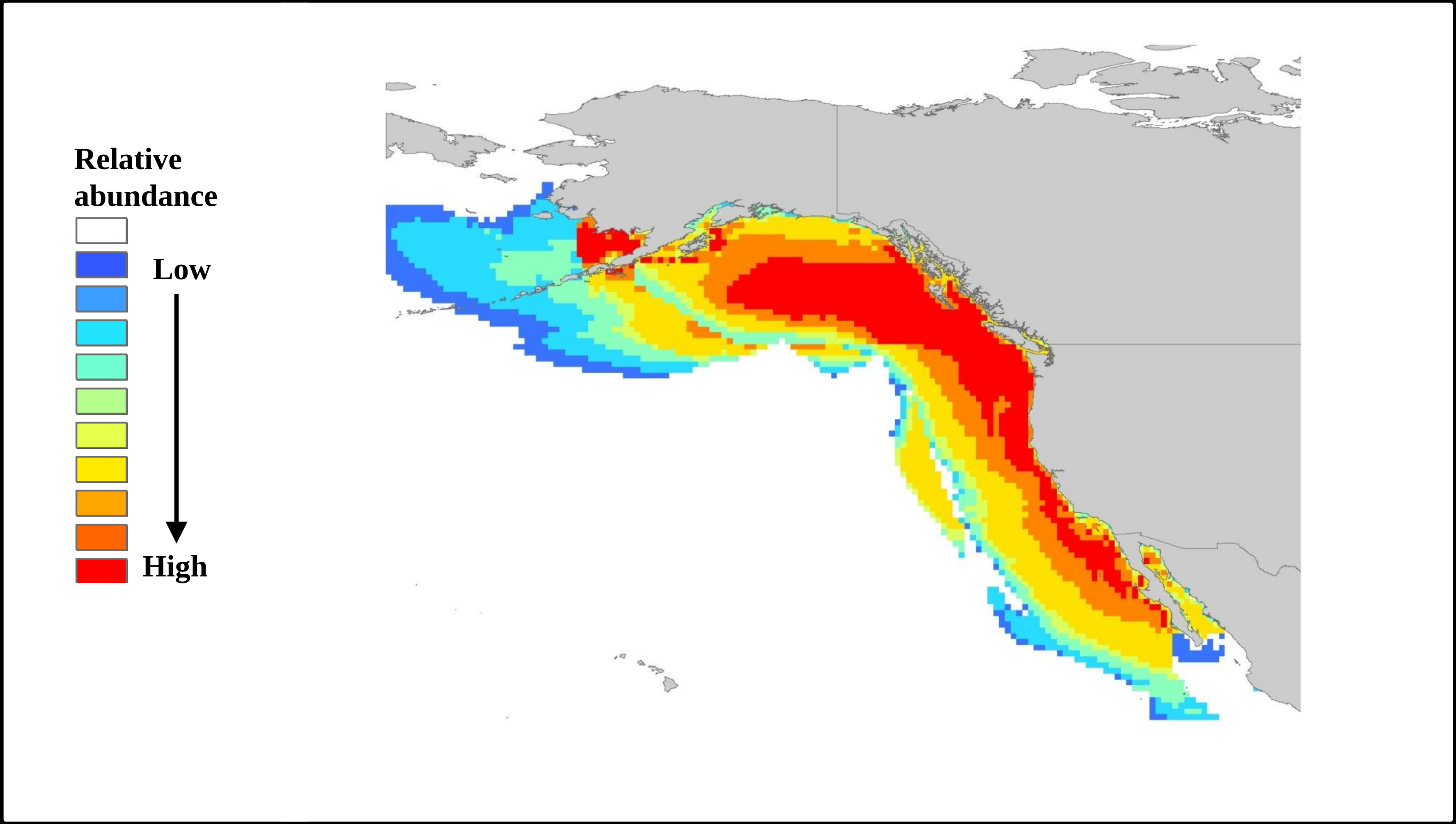
- **NOAA/GFDL (SRES A1B)**



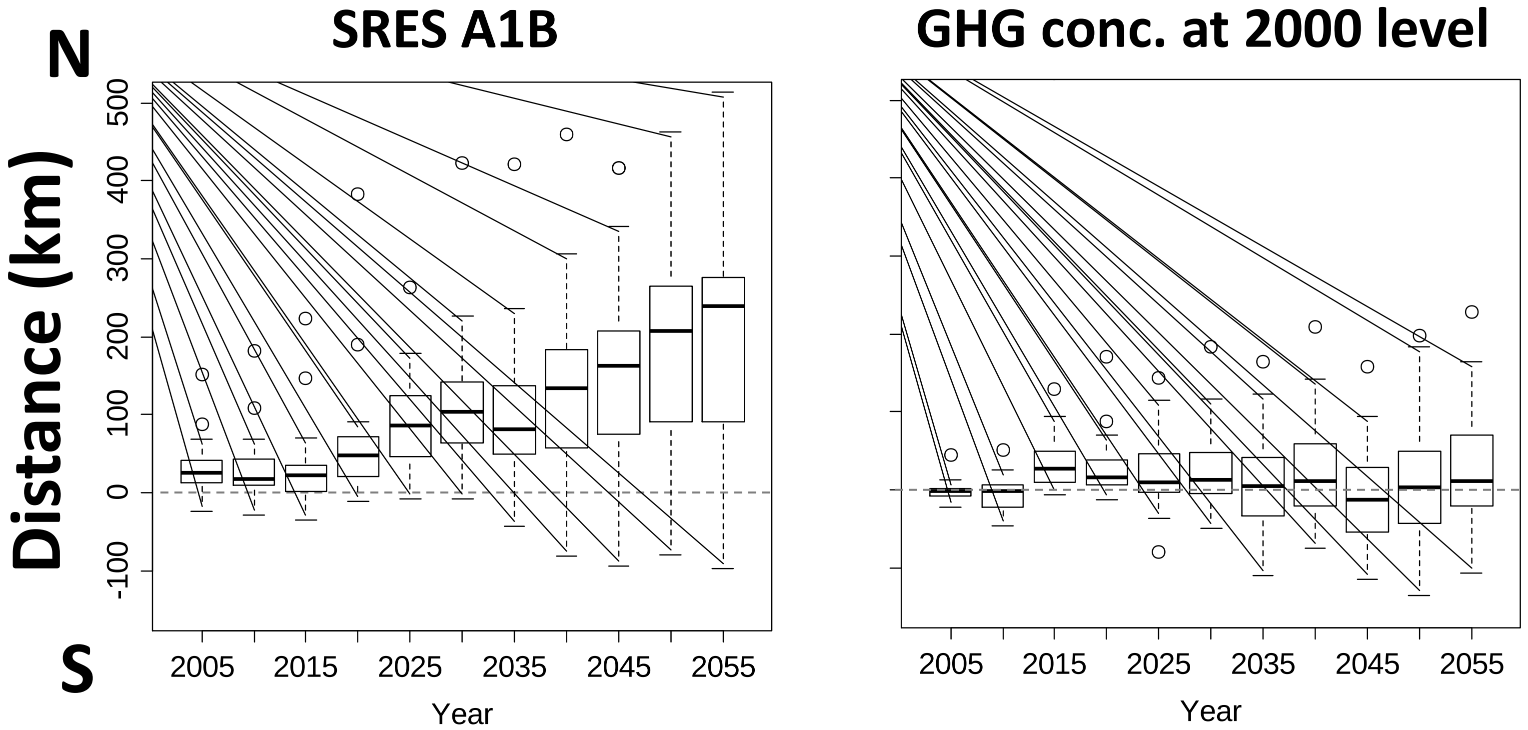
# Pacific jack mackerel

**Year 2050**

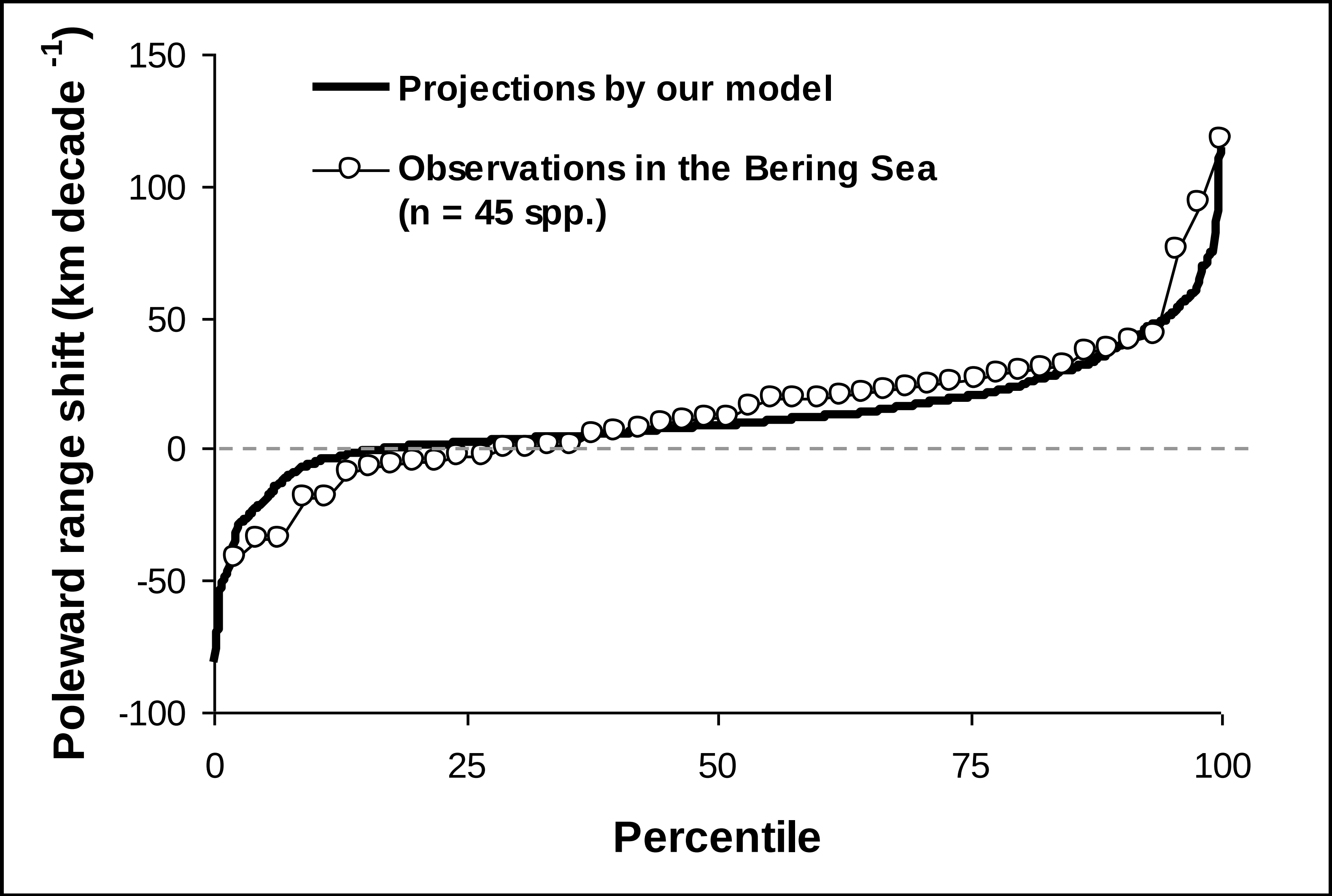
- NOAA/GFDL (SRES A1B)



# Projected latitudinal shift of centroid

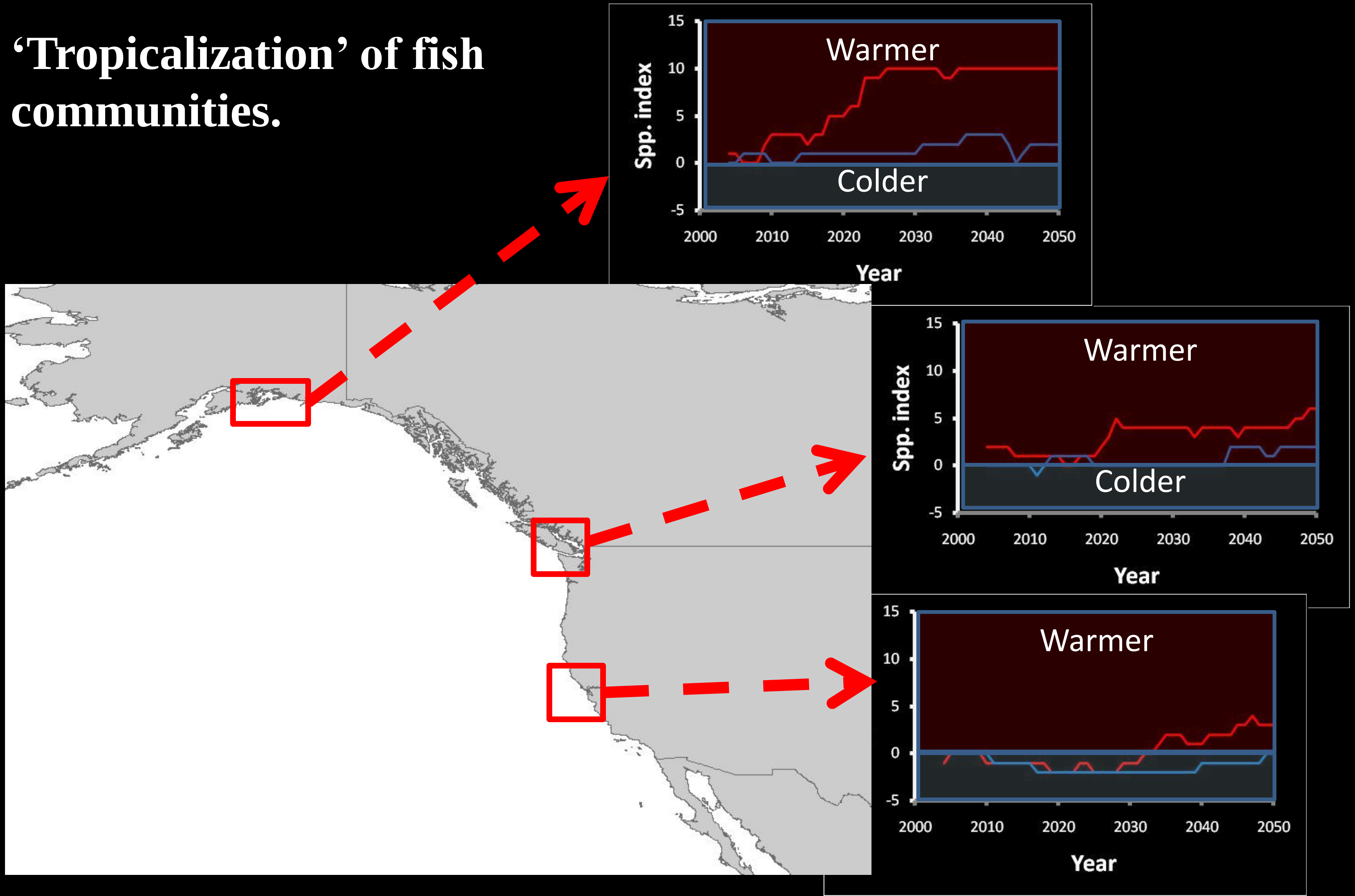


# Model validation: comparing model outputs with empirical data

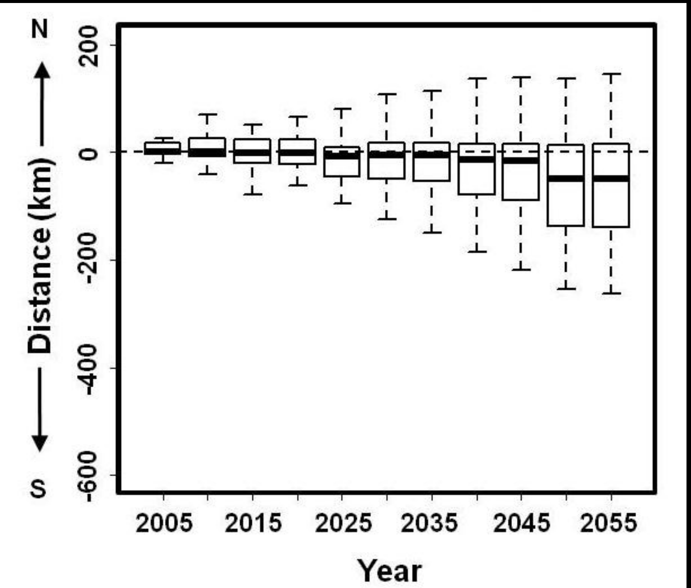


# Detecting climate change effects

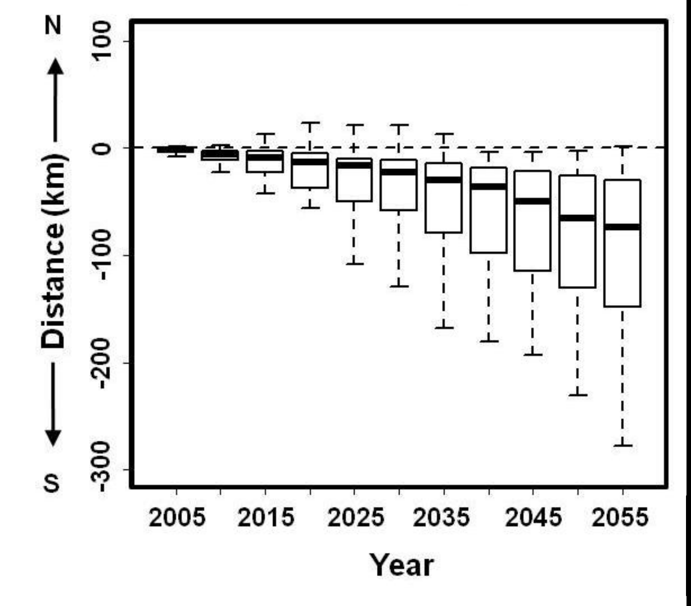
**'Tropicalization' of fish communities.**



# Comparing projections using GCM and ROM (Cheung *et al*. in press. Mar. Fresh. Res.)

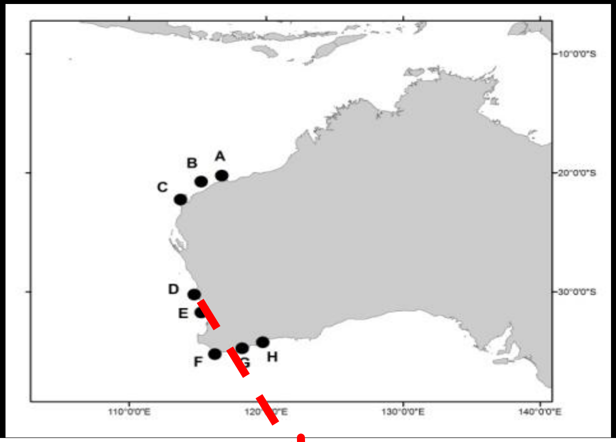


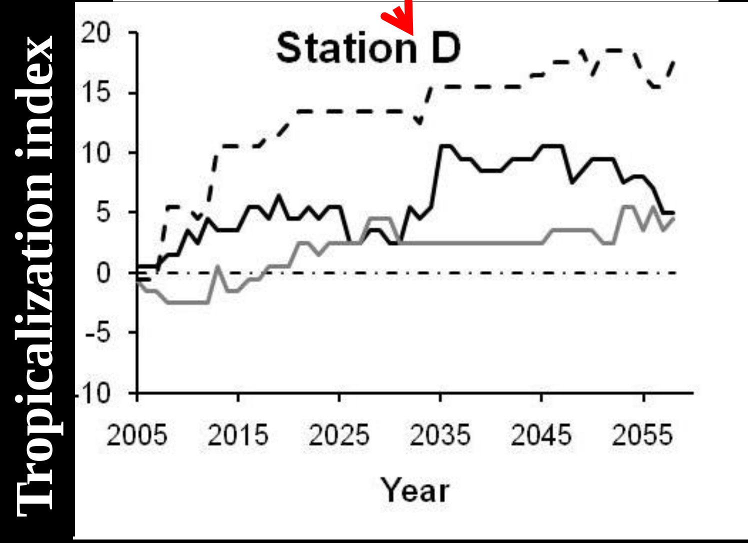

GFDL CM2.1




CSIRO OFAM

## Fish and invertebrates assemblages in W Australia



# Outline

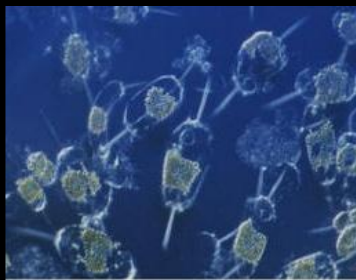
- Key theories and hypotheses;

- Impacts of climate change on marine biodiversity;

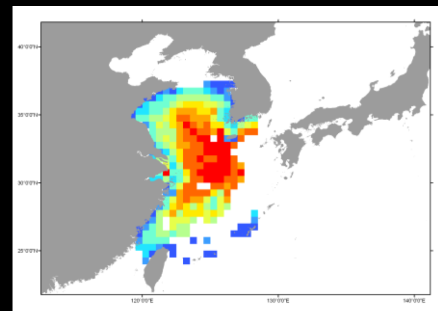
- Impacts of climate change on fisheries;

- Future research direction.

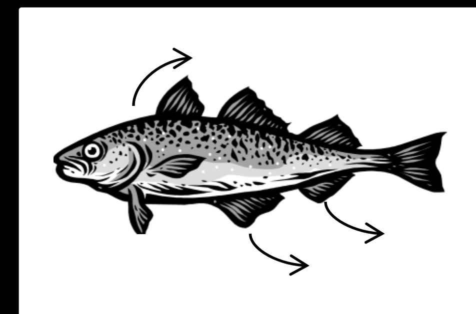
# Predicting future catch potential



Projected future primary production and phytoplankton community structure



Future species distribution



Eco-physiology

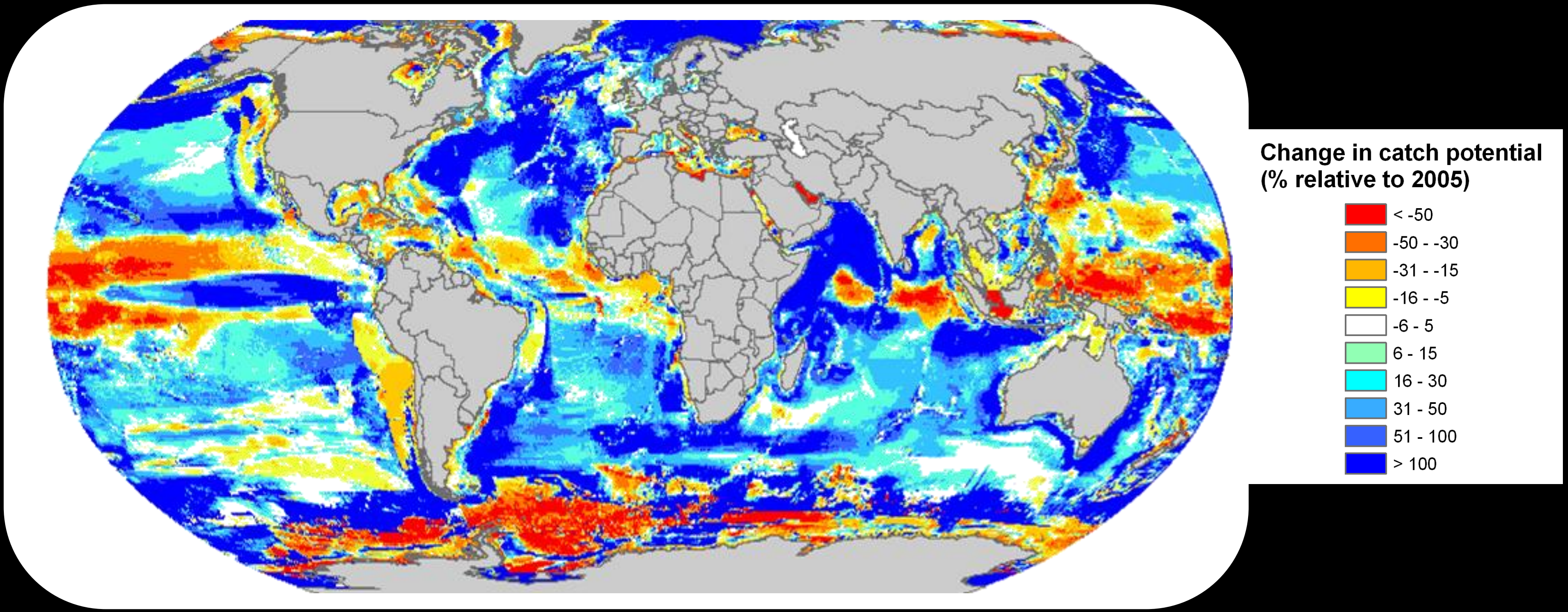
Catch potential

$$\log_{10}\mathrm{MSY}' = -2.881 + 0.826 \times \log_{10} P' - 0.505 \times \log_{10}(A) - 0.152 \times \lambda + 1.887 \times \log_{10}\mathrm{CT} + 0.112 \times \log_{10}\mathrm{HTC}' + \varepsilon$$

Cheung *et al*. (2008) Mar. Ecol. Prog. Ser. 365: 187-197.

# Projected change in catch potential by 2055

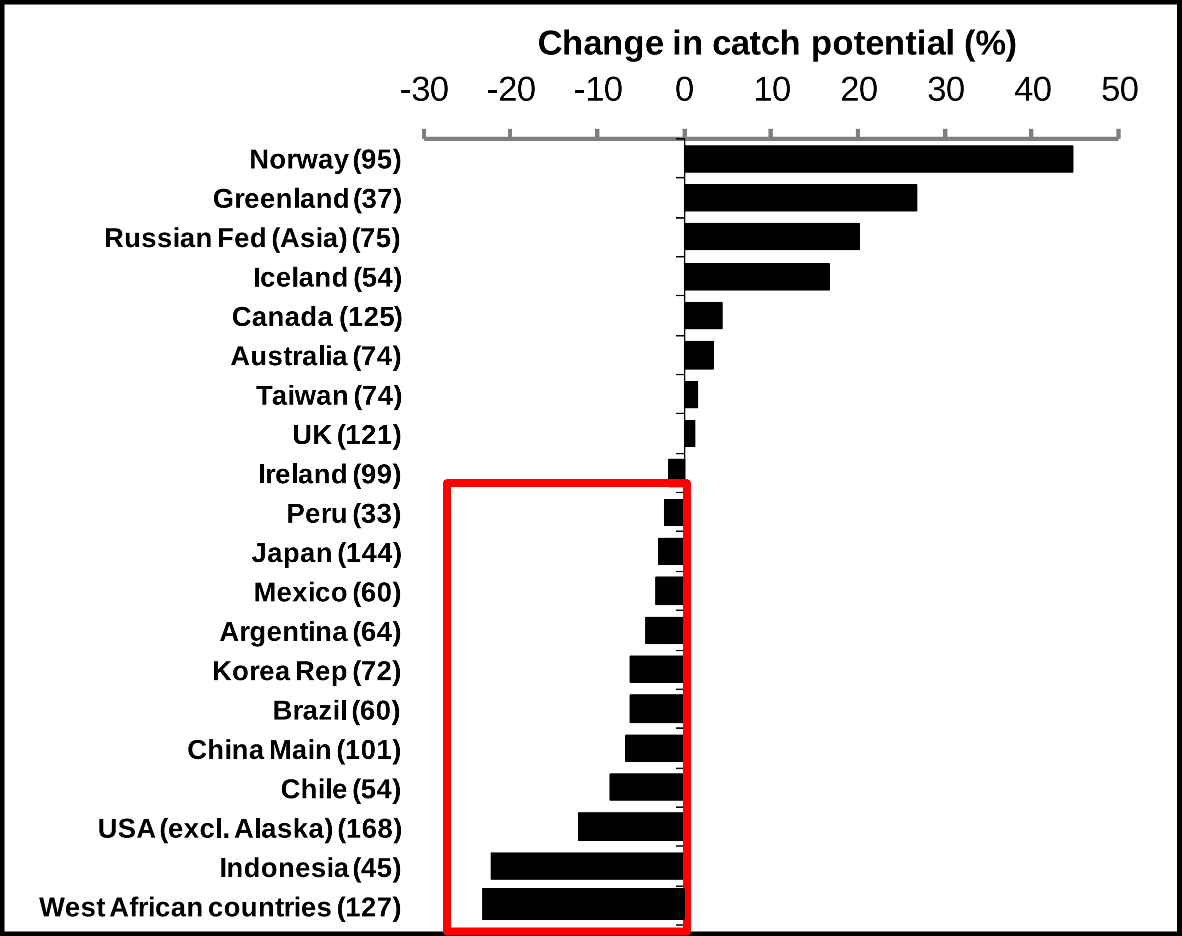
## Consideration: Physical and total primary production changes only




- **Regions in the tropics may suffer from losses while high latitude regions are projected to gain in catch potential.**

**Source: Cheung, Lam, Kearney, Sarmiento, Watson and Pauly (2010) Global Change Biology**

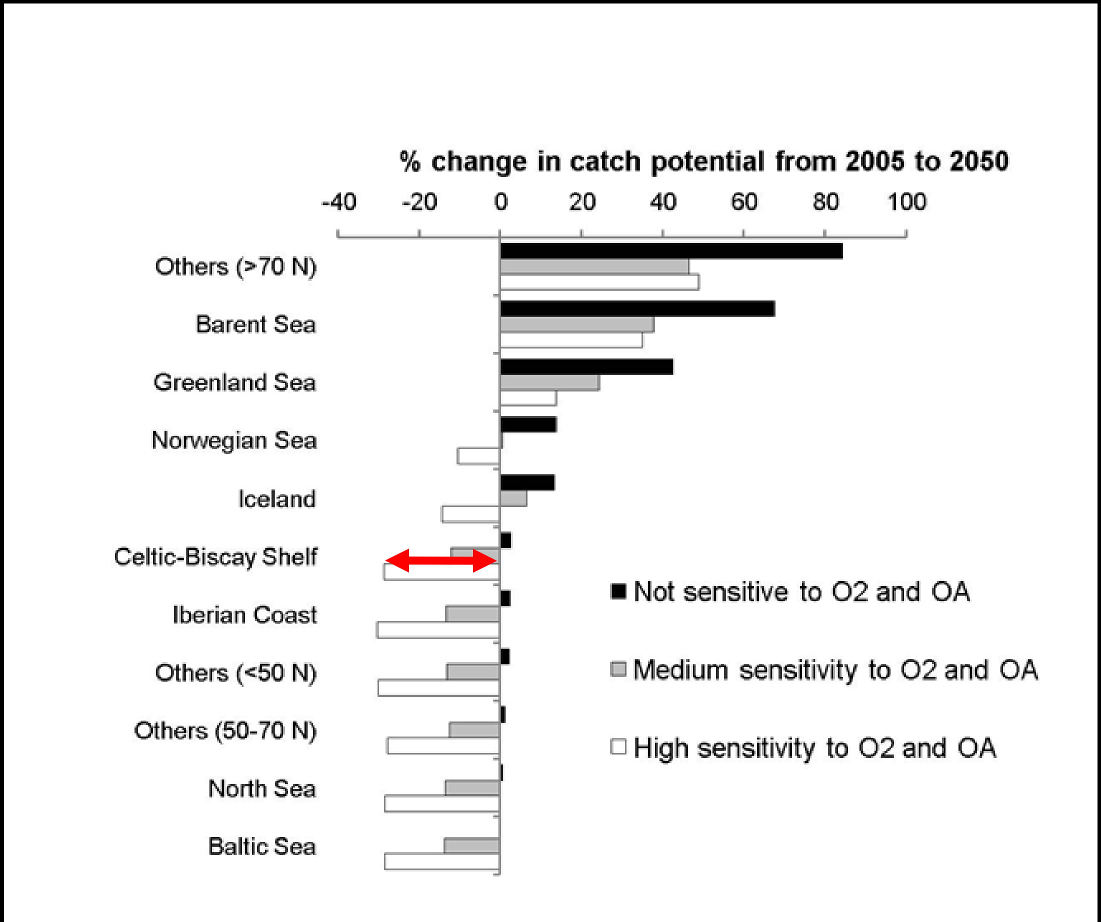
# Change in catch potential by 2050 relative to 2005




Source: Cheung *et al*. (2010)

# Effects of ocean acidification, oxygen content and phytoplankton community structure

## Example: Northeast Atlantic

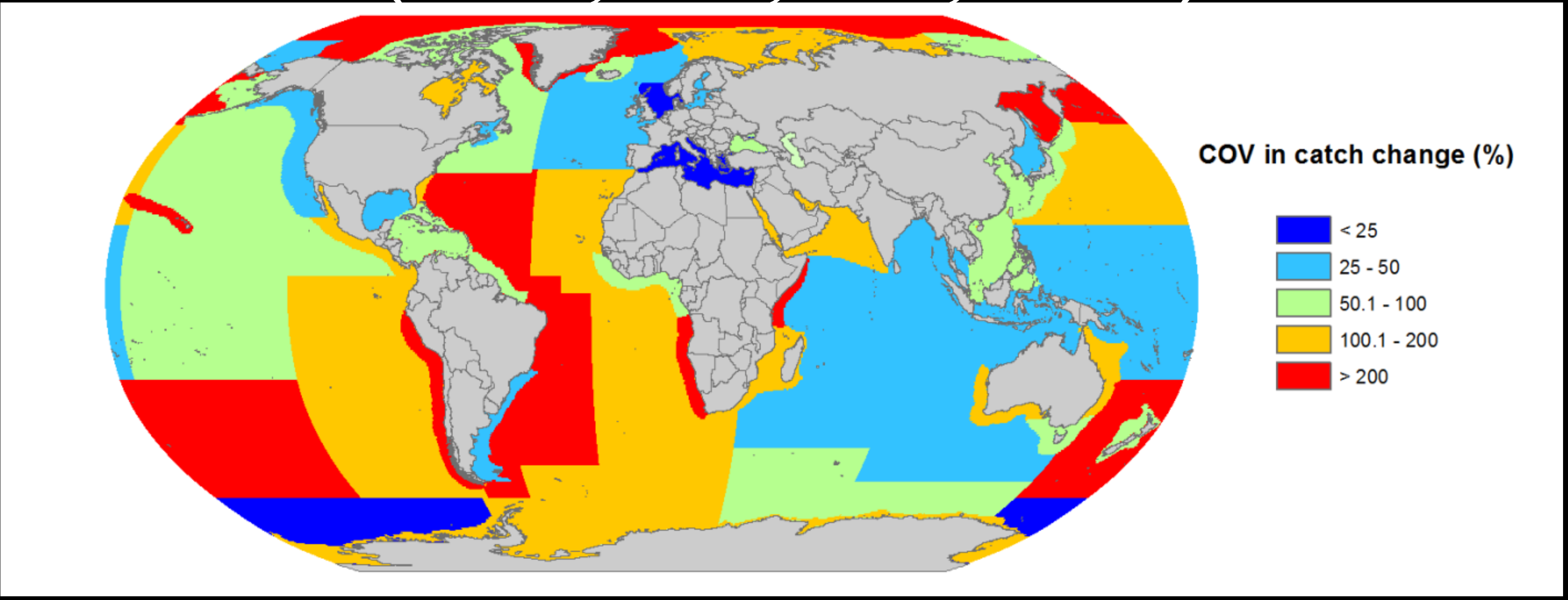



- Considerations of ocean acidification may lead to up to 20-35% additional reduction in maximum catch potential;
- Highlight the need to understand the impacts of OA.

Source: Cheung, Dunne, Sarmiento and Pauly (2011) ICES Journal of Marine Science

# Variability of projections using different outputs from 4 different Earth System Model

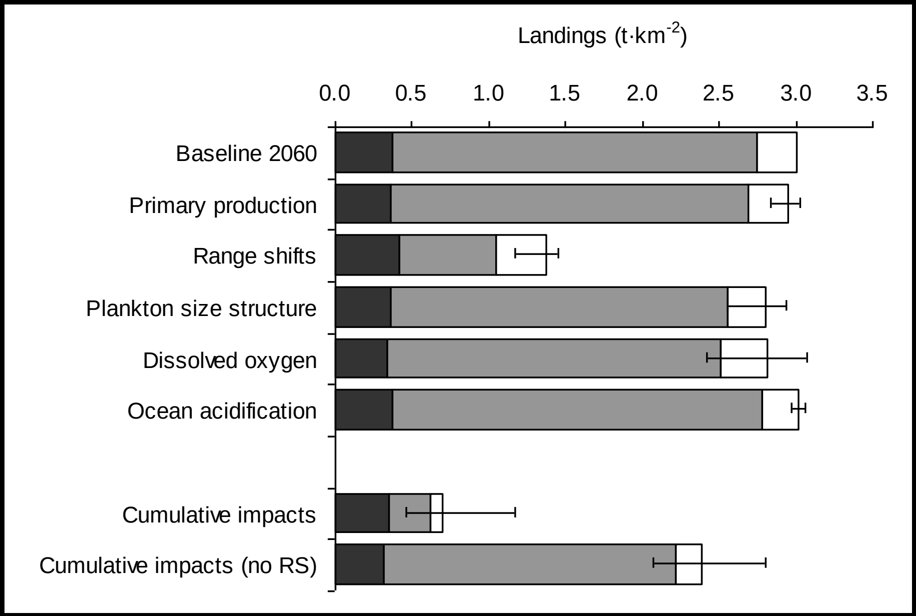
# (GFDL, IPSL, CSM, CCSM)




- **Variability in North Atlantic, NE Pacific, and SW Pacific regions are low;**
- **Projections for Arctic, North Pacific, Central and SW Atlantic, Southern Oceans are uncertain.**

**Source: Cheung *et al* . (in prep.)**

# Addressing trophic interactions




- Using predicted range shift as inputs to Ecosim to explore the impacts on fisheries in NE Pacific with consideration of species interaction;
- Cumulative impacts on fisheries landings from different climate factors are significantly higher.

Source: Ainsworth, Samhouri, Busch, **Cheung**, Dunne, Okey (2011)

# Outline

- Key theories and hypotheses;

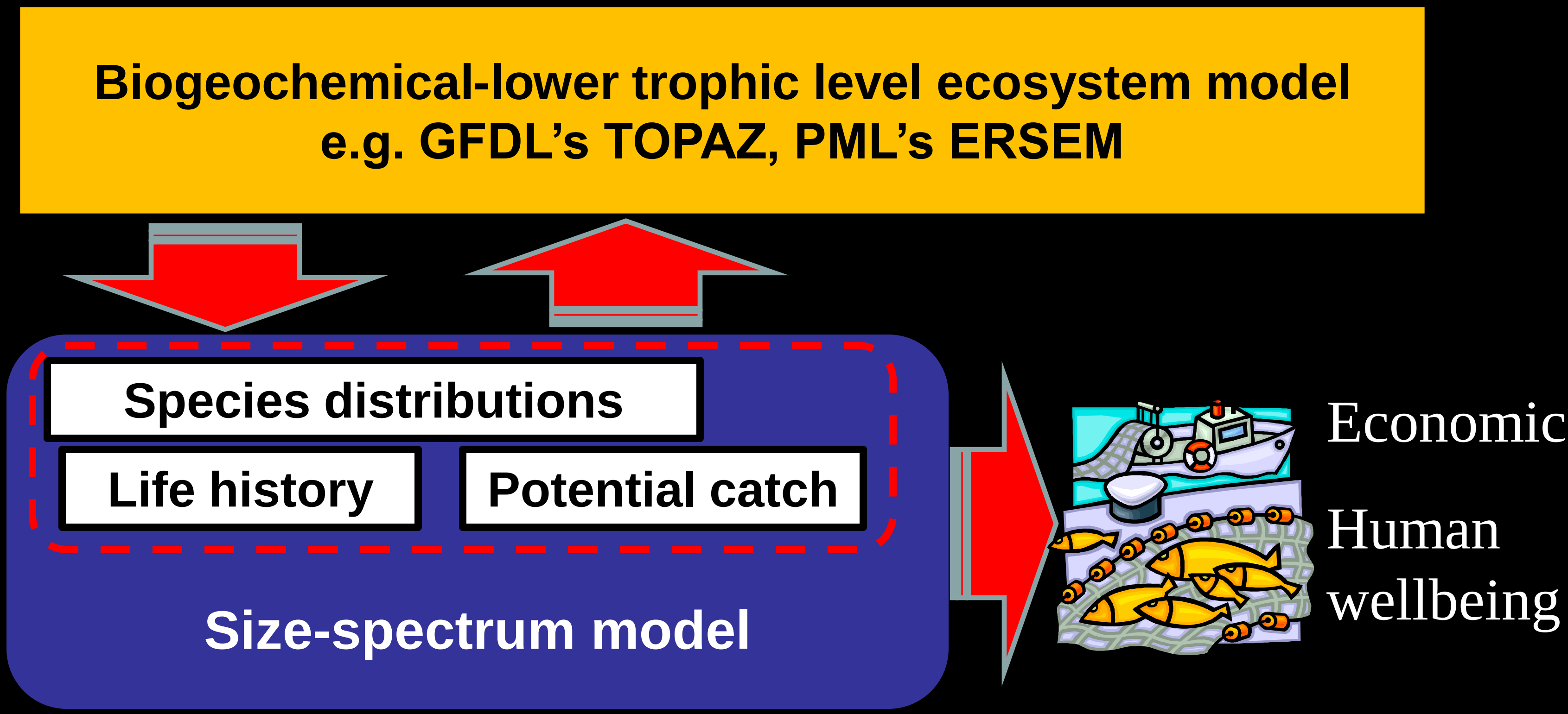
- Impacts of climate change on marine biodiversity;

- Impacts of climate change on fisheries;

- Future research direction.

# Incorporating trophic interactions

# EU-funded project (EURO BASIN)



# Other on-going research/idea being developed

- Cummulative impacts of CC, OA and fishing;
- Hindcasting and model comparisons;
- Regional  assessments;
- Adaptive responses – ecological and human dimension.

# Summary

- Climate change, in addition to ocean acidification and deoxygenation, is expected to alter patterns of biodiversity and reduce global fisheries catch potential;
- This will impact the wellbeing of the society through loss of revenues and decrease in protein supply;
- The ultimate solution is to reduce greenhouse gas emission;
- It is also important to help affected communities to adapt to these changes – an adaptation fund is an option.

**Thank you**

# Acknowledgement

**Collaborators**

- **D. Pauly, J. Sarmiento, R. Sumaila, V. Lam, R. Watson, D. Zeller, D. Palomares, J. Pinneger, S. Jennings, S. Dye, J. Dunne, M. Barange, I. Allen, and others;**

**Post-doc and students**

- **J. Fernades, M. Jones, T. Kerby;**

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**Thank you**