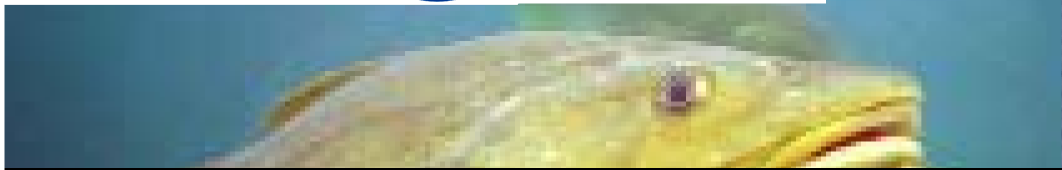
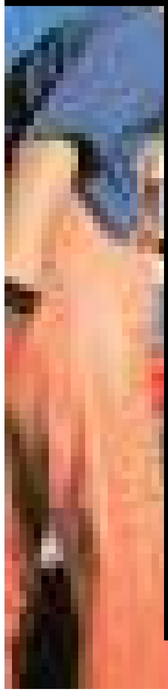



Detection and projection of climate change impacts on marine fisheries




William W.L. Cheung

w.cheung@fisheries.ubc.ca

Changing Ocean Research Unit & Nippon Foundation-Nereus Program, The University of British Columbia

AIMEN, Brest, France

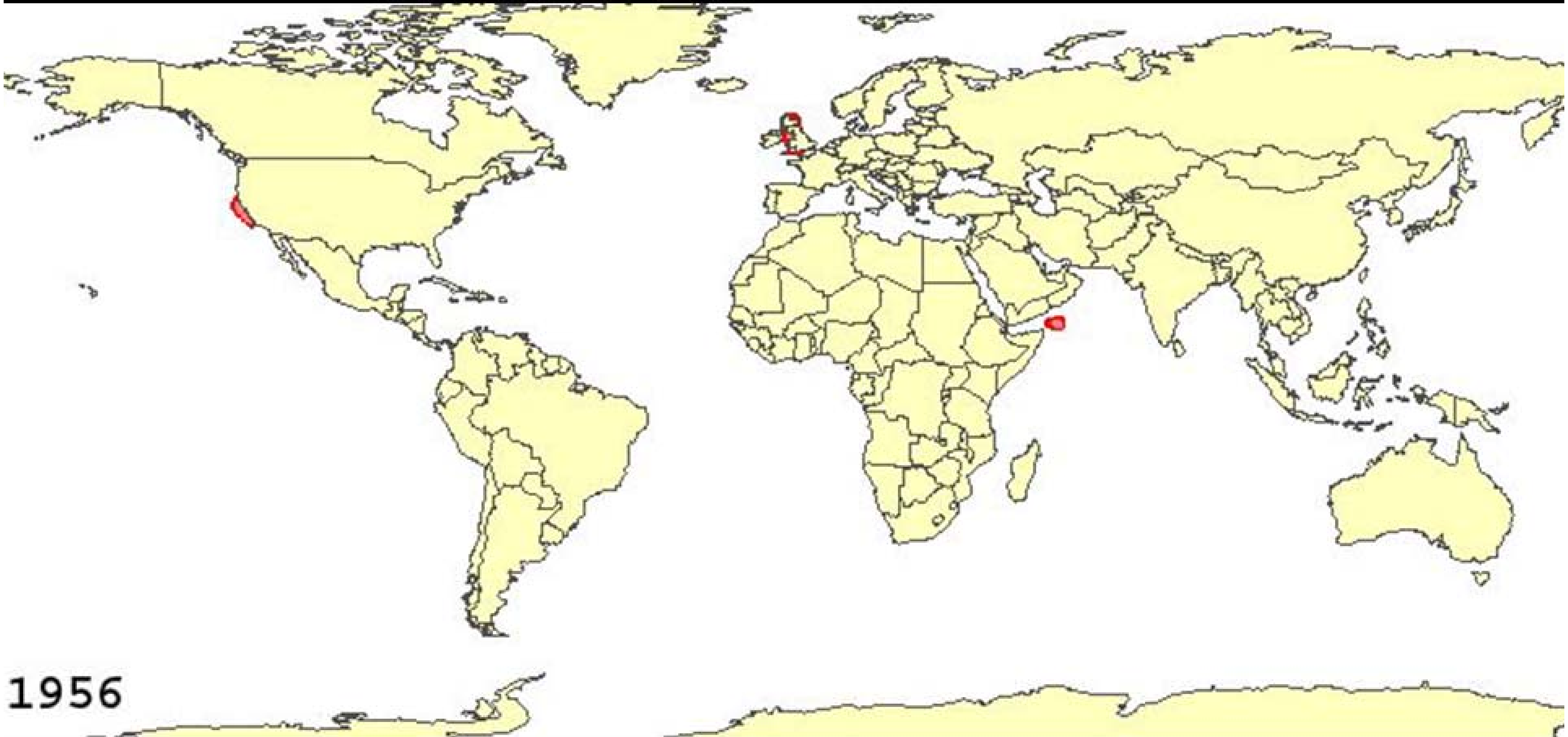
23 August 2013

Key focus of this talk

- **Present selected studies of empirical and simulation modelling to understand large-scale pattern and magnitude of climate change impacts on fisheries;**
  - **Detecting and attributing climate change effects on global fisheries;**
  - **Projecting changes in distribution of exploited species;**
  - **Effects of climate change on body size of fishes;**
  - **Projecting changes in fisheries catch potential.**

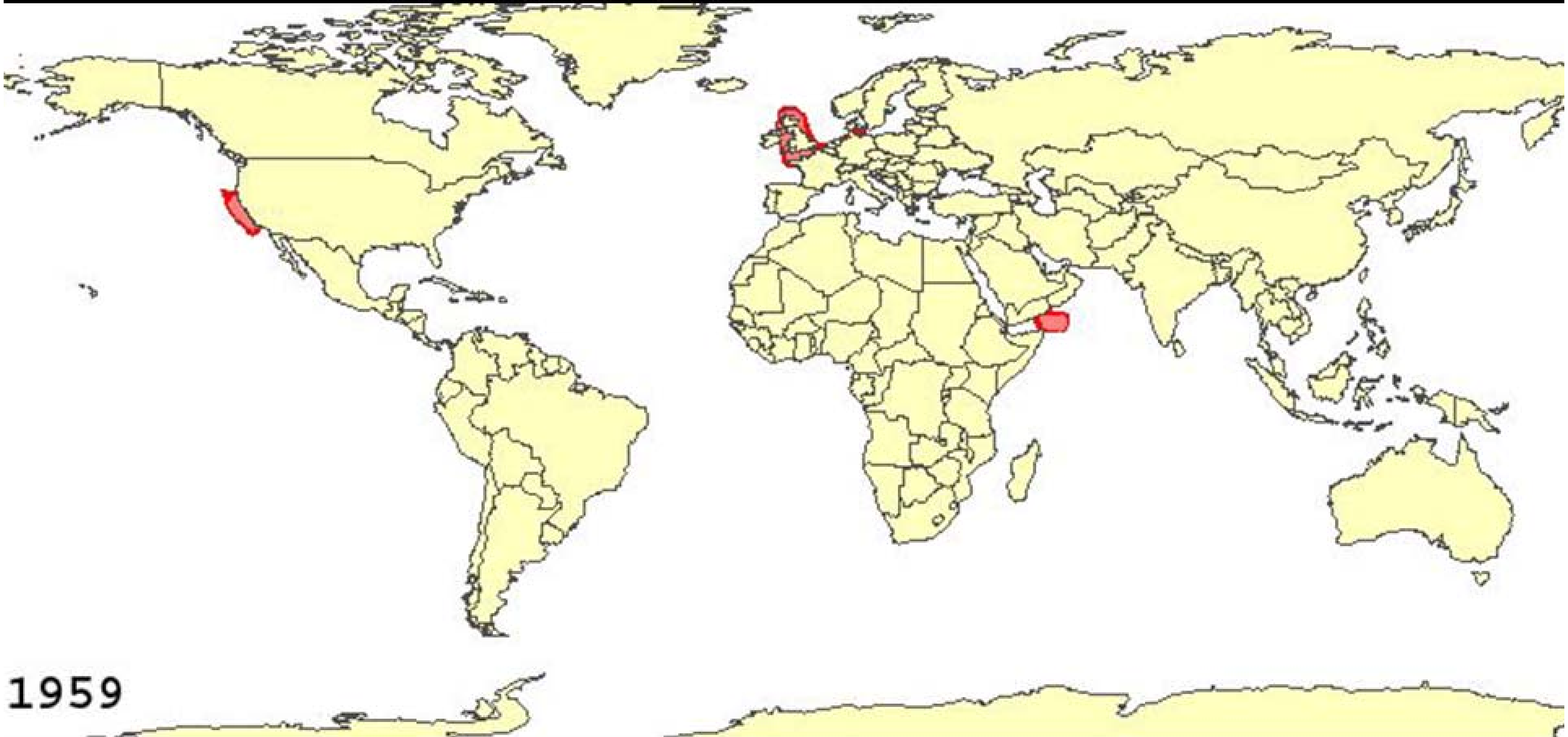
Human impacts on marine ecosystems

Year of Maximum Catch



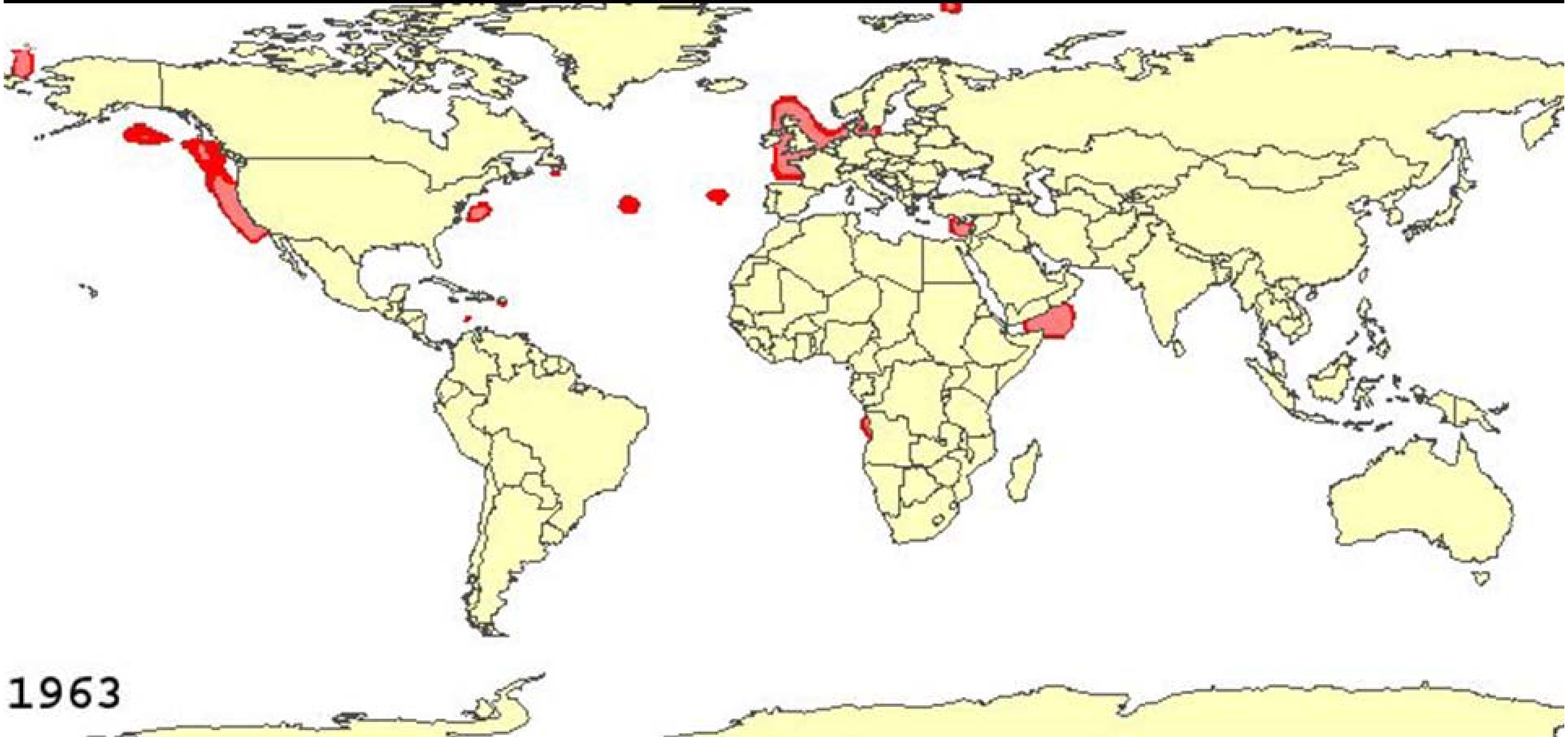
www.seaaroundus.org

Year of Maximum Catch



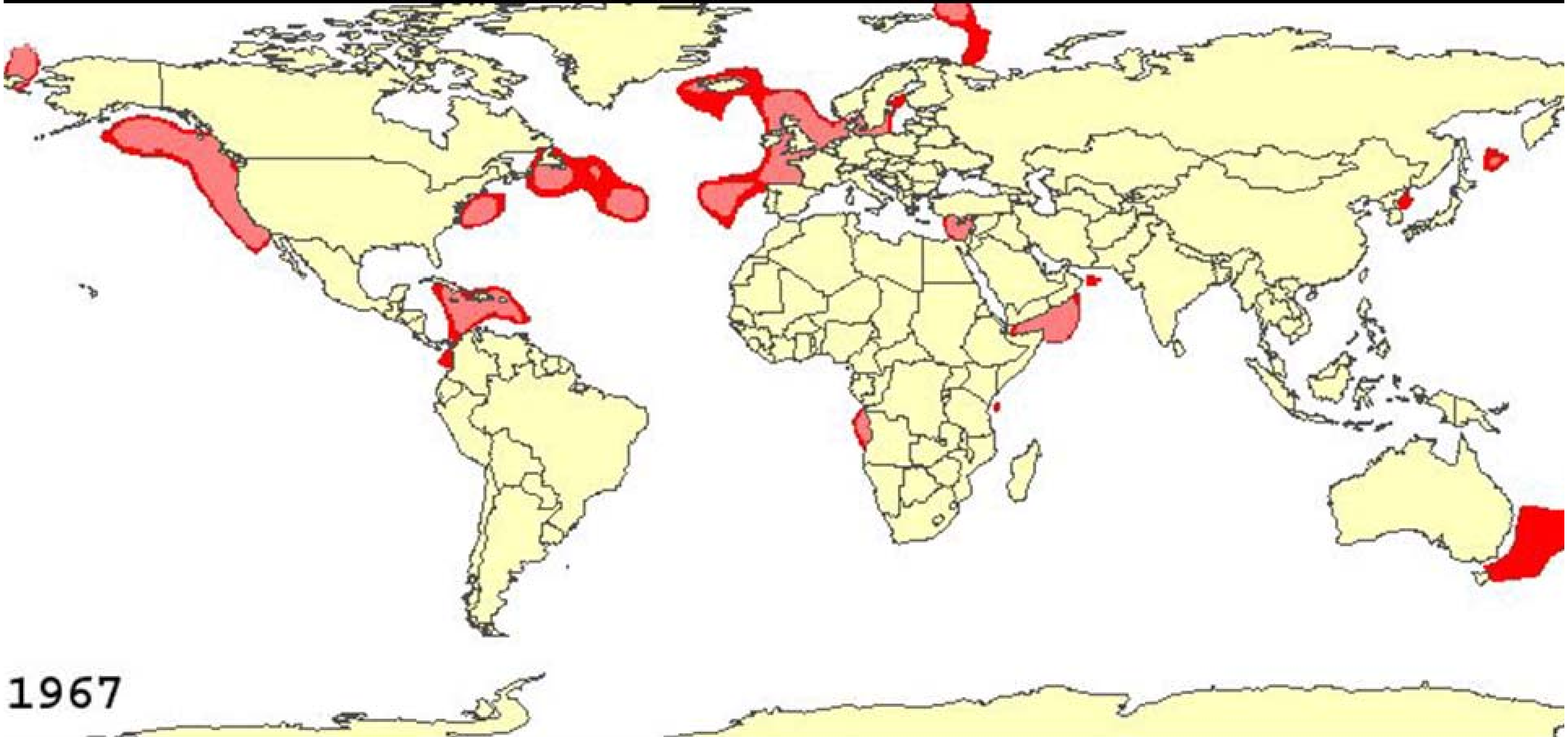
www.seaaroundus.org

Year of Maximum Catch



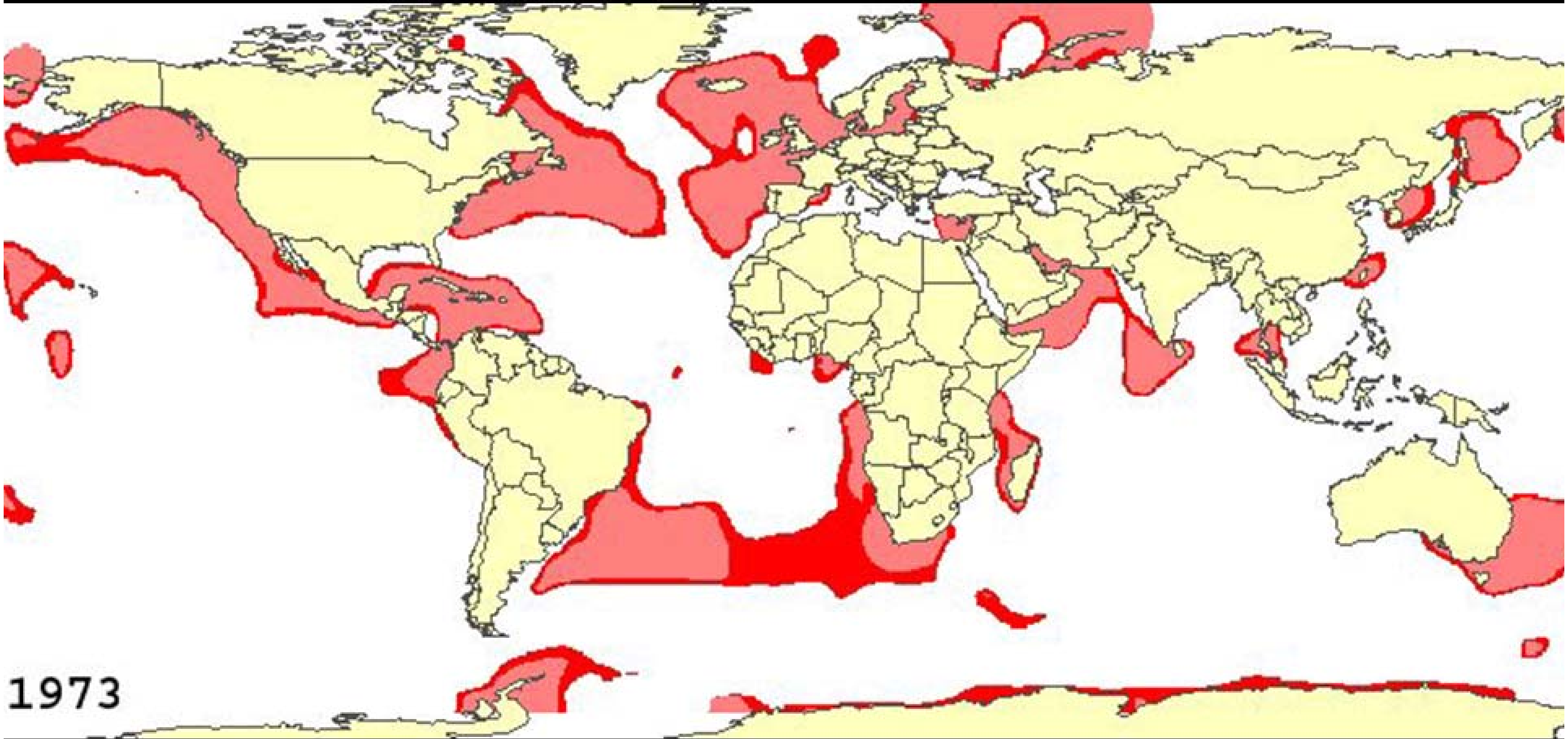
www.seaaroundus.org

Year of Maximum Catch



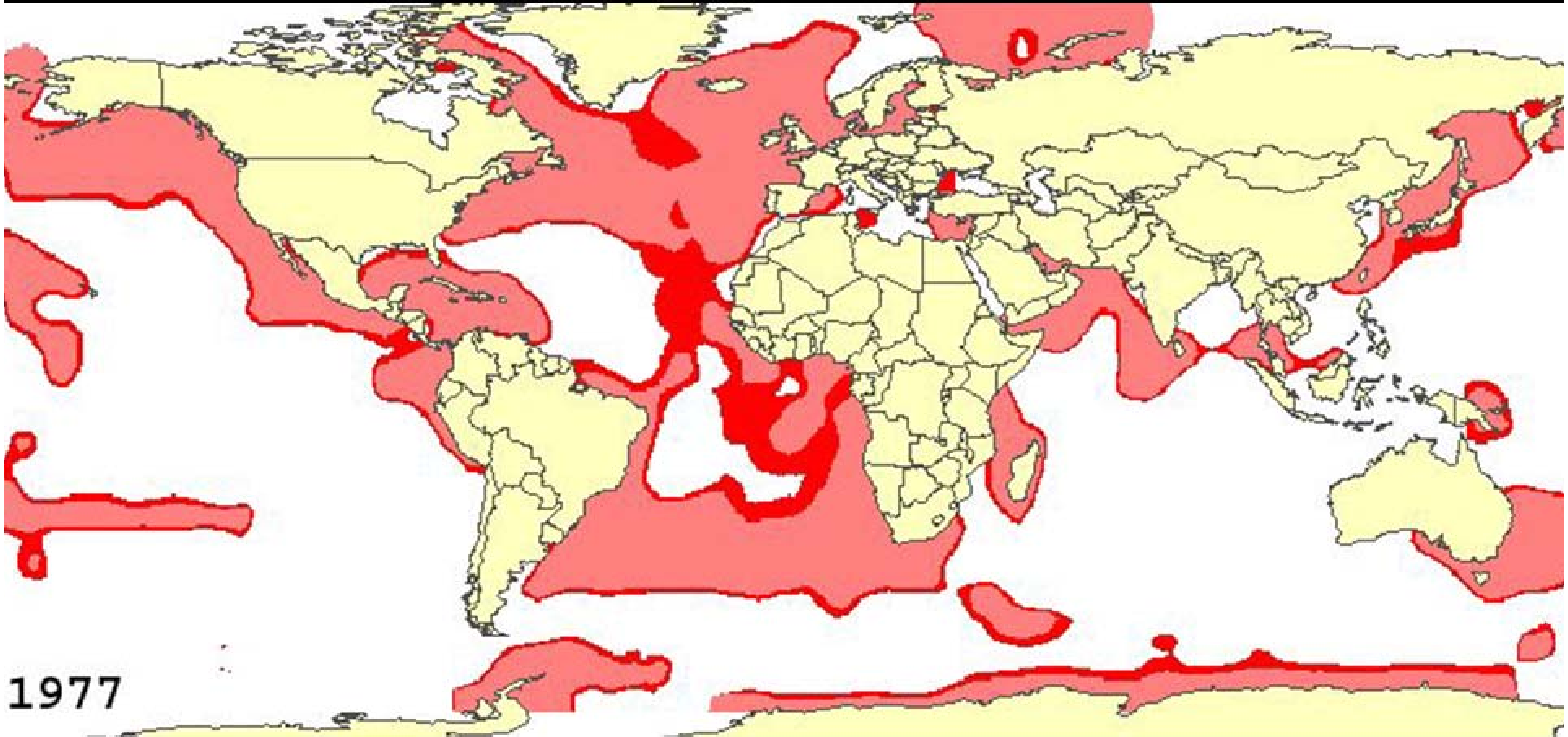
www.seaaroundus.org

Year of Maximum Catch

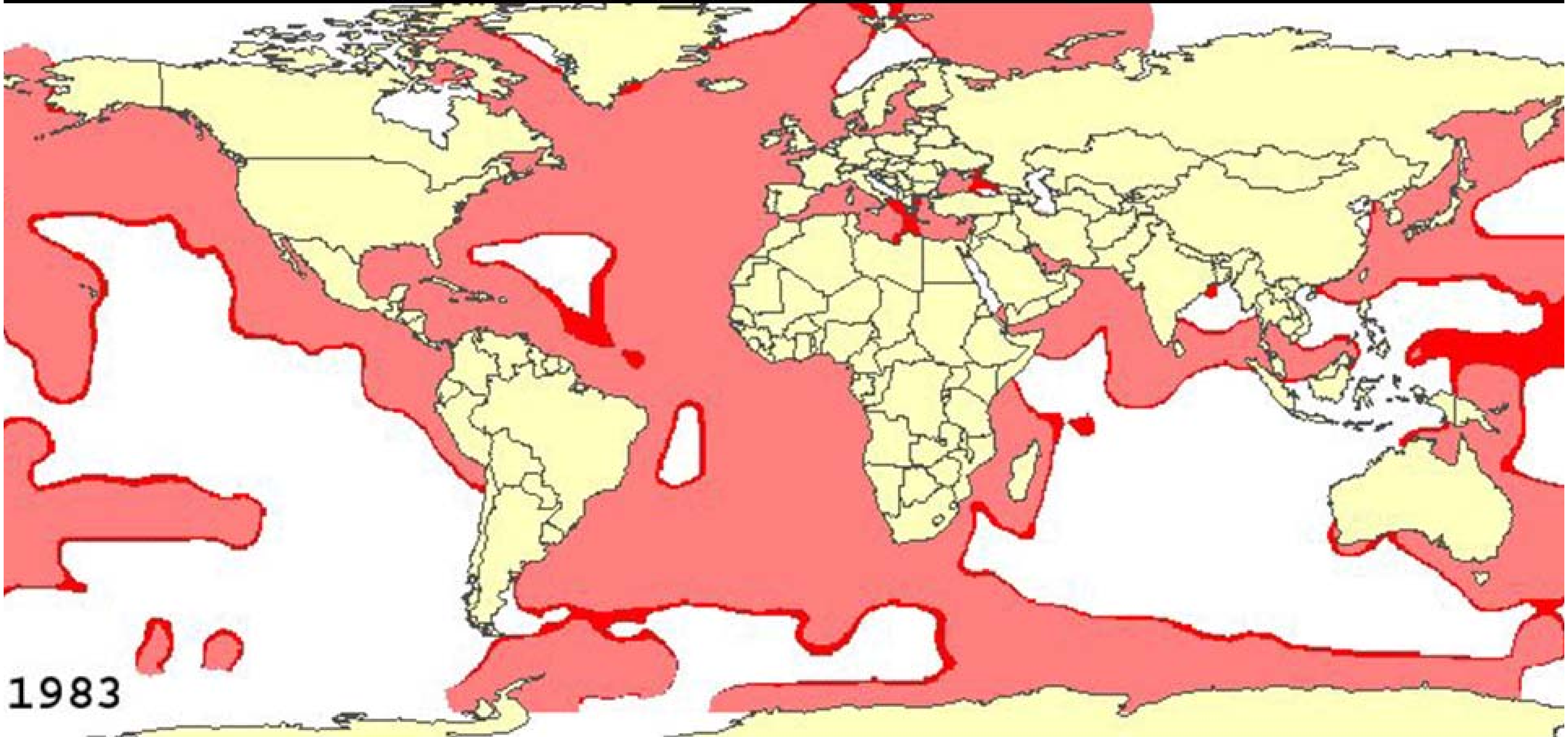


www.seaaroundus.org

Year of Maximum Catch

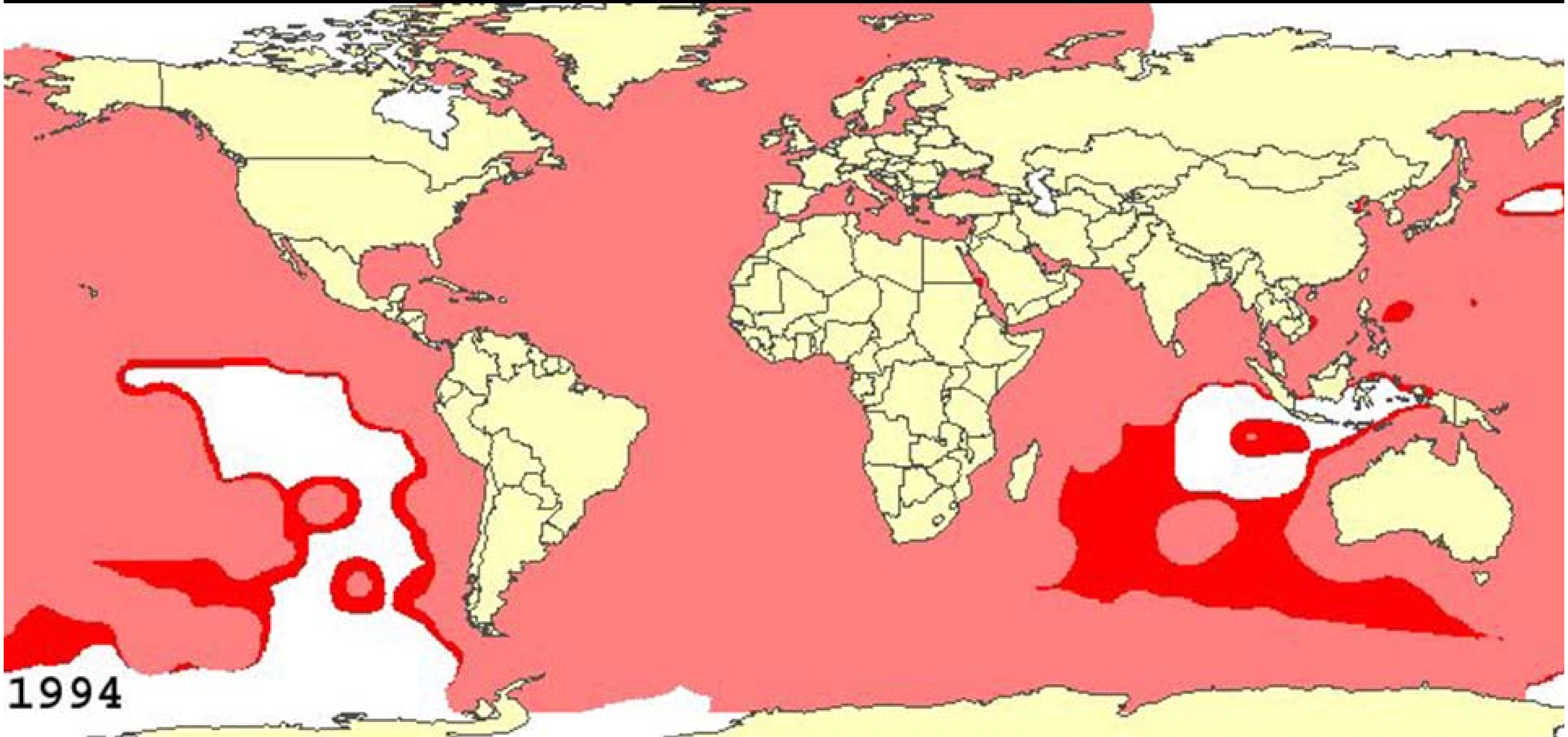


Year of Maximum Catch



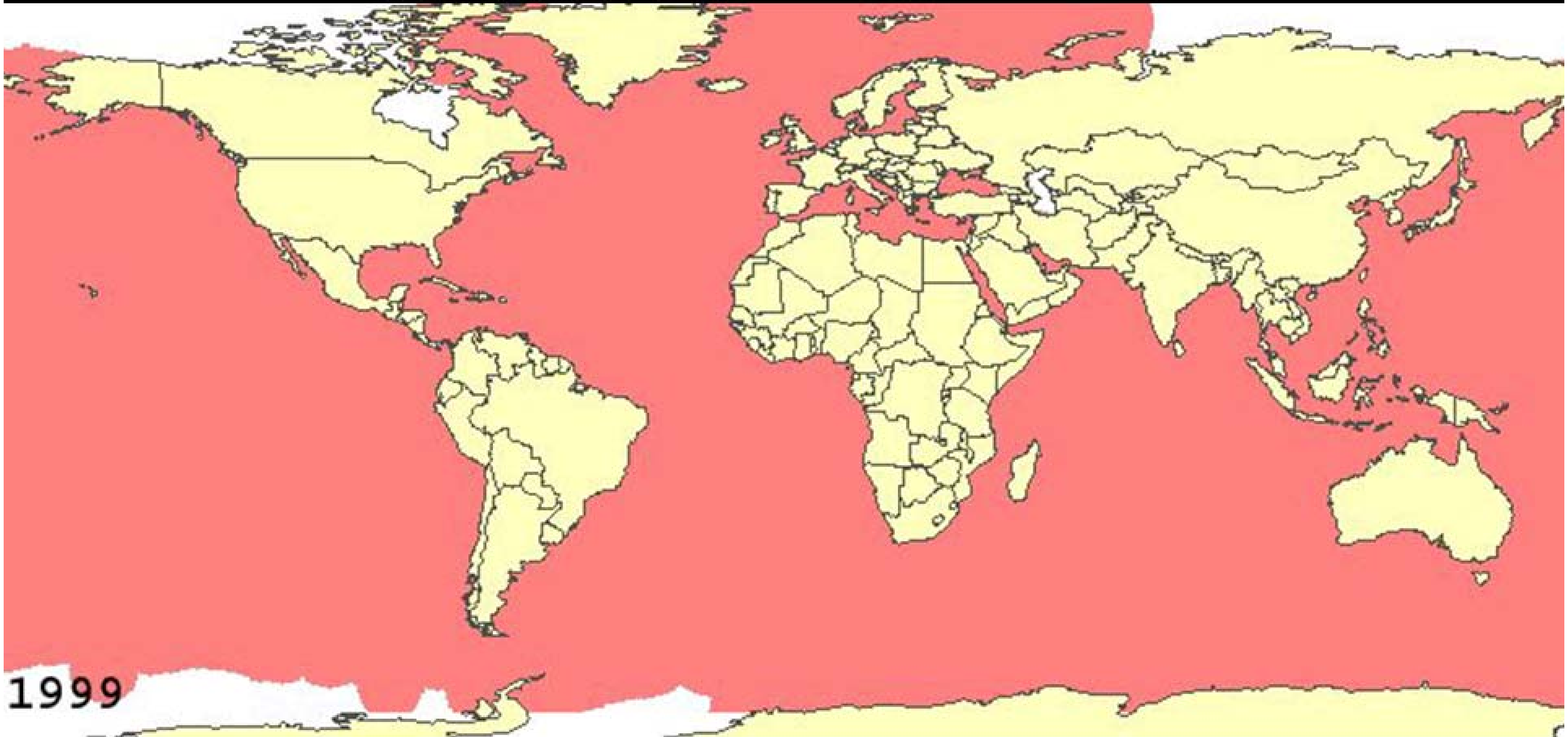
www.seaaroundus.org

Year of Maximum Catch



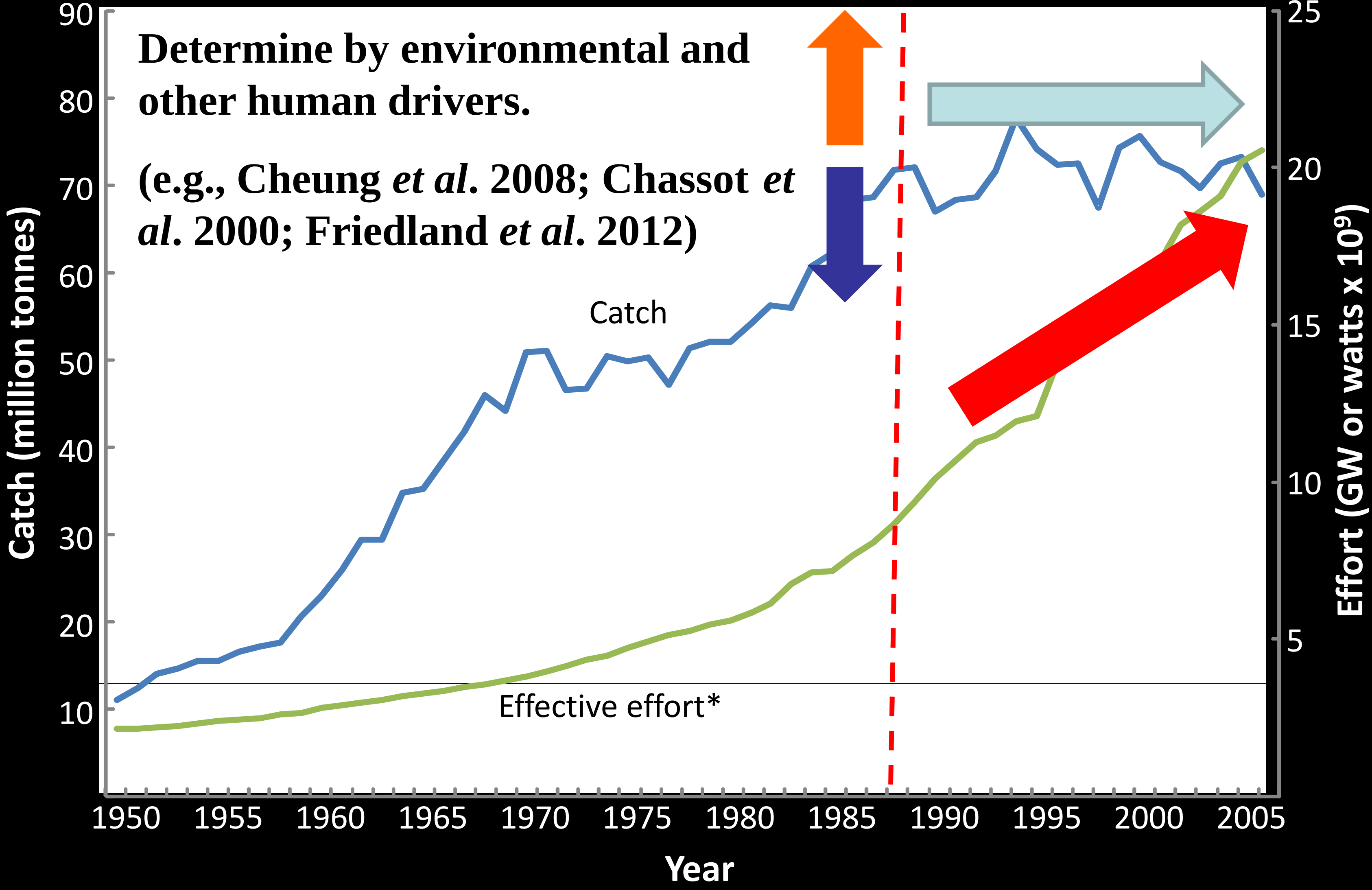
www.seaaroundus.org

Year of Maximum Catch



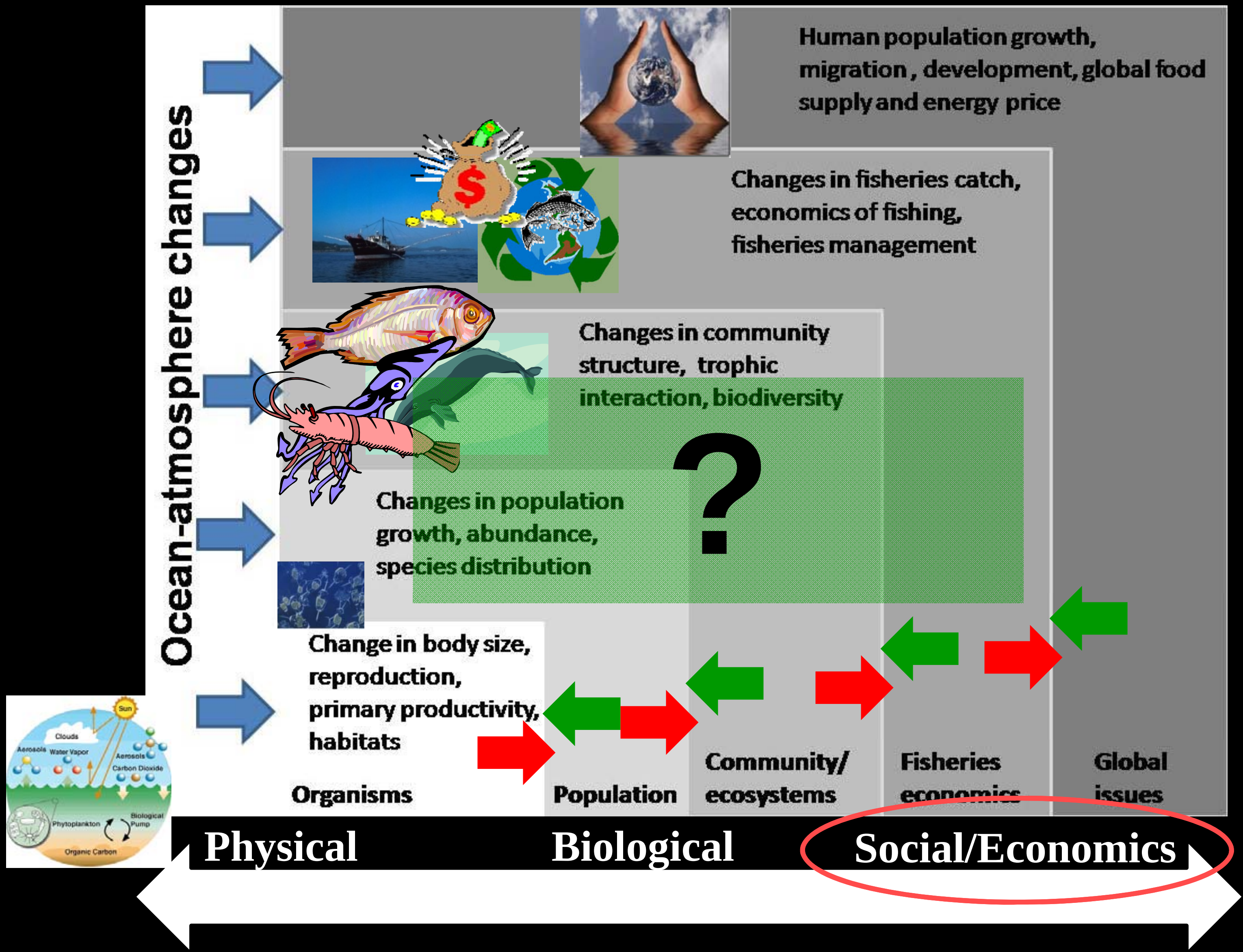
www.seaaroundus.org

Limit to global fisheries production



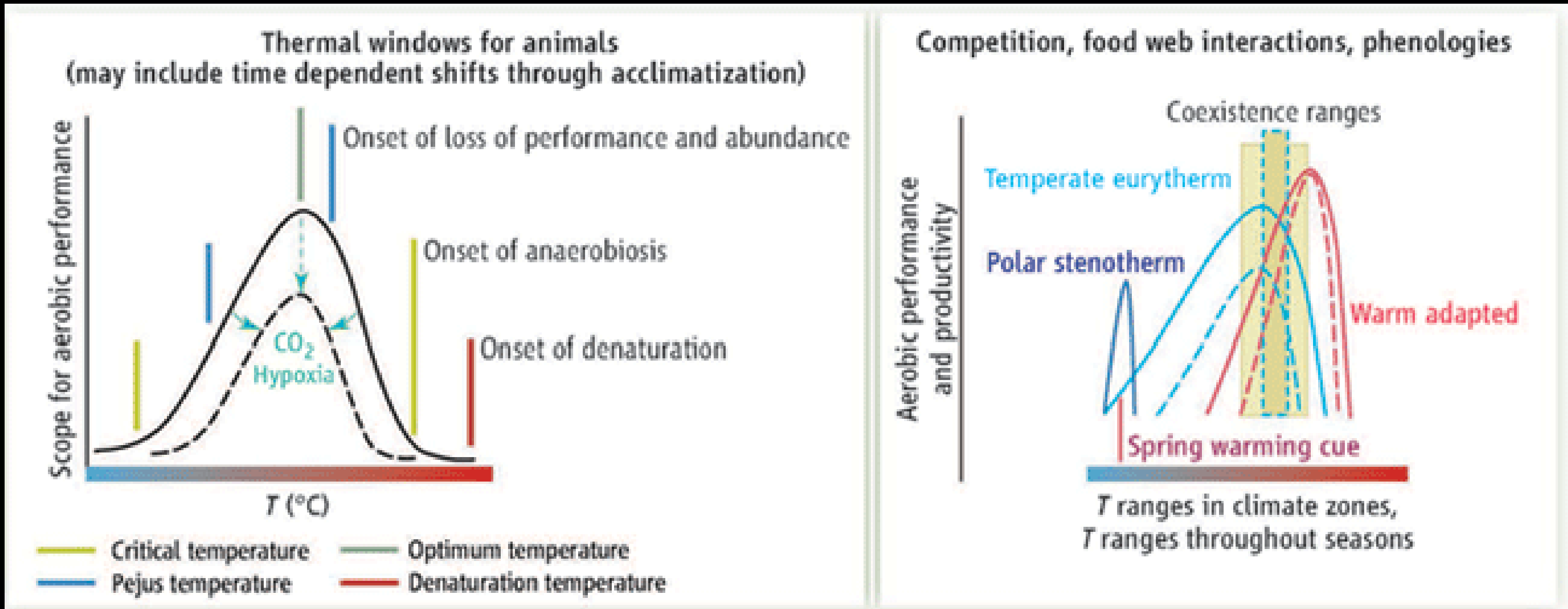
Data source: Watson, Cheung *et al*. (2012) Fish and Fisheries

Climate change effects in the ocean



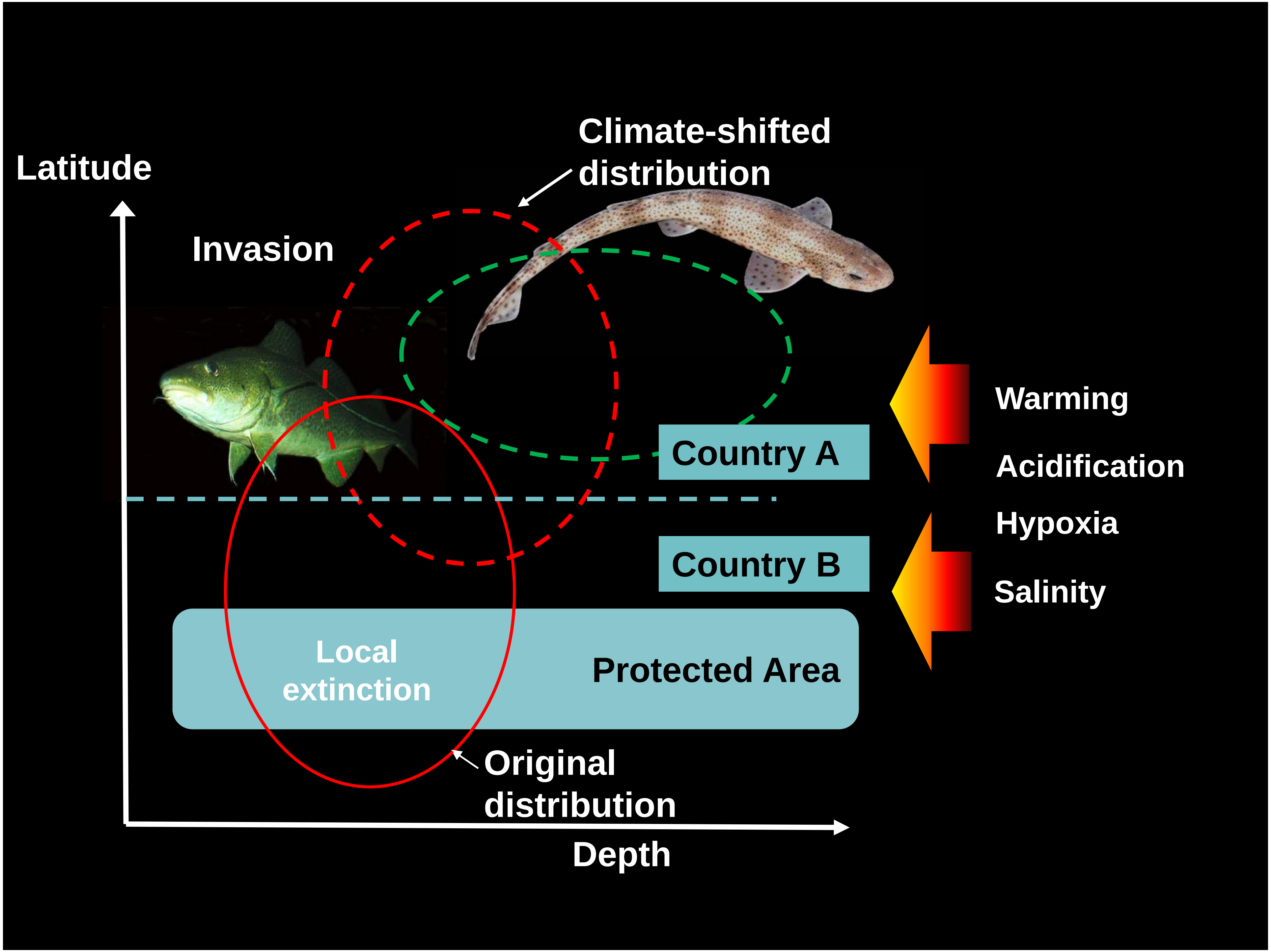
From: Sumaila, Cheung, Lam, Pauly, Herrick (2011) Nature Climate Change

Thermal biology of marine fishes and invertebrates



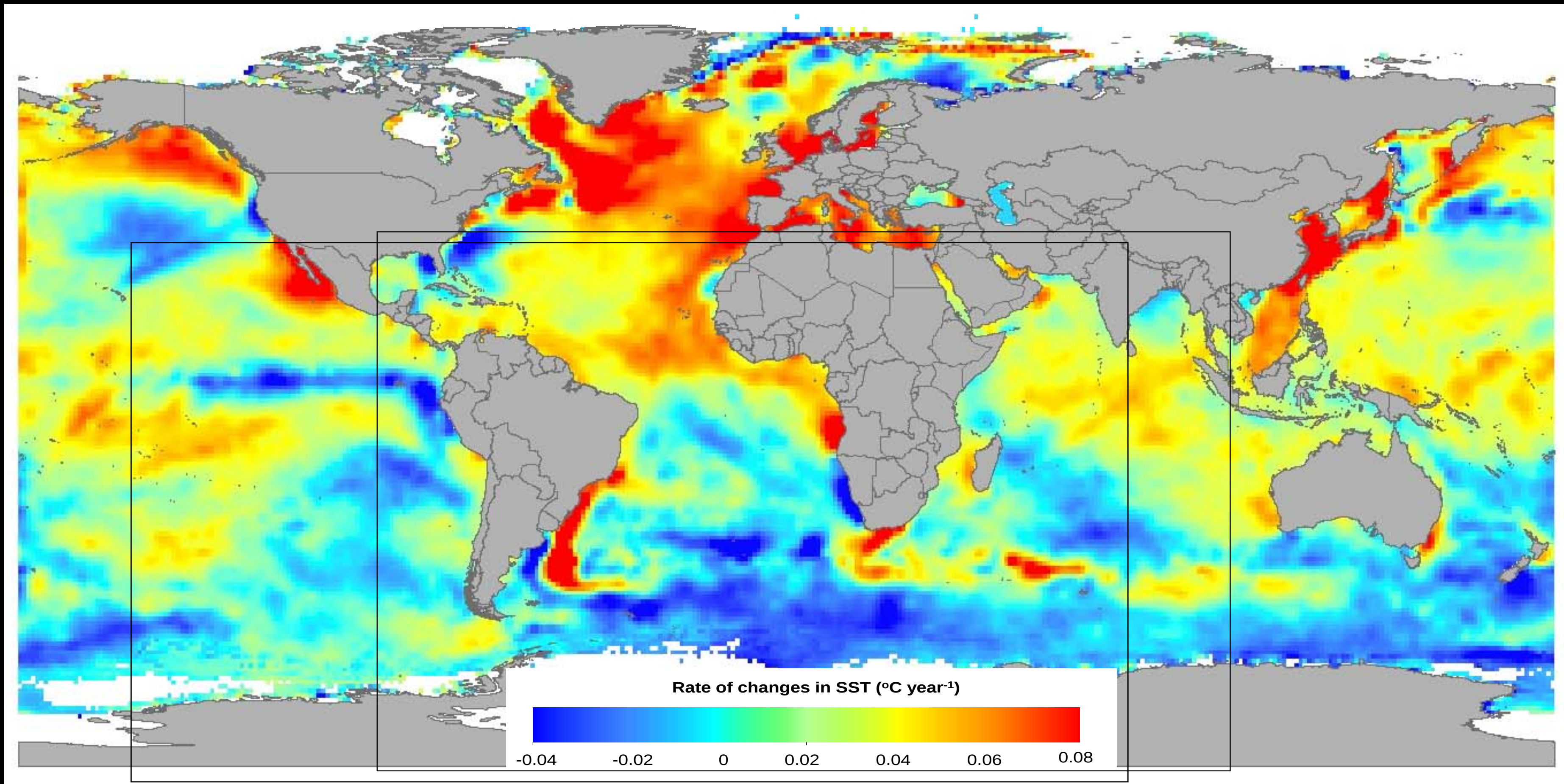
From: Pörtner & Farrell (2008) Science

- Theory predicts that aquatic ectotherms distribute themselves to maximize their growth performance.

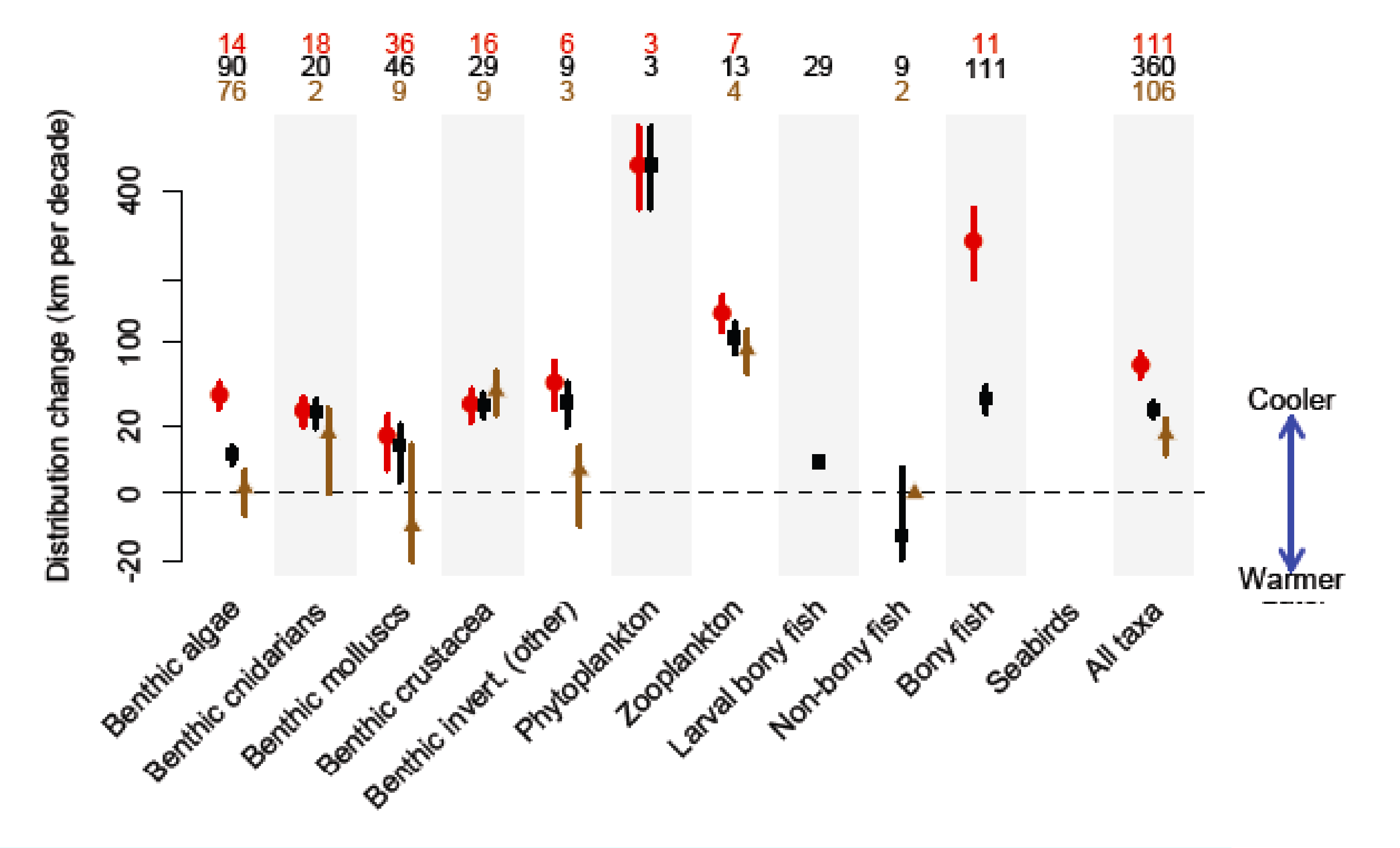


Climate-shifted
distribution
Latitude
Invasion
Warming
Acidification
Hypoxia
Salinity
Country A
Country B
Local
extinction
Protected Area
Original
distribution
Depth

Rate of change in SST from 1970 to 2010



Examples of evidence of climate change effects on fisheries in specific areas



From: Poloczanska *et al.* (2013) Nature Climate Change

Does climate change affect fisheries?

Hypothesis

- Ocean warming has led to changes in species composition of fisheries catches.





Mean Temperature of Catch (MTC)

MTC =
Average preferred temperature weighted by the catch

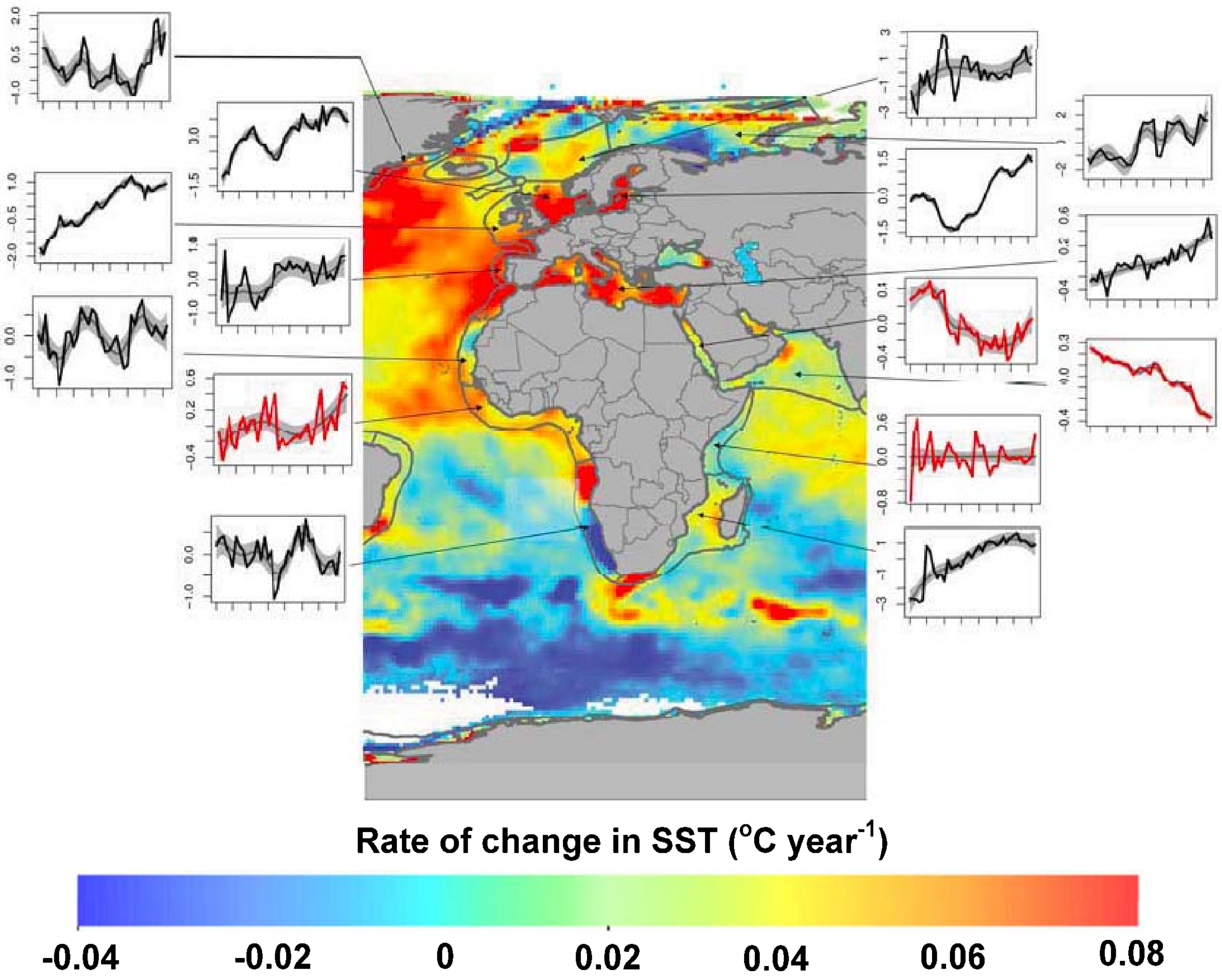
Median preferred temperature = 8 ^{o}C

Median preferred temperature = 10 ^{o}C

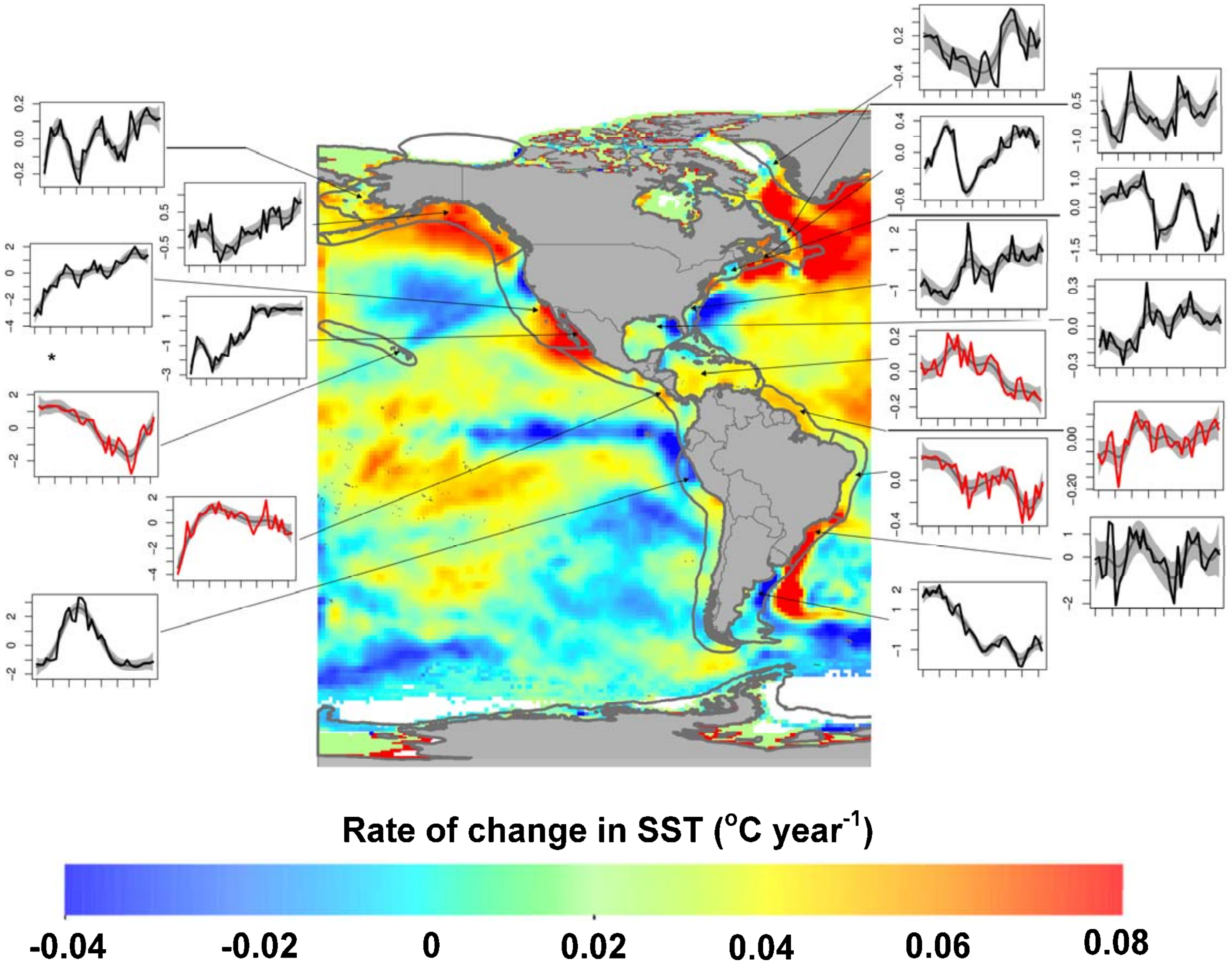
Median preferred temperature = 6 ^{o}C

Cheung, Watson & Pauly (2013) Nature 497: 365-368

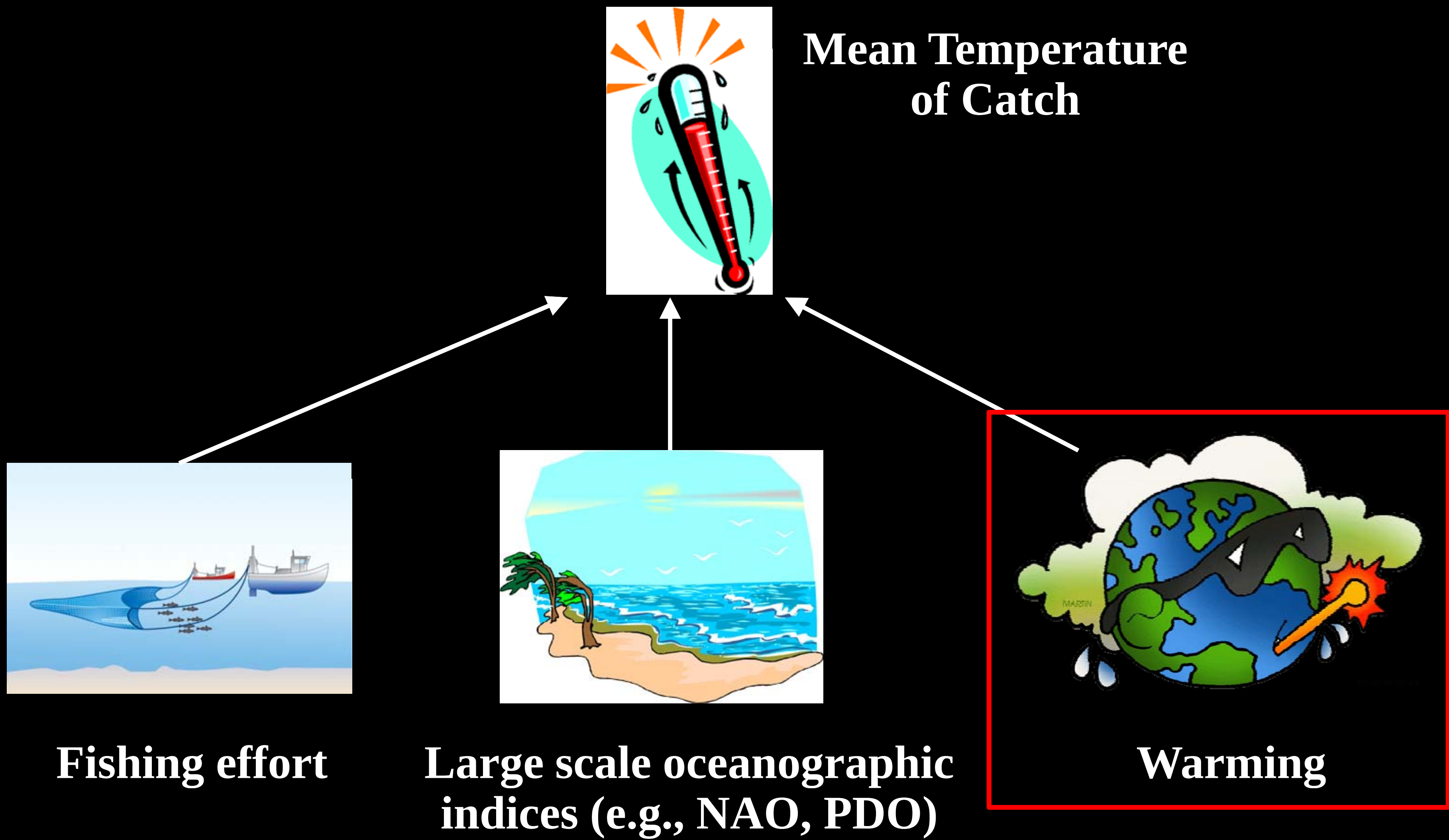
Mean Temperature of Catch



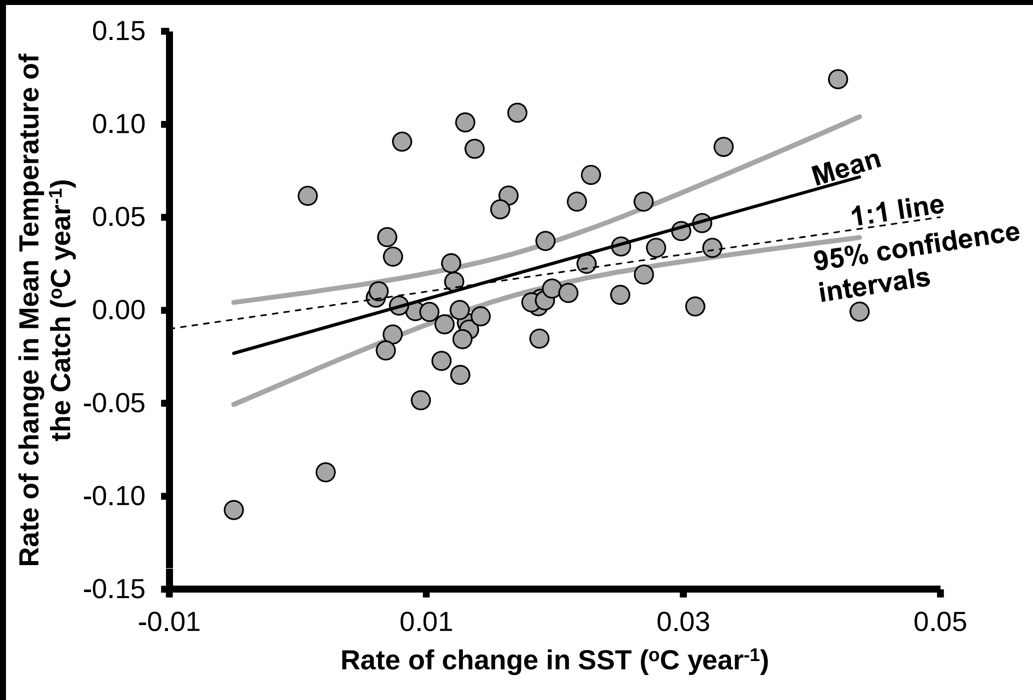
Mean Temperature of Catch



Attributing climate change effects with generalized additive mixed model



Changes in catch composition are attributed partly to warming

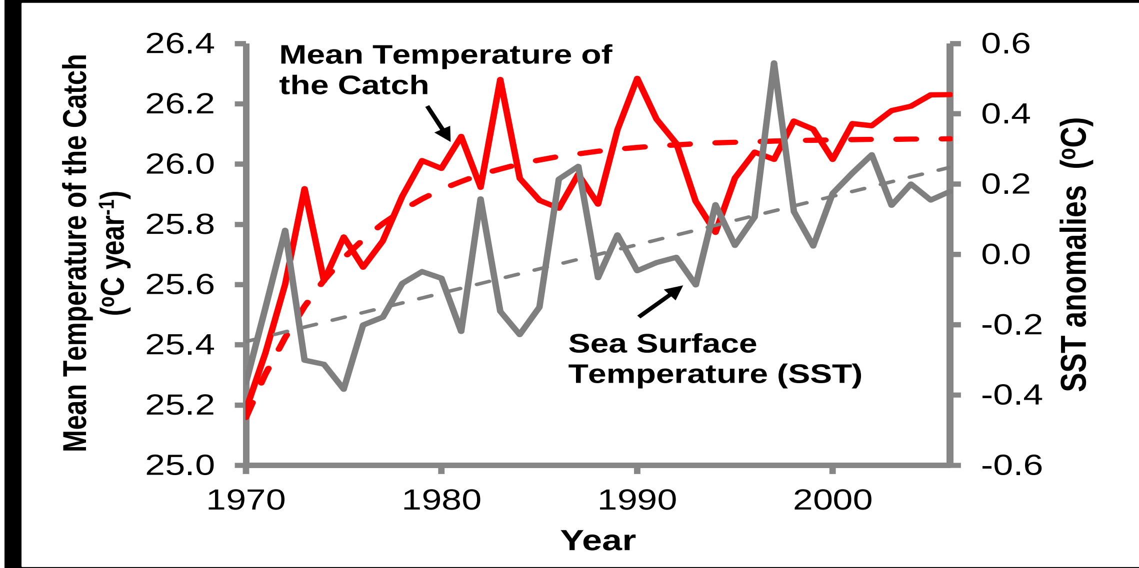


All Large Marine Ecosystems (LMEs)

- **Mean Temperature of Catch increased at a rate of 0.19 ^{o}C decade^{-1};**
- **Significantly related to changes in SST;**
- **Robust to alternative species distribution modelling method, indicator of species temperature preference, mis-reporting of catch data.**

From: Cheung, Watson & Pauly (2013) Nature.

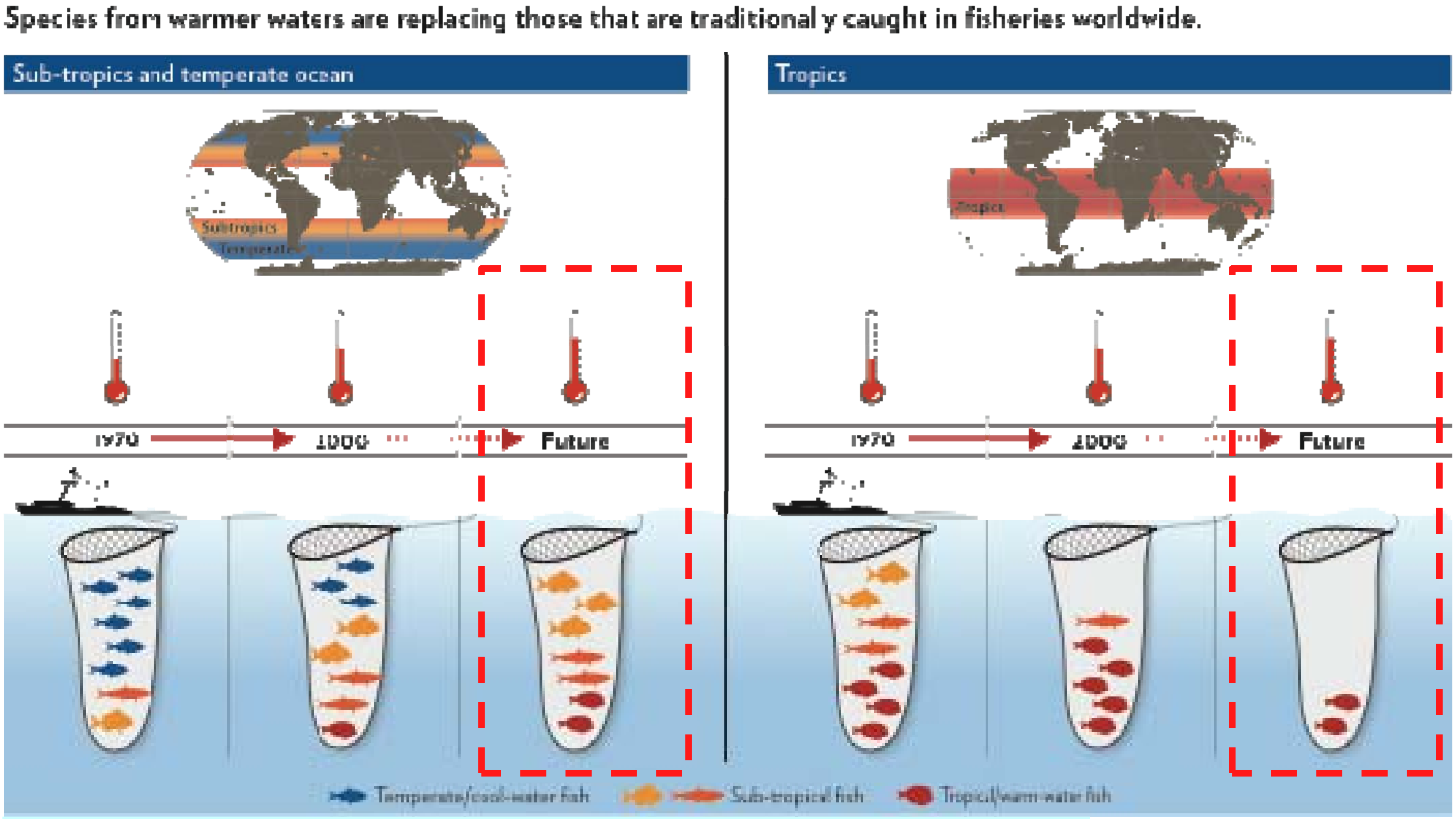
Changes in catch composition in the tropics



Tropical LMEs only

- **Increased initially at 0.6 ºC decade^{-1};**
- **Stabilized afterward;**
- **Hypothesis: initial reduction in representation of sub-tropical species.**

Hypothesis of changes in catch composition

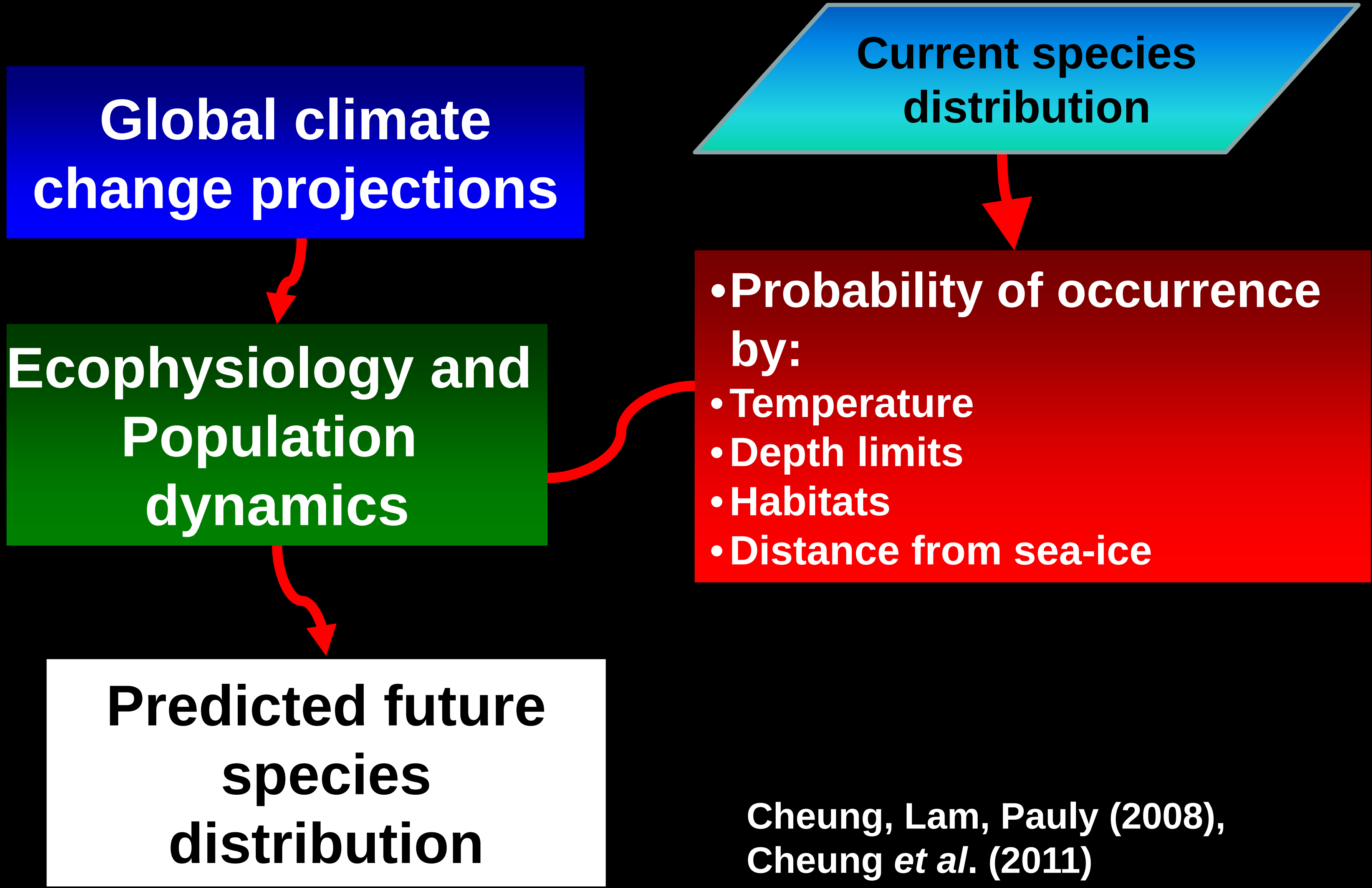


Credit: Pew Charitable Trust; Based on Cheung *et al*. (2013)

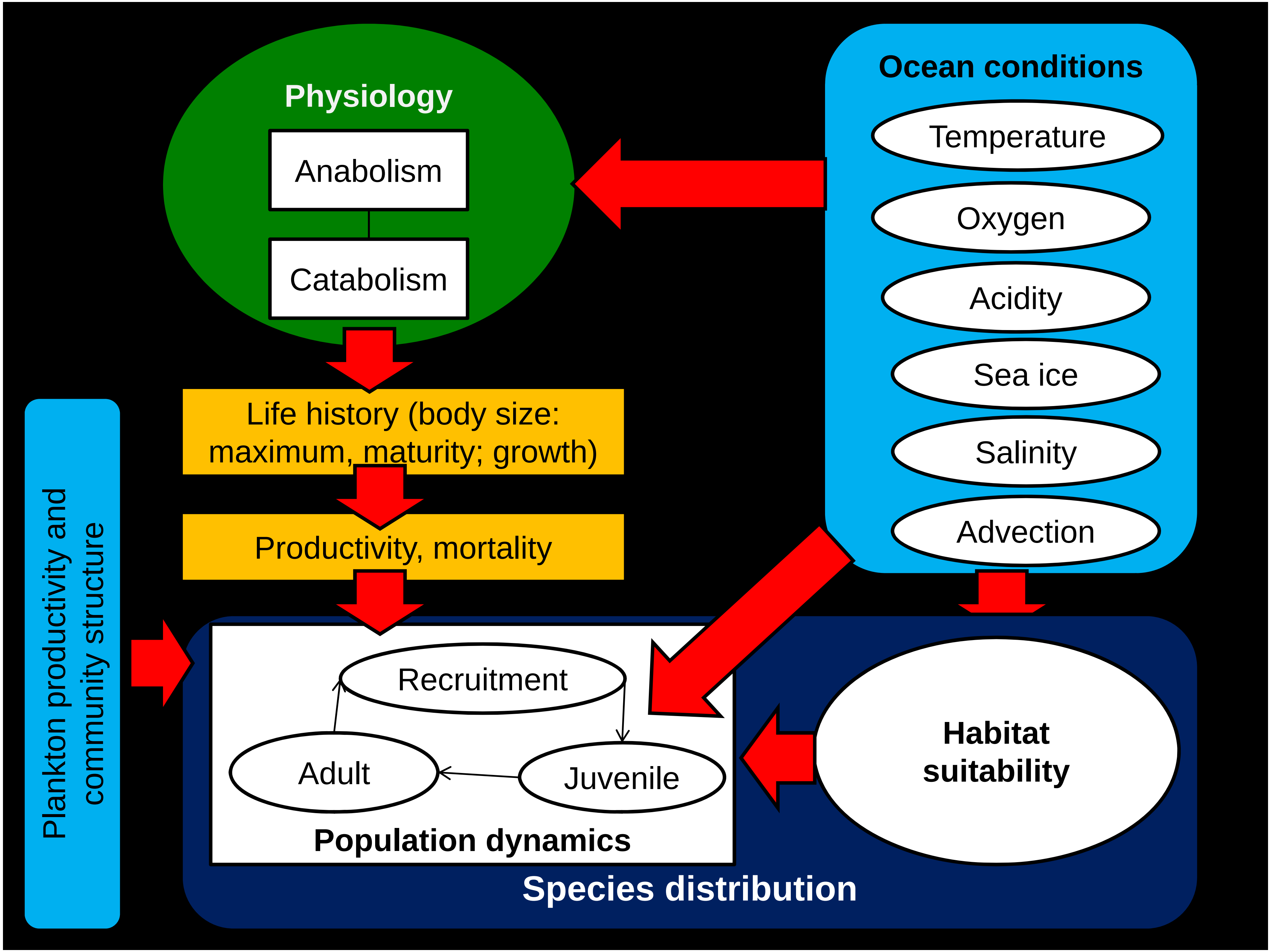
Projecting future responses of marine fisheries to climate change:

How will distribution of marine fish stocks be affected by climate change by 2050?

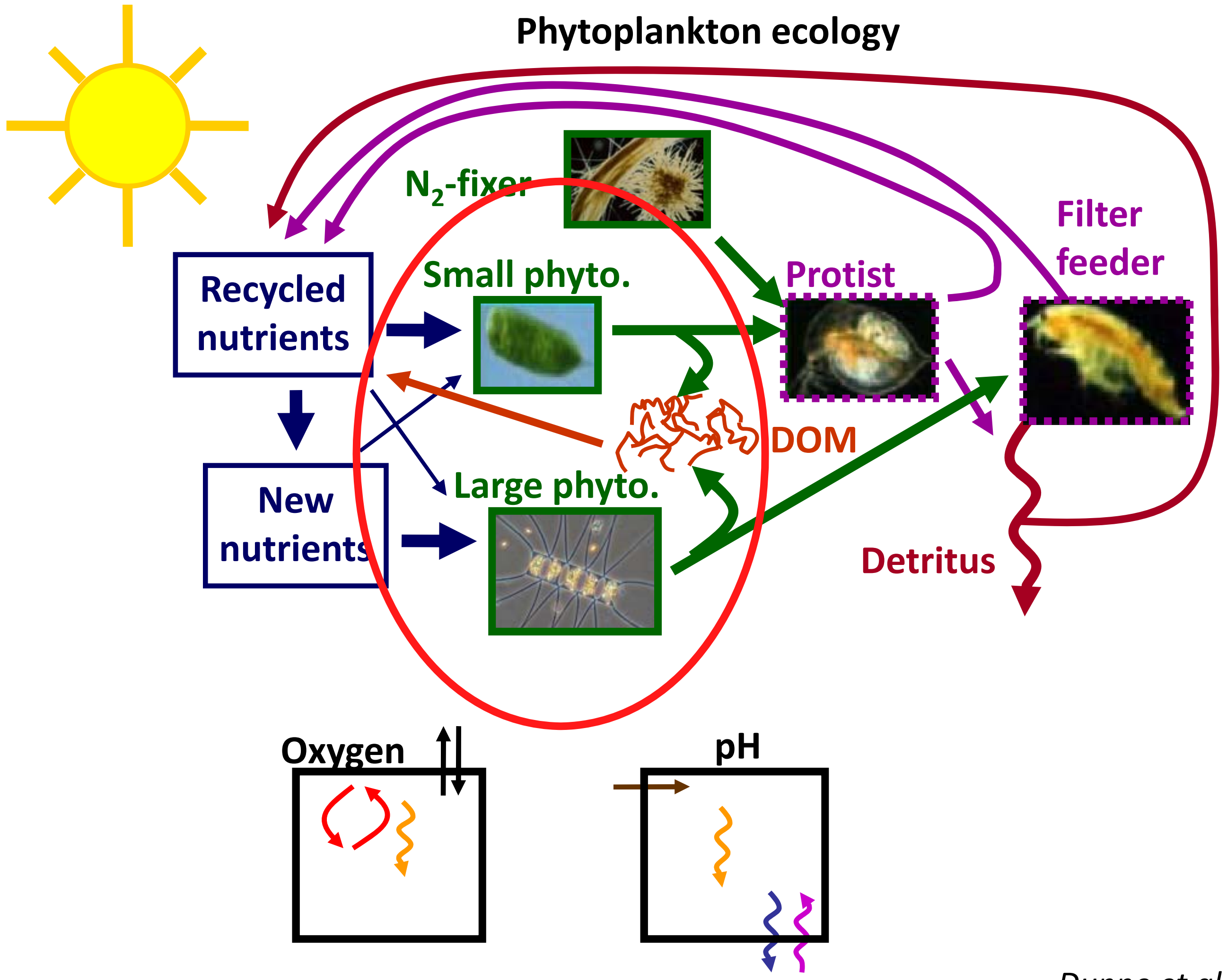
Dynamic bioclimate envelope model



Cheung, Lam, Pauly (2008), Cheung *et al*. (2011)


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

Biogeochemical forcing from Earth System Models
NOAA's GFDL ESM2.1

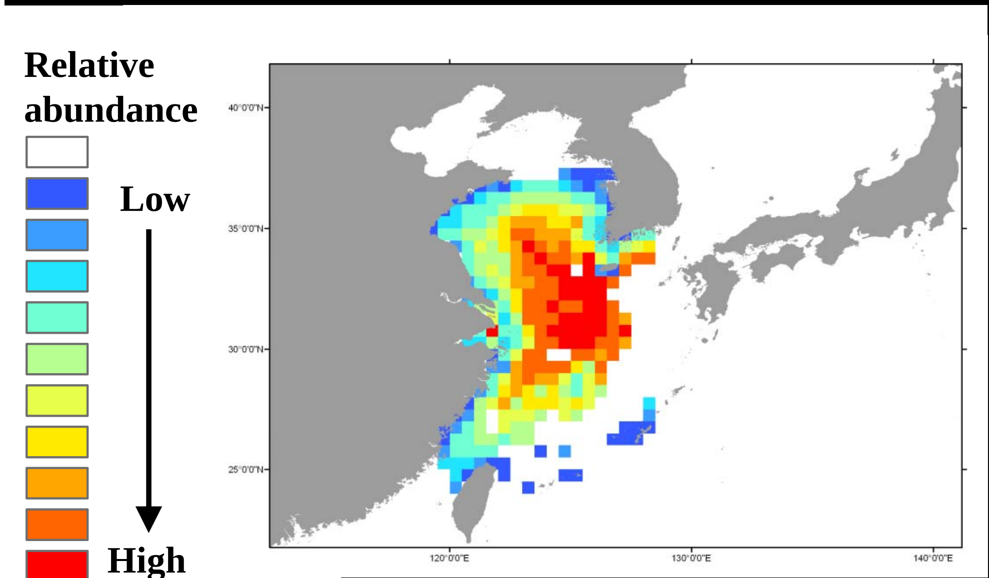


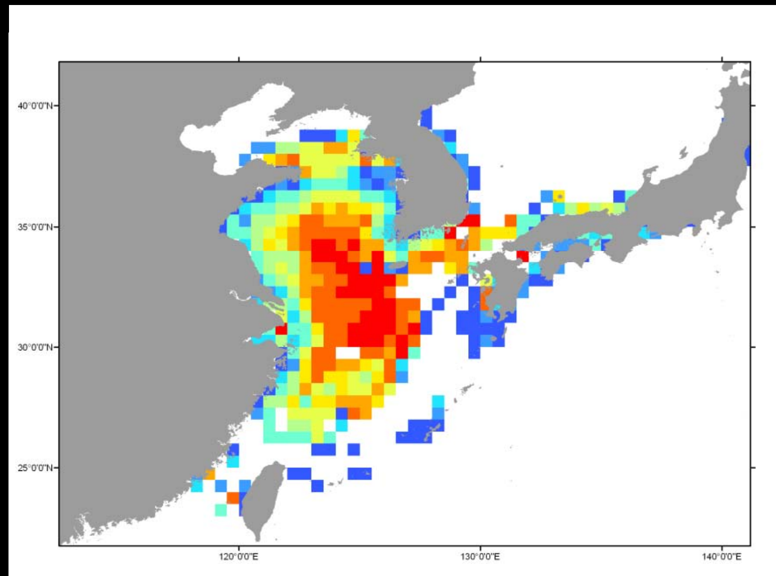
Dunne et al (2005, 2007)

Example: Small yellow croaker (*Larimichthys polyactis*)

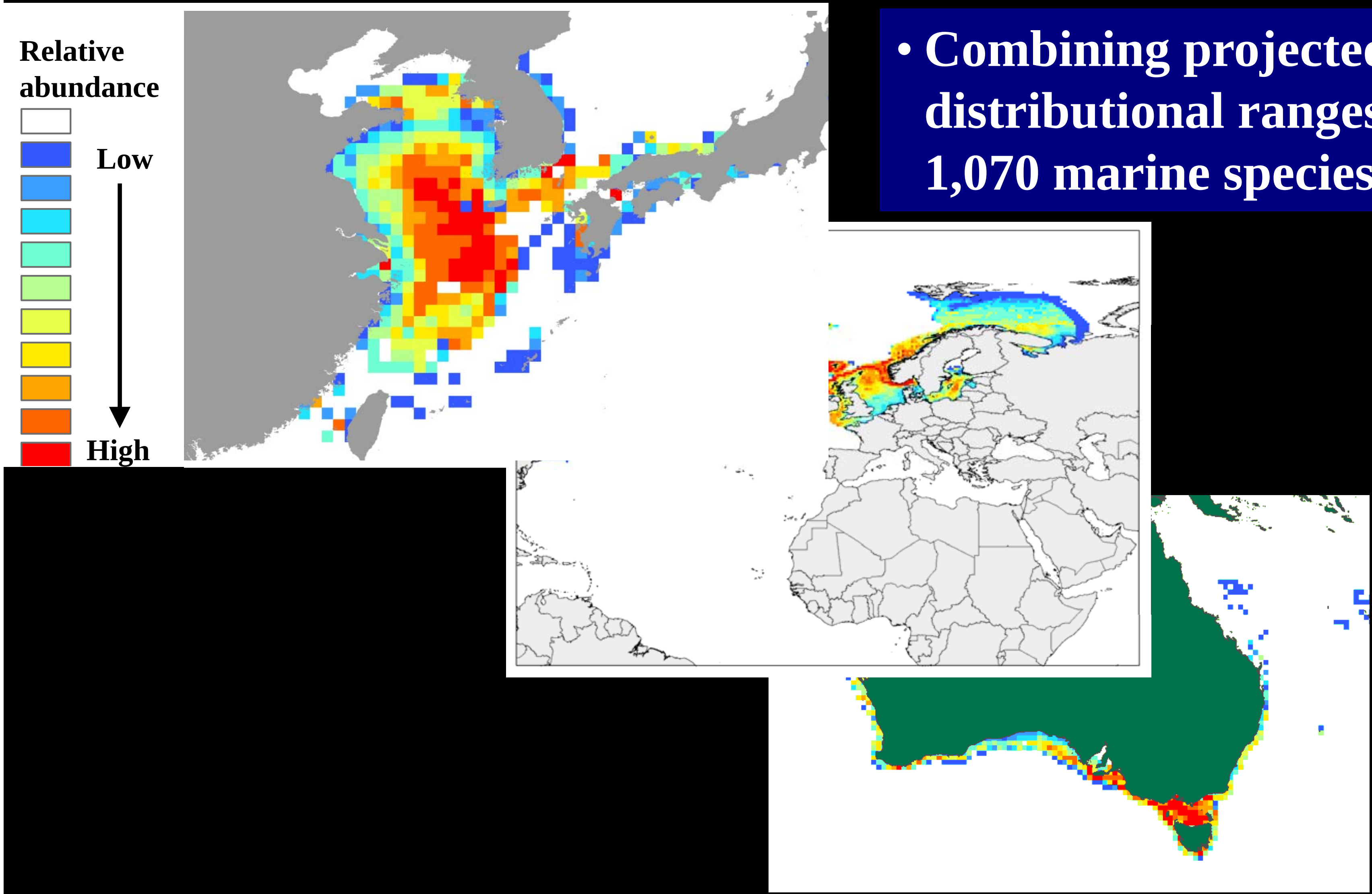
Original (static) distribution

Distribution after 50 years
(Climate projection from NOAA/GFDL CM 2.1)



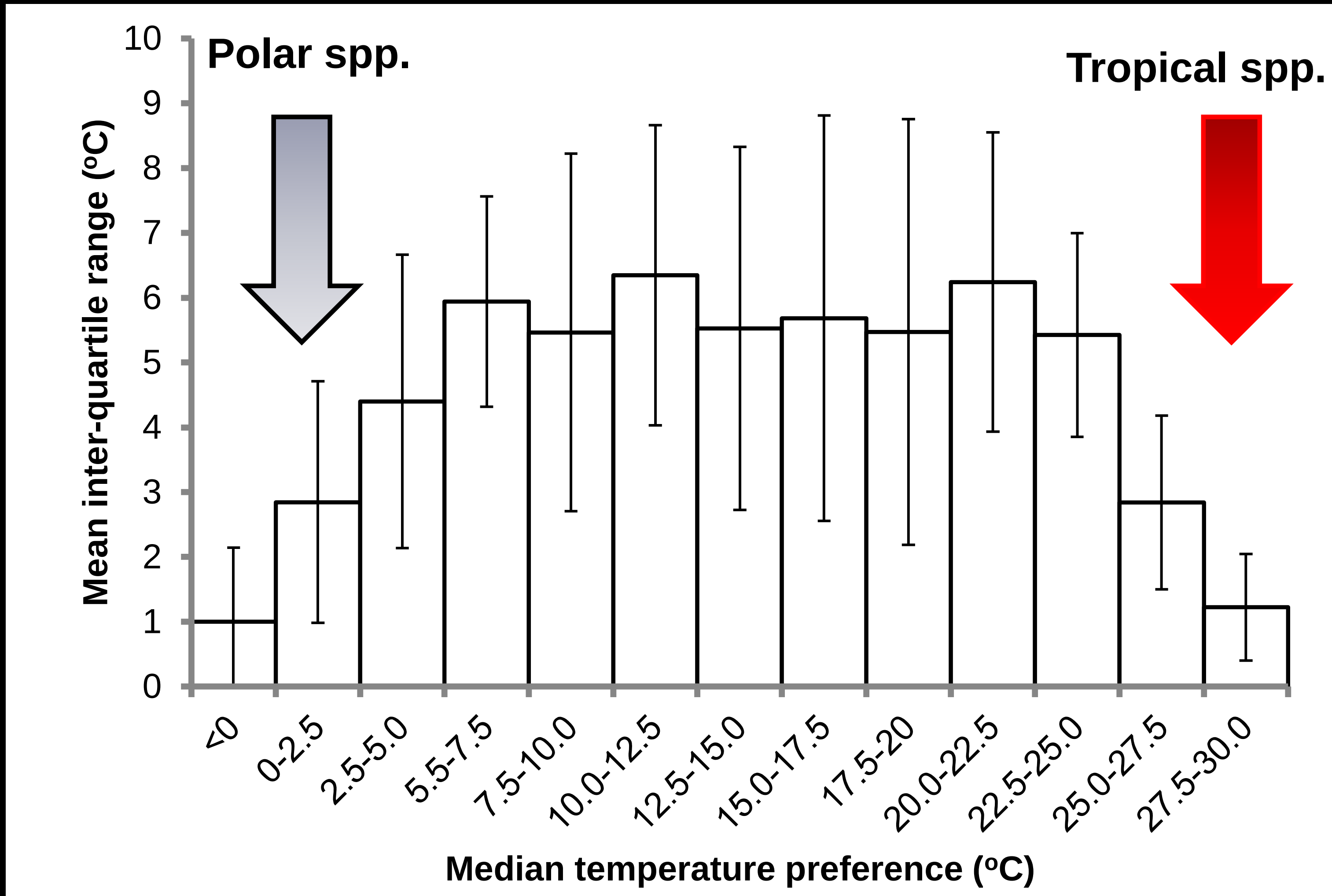


Predicting climate change impacts on marine biodiversity



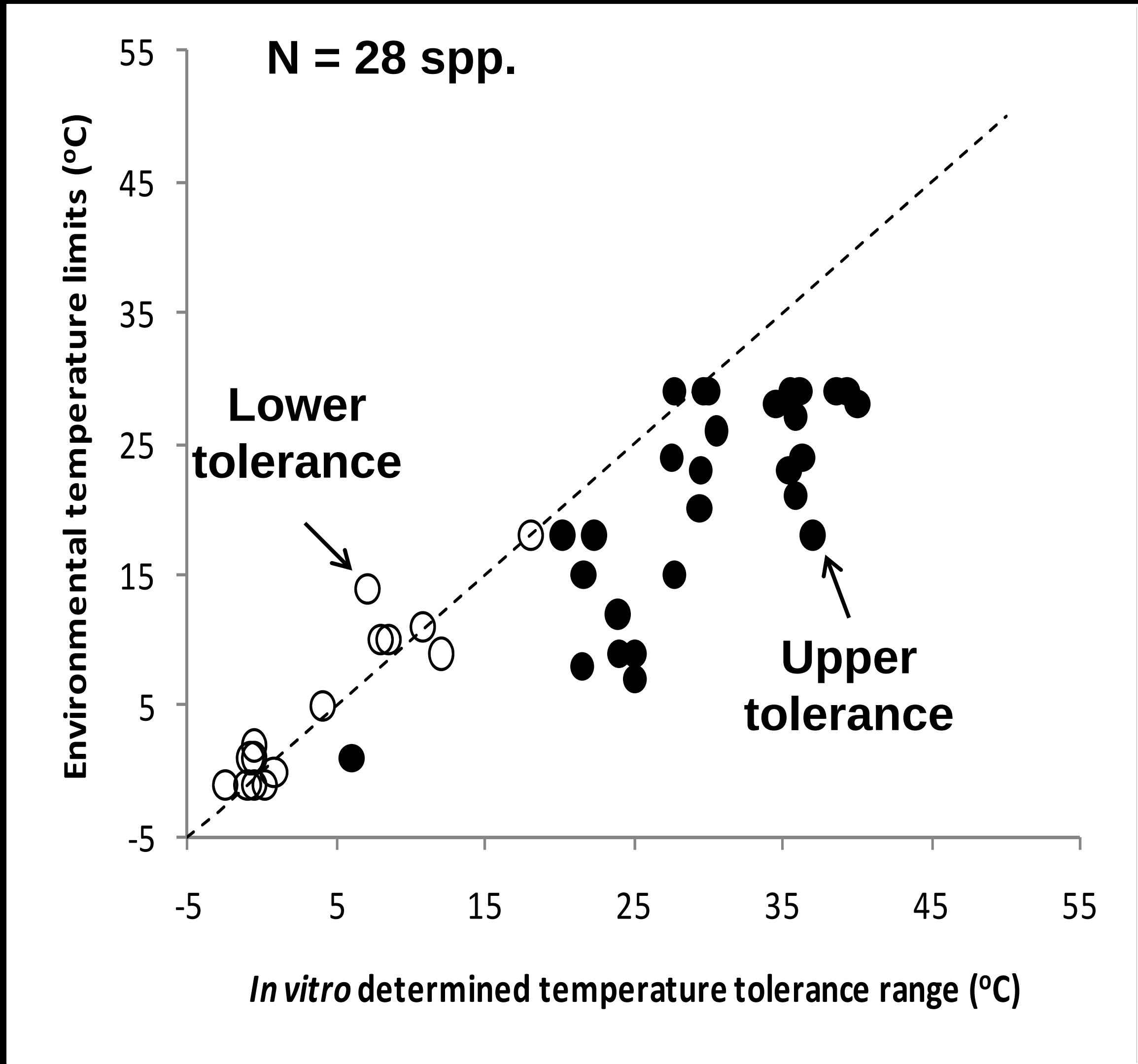
- **Combining projected distributional ranges of 1,070 marine species.**

Temperature preference ranges of exploited fishes and invertebrates



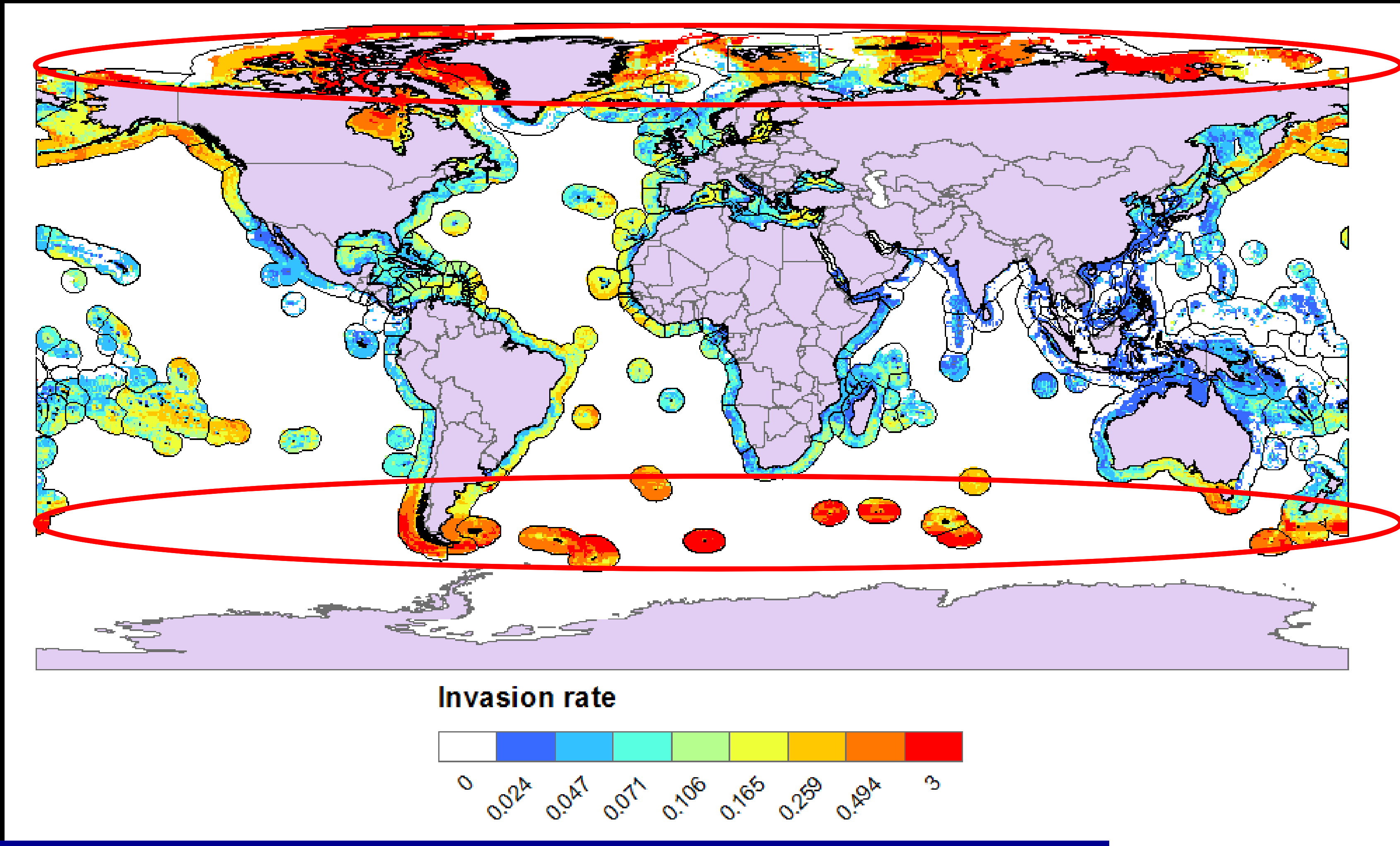
Source: Cheung, Watson & Pauly (2013)

Comparing temperature preference from distribution range with laboratory-determined tolerance limits



Species invasion rate (N=1,070 spp.)

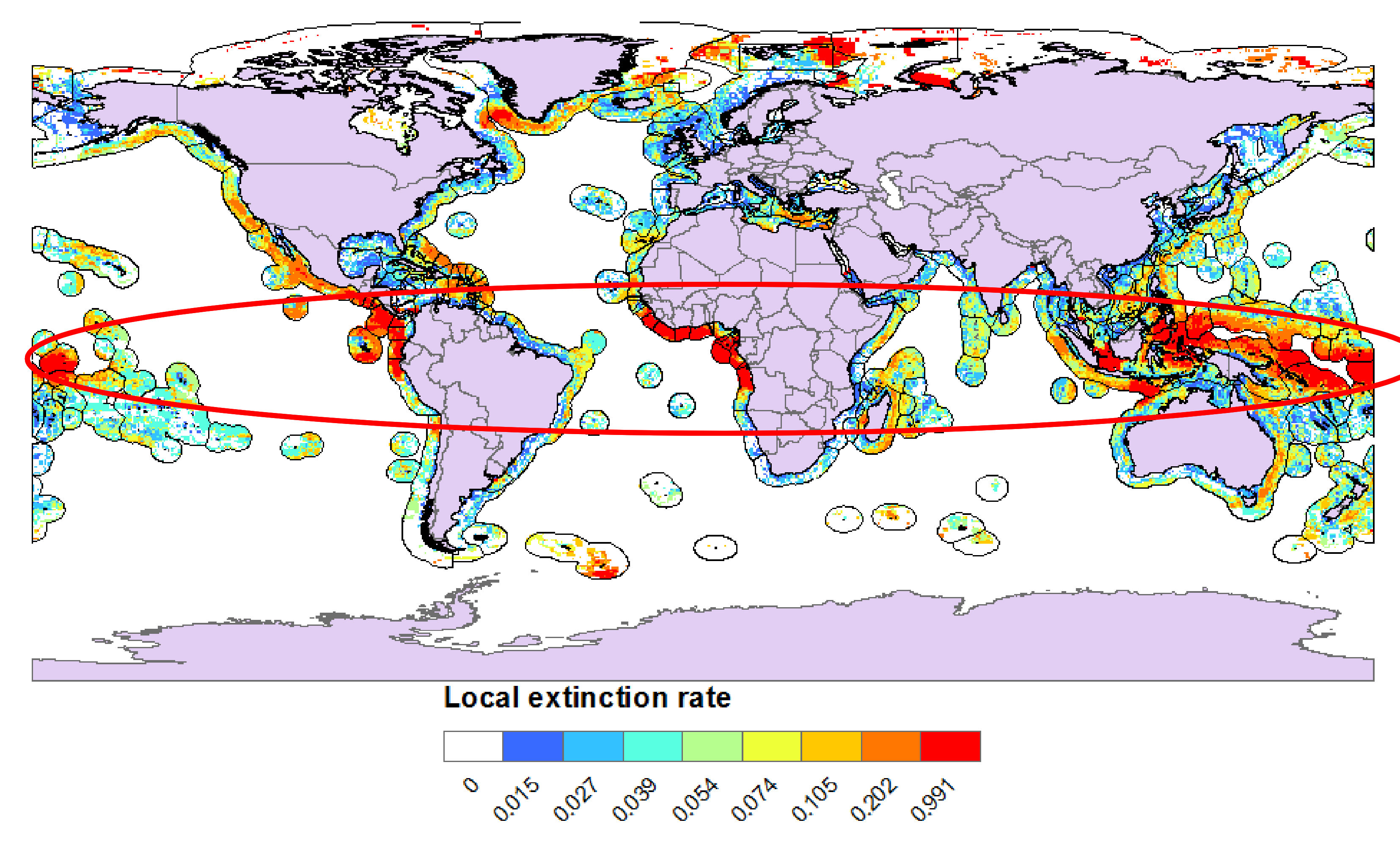
(2050 relative to 2000 with RCP8.5: +4^{o}C warming)



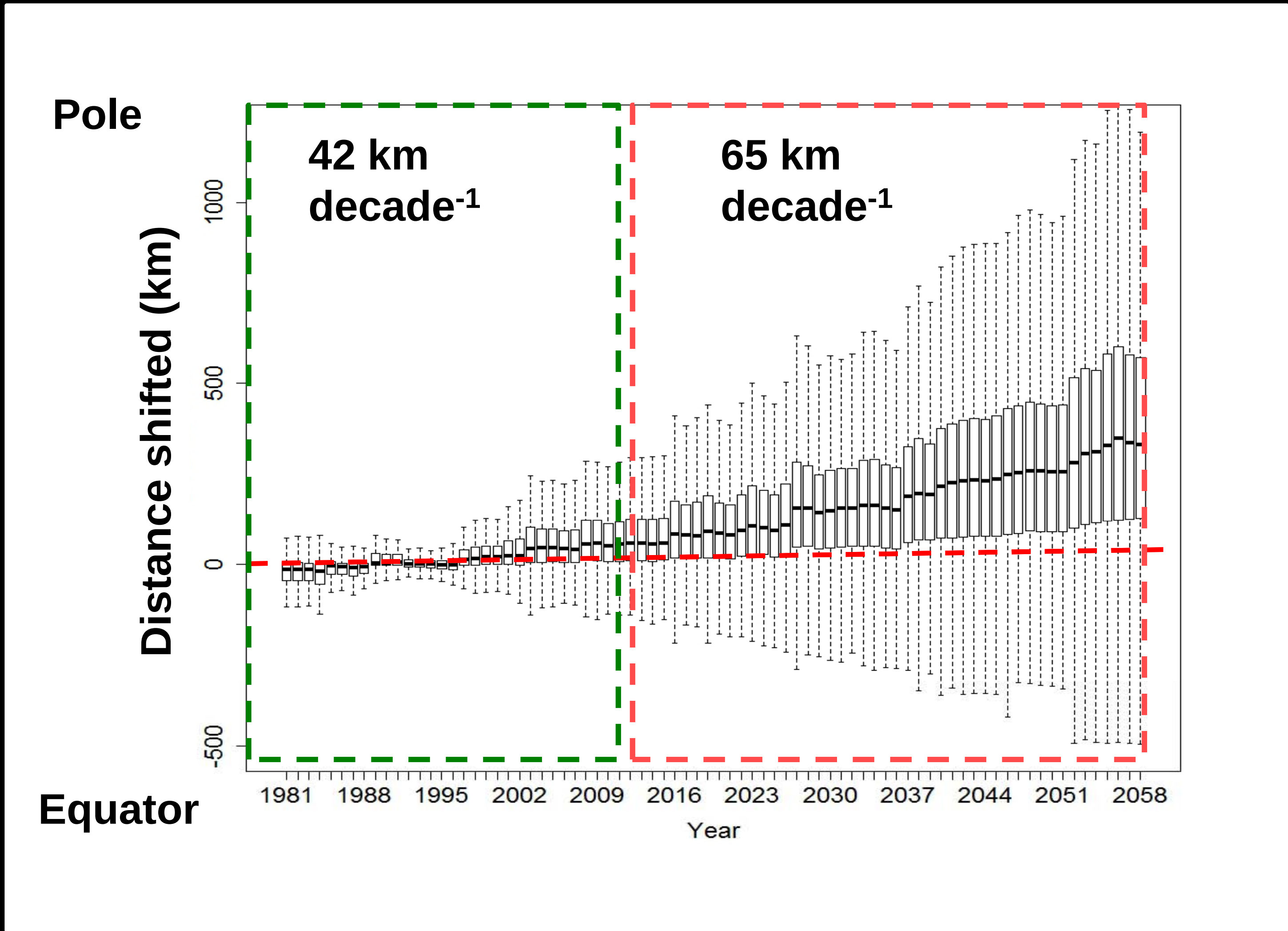
New version from Cheung *et al*. (2009) Fish and Fisheries

Species local extinction

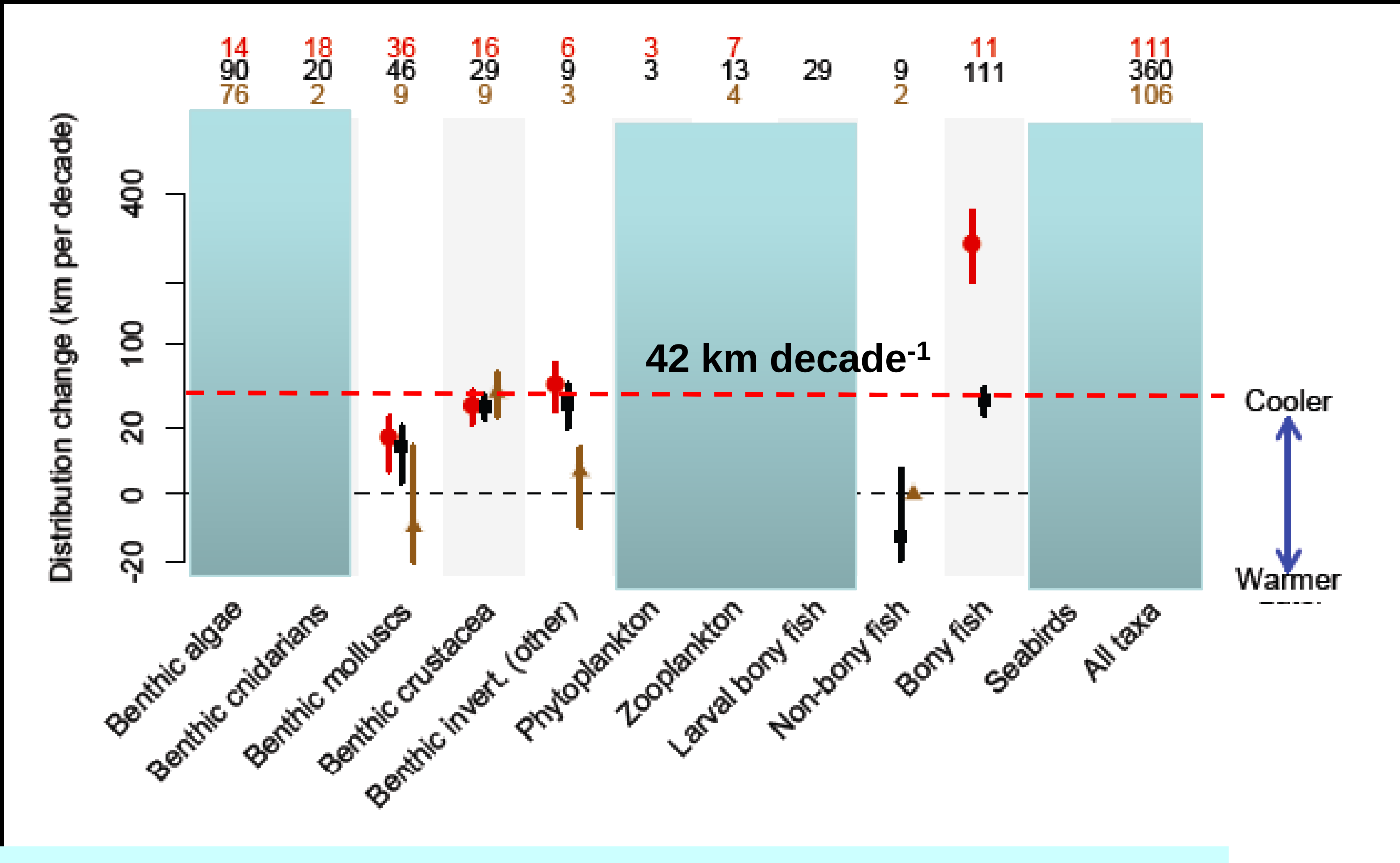
(2050 relative to 2000 with RCP8.5: +4ºC warming)



Shift in latitudinal centroid of 1077 spp. of fishes and invertebrates in the world ocean from 1970 - 2060

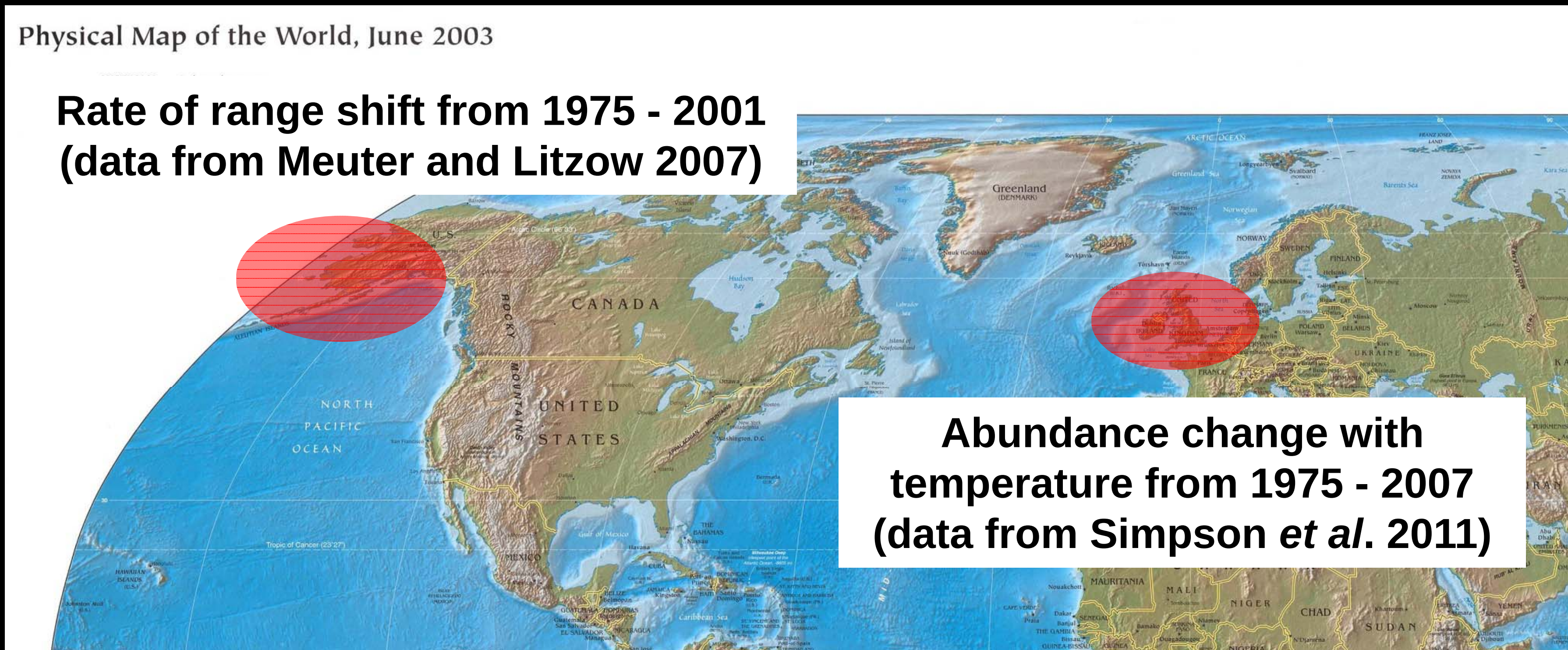


Examples of evidence of climate change effects on fisheries in specific areas



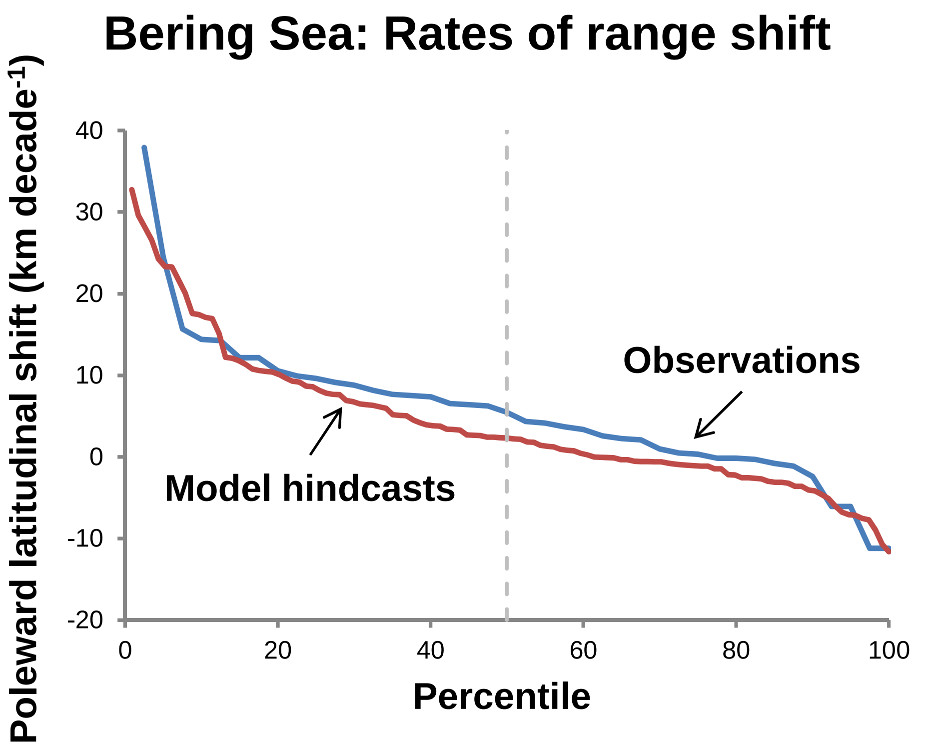
From: Poloczanska *et al.* (2013) Nature Climate Change

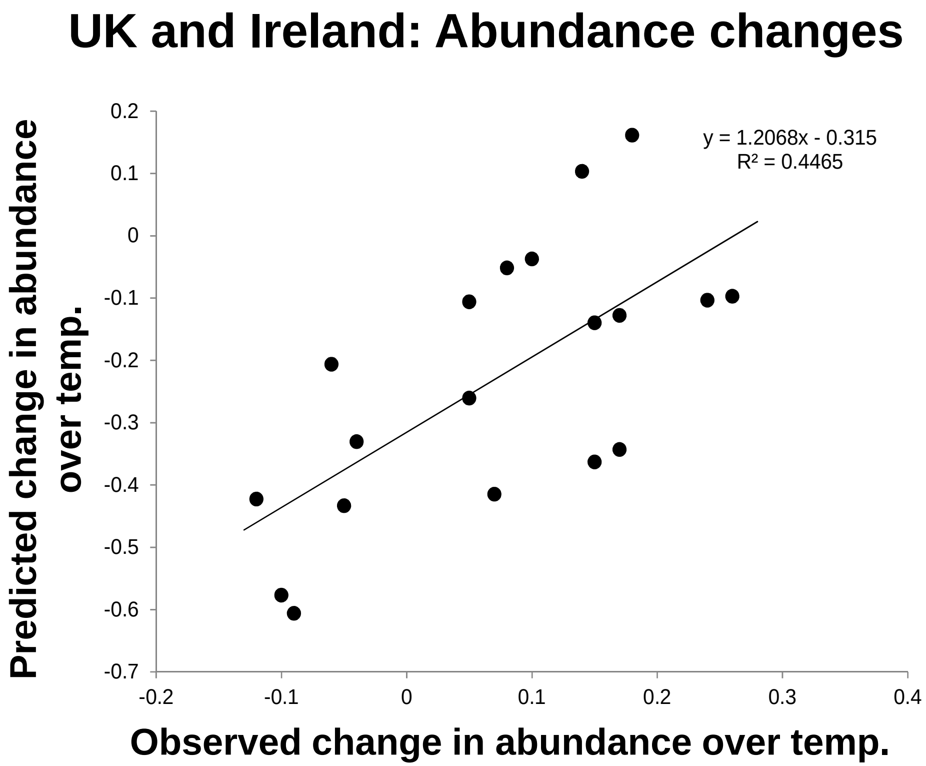
Comparing with observed range shifts
Bering Sea and around the UK and Ireland



Projected range shifts and abundance changes from hindcasts significantly agree with observation

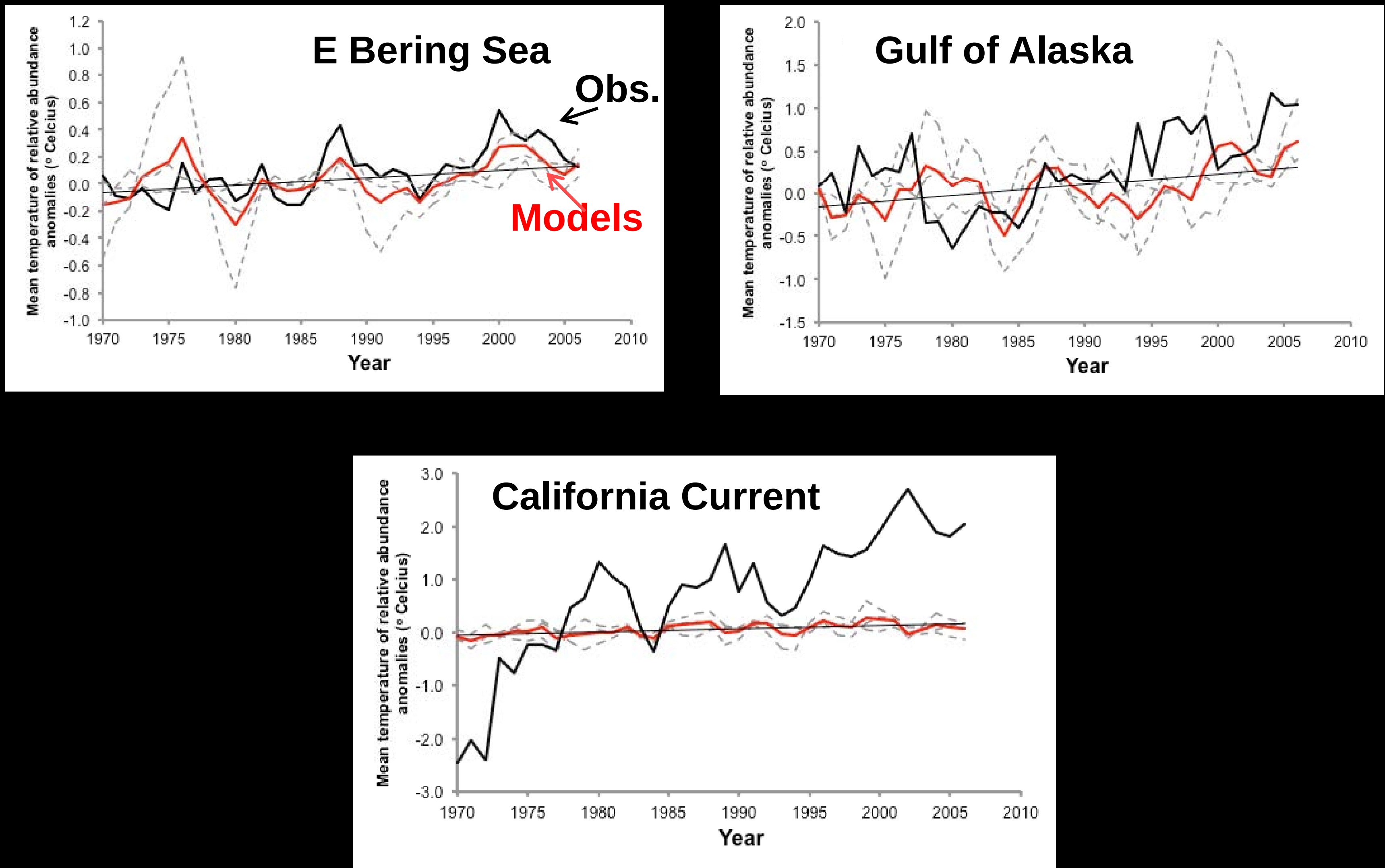
Driven by reanalysis-forced simulation from GFDL ESM2.1





Source: Cheung, Sarmiento, Froelicher, Lam, Palomares, Watson, Pauly (2012)

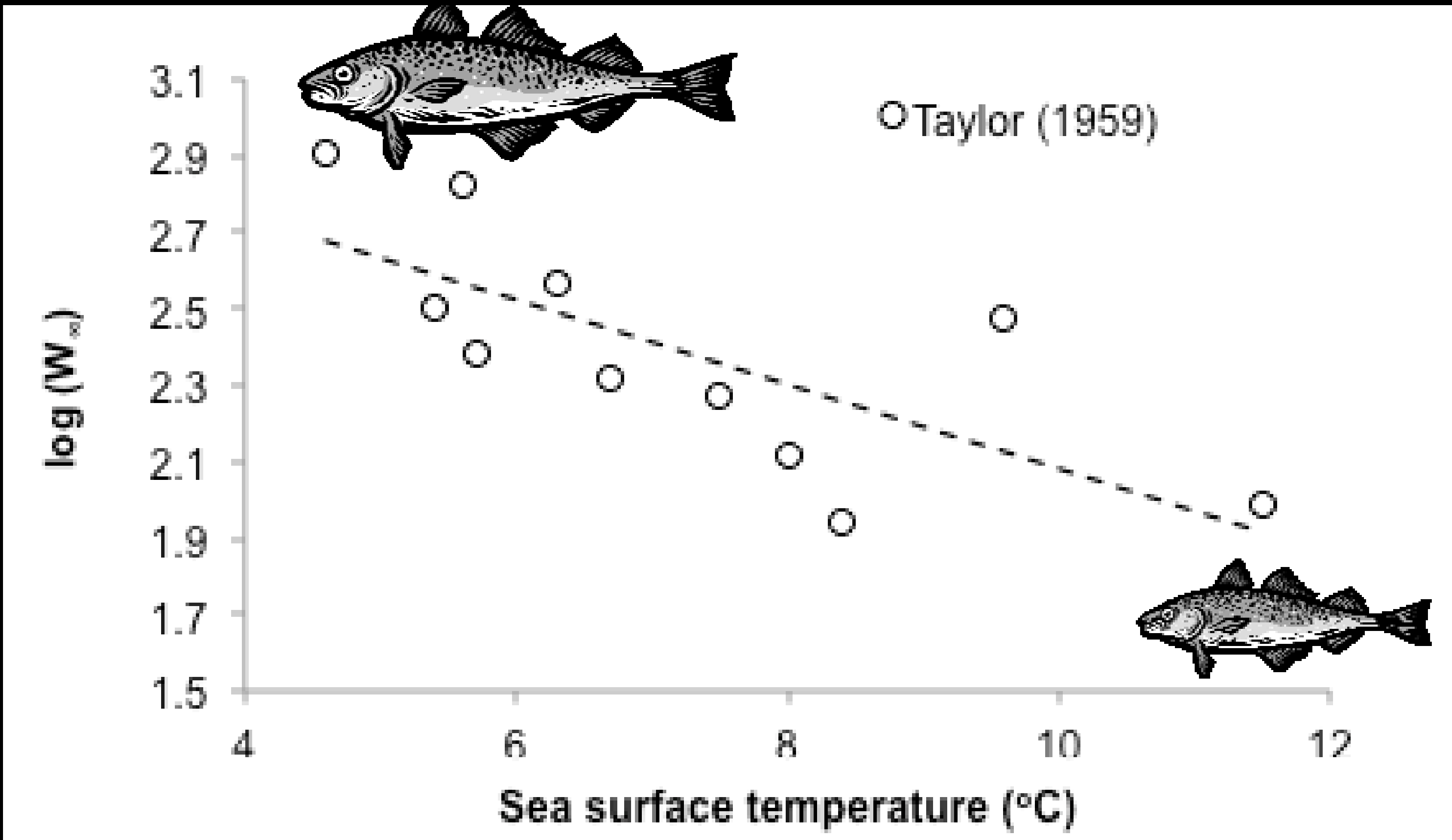
Comparing observed and predicted Mean Temperature of Catch in NE Pacific



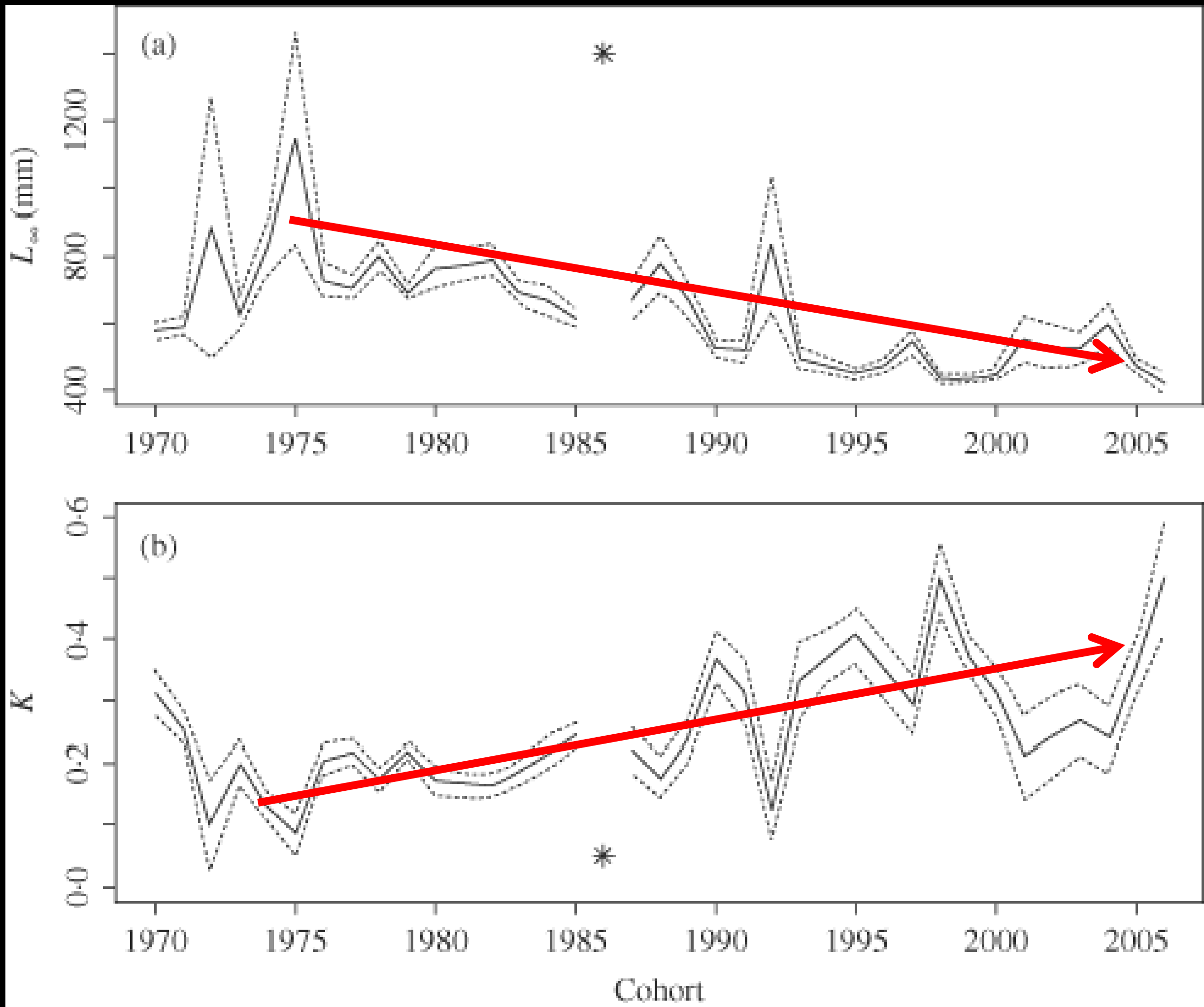
How will climate change affect maximum body size of fishes by 2050?

Maximum body size and temperature:

Atlantic cod (Taylor 1959)



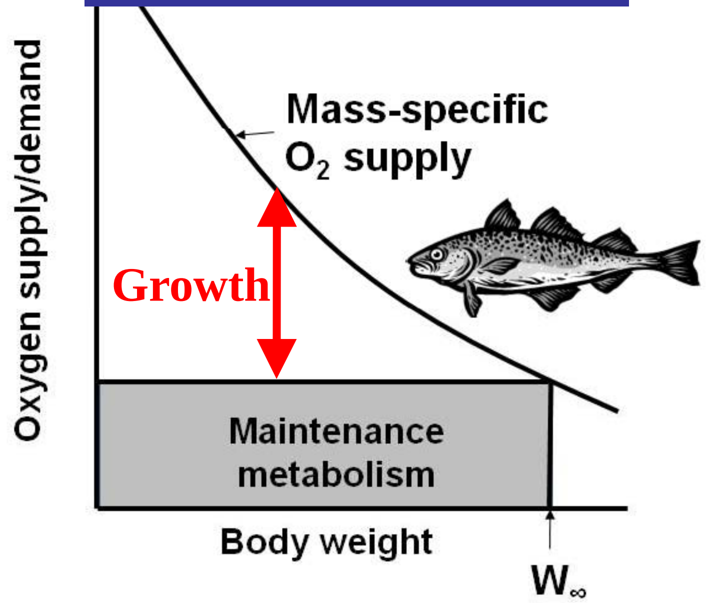
Changes in von Bertalanffy growth parameters (L_∞ and K) of haddock (*Melanogrammus aeglefinus*) in the North Sea that is significantly correlated with SST



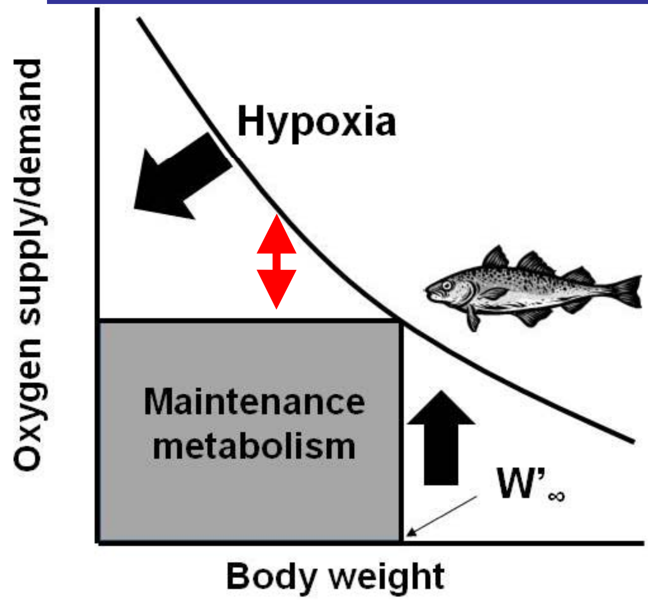
Source: Baudron *et al*. (2011)

Oxygen and capacity limited thermal tolerance

Current condition



Warmer, more acidic or less oxygenated ocean



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

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

Linking ocean conditions to growth functions

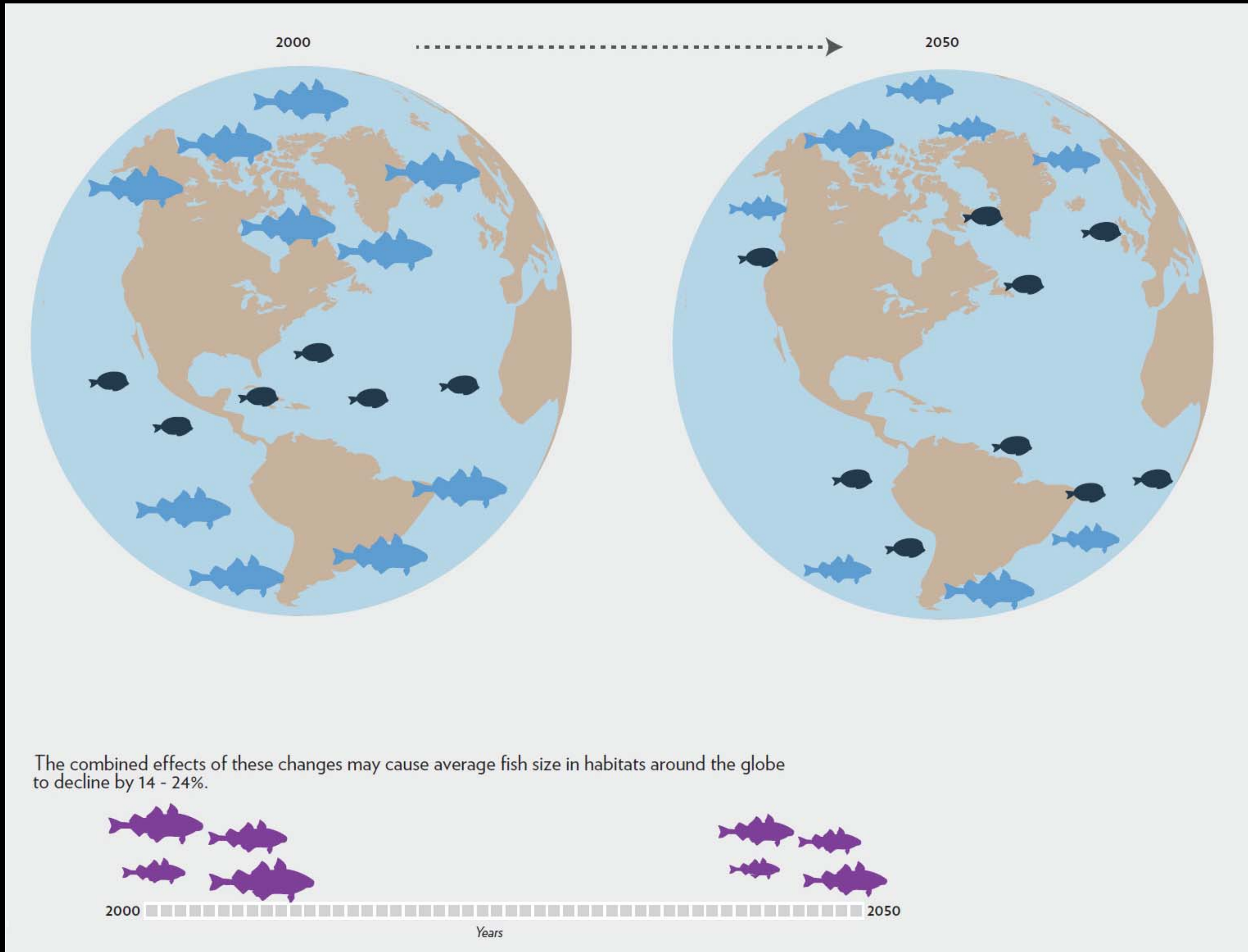
Growth rate | Anabolism | Catabolism

$$dW/dt = H \cdot W - k \cdot W^{a}$$

$$H = g \cdot [O_2] \cdot e^{-j/T}$$

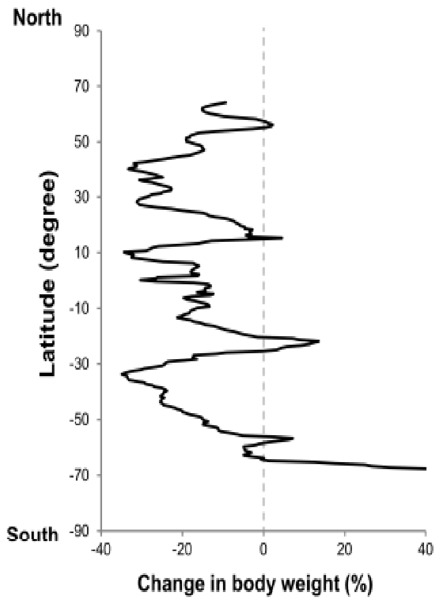
$$k = h \cdot e^{-i/T}$$

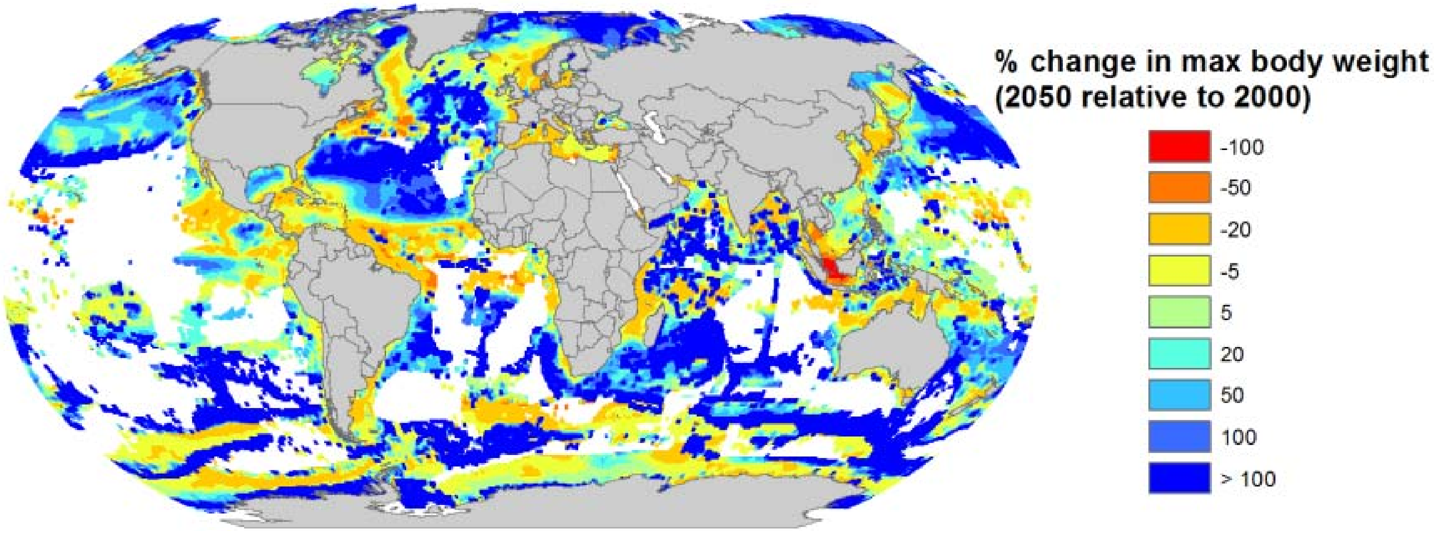
Projected decreases in maximum body size of fishes



Credit: Pew Environmental Trust; Based on Cheung *et al*. (2013) Nature Climate Change

Predicted changes in maximum body weight by 2050 relative to 2000 (+4 °C warming by 2100)

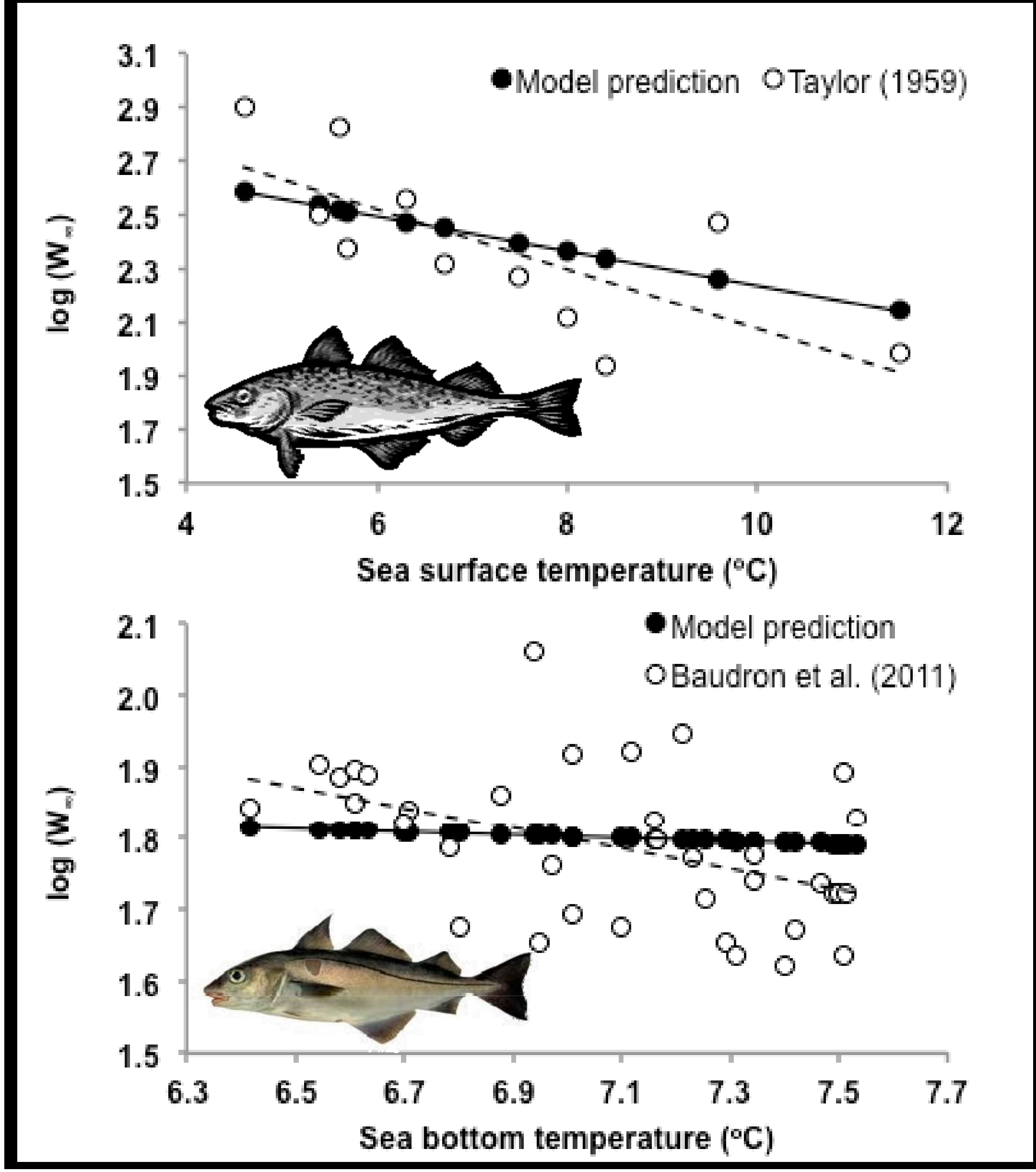




- **Average individual-level decrease in maximum body size (W_∞) is about 8-12%;**
- **Assemblage-averaged W_∞ is projected to decrease by 14 – 24% from 2001 to 2050.**

Source: Cheung *et al*. (2013) Nature Climate Change

Comparing model results with data

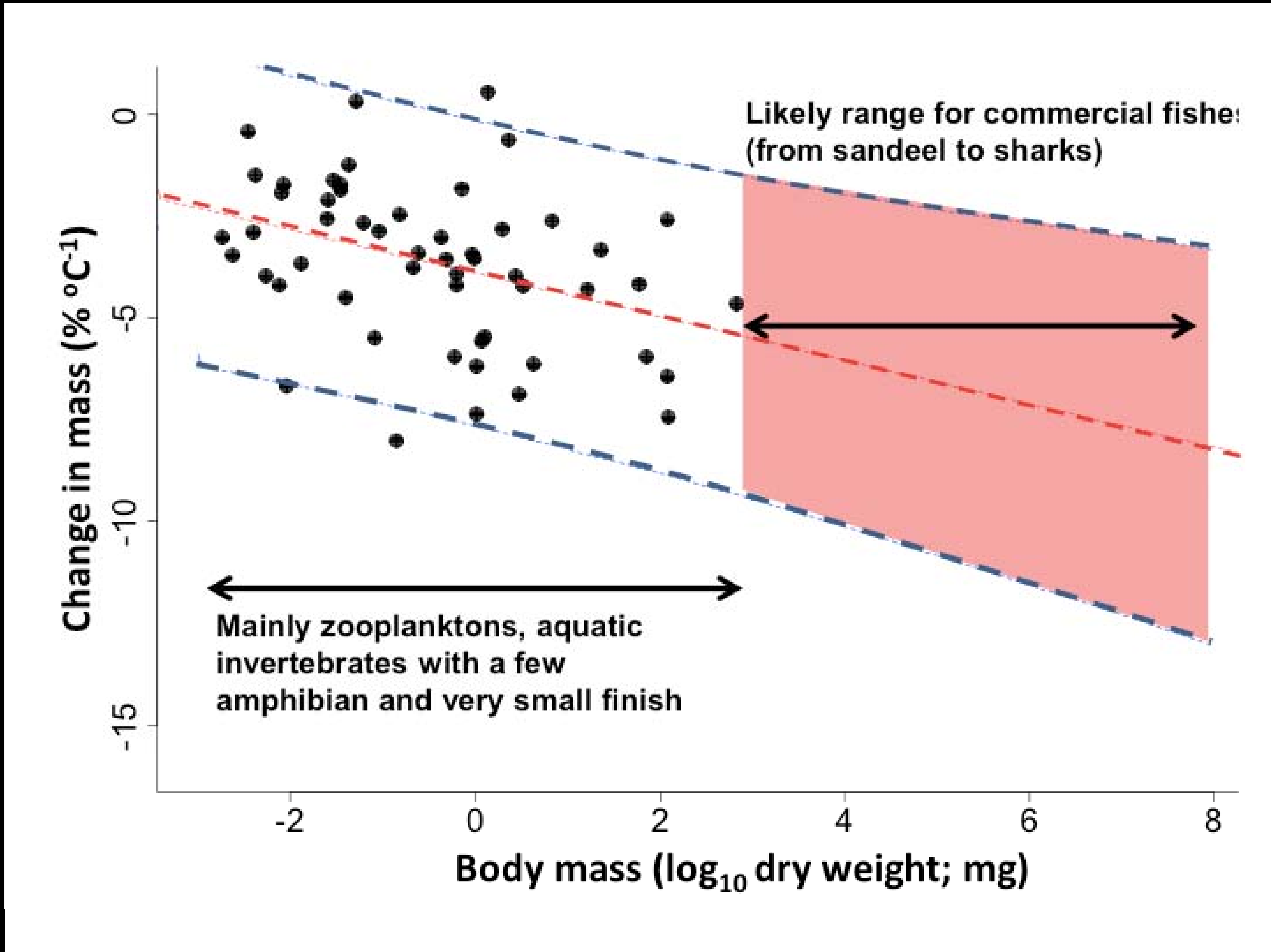


- Consistent trends between model projection and data e.g. cod and haddock;

- However, model results are more conservative.

Cheung *et al*. NCC (2013)

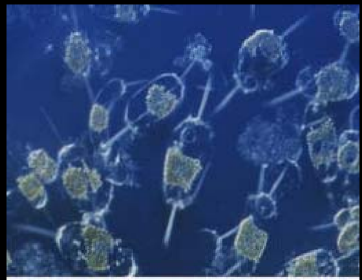
Comparing model results with data



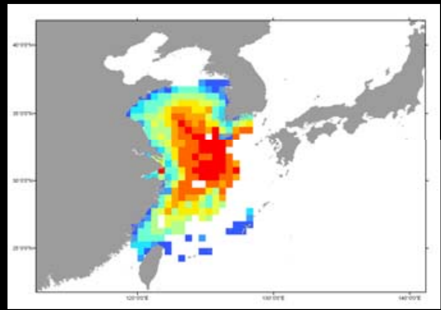
Source: Cheung, Pauly, Sarmiento (2013) ICES J. Mar. Sci.; Forster *et al.* (2012) PNAS

How will climate change affect global fisheries catch potential by 2050?

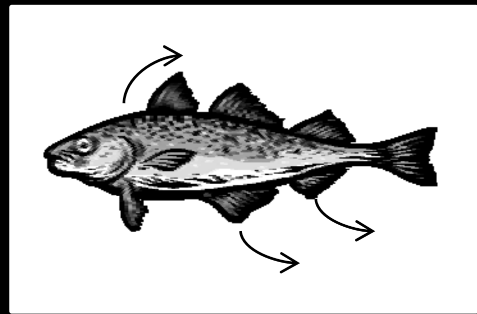
Factors affecting maximum catch potential



Net primary production



Species distribution



Growth & body size

Substituting Eq. (8) into Eq. (6):

$$\frac{4 \times c' \times \mathrm{MSY} \times W^{(b-1)}}{r} = \gamma \times P \times TE^{\lambda-1} \quad (9)$$

Furthermore, W scales negatively and allometrically with intrinsic rate of population increase (r) (Fenchel 1974):

$$r = d \times W^{h} \quad (10)$$

where d and h are constants. Thus,

$$\frac{4 \times c' \times \mathrm{MSY} \times W^{(b-1)}}{d \times W^{h}} = \gamma \times P \times TE^{\lambda-1} \quad (11)$$

The values of the scaling exponents b and h are approximately 0.75 and –0.25, respectively (Fenchel 1974, Jennings et al. 2007). Therefore, W can be eliminated from the equation:

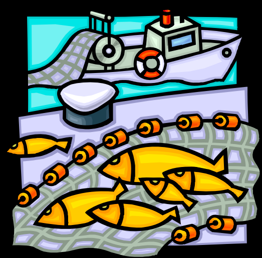
$$\frac{4 \times c'}{d} \times \mathrm{MSY} = \gamma \times P \times TE^{\lambda-1} \quad (12)$$

Taking logarithmic transformation at both sides, and rearranging terms,

$$\log \mathrm{MSY} = \log P + (\lambda - 1) \times \log TE + \log \gamma - \log \frac{4 \times c'}{d} \quad (13)$$

However, in many cases, only a fraction of the entire geographic range of a species is exploited. Assuming that the exploited range encompasses unit stocks, primary production from the exploited range (P') is considered in calculating the average MSY. MSY from the exploited range, or MSY', can be calculated from:

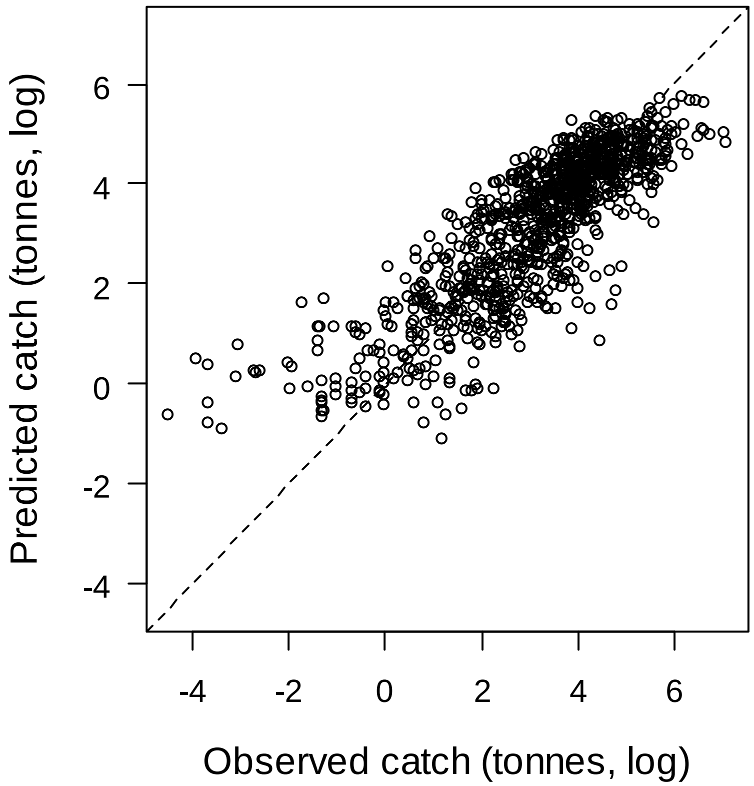
$$\log \mathrm{MSY'} = \log(P') + (\lambda - 1) \times \log TE + \log \gamma - \log \frac{4 \times c'}{d} \quad (14)$$



Catch potential

Empirical model predicting maximum catch potential

N = 1,000, P < 0.001, R^2 = 0.70

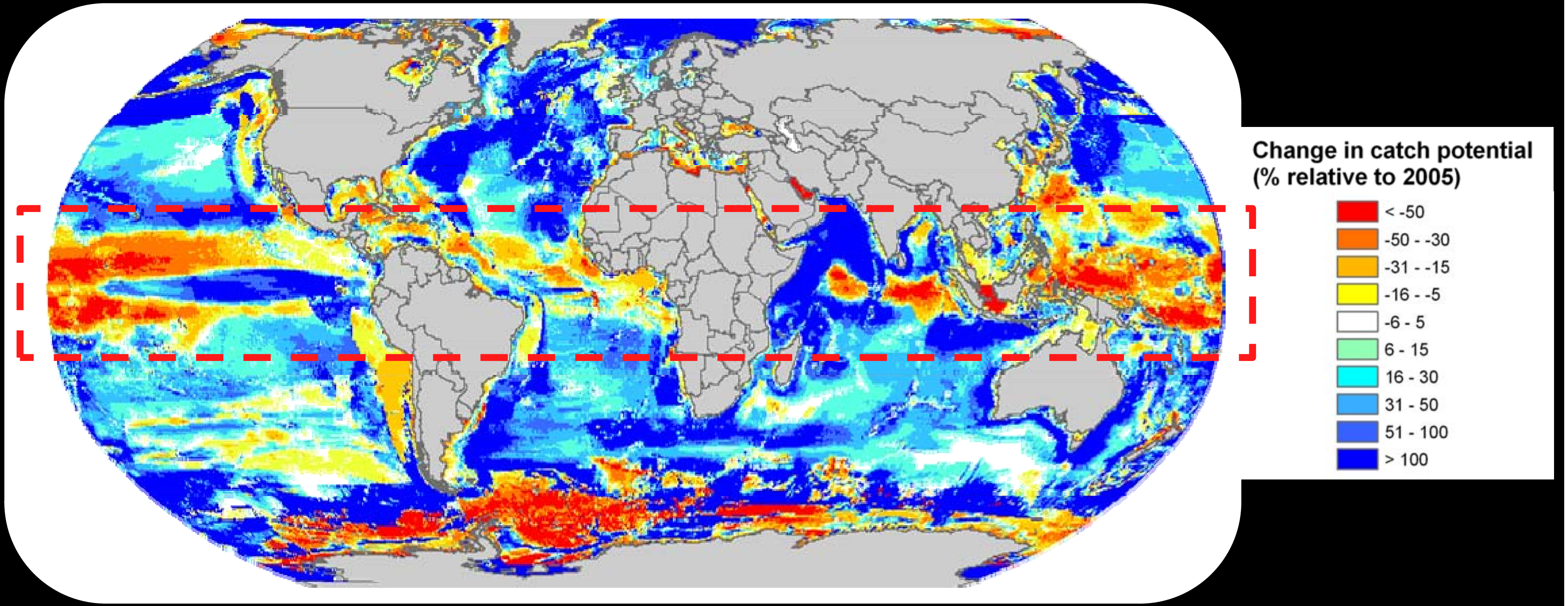


$$\log_{10} MSY' = -2.881 + 0.826 \times \log_{10} P' - 0.505 \times \log_{10}(A) - 0.152 \times \lambda + 1.887 \times \log_{10} CT + 0.112 \times \log_{10} HTC' + \varepsilon$$

- Fit the model to observed maximum catch potential of 1,000 spp of marine fishes and invertebrates;
- Include species from krill to tuna and sharks;
- The model has high explanatory power and agrees with expectations from theory.

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

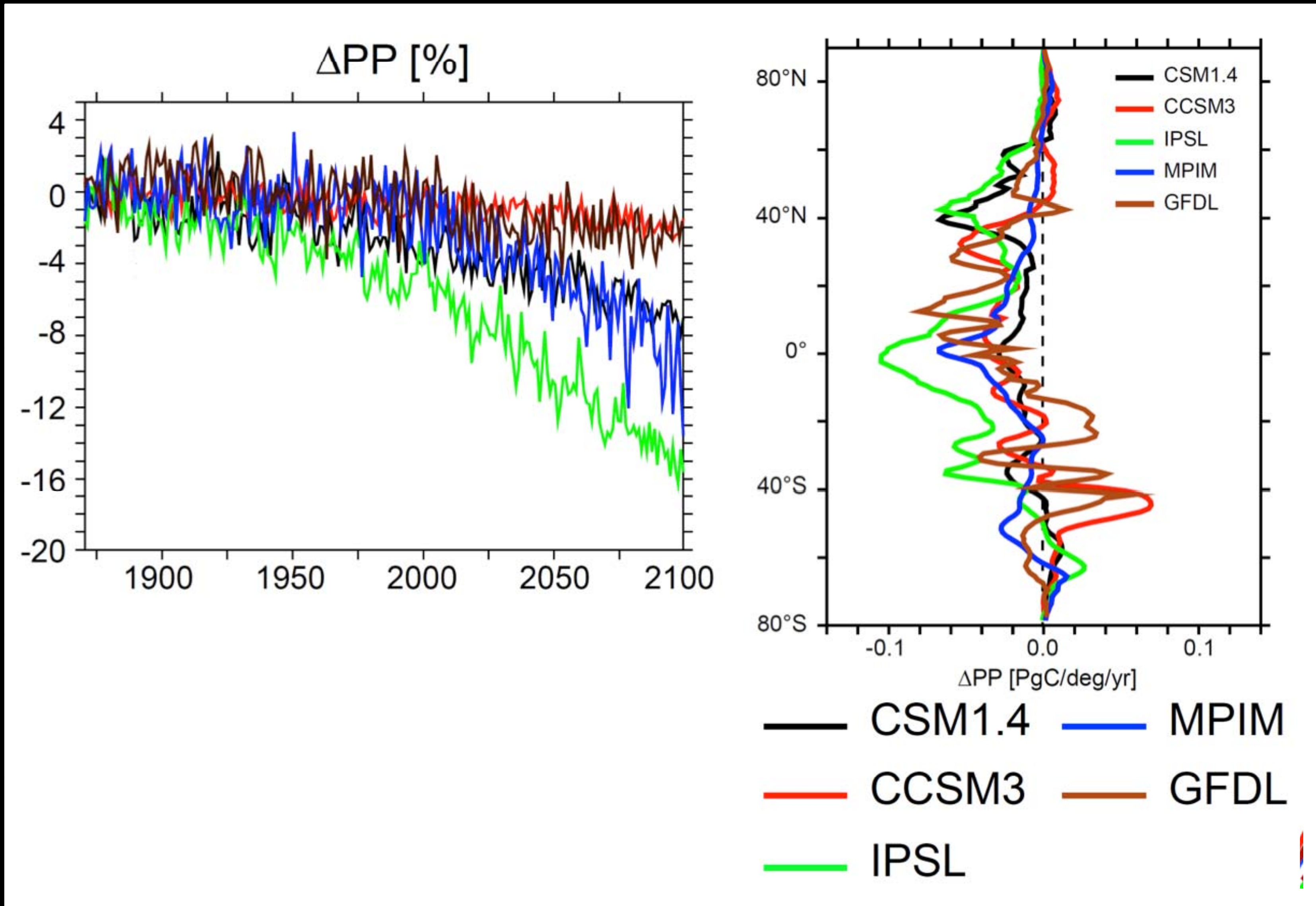
Projected change in catch potential by 2055



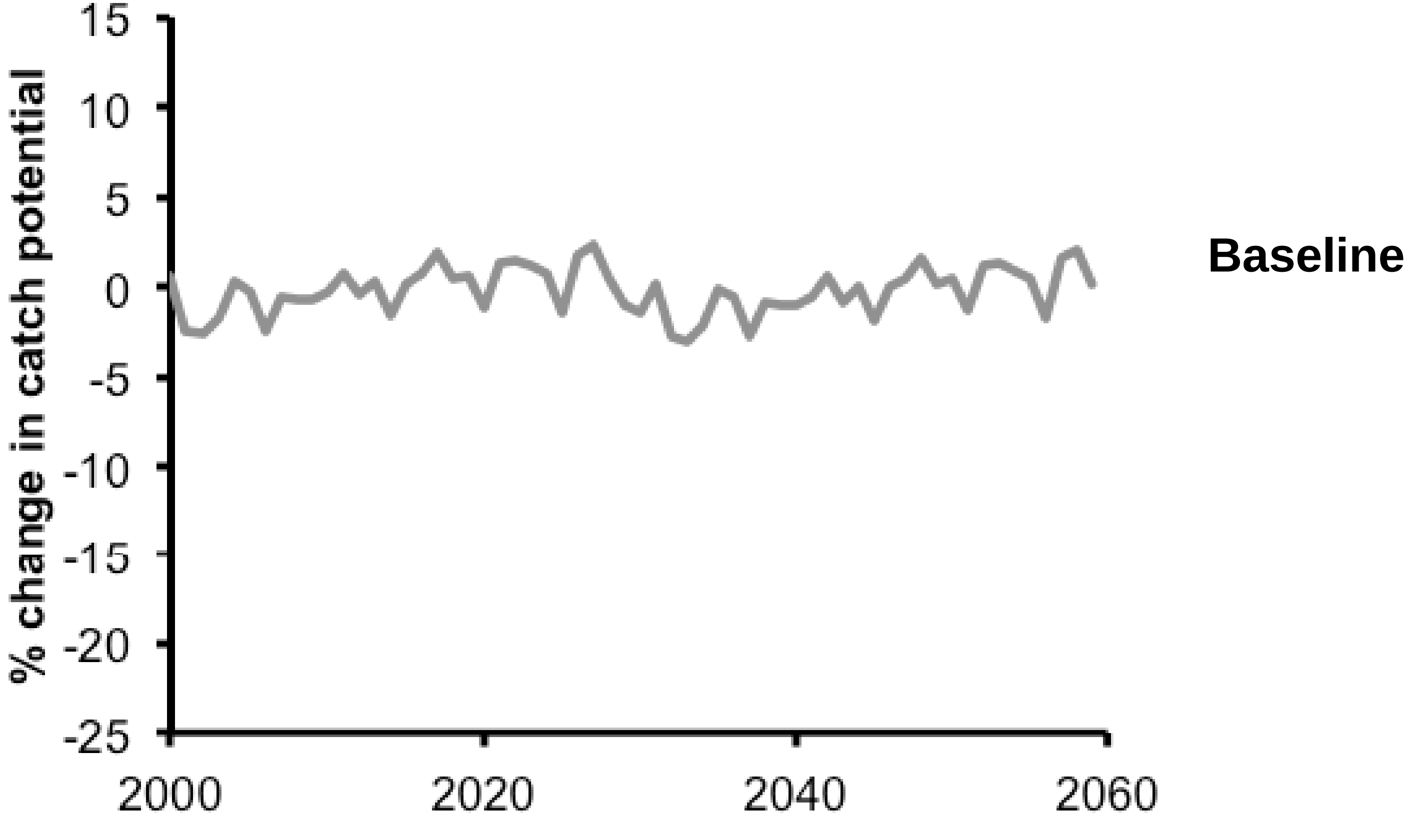
- **Tropical regions are projected to suffer from losses while high latitude regions are projected to gain in catch potential.**

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

Projected decadal mean changes in marine primary production from 1860s to 2090s



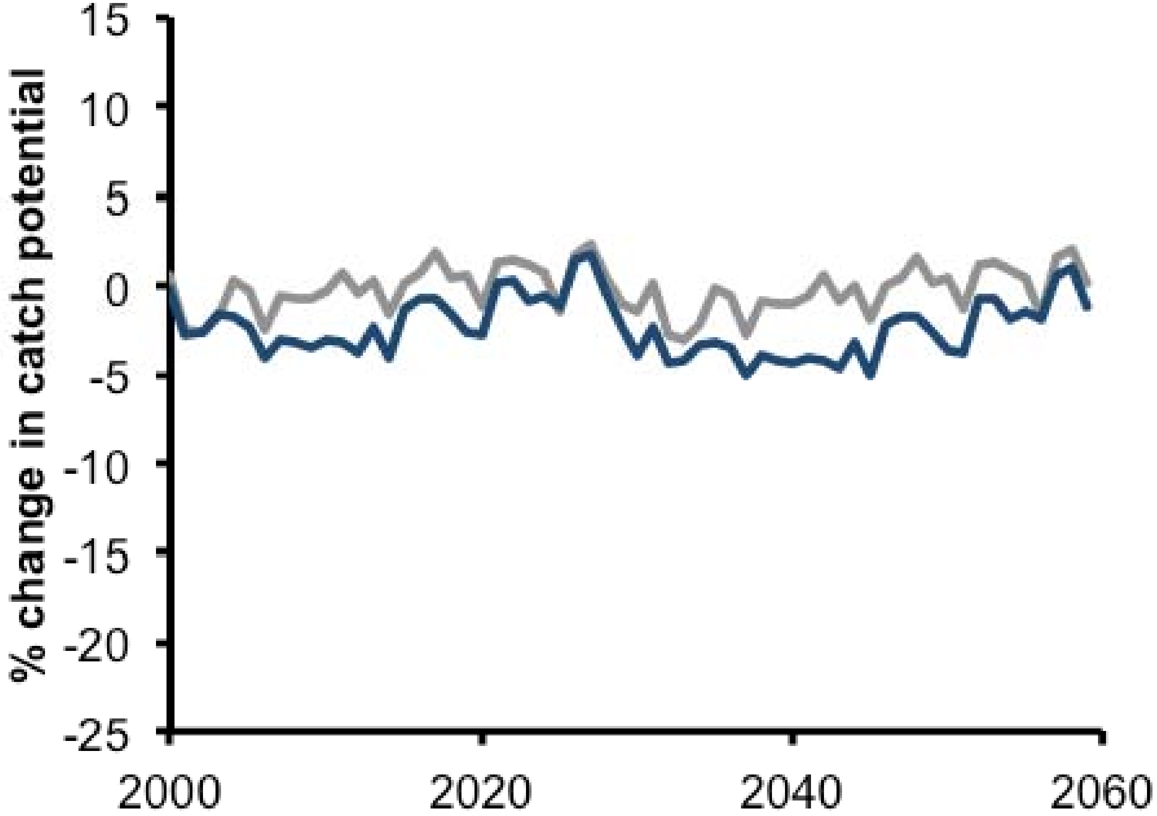
By 2050, warming and de-oxygenation combined are predicted to decrease catch potential



- **This analysis considered 778 exploited species.**

Source: Cheung, Sarmiento, Frölicher, *et al.* (in prep.)

By 2050, warming and de-oxygenation combined are predicted to decrease catch potential

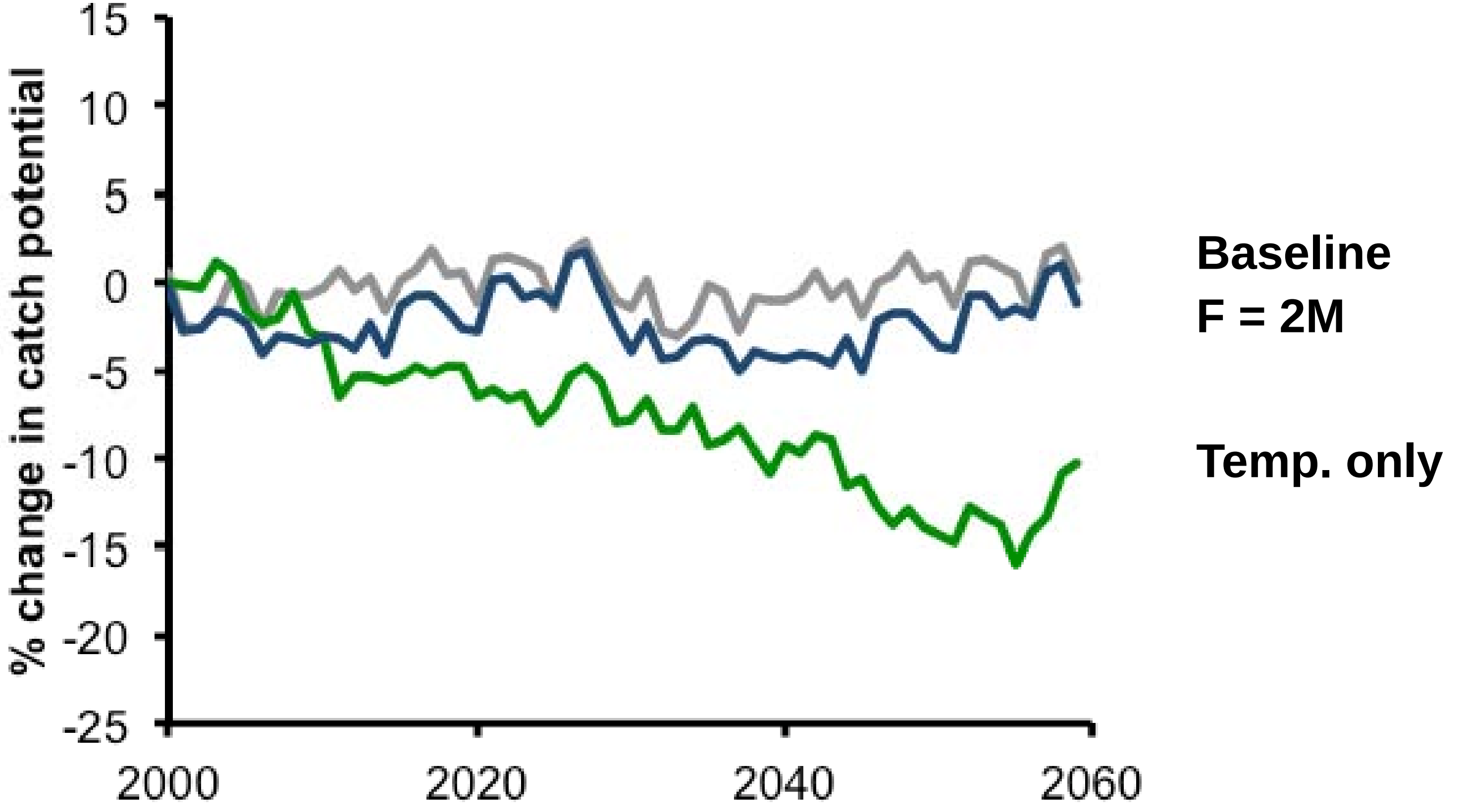


Baseline
F = 2M

- **This analysis considered 778 exploited species.**

Source: Cheung, Sarmiento, Frölicher, *et al.* (in prep.)

By 2050, warming and de-oxygenation combined are predicted to decrease catch potential



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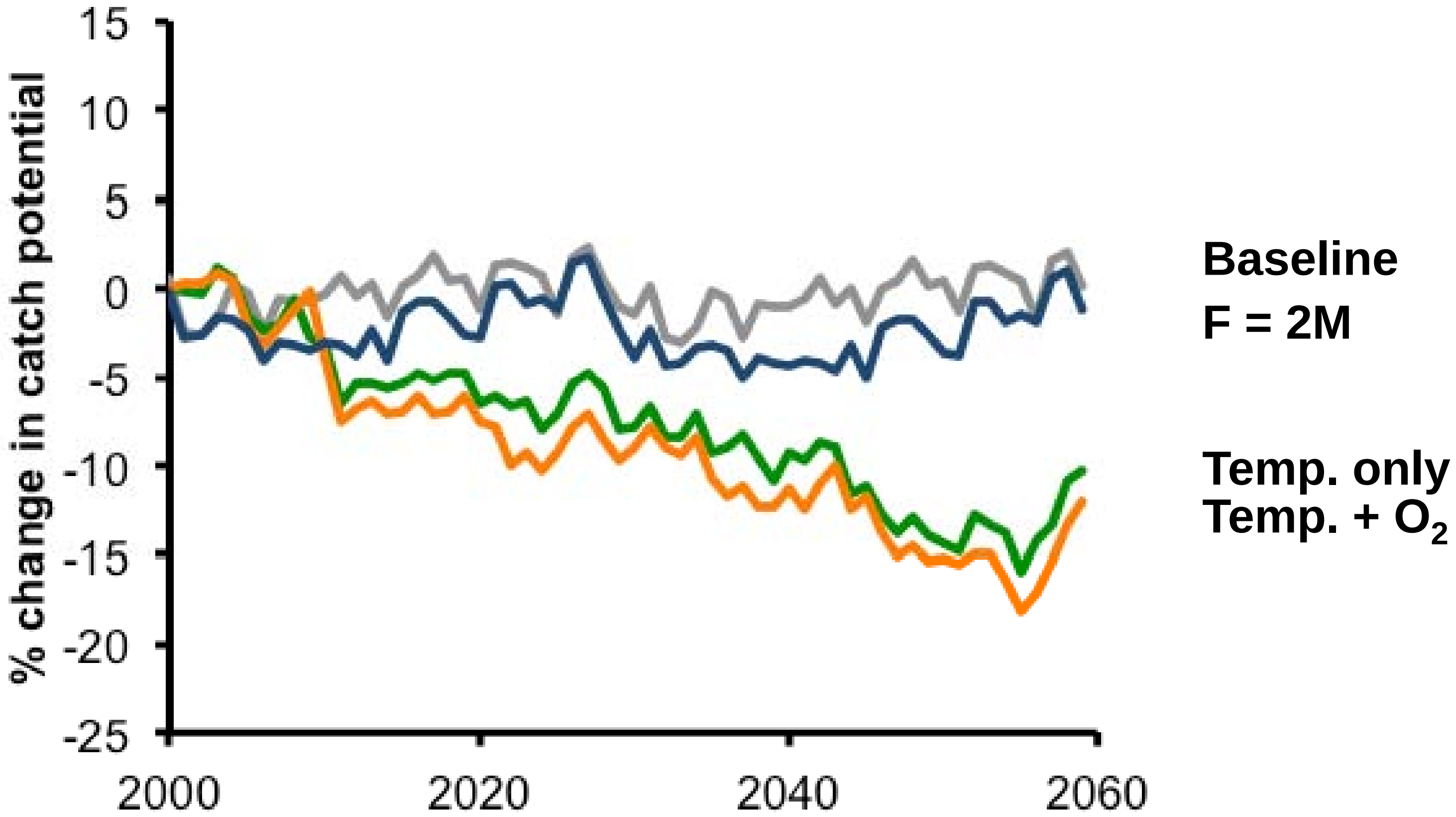
By 2050, warming and de-oxygenation combined are predicted to decrease catch potential



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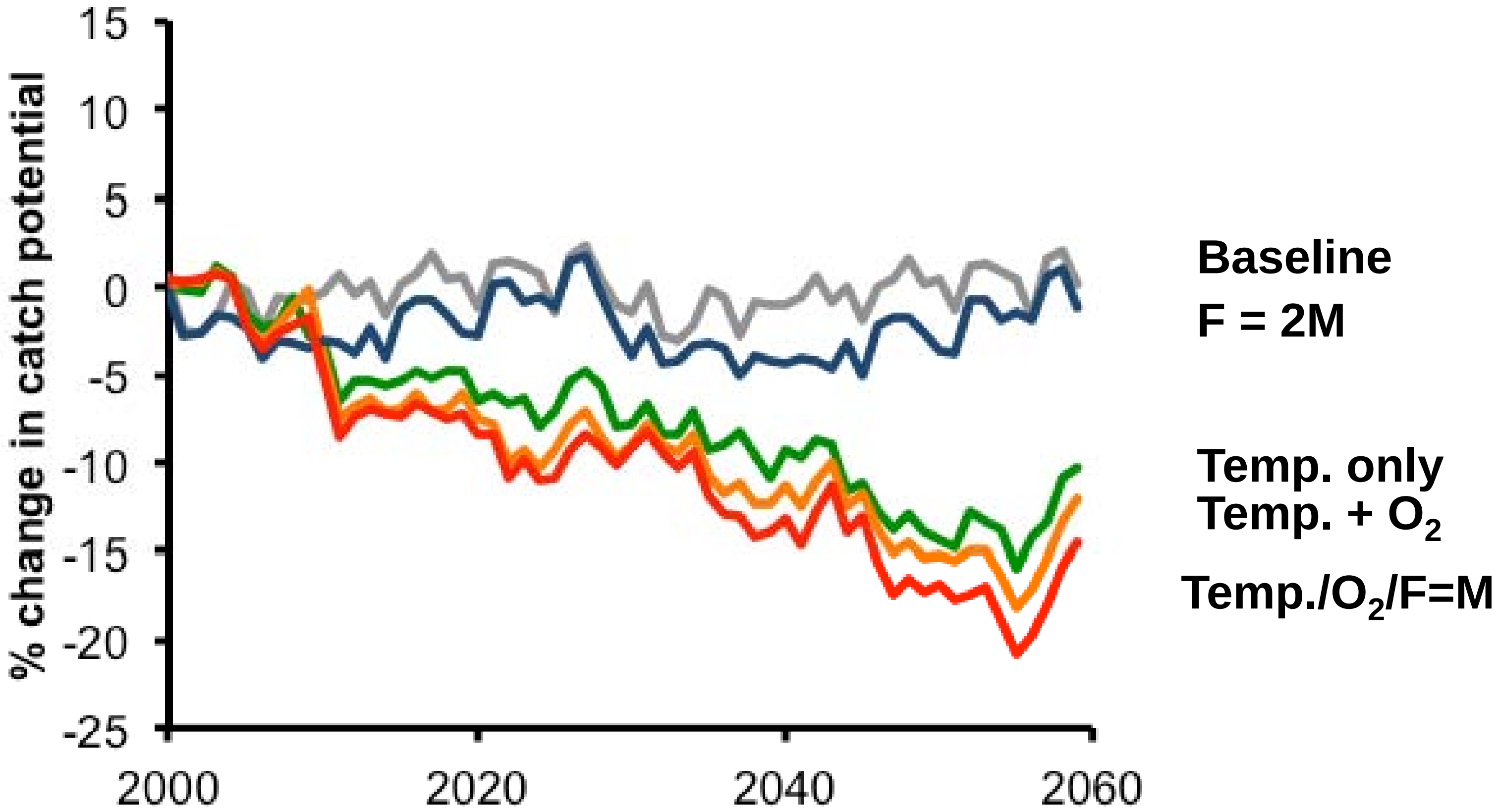

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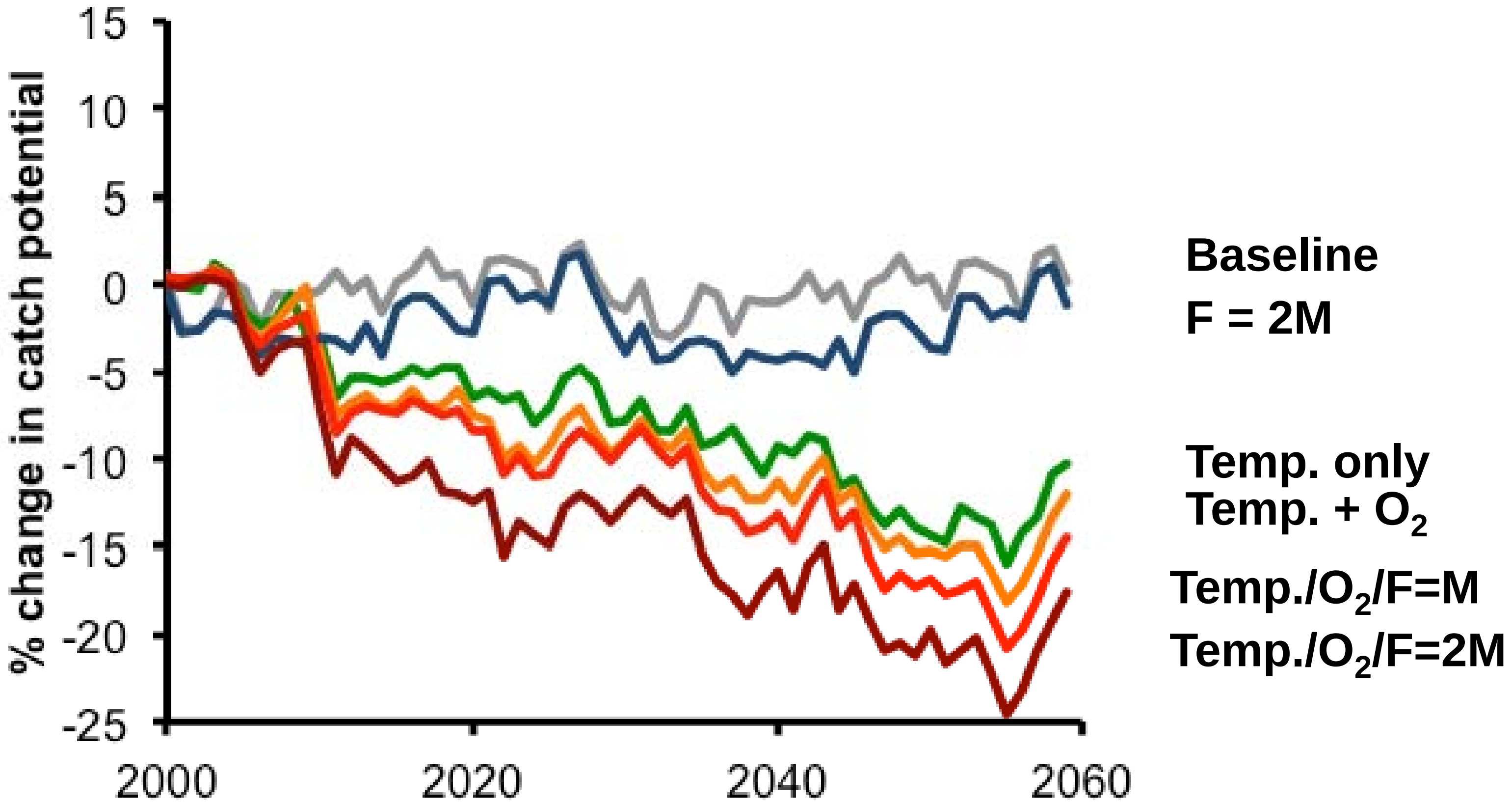
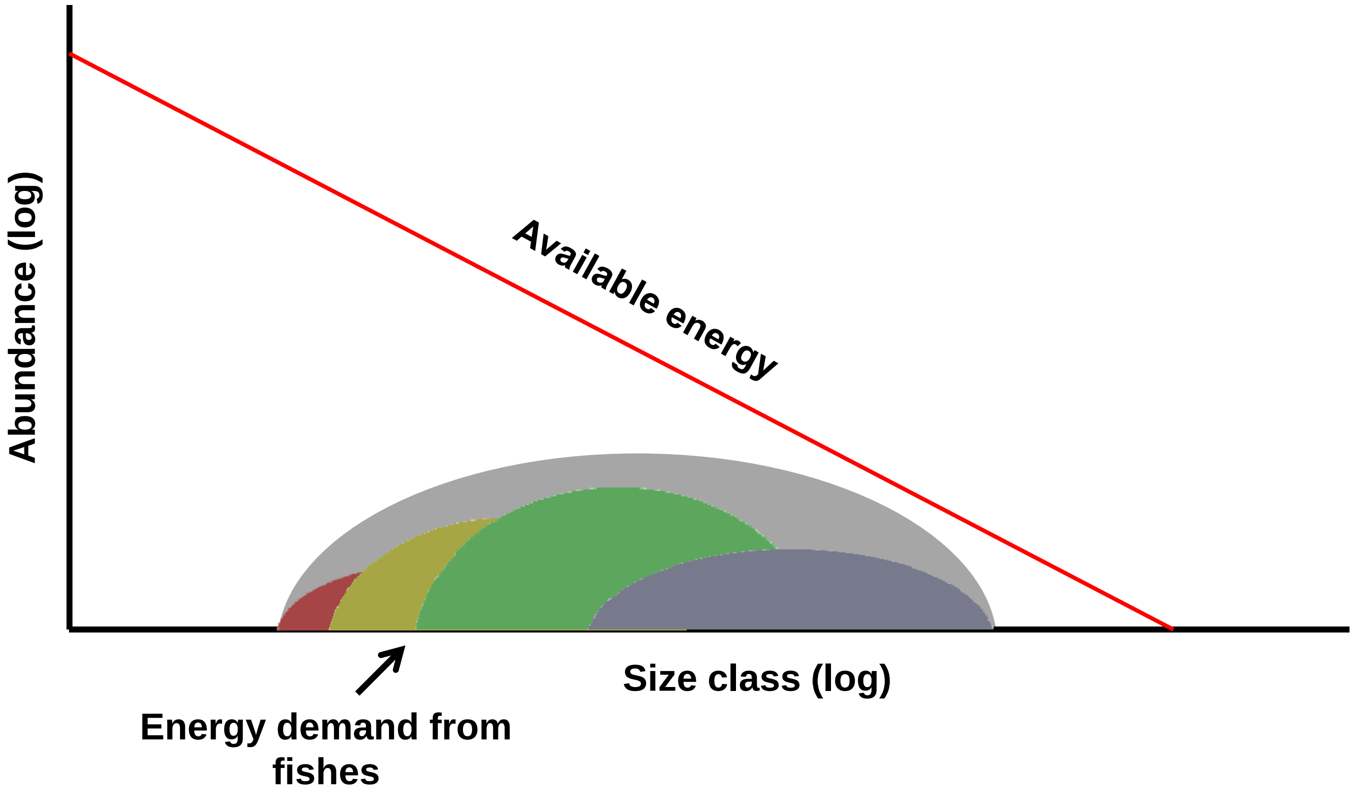


- **This analysis considered 778 exploited species.**

Source: Cheung, Sarmiento, Frölicher, *et al.* (in prep.)

Incorporating trophic interactions into Dynamic Bioclimate Envelop Model



From: Fernandes, Cheung, Jennings, Grant (2013) Global Change Biology

Comparing projections with data in N. Atlantic

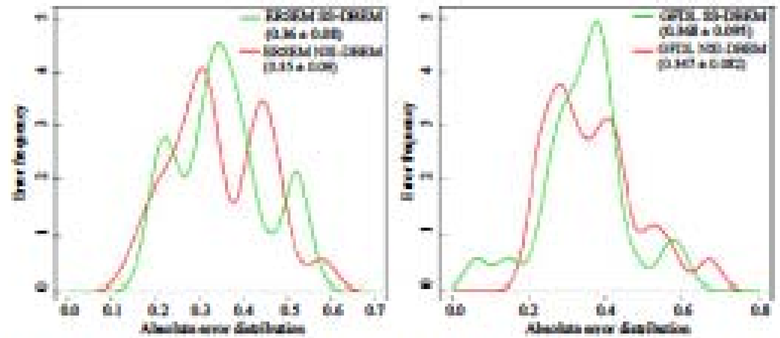


Fig. 4 Distribution of absolute error of predicted biomass for SS-DBEM and NSI-DBEM and the biomass estimated from stock assessments for the 1991–2003 period in the Northeast Atlantic (FAO Area 27). The time series have been normalized between 0 and 1 before calculating the absolute error, to ensure that species' absolute abundances do not affect the results. The comparison is presented for European Regional Seas Ecosystem Model (ERSEM) (left) and Geophysical Fluid Dynamic Laboratory (GFDL) (right) showing in the legend mean and standard deviation of the absolute error. A narrower distribution of error (lower standard deviation) in SS-DBEM is indicative of a higher precision.

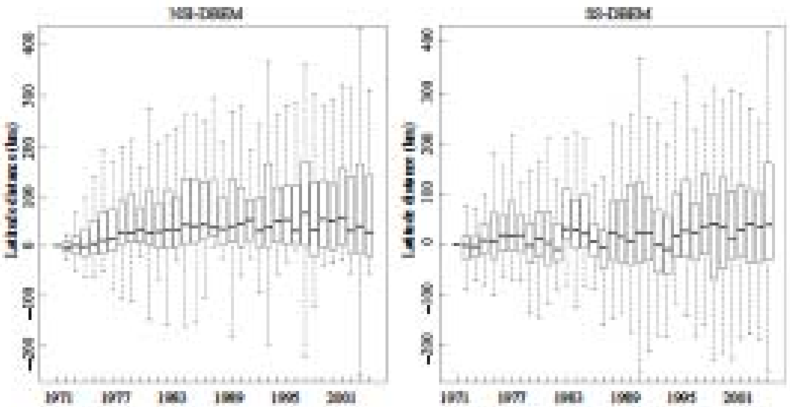
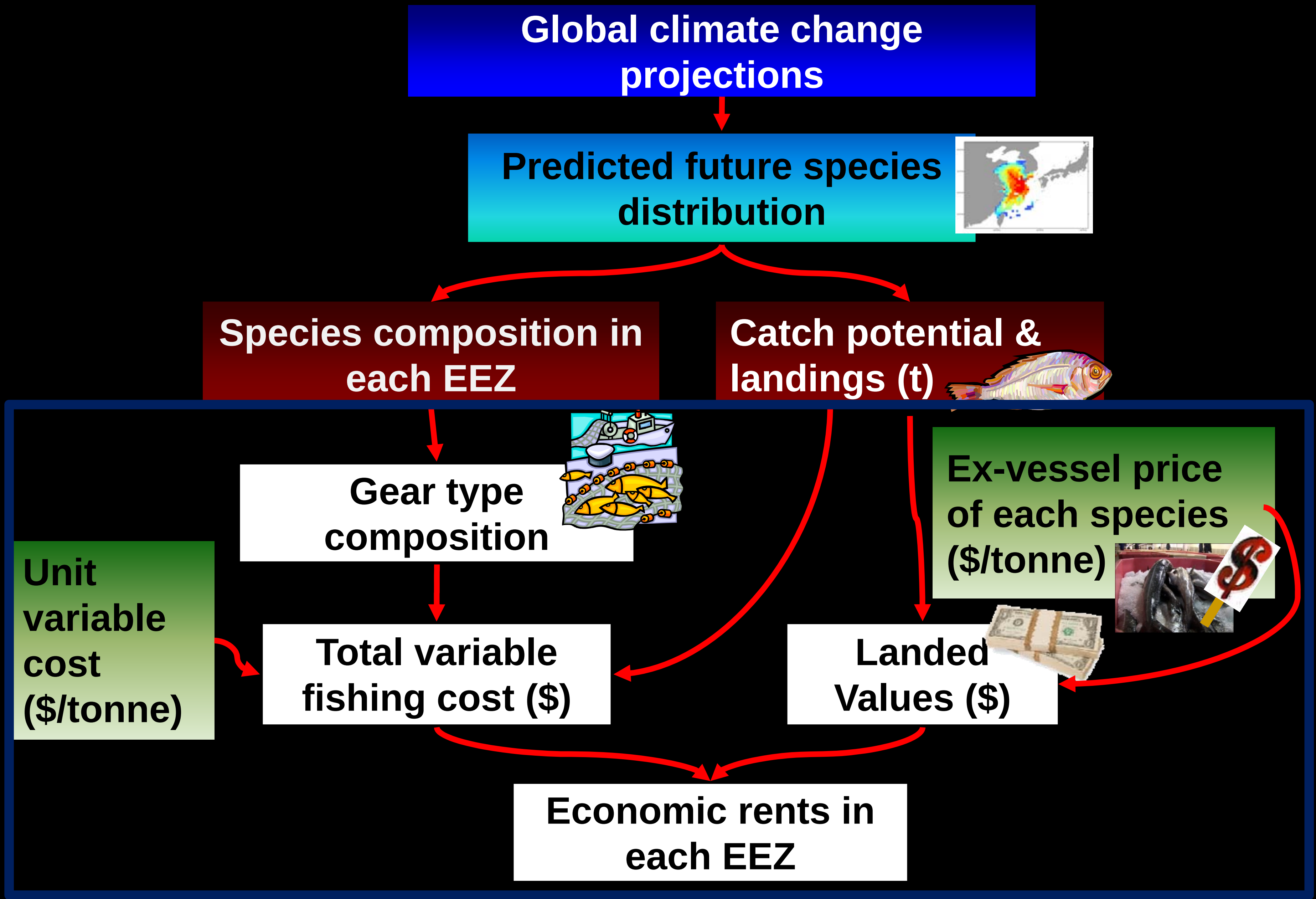


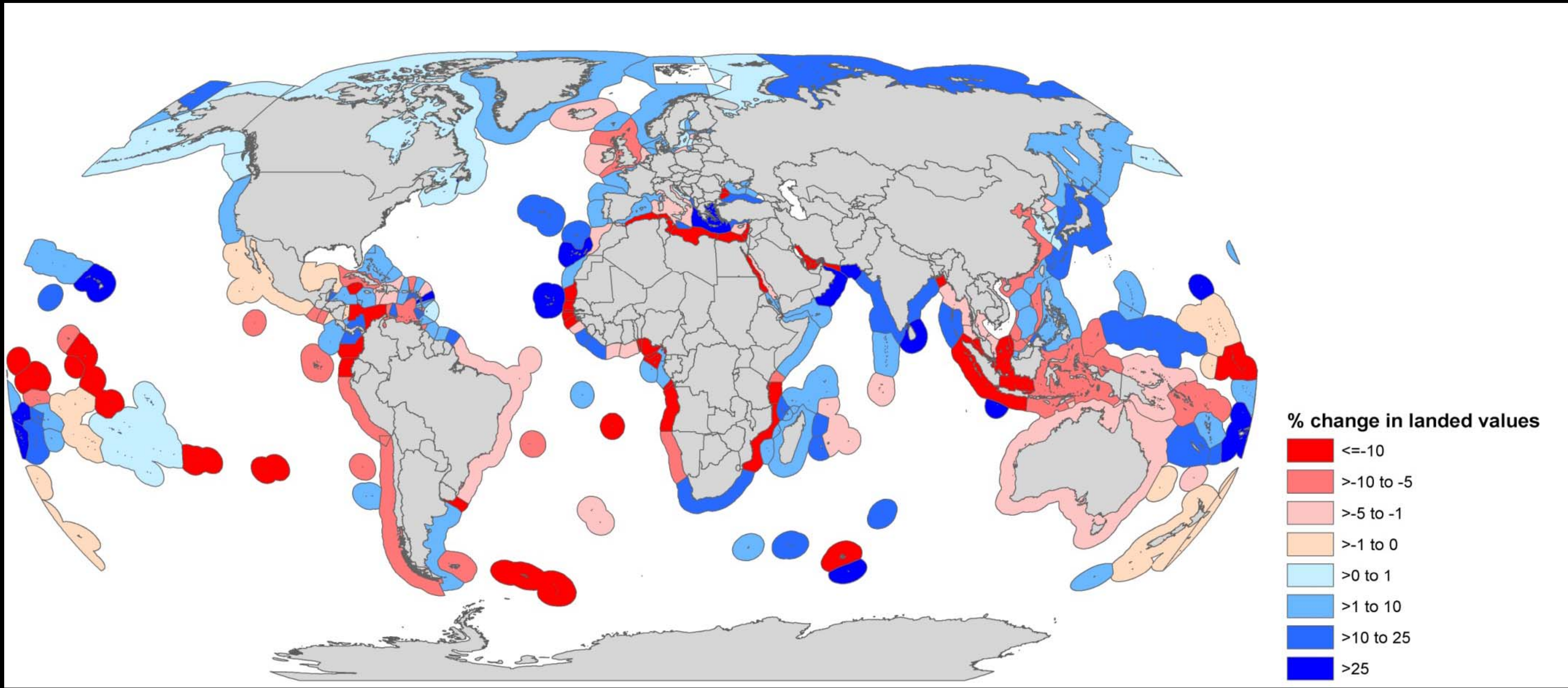
Fig. 5 Predicted latitudinal shift of distribution centroids of 49 species of fishes from 1971 to 2004 using European Regional Seas Ecosystem Model (ERSEM) climatic dataset for the NSI-DBEM and SS-DBEM. The thick dark bar represents the median shift of all the species in a year, the lower and upper boundaries of the box represent the 25% and 75% quantiles respectively. Positive value indicates poleward shift relative to species distribution in 1971.

What are the socio-economic implications?

Linking to economic and social impacts

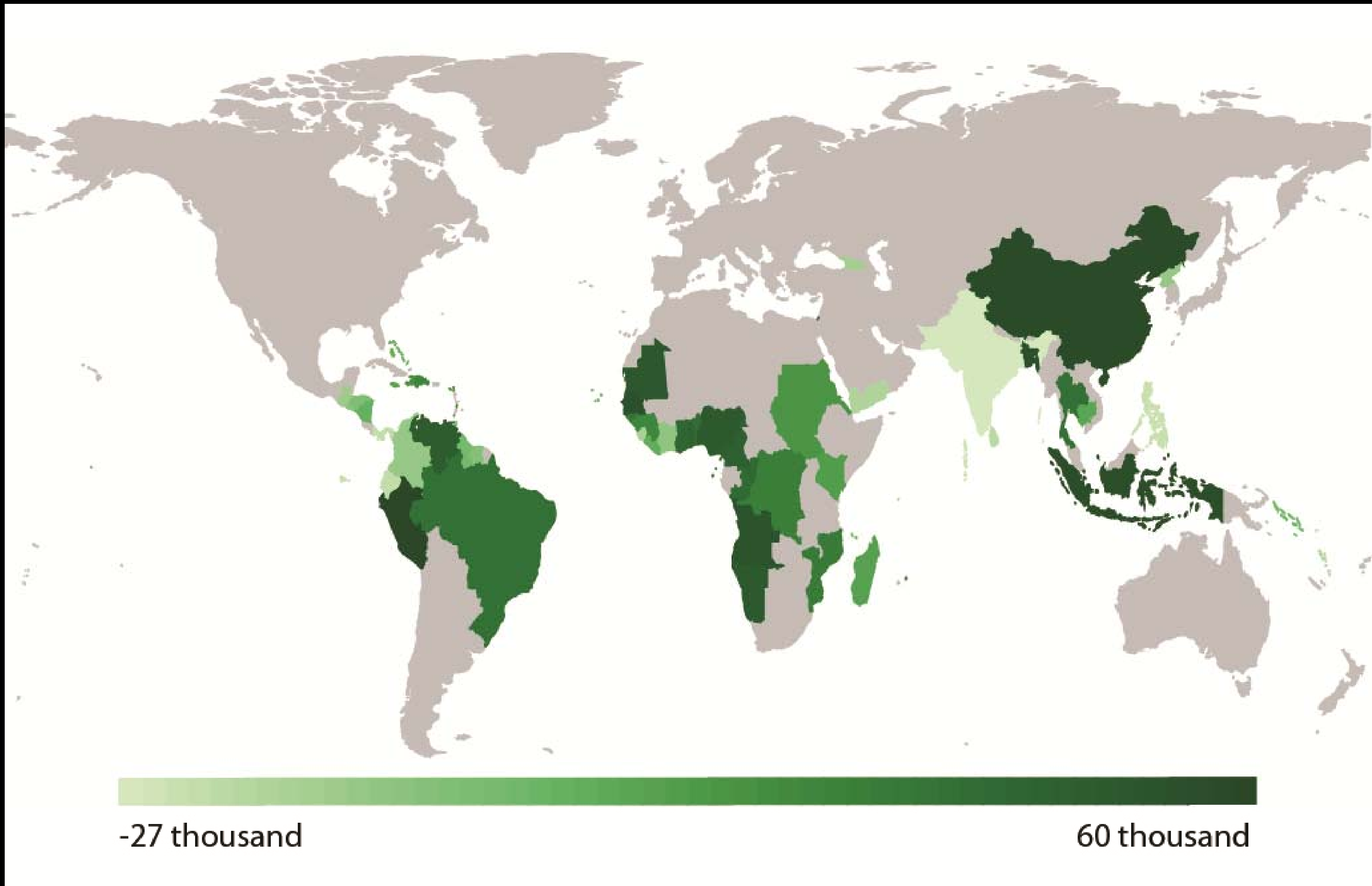


Percentage change in landed values in each EEZ in the 2050s



Source: Lam *et al*. (submitted)

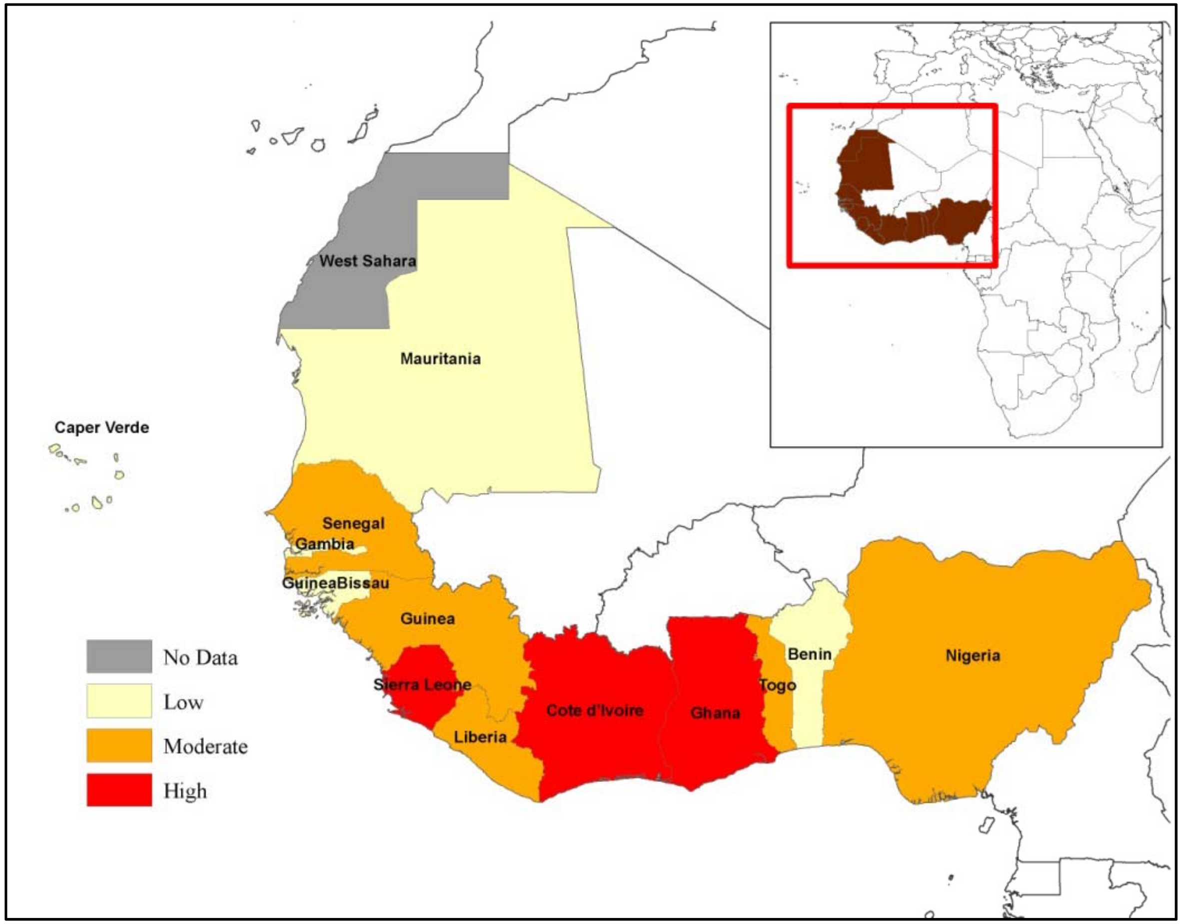
Change in undernourishment due to climate change



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

Implications on local economies

Vulnerability Index



Country	Vulnerability Index	Rank
Cote d'Ivoire	0.66	1
Ghana	0.66	2
Sierra Leone	0.61	3
Nigeria	0.54	4
Togo	0.51	5
Liberia	0.51	6
Senegal	0.47	7
Guinea	0.45	8
Mauritania	0.40	9
Guinea-Bissau	0.37	10
Benin	0.36	11
Gambia	0.30	12
Cape Verde	0.28	13

Vulnerability of national economies to the impact of climate change on fisheries in WA countries under high range GHG emission scenario (SRES A1B)

From: Lam, Cheung, Swartz and Sumaila (2012) African J. of Marine Sci.

Uncertainties

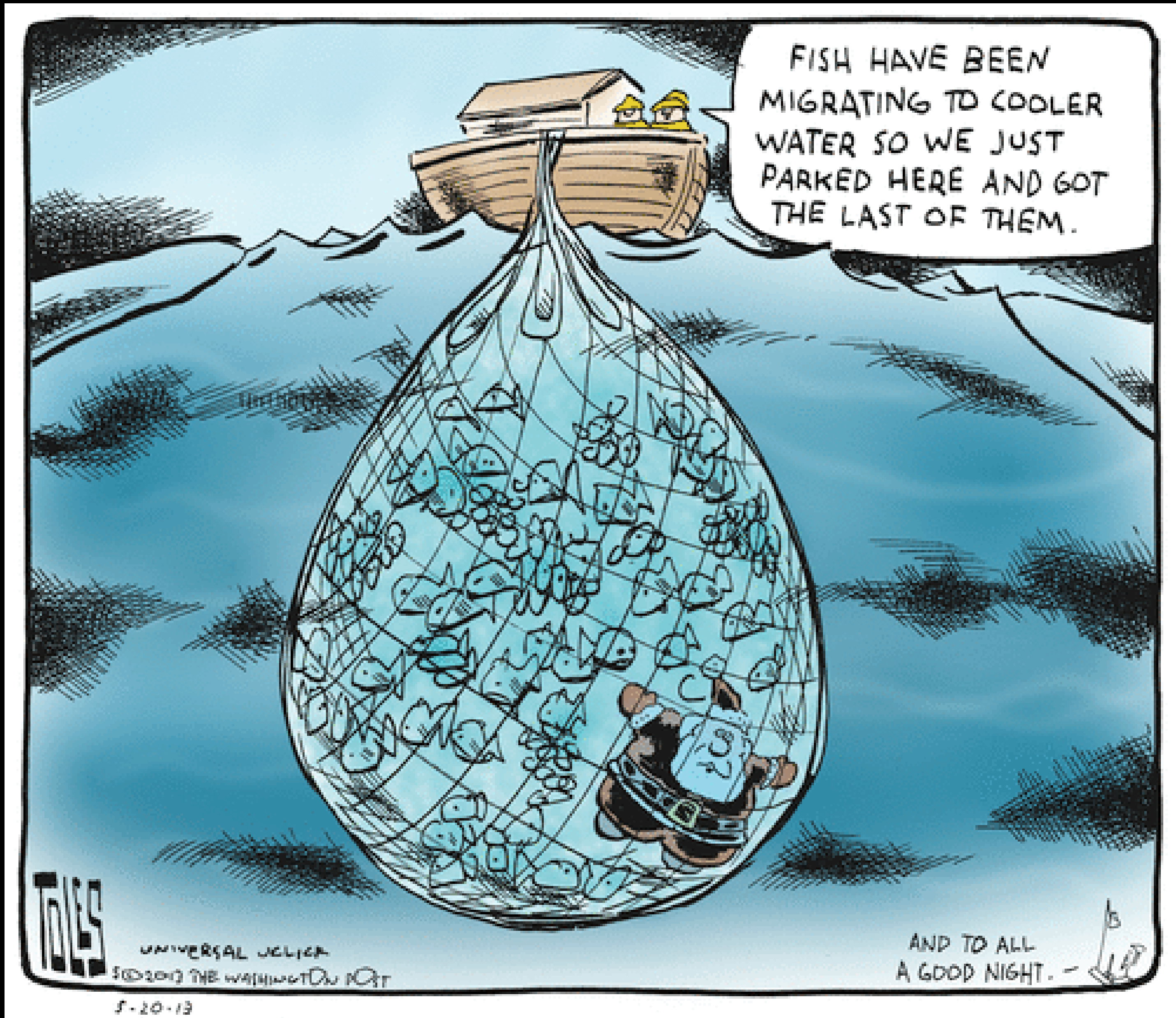
- **Physical and lower-trophic level models;**
- **Species' adaptation to environmental changes (on-going PhD project);**
- **Multi-model comparisons and ensembles (regionally: North Sea - Jones *et al*. 2013a, b, NE Pacific - Cheung *et al*. submitted; globally: on-going project).**

Summary

- Long-term changes in ocean temperature has led to changes in species composition of catch since the 1970s;
- In higher latitude regions, increasing dominance of warmer water species in catch;
- In tropical regions, further warming may impact the production of tropical species which have now become the dominant species in catch;
- Shrinking of fishes may further exacerbate the impact;
- On-going and future works to further address uncertainties and model skills testing.

Acknowledgement

- Nippon Foundation-Nereus Program;
- National Geographic Society;
- Natural Sciences and Engineering Research Council of Canada;
- Pew Charitable Trust;



By Tom Tales: published in Washington Post: 20 May 2013

Group discussion (A)

Progress in Oceanography 88 (2011) 1–27

Contents lists available at ScienceDirect

Progress in Oceanography

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Review

On the use of IPCC-class models to assess the impact of climate on Living Marine Resources

Charles A. Stock[a,*], Michael A. Alexander[b], Nicholas A. Bond[c], Keith M. Brander[d], William W.L. Cheung[e], Enrique N. Curchitser[f], Thomas L. Delworth[a], John P. Dunne[a], Stephen M. Griffies[a], Melissa A. Haltuch[g], Jonathan A. Hare[h], Anne B. Hollowed[i], Patrick Lehodey[j], Simon A. Levin[k], Jason S. Link[l], Kenneth A. Rose[m], Ryan R. Rykaczewski[a], Jorge L. Sarmiento[n], Ronald J. Stouffer[a], Franklin B. Schwing[o], Gabriel A. Vecchi[a], Francisco E. Werner[f]

Questions for discussion

- **What are the major challenges in developing models to assess climate change impacts on living marine resources?**

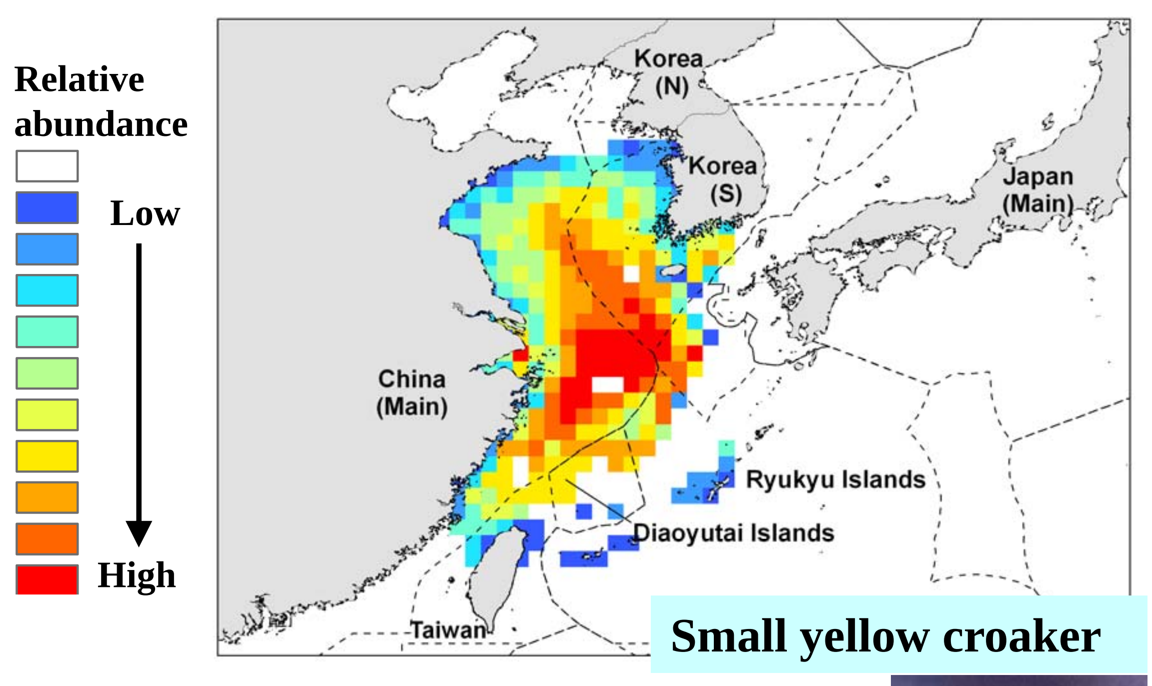
- **What are the possible ways to address these challenges?**

Predicting species distributions

- Current (1970-2000) distributional ranges of over 1,000 species of marine fishes and invertebrates are predicted from:

Attributes:

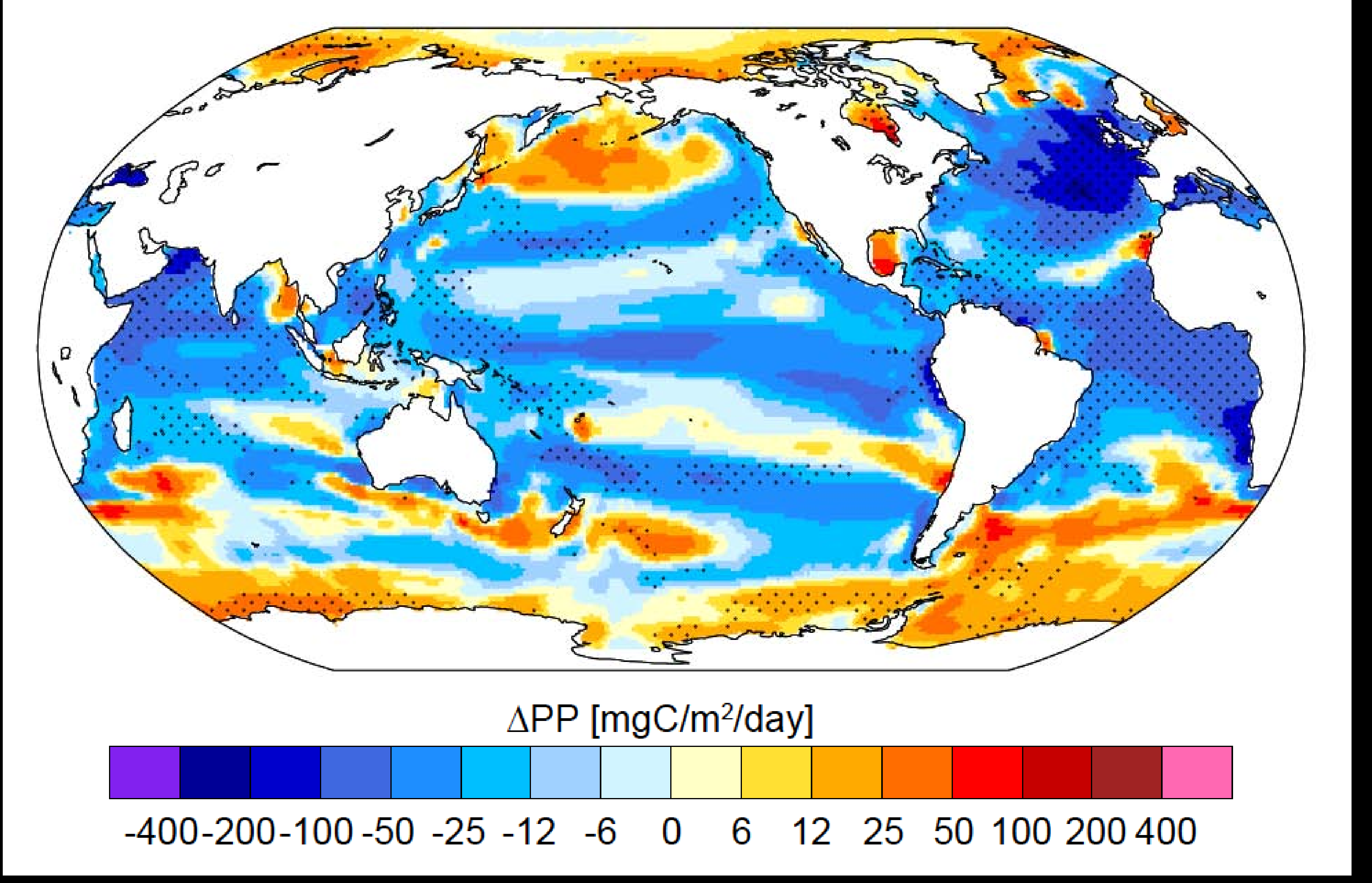
- Depth limits;
- Latitudinal limits;
- Associated habitats;
- Known range boundary.



Small yellow croaker

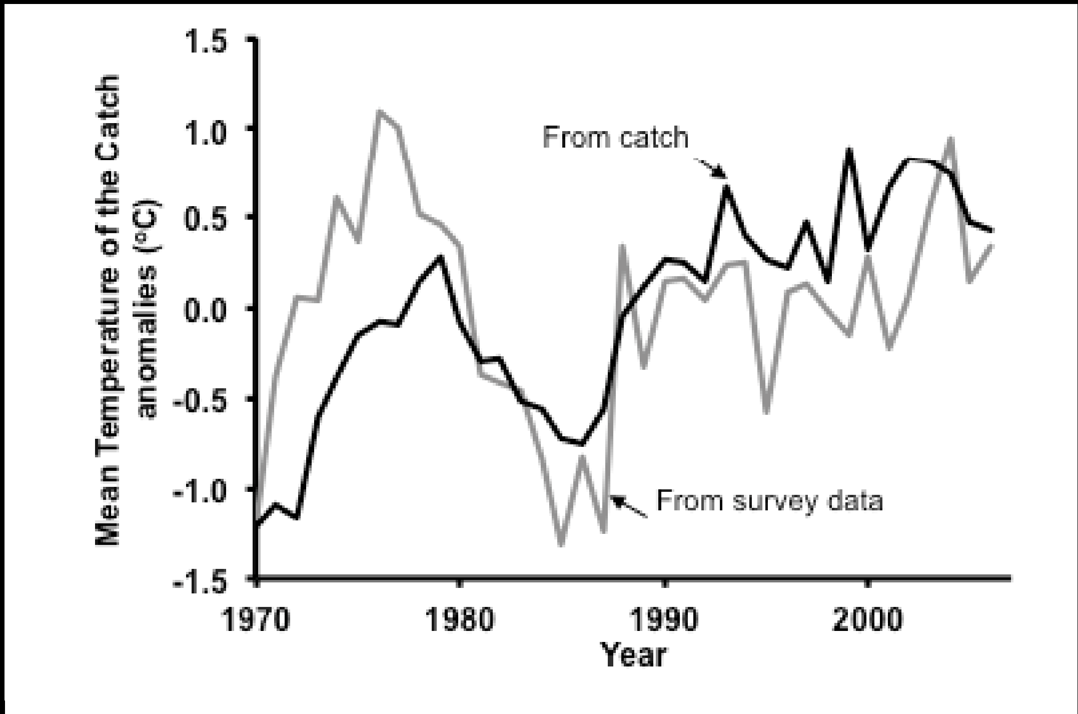
Close, Cheung, Hodgson, Lam, Watson, Pauly (2006) Fisheries Centre Research Report 14(4)

Projected changes in net primary productivity



Source: Redrawn using data presented in Steinacher *et al*. (2010) Biogeosciences.

Comparison with MTC calculated from survey data



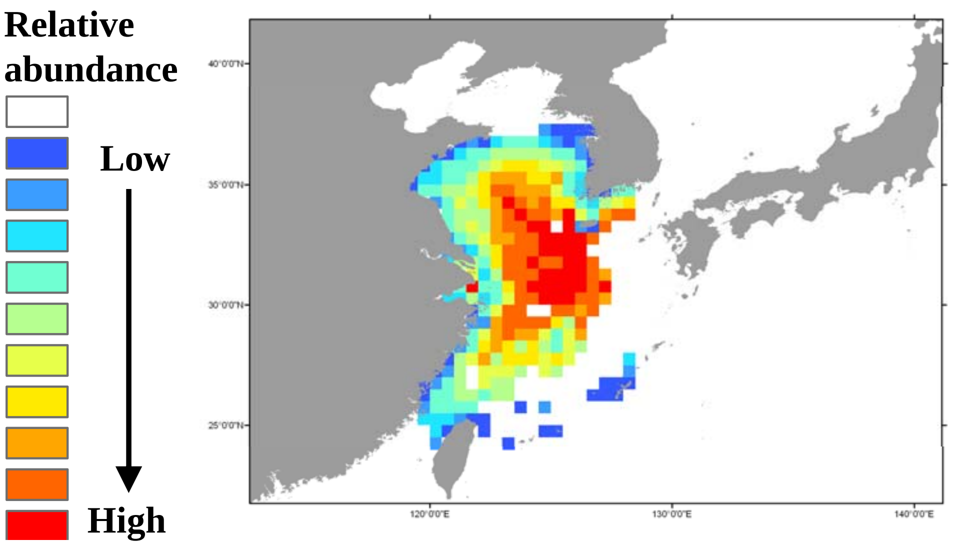
- E.g., in North Sea;
- No significant difference in the rate of change of MTC (ANCOVA).

Calculating median preferred temperature

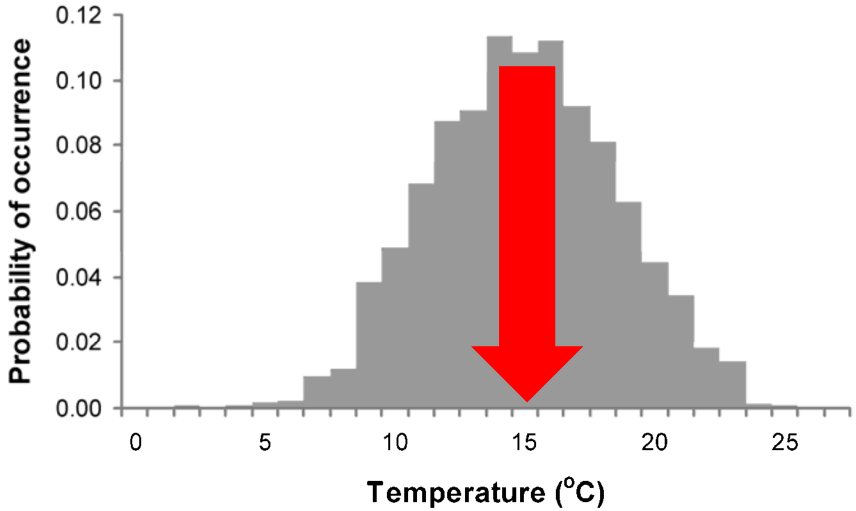
Example: Small yellow croaker (*Larimichthys polyactis*)

Original (static) distribution

(1971-2000)



Probability of occurrence by water temperature



Source: Cheung, Lam & Pauly (2008)