Projections of changes in the spatial distribution of zooplankton for the end of this century: Consequences for higher trophic levels

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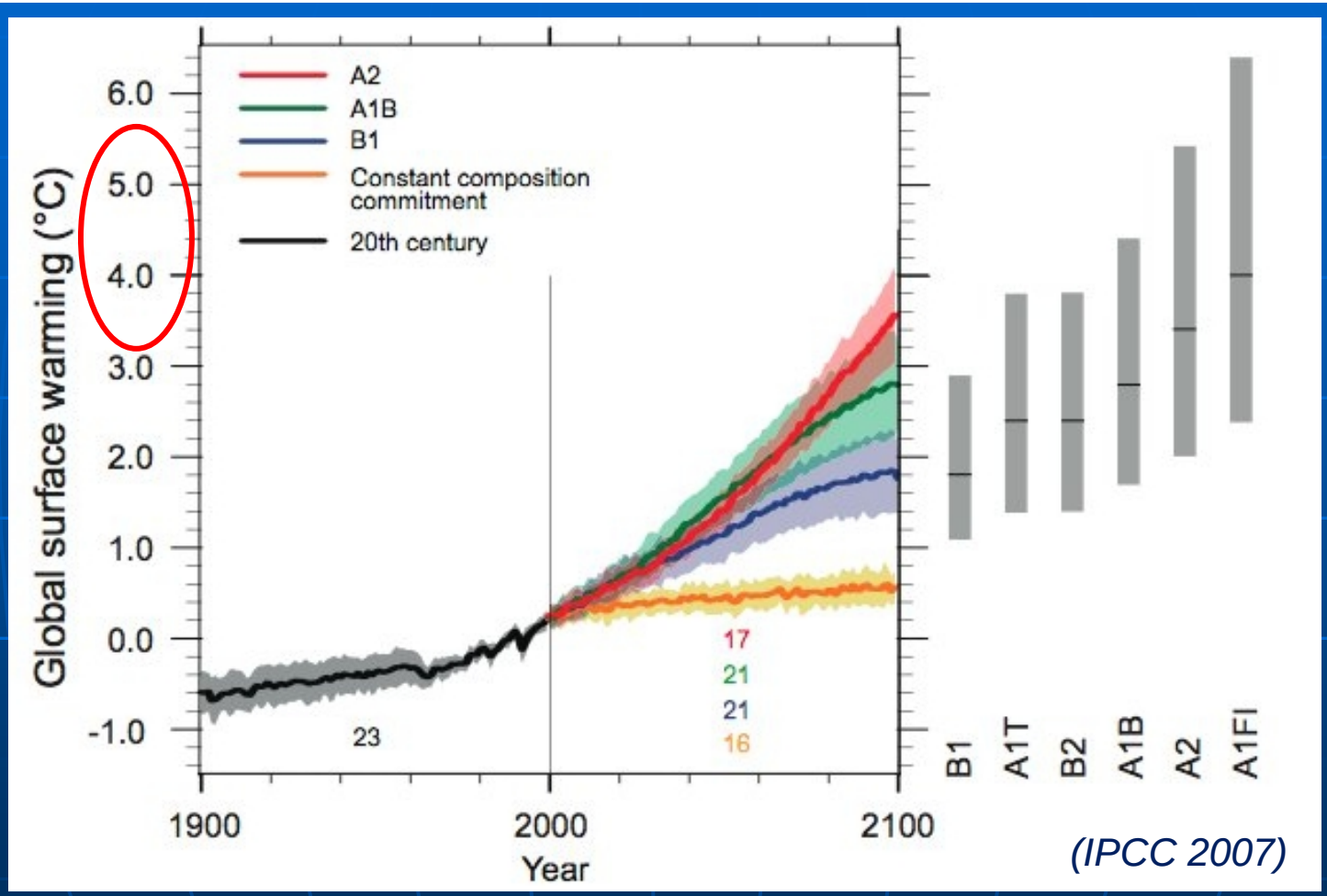
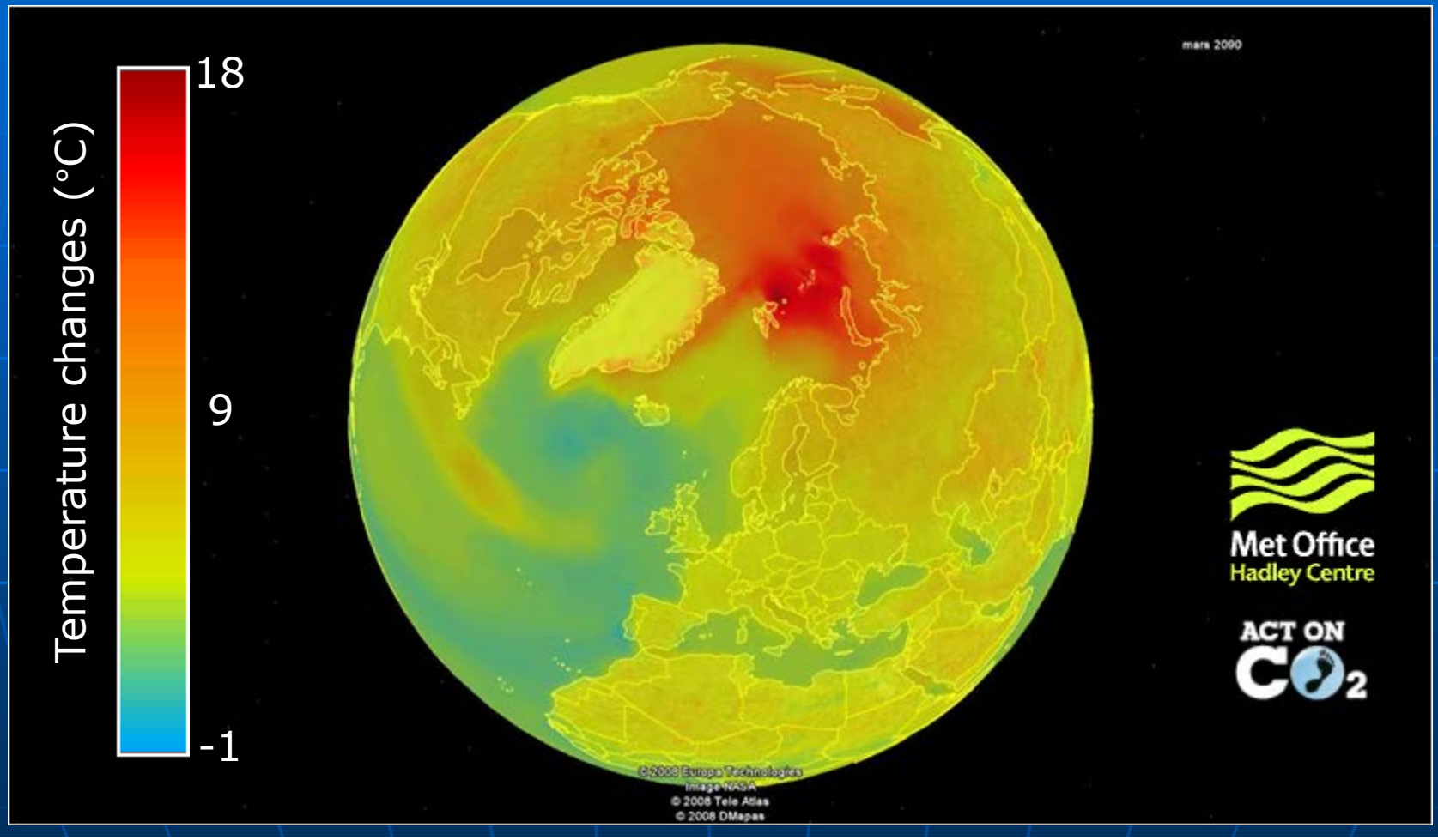
Expected climate change



(IPCC 2007)

Warming could reach 4 or 5°C
Where this warming will occur?

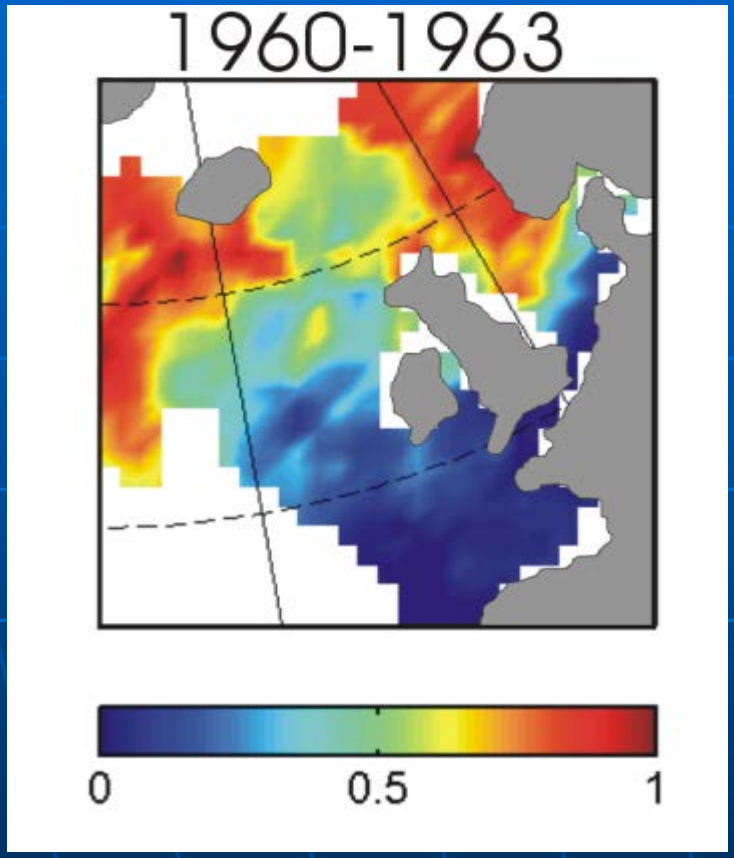
Temperature differences between March 2099 - March 2000 scenario B2



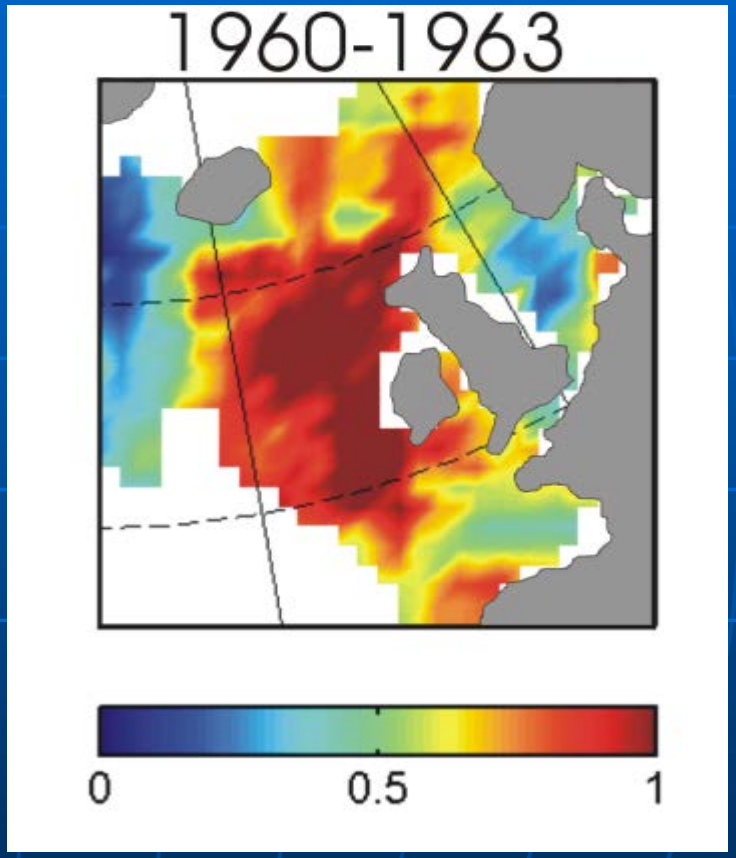
The climate warming affects the world ocean
What kind of consequences for marine life?

Large-scale impact on the species association biogeography of copepod in North Atlantic

Subarctic species



Cold-temperate species

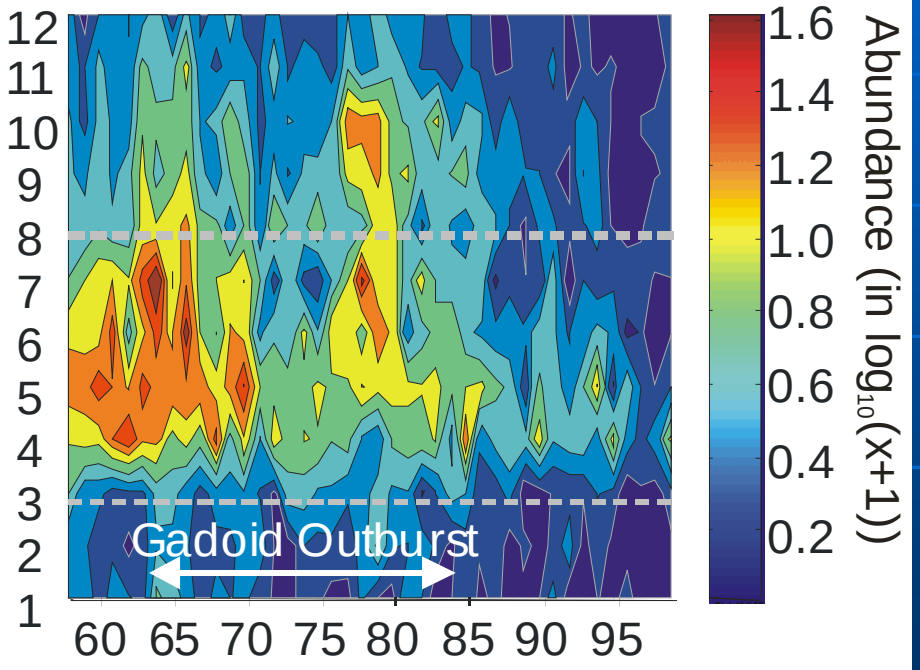


Mean number of species per association (*Beaugrand et al. 2002 Science*)

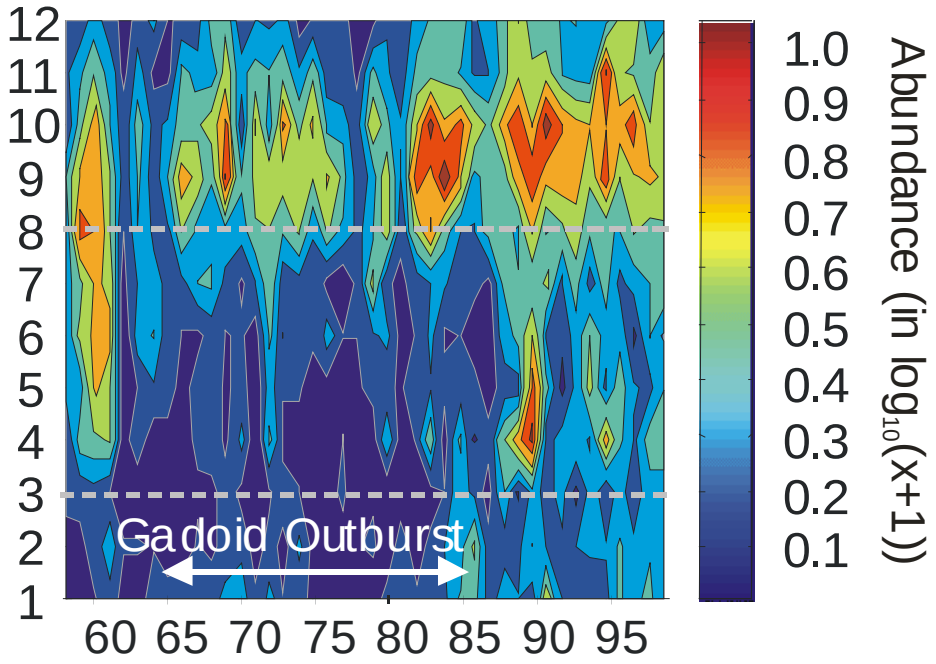
Biogeographical shift of 10° latitude in 40 years

Timing of two Calanus prey and larval Atlantic cod in the North Sea

Abundance of *C. finmarchicus*



Abundance of *C. helgolandicus*



(Beaugrand et al. 2003)

Mismatch between cod and its preferential prey
Impact on cod recruitment

Research objectif

How predict induced climate changes in copepod community

Spatial Distribution

Abundance

Species Dominance

Potential consequences for higher tropic level ex: Atlantic cod

Spatial Distribution

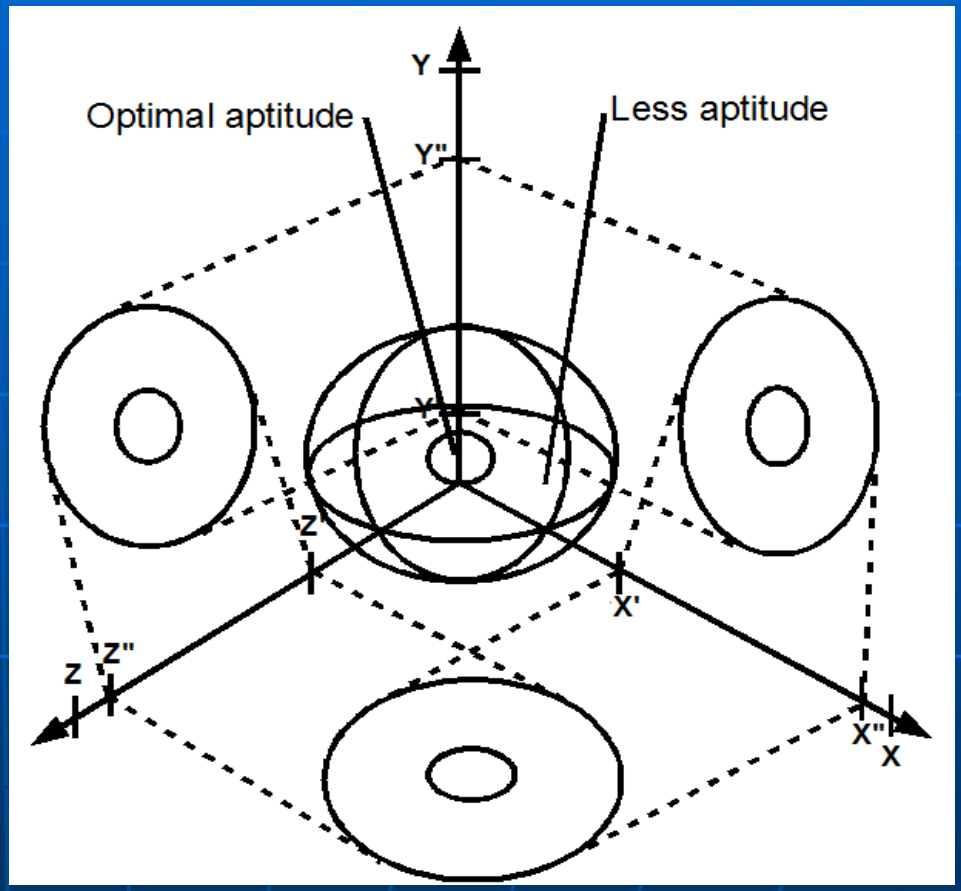
Abundance

New tools are needed: ecological niche model

The ecological niche sensu Hutchinson

"an n-dimensional hypervolume is defined, every point in which corresponds to a state of the environment which would permit the species to exist indefinitely"

(Hutchinson 1957 Cold Spring Harbor Symposium Quantitative Biology)



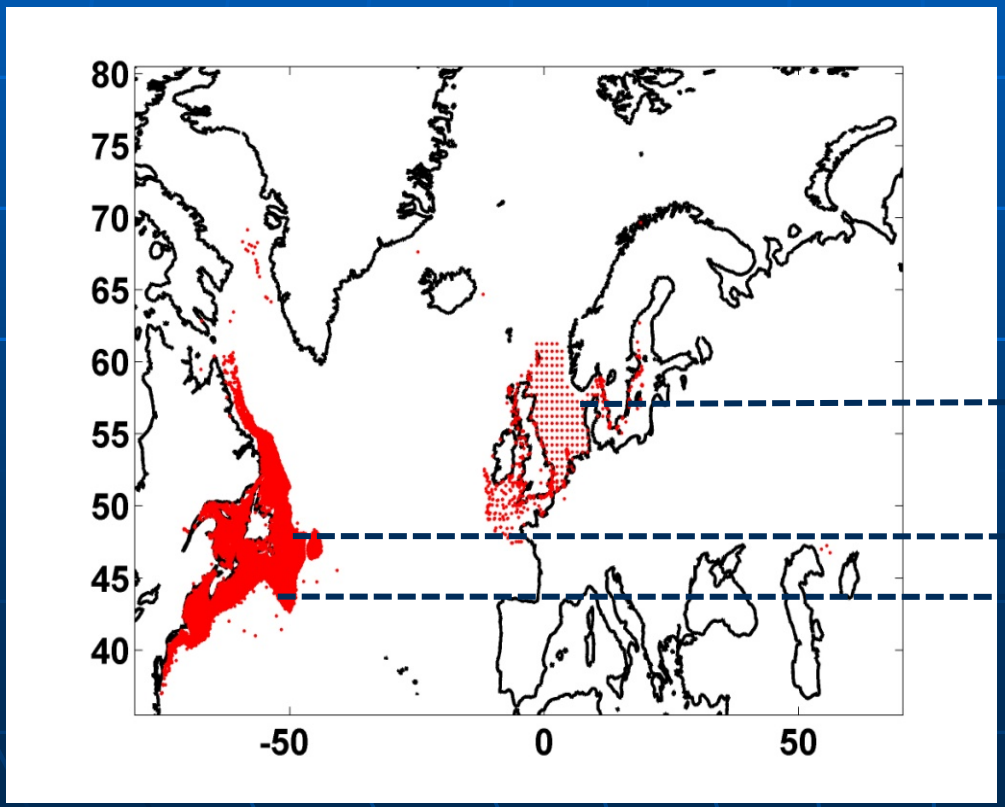
Estimation of the species ecological niche
Calculation of the species occurrence probability

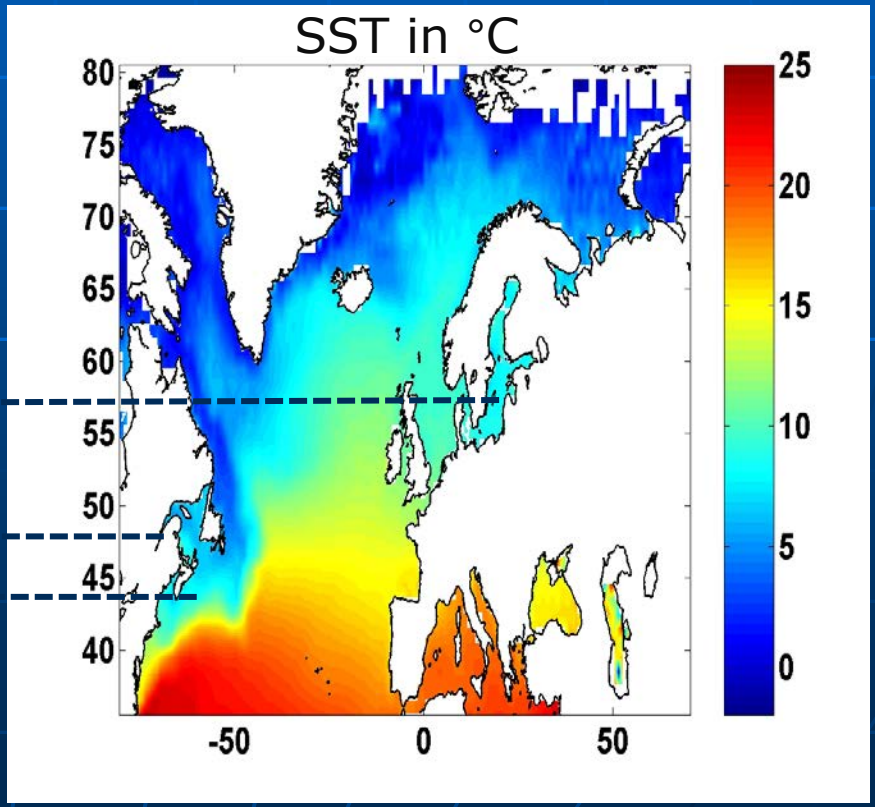
Estimation of species ecological niche based on occurrence data

Sea surface temperature (SST)

Sea surface salinity (SSS)

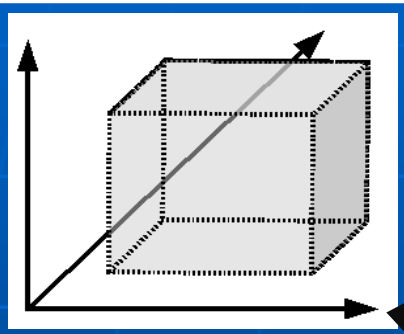
Bathymetry



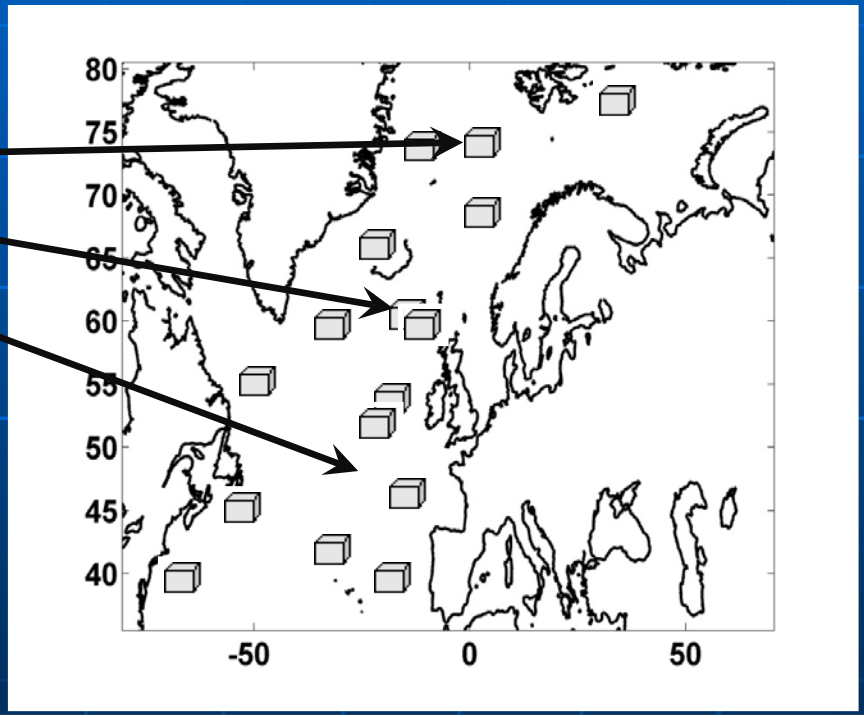


To what extent the available environmental envelops can be a potential habitat

Estimated niche



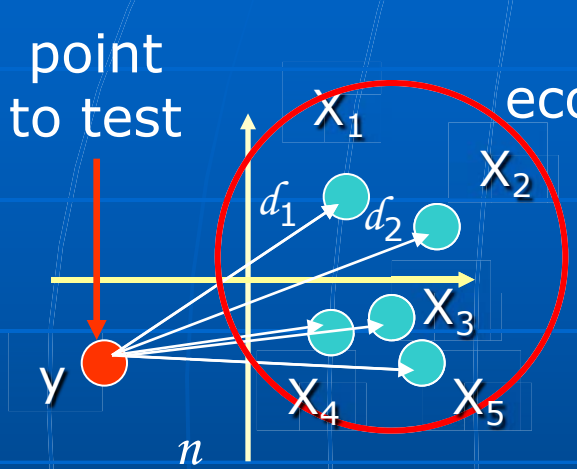
Available environmental envelops



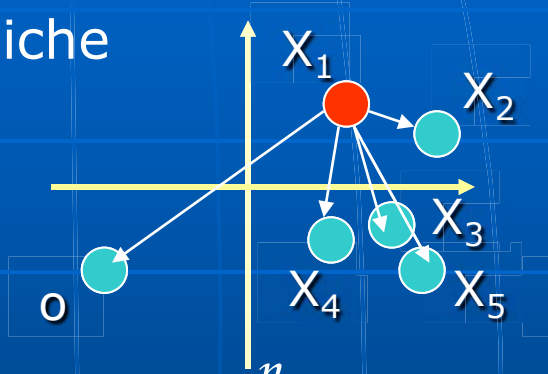
A model to test whether a geographical point belongs to the estimated niche:
NPPEN model *(Beaugrand et al. 2010 MEPS)*

The NPPEN calculates the occurrence probability of a species at a given geographical point

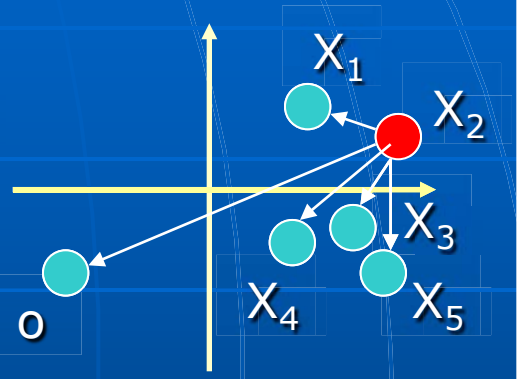
Calculation of the occurrence probability: permutation test



$$\varepsilon_0 = \frac{\sum_{i=1}^{n} d_i}{n}$$



$$\varepsilon_s = \frac{\sum_{i=1}^{n} d_i}{n}$$



$$\varepsilon_s = \frac{\sum_{i=1}^{n} d_i}{n}$$

The probability *p* is determined as the number of time that $\varepsilon_s \geq \varepsilon_0$

$$p = \frac{q_{\varepsilon_s \geq \varepsilon_0}}{n}$$

A distance but which one?

$$\varepsilon_0 = \frac{\sum_{i=1}^{n} d_i}{n}$$

Distance d_i ?

Euclidean distance

Not suitable in the context of ecological niche

Cord distance

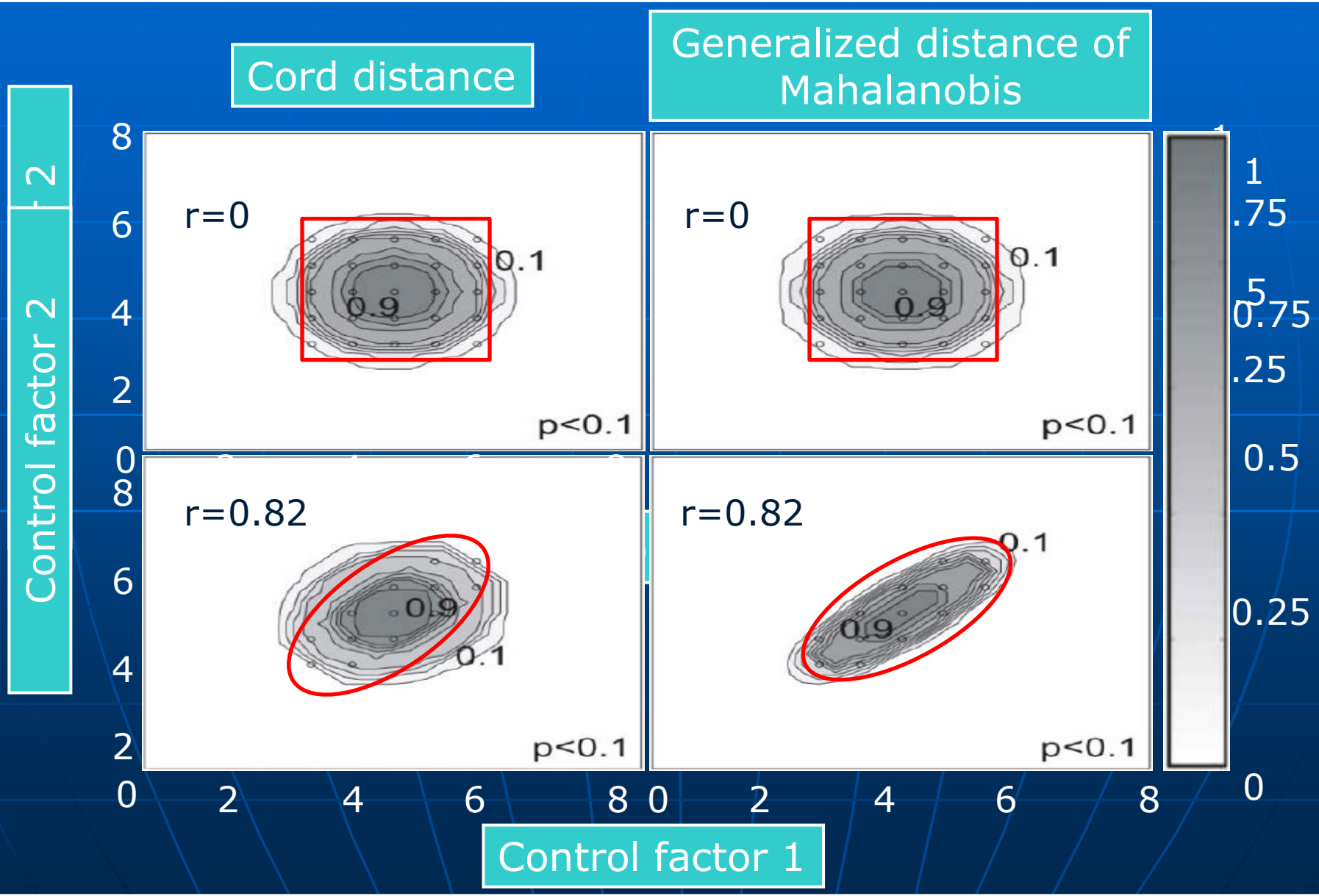
Independence of the scale descriptors

Generalized distance of Mahalanobis

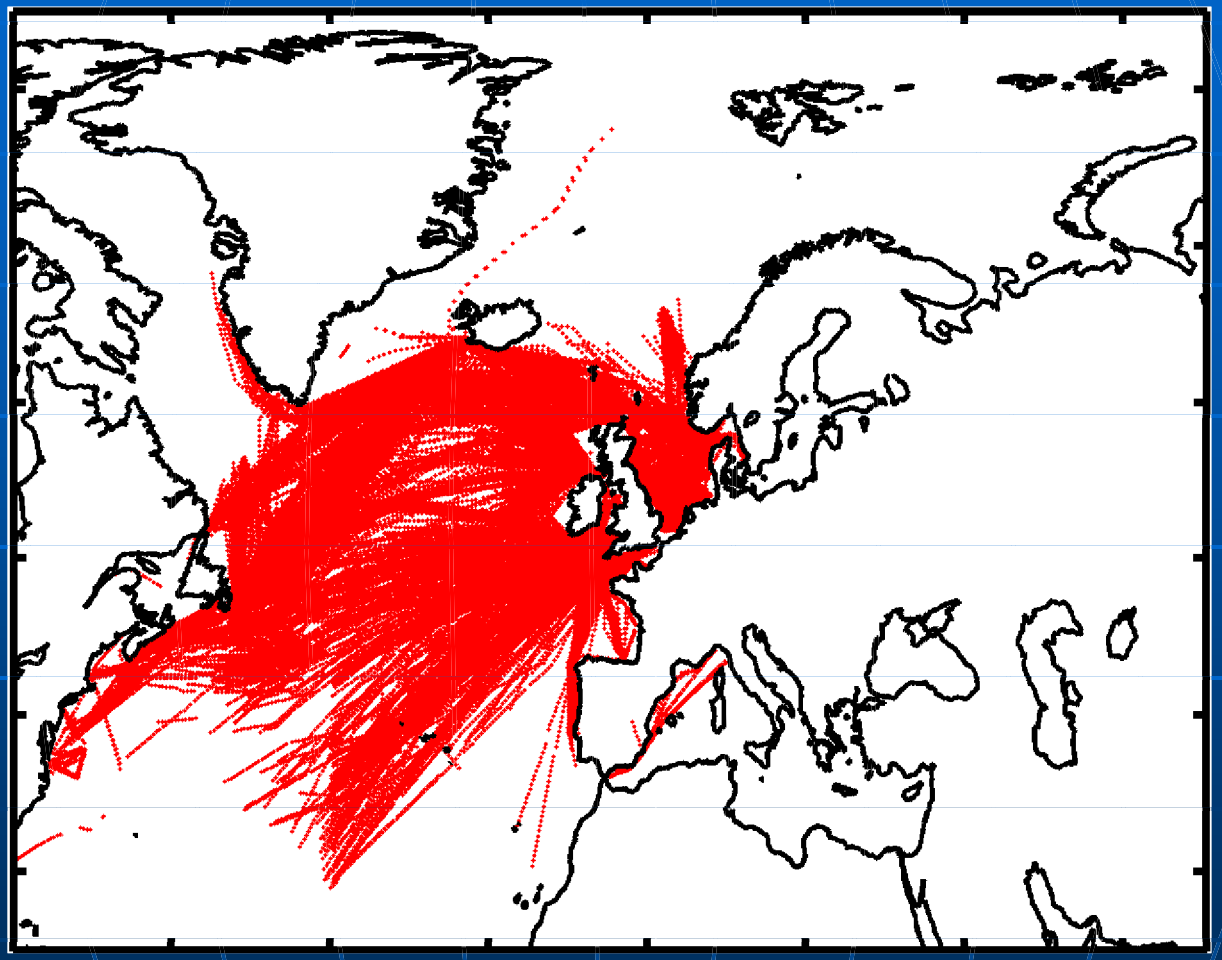
Independence of the scale descriptors
+ correlation of descriptor taking into account

$$D^2_{y,x} = k'V^{-1}k \qquad V=1/n[Z-Z]'[Z-Z]$$

Benefits of generalized distance of Mahalanobis : illustration

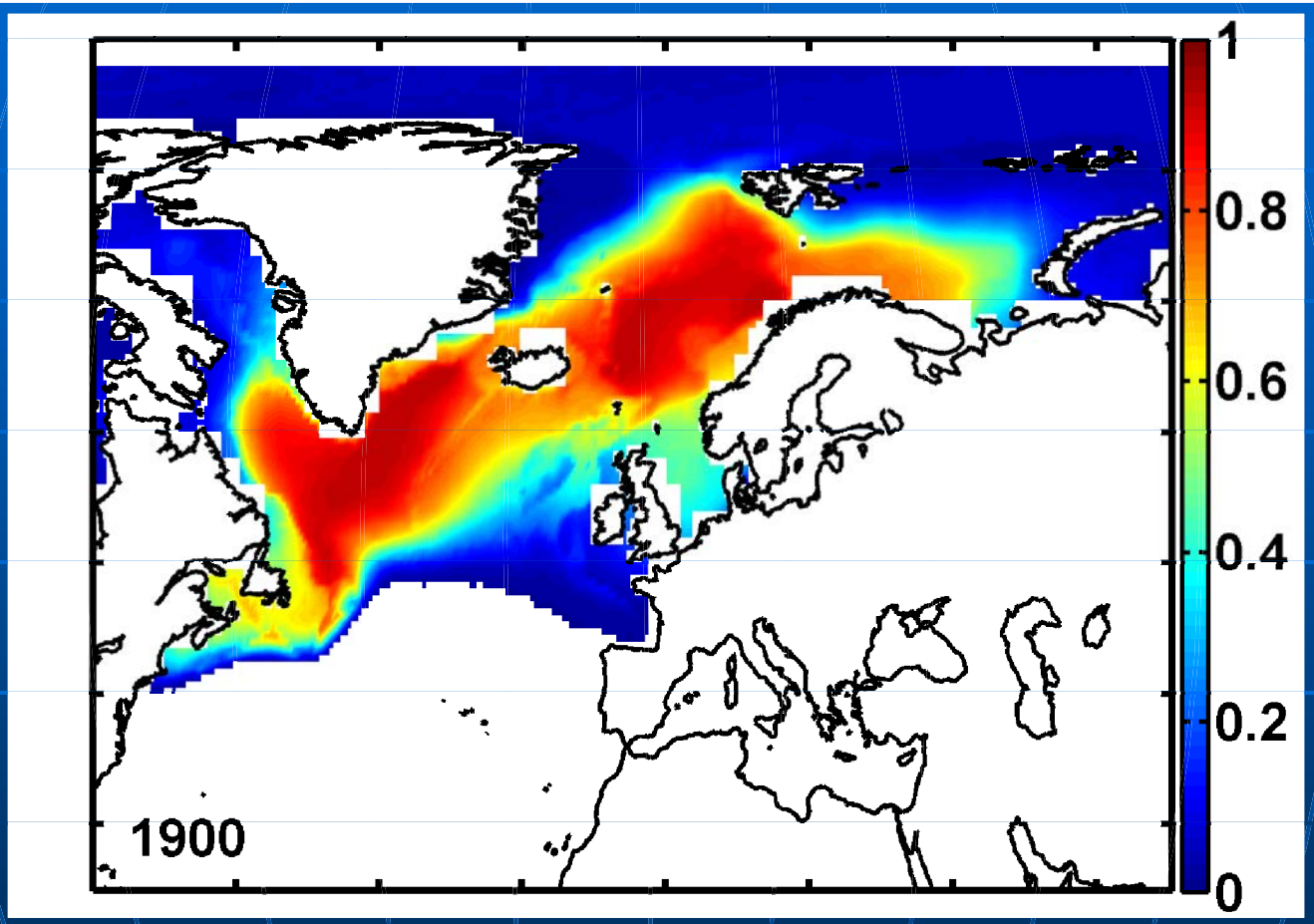


Real occurrences of C. finmarchicus obtained from CPR data



N=203 254 occurrences

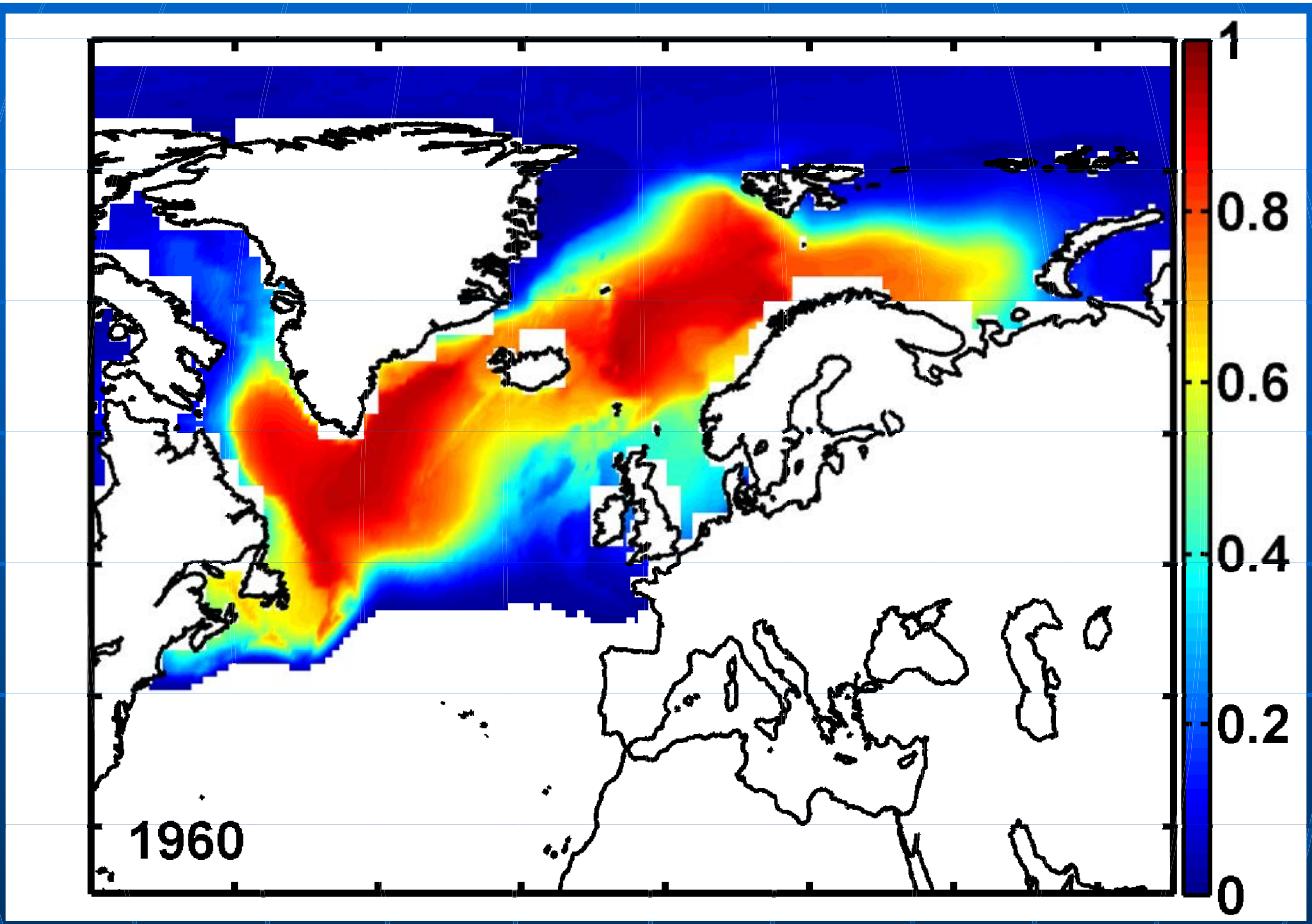
Modelised distribution of Calanus finmarchicus using the NPPEN model



(Lenoir et al. in prep.)

The past distribution can be drawn

Modelised distribution of Calanus finmarchicus using the NPPEN model



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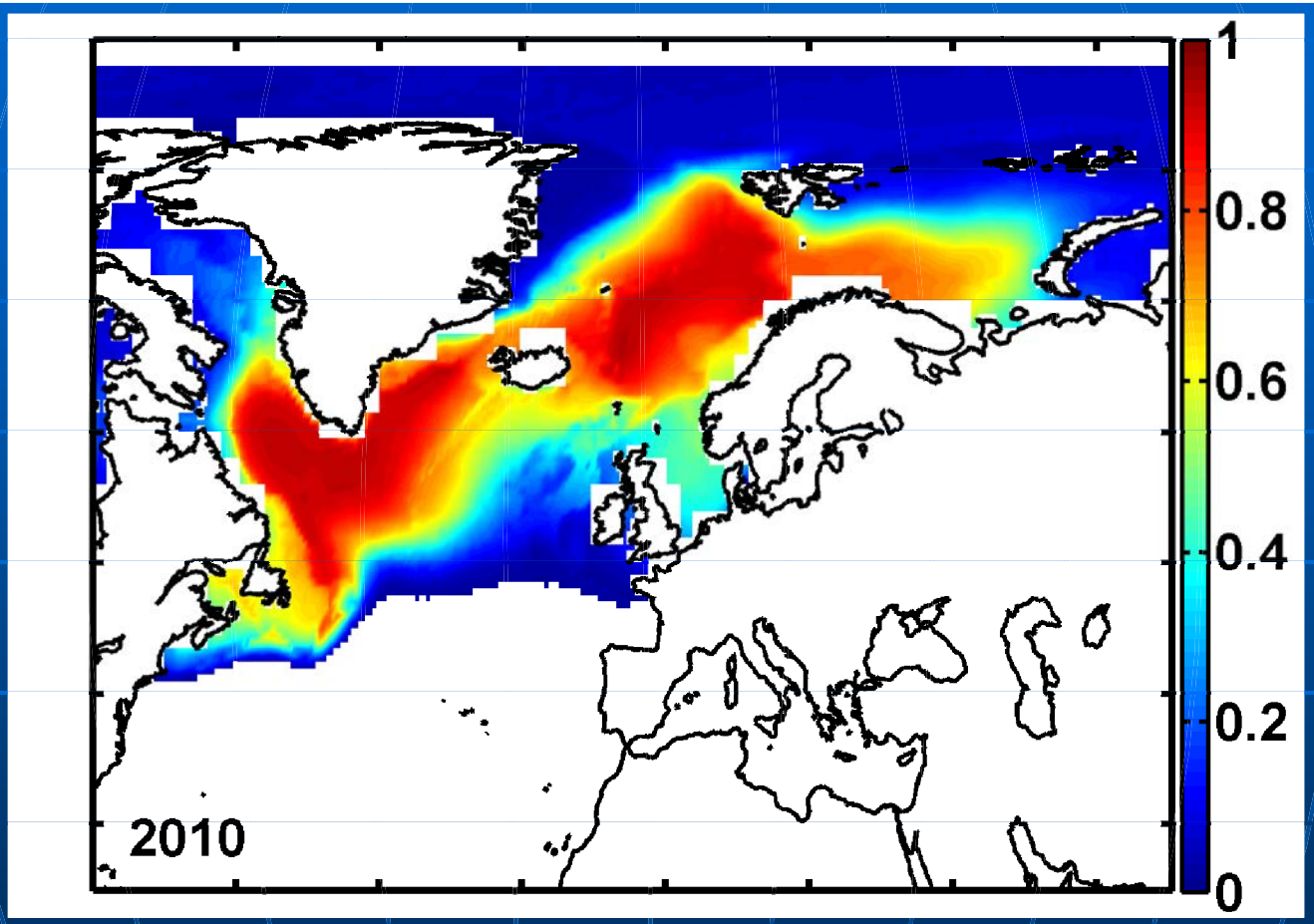
Modelised distribution of Calanus finmarchicus using the NPPEN model



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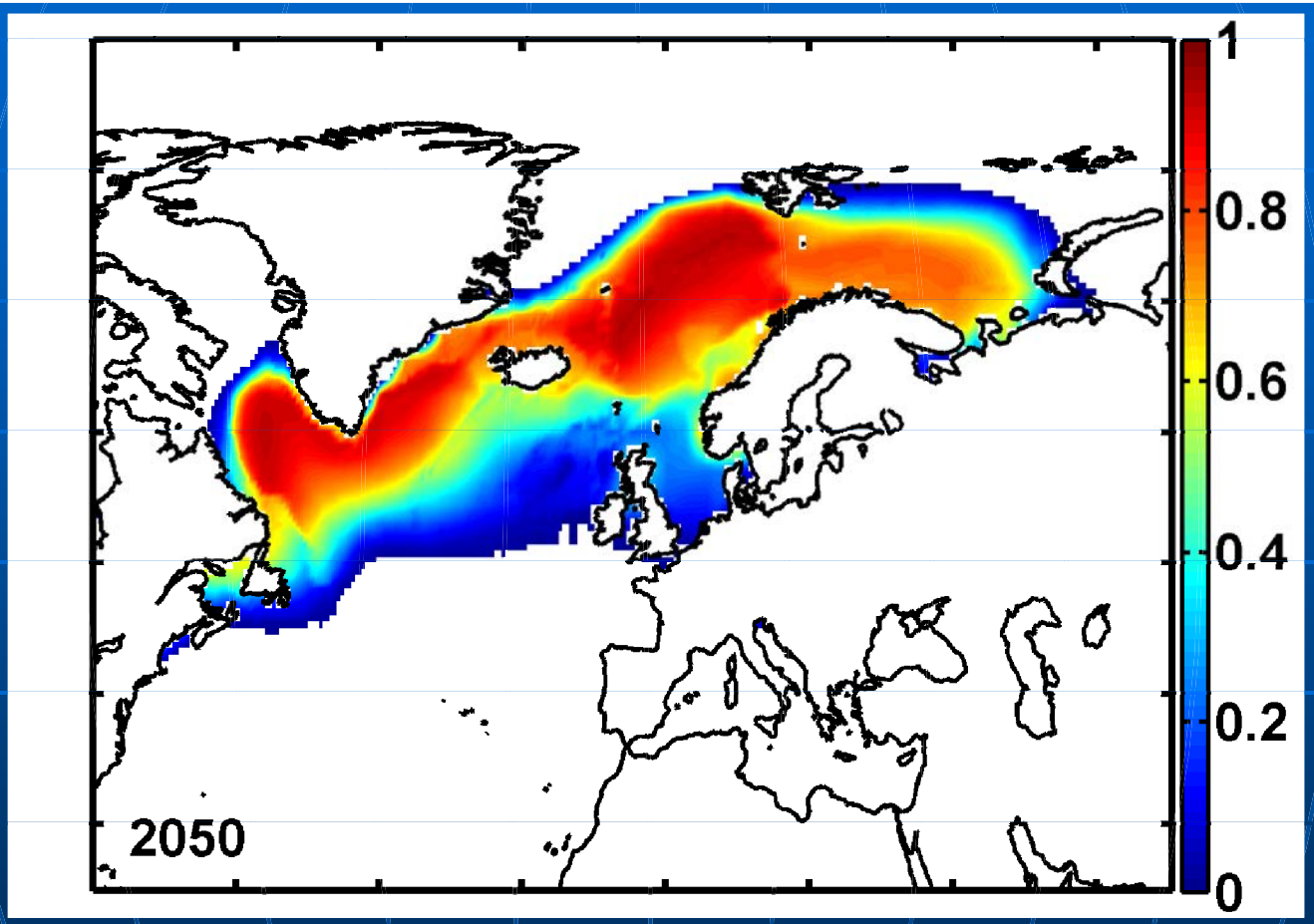
The present distribution can be drawn

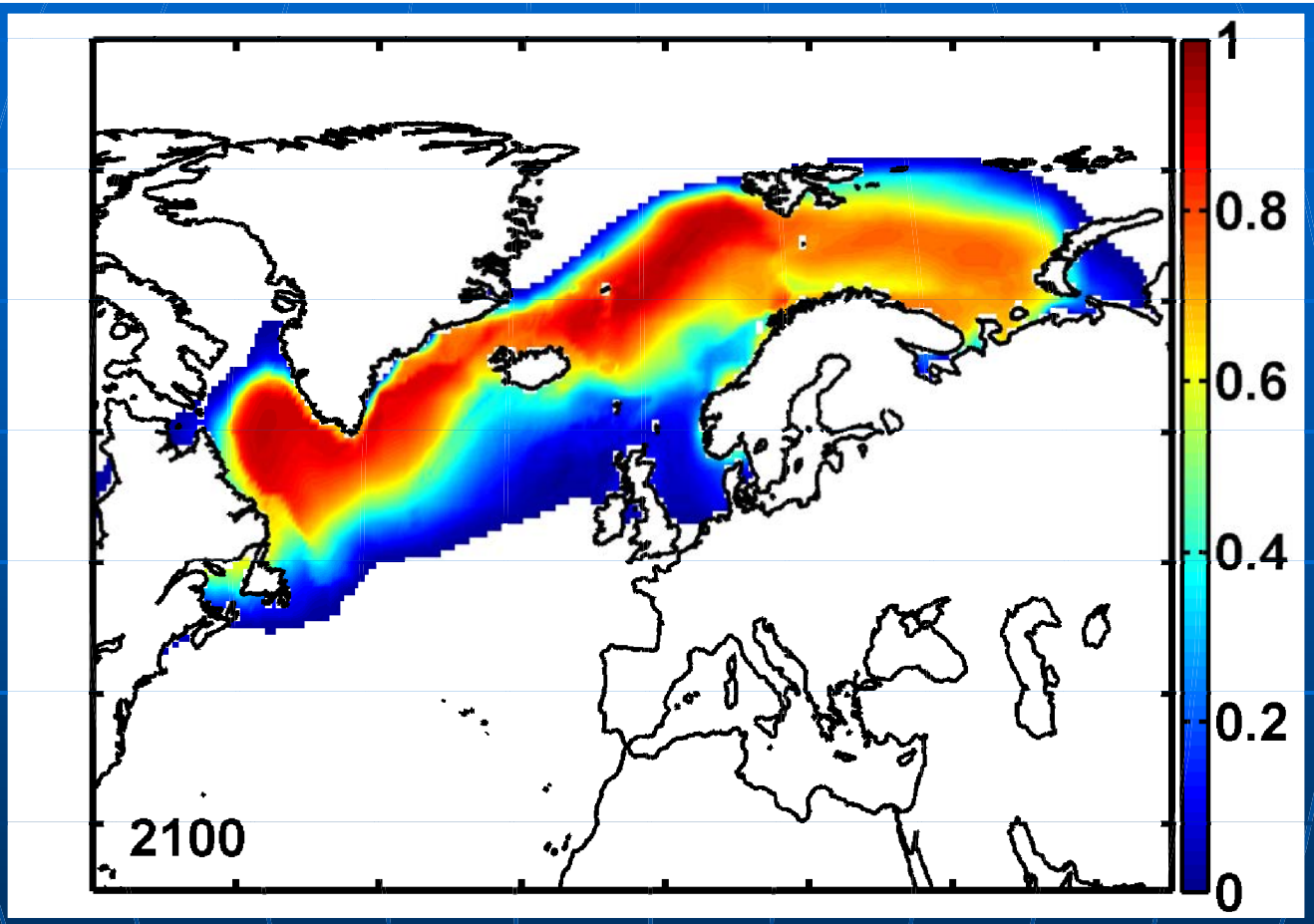
Modelised distribution of Calanus finmarchicus using the NPPEN model



(Lenoir et al. in prep.)

The potential futur distribution can be drawn (scenario ECHAM4 B2)

Modelised distribution of Calanus finmarchicus using the NPPEN model



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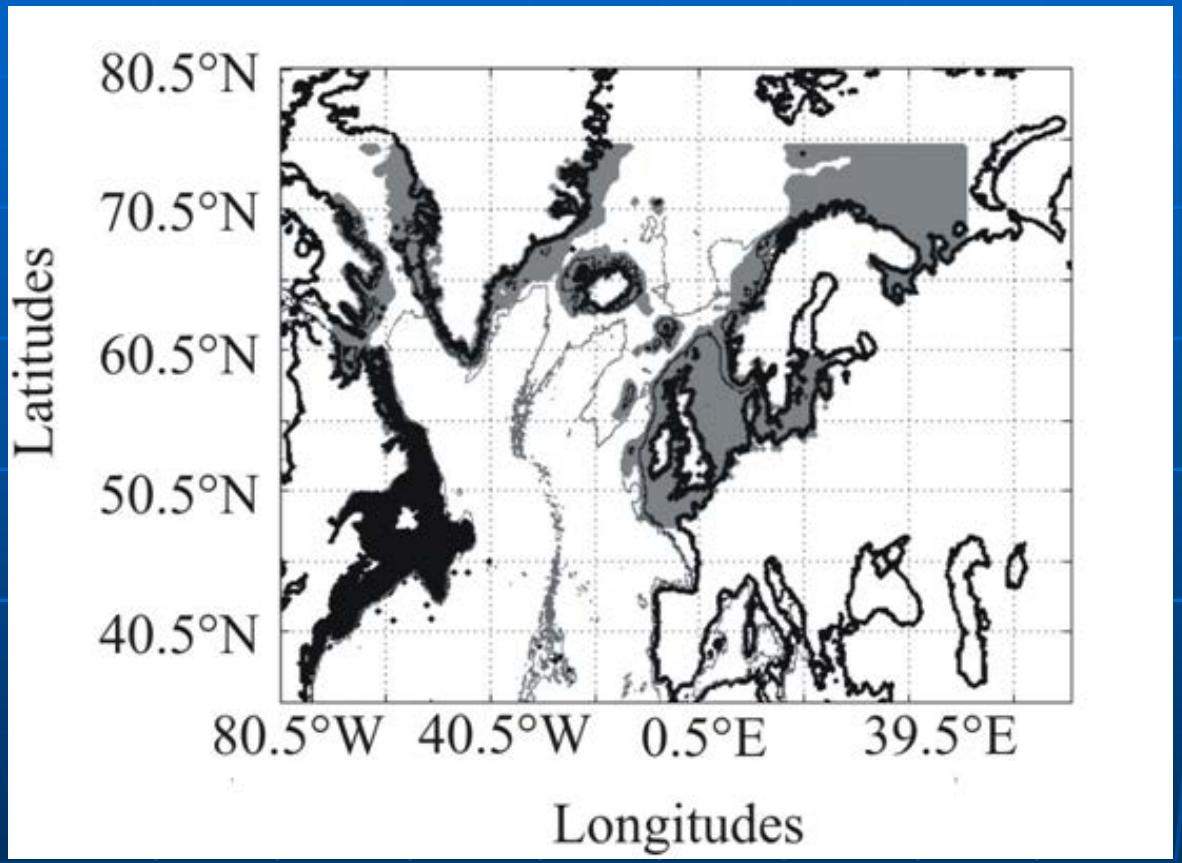
The potential futur distribution can be drawn (scenario ECHAM4 B2)

Climate-drived changes in distribution of C.finmarchicus and potential impact on the Atlantic cod



Sea surface temperature

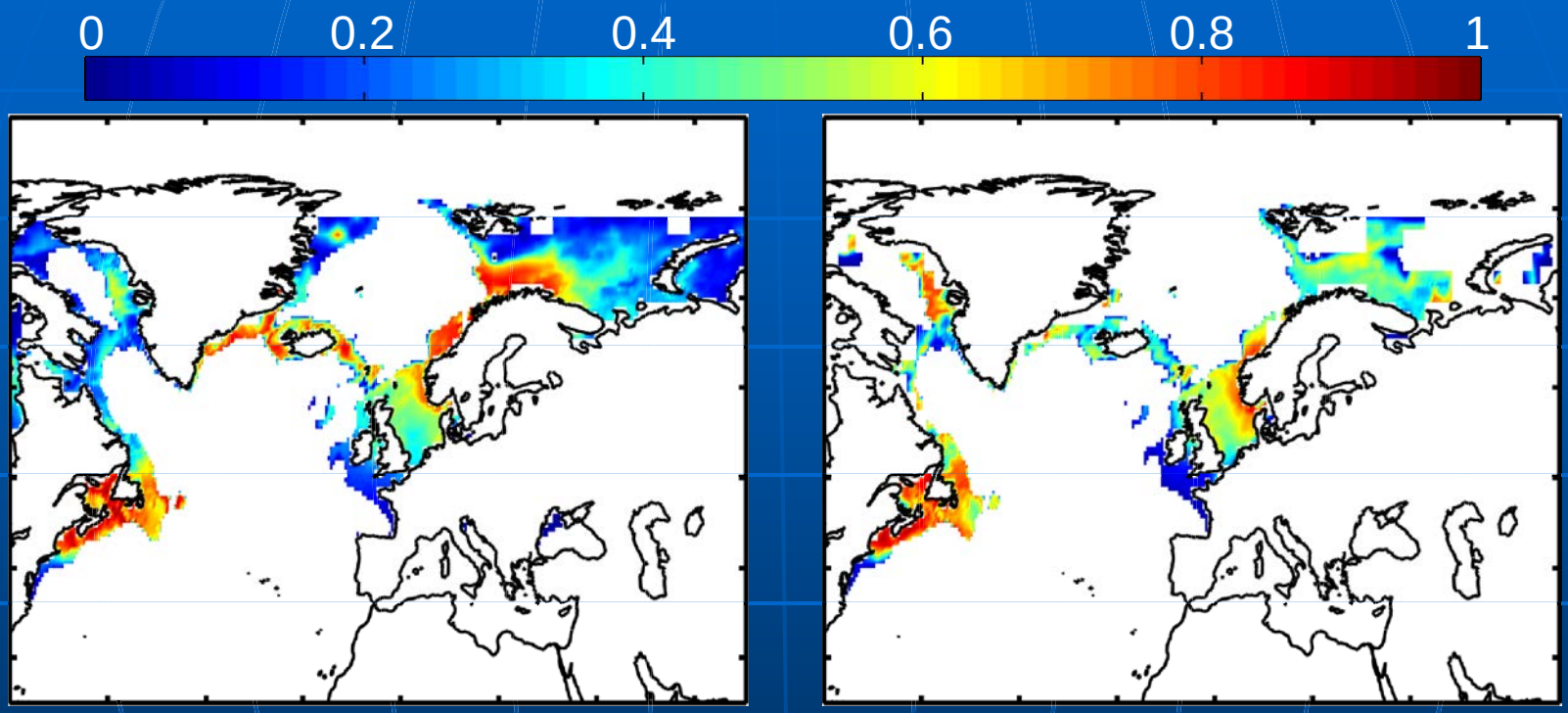
Bathymetry

Sea surface salinity

C. finmarchicus

Use of C. finmarchicus as new ecological niche factor

Modelisation of Atlantic cod biogeographical change : decade 1960s



Without *C. finmarchicus*

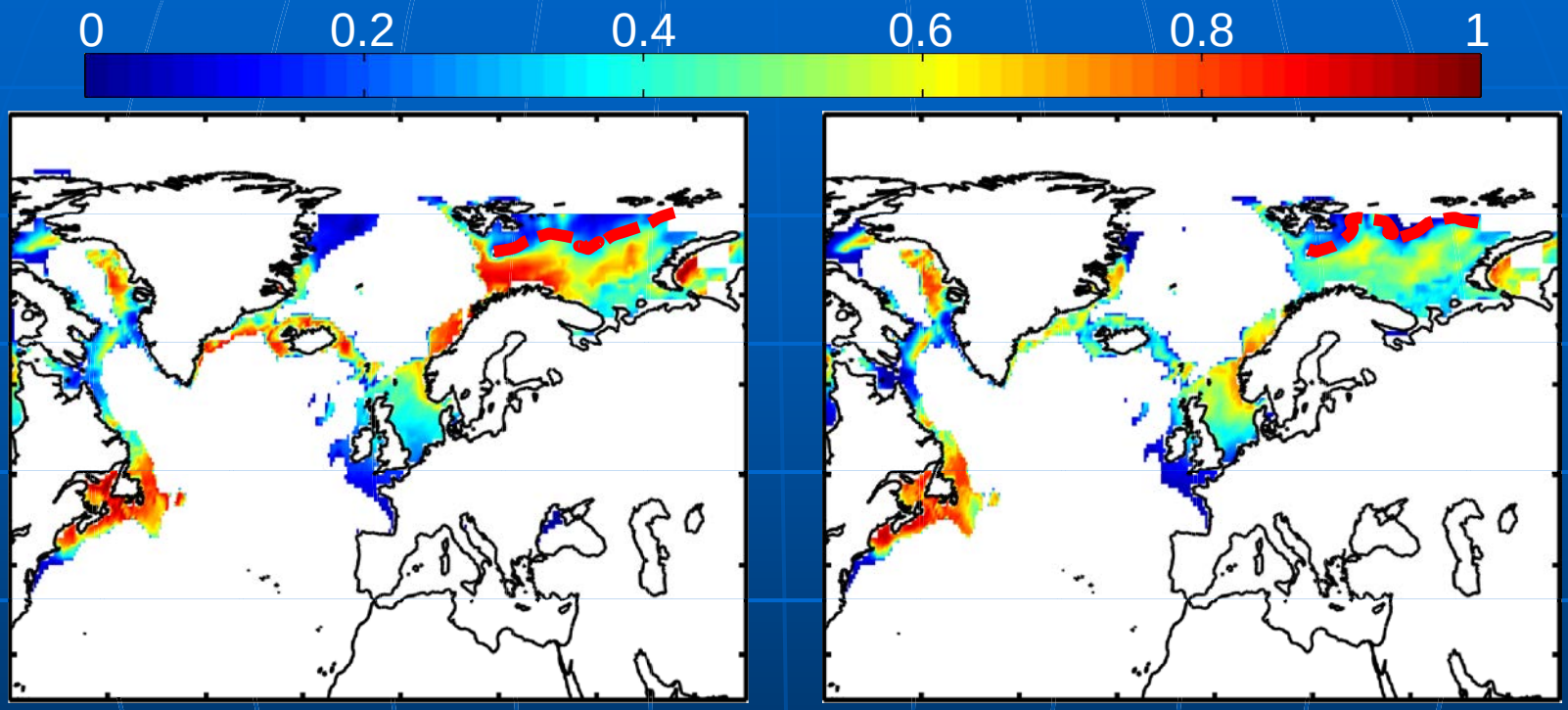
With *C. finmarchicus*

(Lenoir et al. in prep.)

Trophic amplification of the climate warming?

(Kirby & Beaugrand 2009 Proceedings of the Royal Society B)

Modelisation of Atlantic cod biogeographical change : period 2000-2006



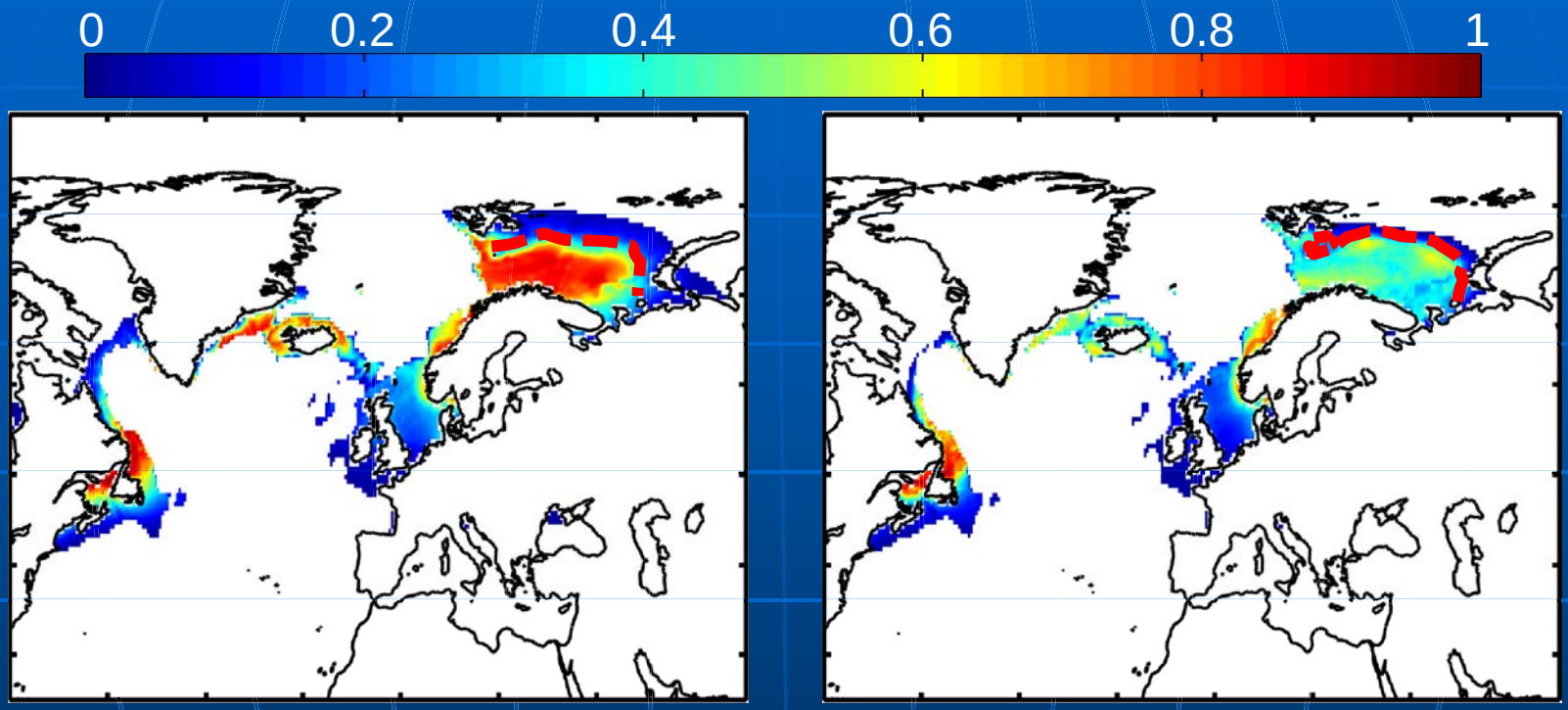
Without *C. finmarchicus*

With *C. finmarchicus*

(Lenoir et al. in prep.)

No clear evidence of trophic amplification

Modelisation of Atlantic cod biogeographical change : decade 2090s



Without *C. finmarchicus*

With *C. finmarchicus*

(Lenoir et al. in prep.)

Trophic amplification observed near the north boundary of the distribution

Conclusions

Climate warming

- Many biogeographical changes observed for some marine species have been attributed to climate warming

- Evidences of amplification of the climatic signal inside the foodweb and particularly near the limits of species distribution

Biogeographical change modelling

- The model NPPEN gives valid predictions of climate-induced changes in spatial distribution of calanoid copepod and marine fishes

- The ecological niche model constitutes a interesting way to assess and to predict the importance of trophic amplification of climate warming

Thank you for your attention