PICES 15th Annual Meeting,
Yokohama, Japan October 2006

The Response of North Atlantic Boundary Currents and their Ecosystems to Climate Variability and Change – Contrasts and Comparisons with the North Pacific

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ICES CIEM International Council for the Exploration of the Sea Conseil International pour l'Exploration de la Mer

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Outline

1. Introduction
    - N. Atlantic Boundary Currents
    - Ecosystem Aspects

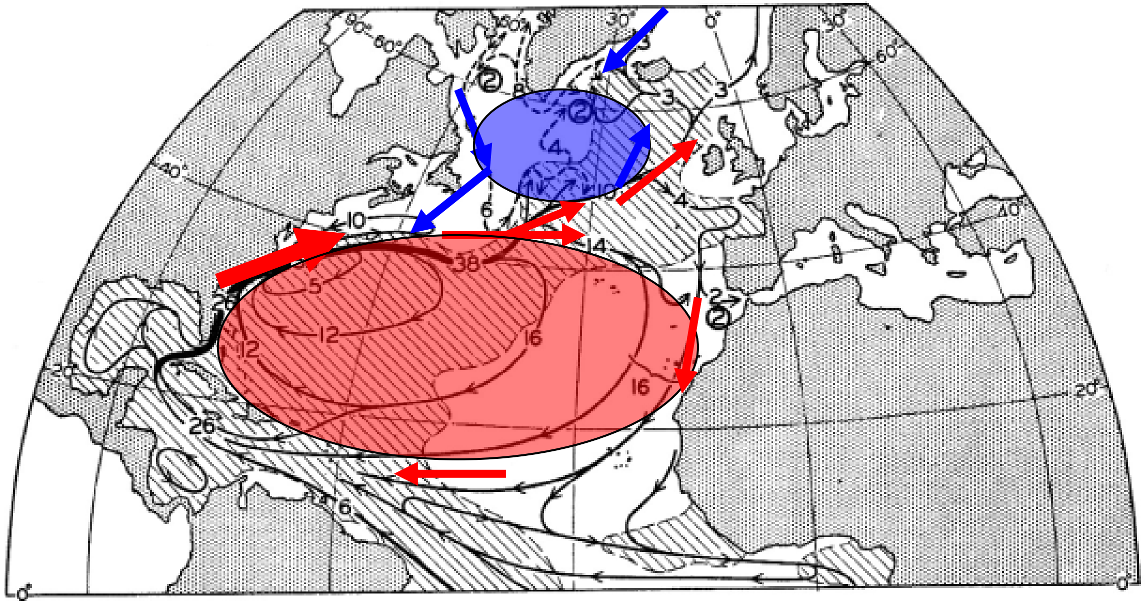
2. Past and Present Climates

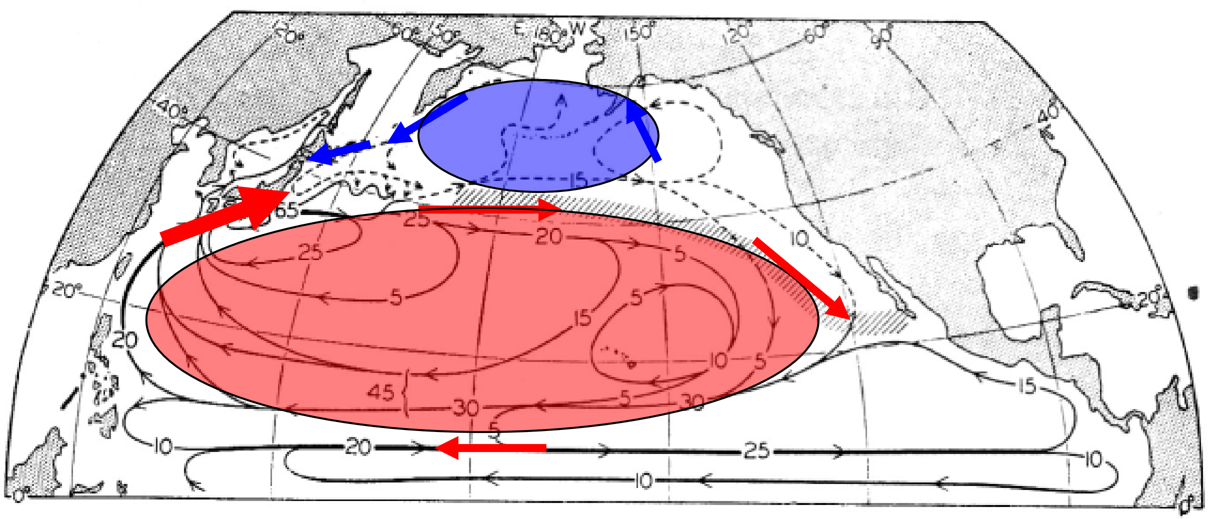
3. Future Climate

4. Climate and Fishing

5. Summary

Surface Circulation in the N. Atlantic and N. Pacific



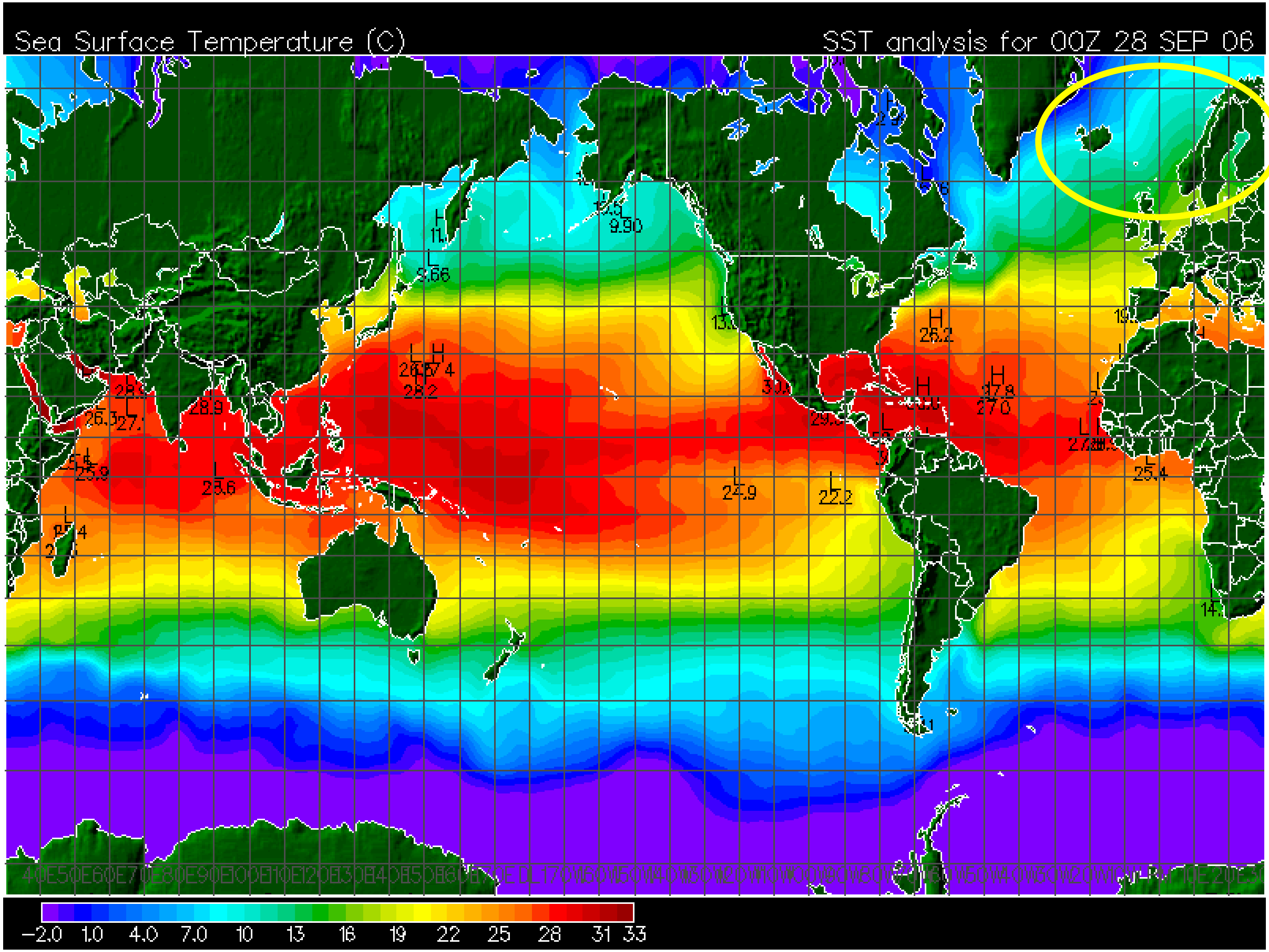


Subtropical Gyres

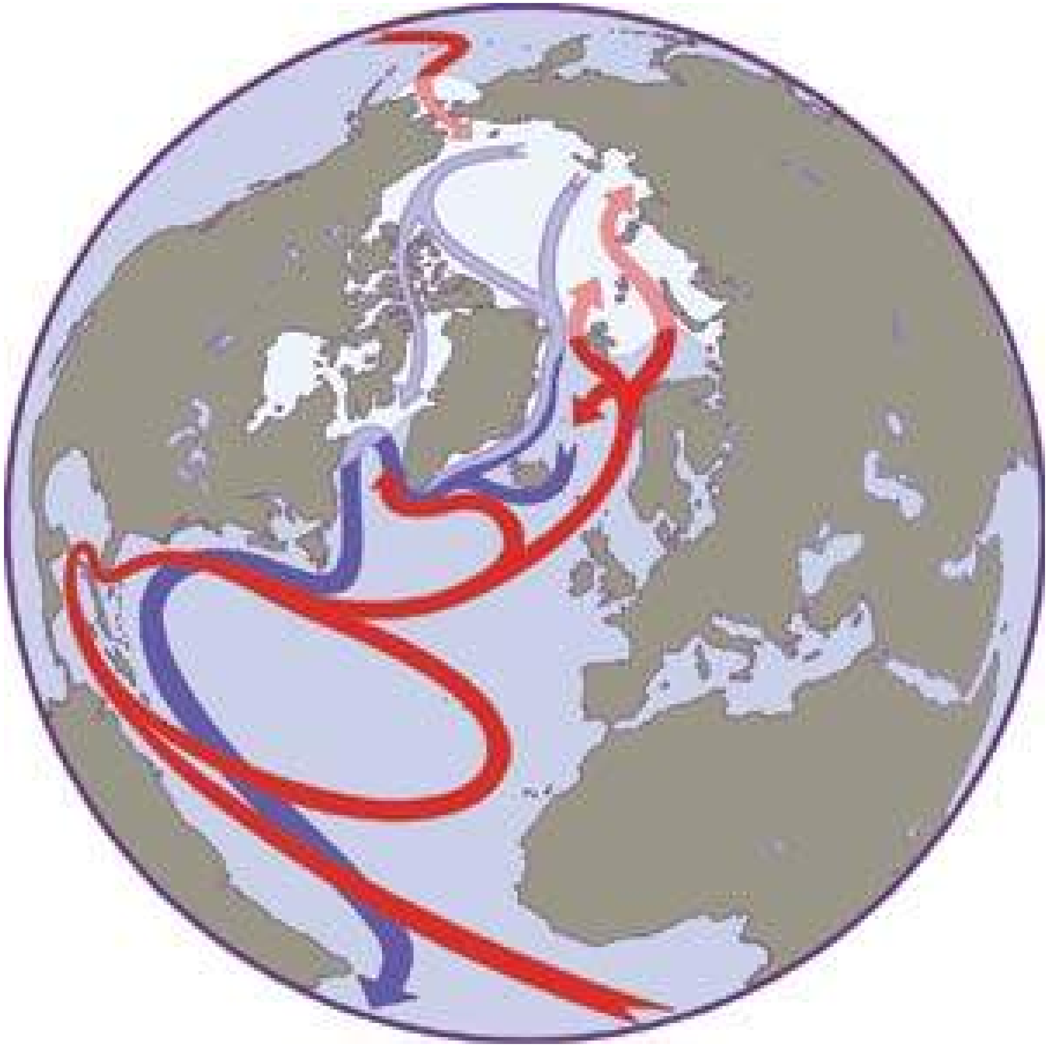
Subpolar Gyres

Sverdrup, Johnston & Fleming (1942)

SSTs (28 Sept 06)



Arctic Interactions



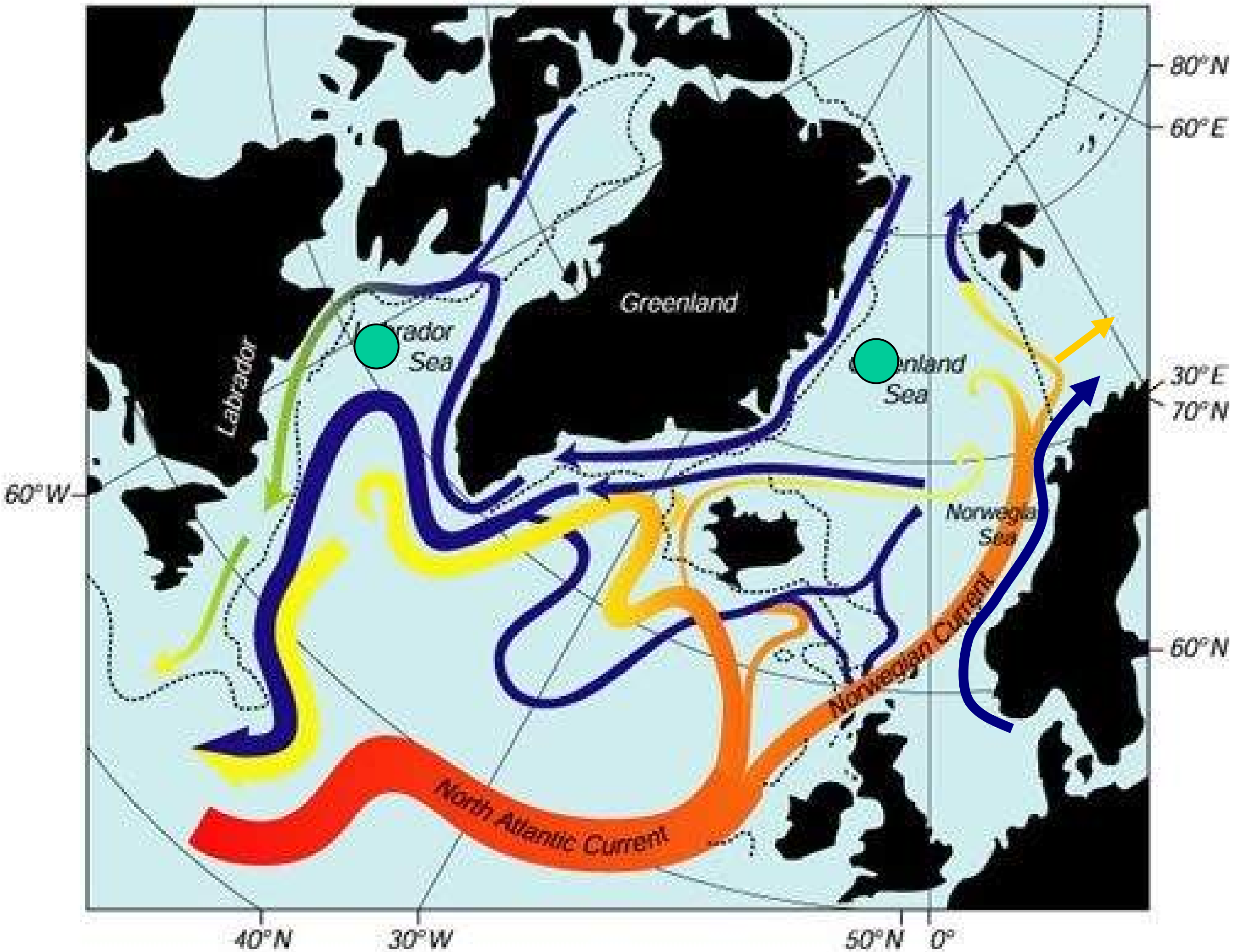
Pacific Inflow to Arctic (~1 Sv).

Atlantic inflow to Arctic (~3 Sv).

Arctic outflow (~4 Sv) is to the Atlantic.

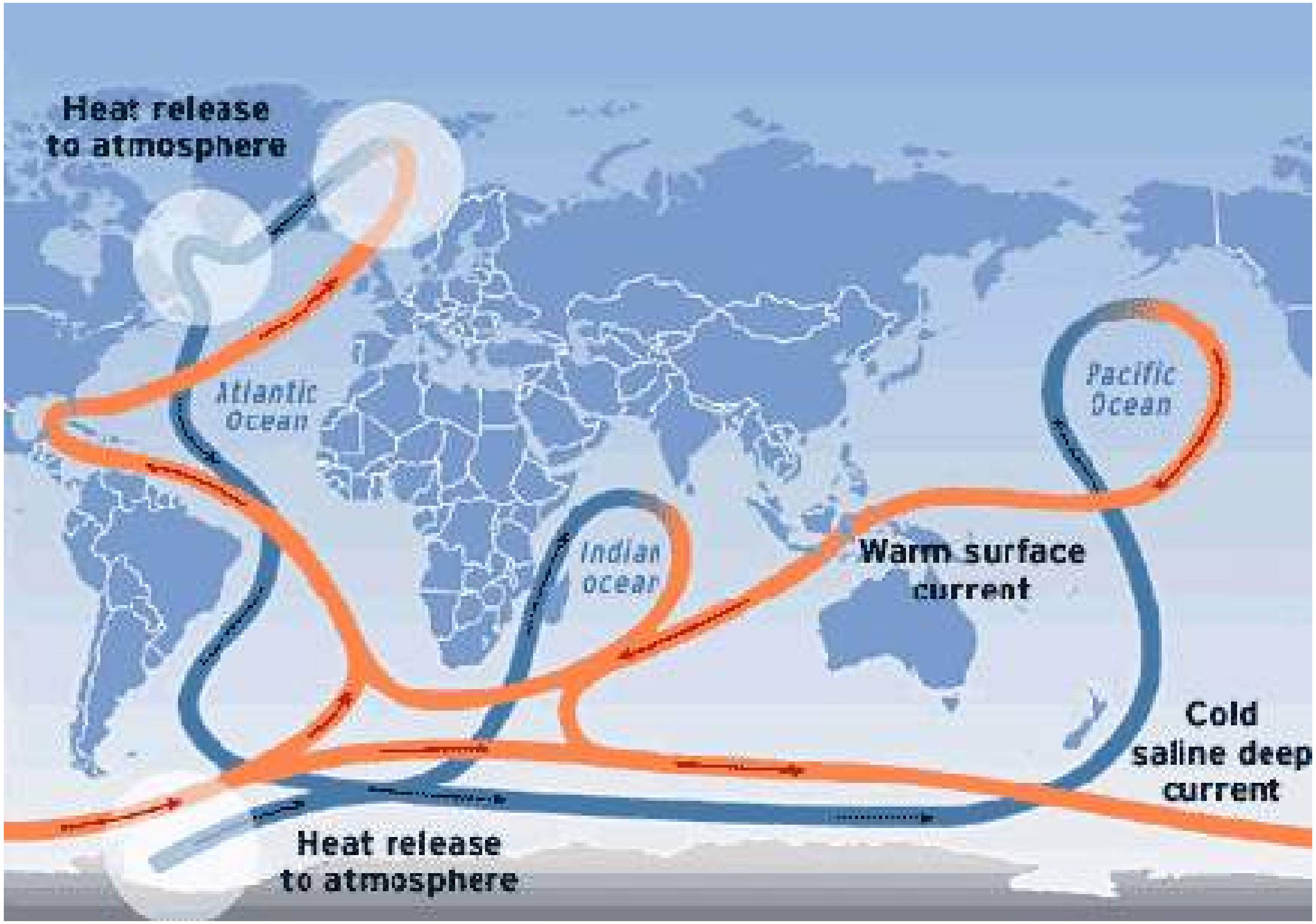
Hansen & Østerhus 2000

N. Atlantic Circulation

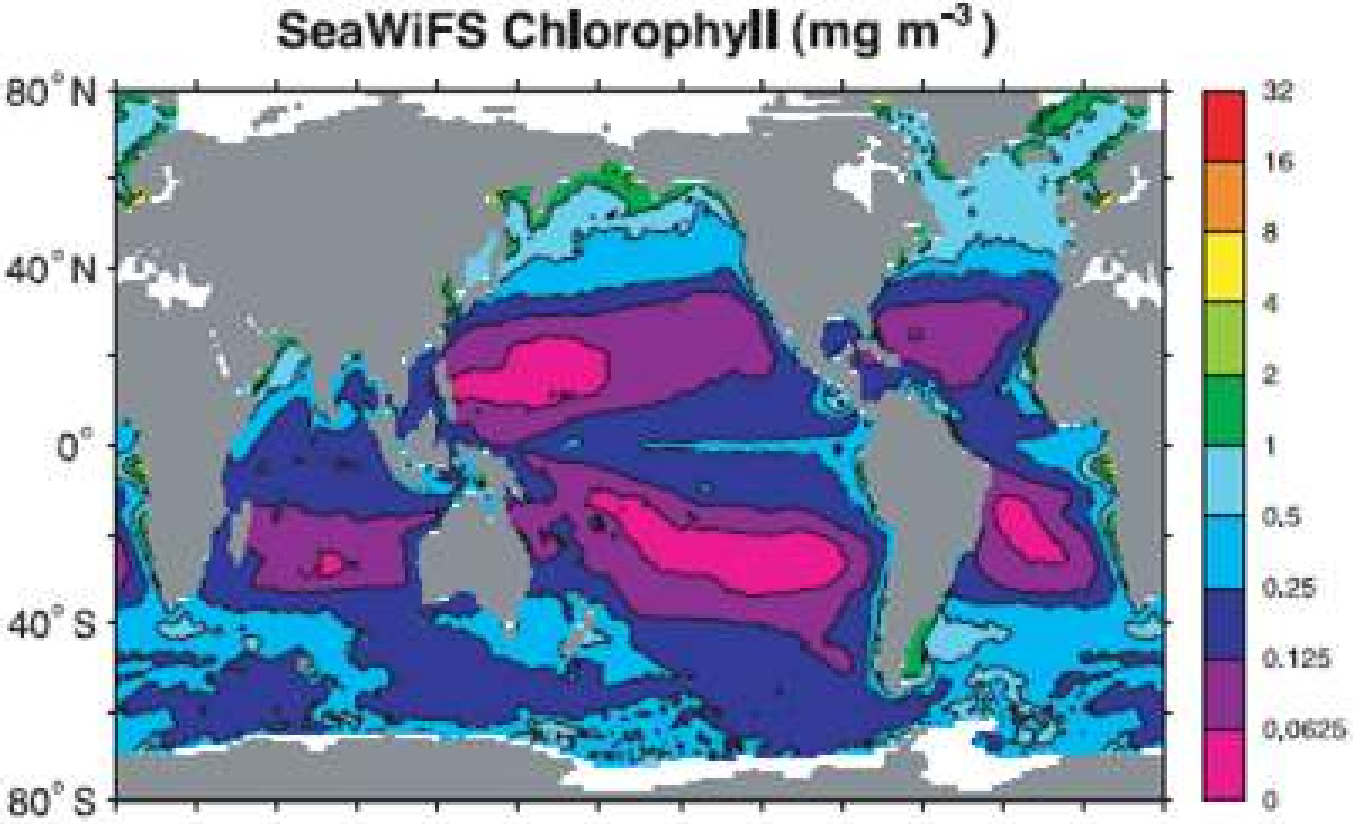


Sites of Convective Overturning

Atlantic Meridional Overturning Circulation (AMOC) and the Global Conveyor Belt



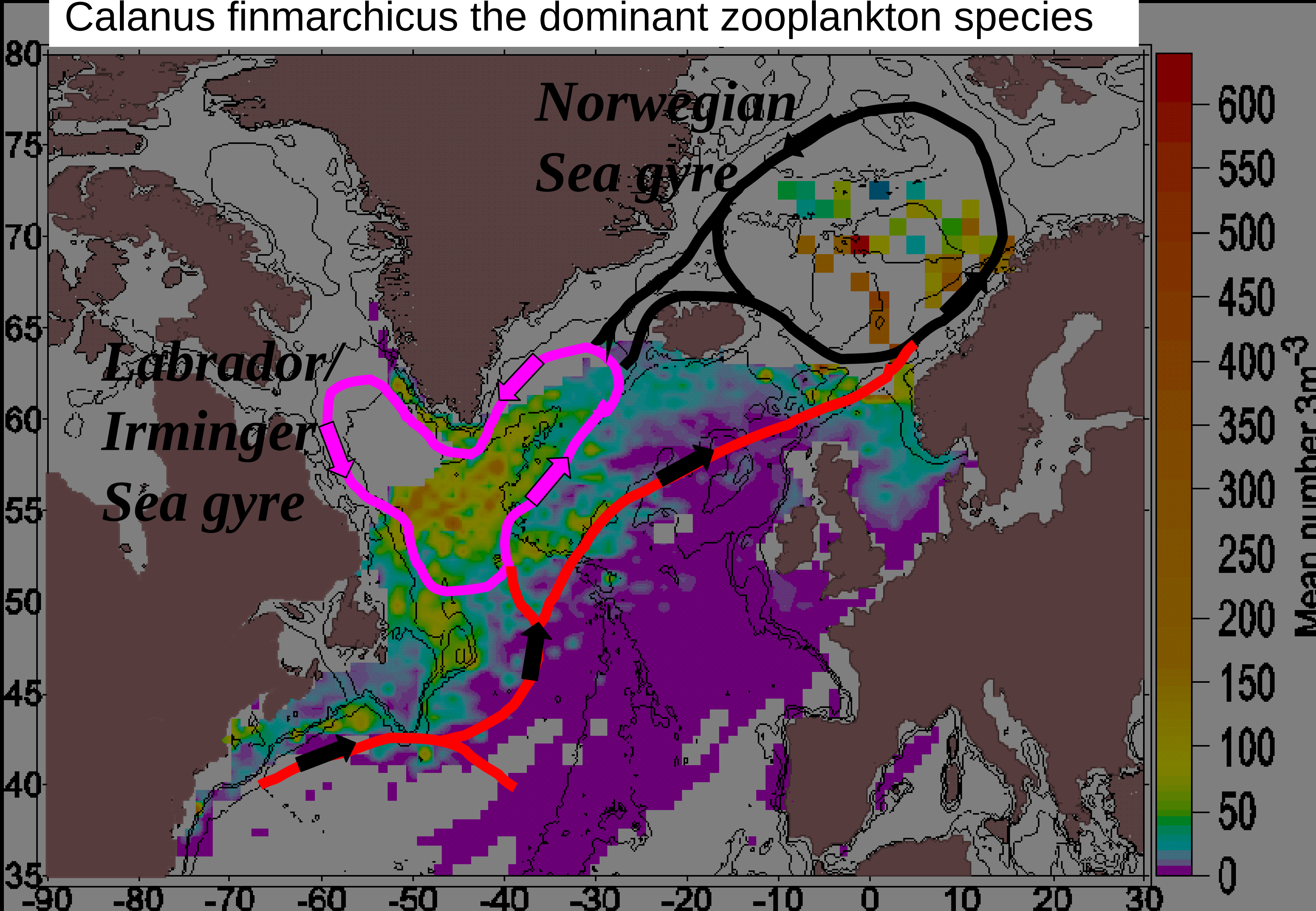
Ecosystem Characteristics



Relatively high ocean primary production
and strongly seasonal

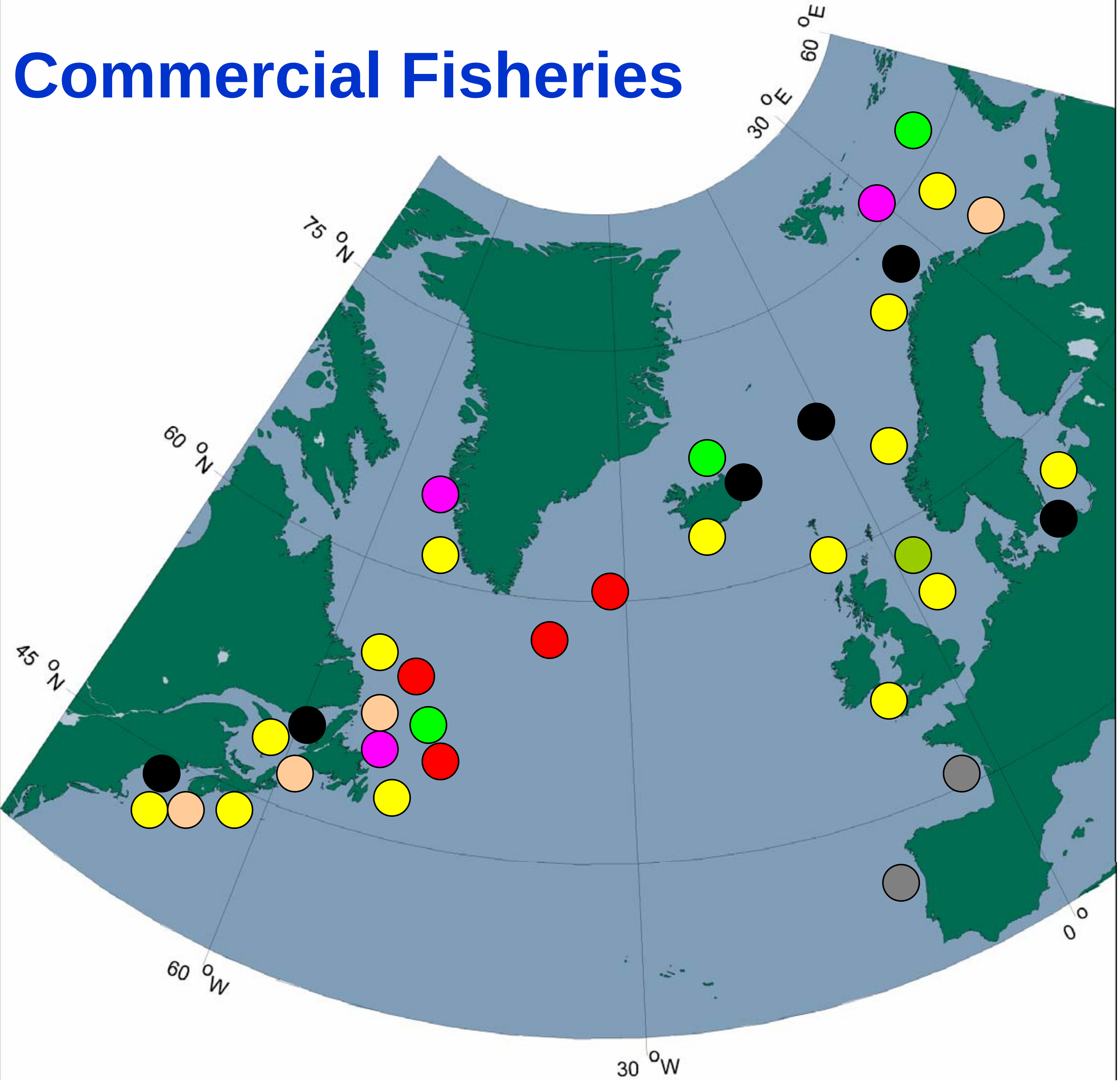
Sarmiento et al. 2004

Calanus finmarchicus the dominant zooplankton species



1950-1999 mean abundance

Commercial Fisheries



- Gadids
- Redfish
- Shrimp
- Crab, Lobster
- Capelin
- Herring
- Sardine, Anchovy

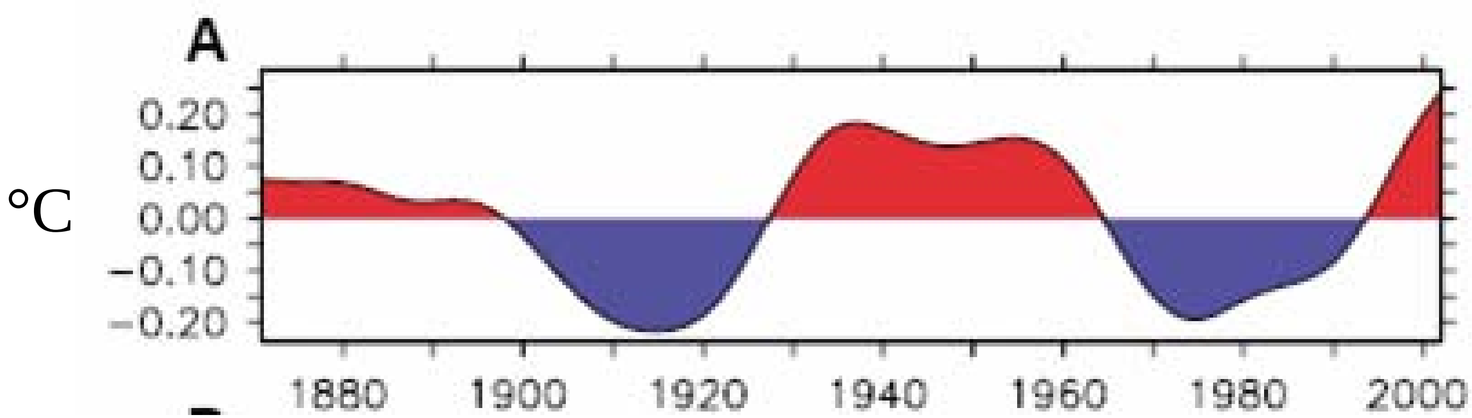
Most fisheries are on the continental shelves and slope and influenced by what happens to the boundary currents.

Past Variability

- Annual
- Decadal (North Atlantic Oscillation - NAO)
- Multidecadal (Atlantic Multidecal Oscillation - AMO)

The ecosystem response differs depending upon the frequency of the forcing.

Atlantic Multidecadal Oscillation (AMO)

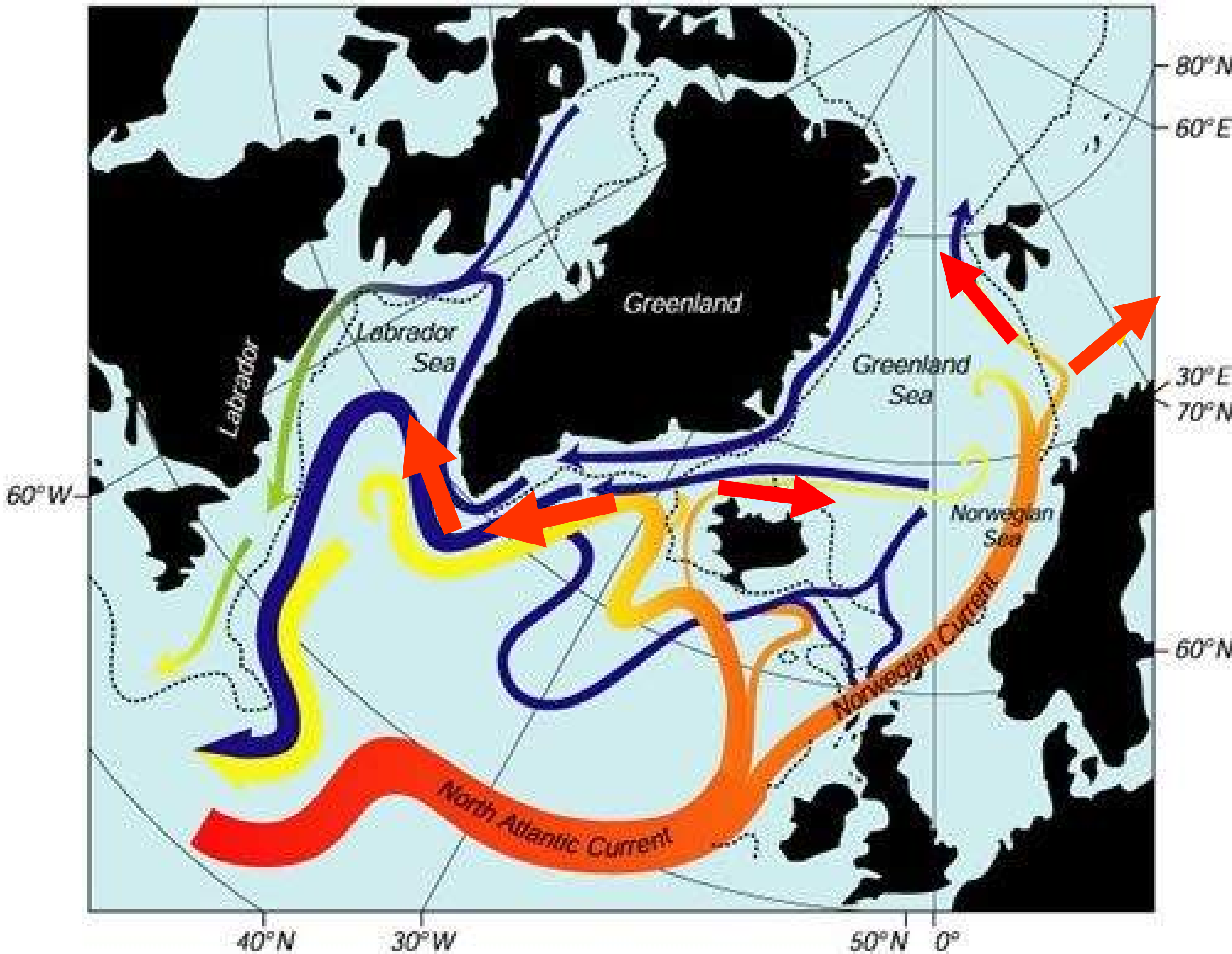


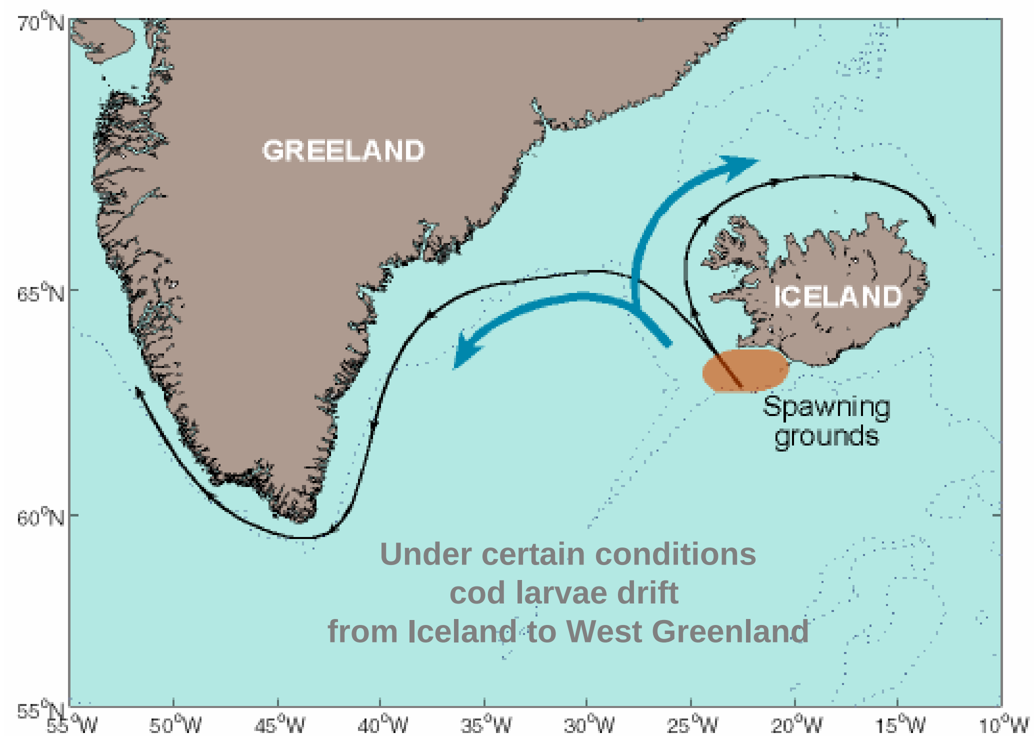
Low-passed filtered North Atlantic SSTs

Warm period in the 1930s-1960s produced large ecosystem responses

Sutton and Hodson, 2005

Not only was there increased heat from the atmosphere but there was increased transport of warm water into the Barents Sea, north along Svalbard, along northern Iceland and into the Labrador Sea.

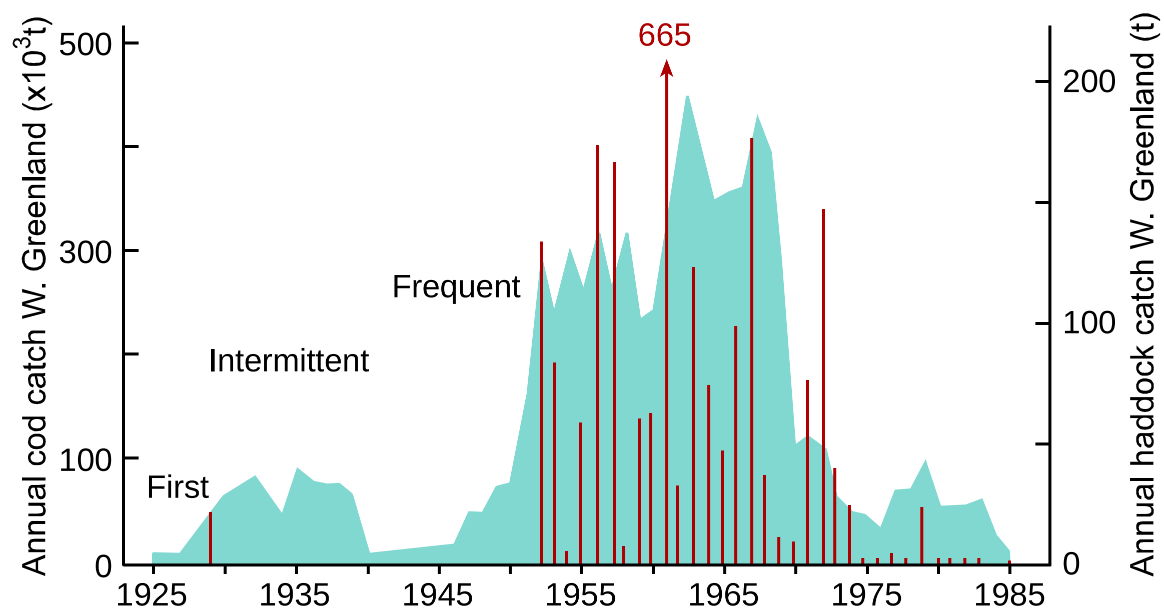




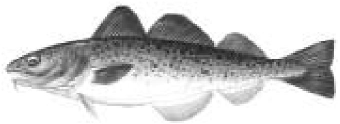
What were some of ecosystem impacts?

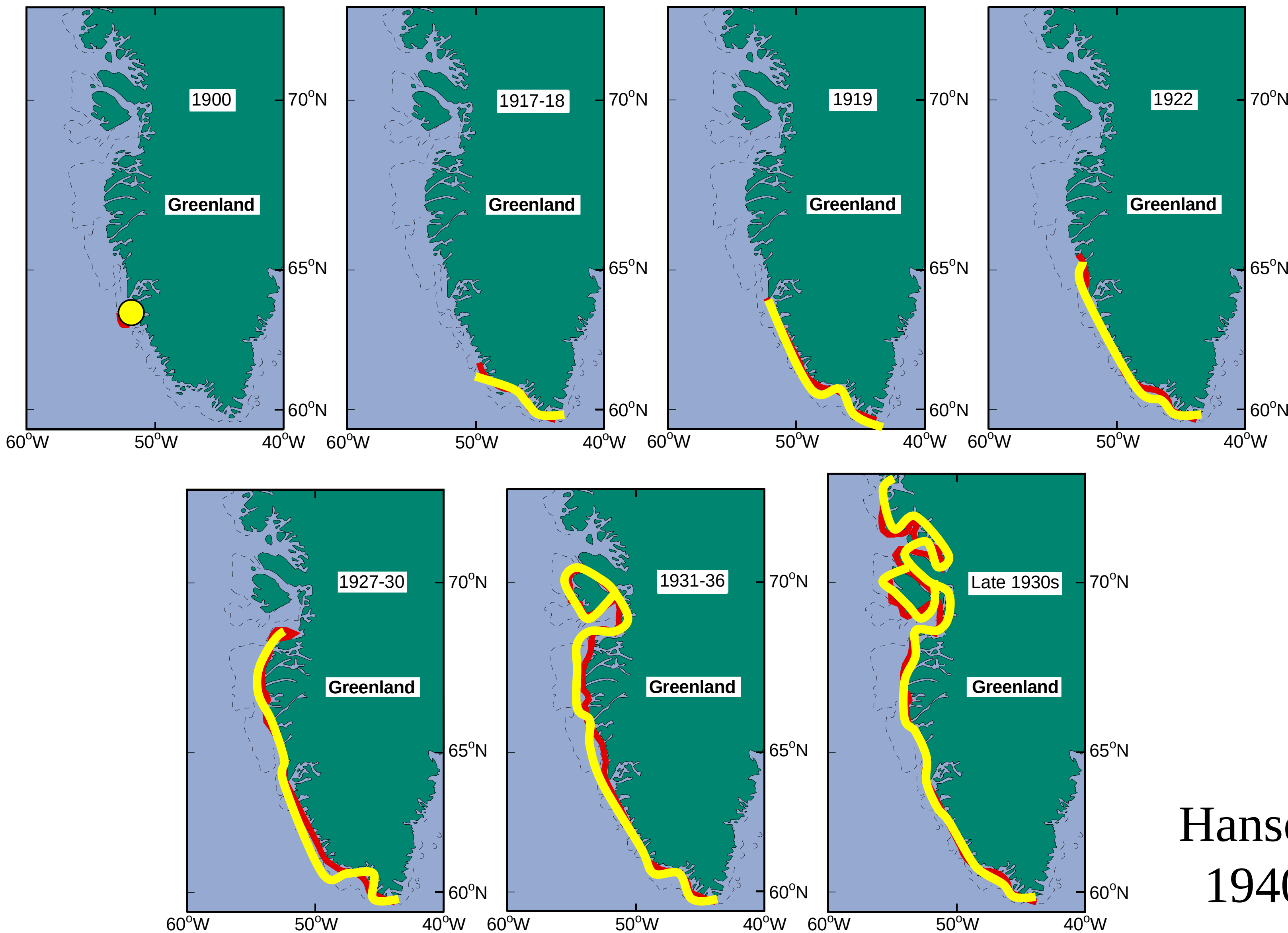
West Greenland-Iceland Connection for Atlantic cod

Conditions in 1920s-1960s resulted in the drift of larvae from Iceland to West Greenland and their survival.



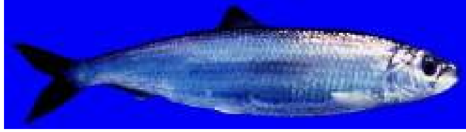
Atlantic cod moved northward by 1500 km in response to warming.

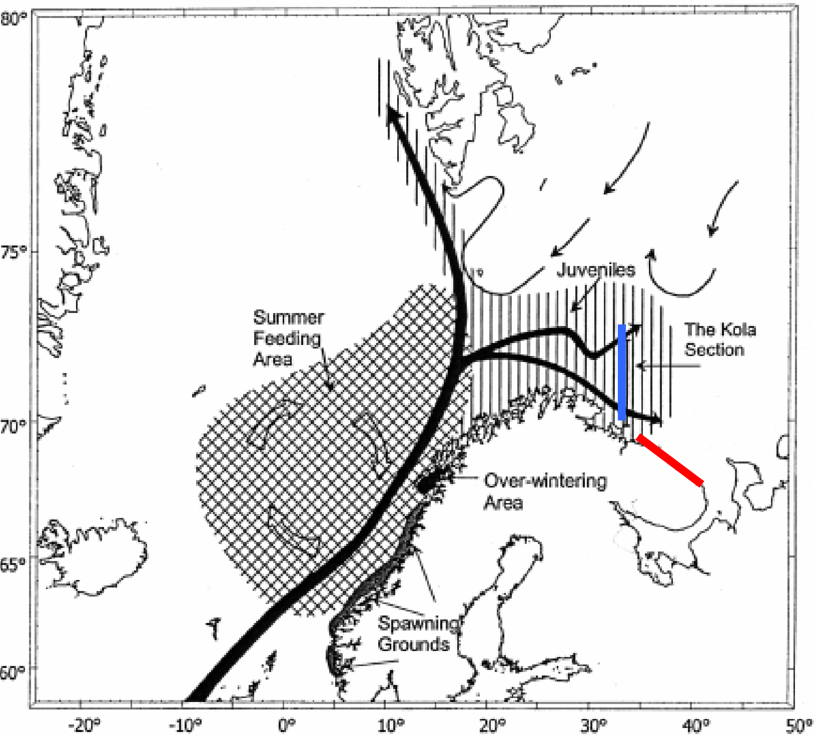




Hansen 1940

Atlantic Herring

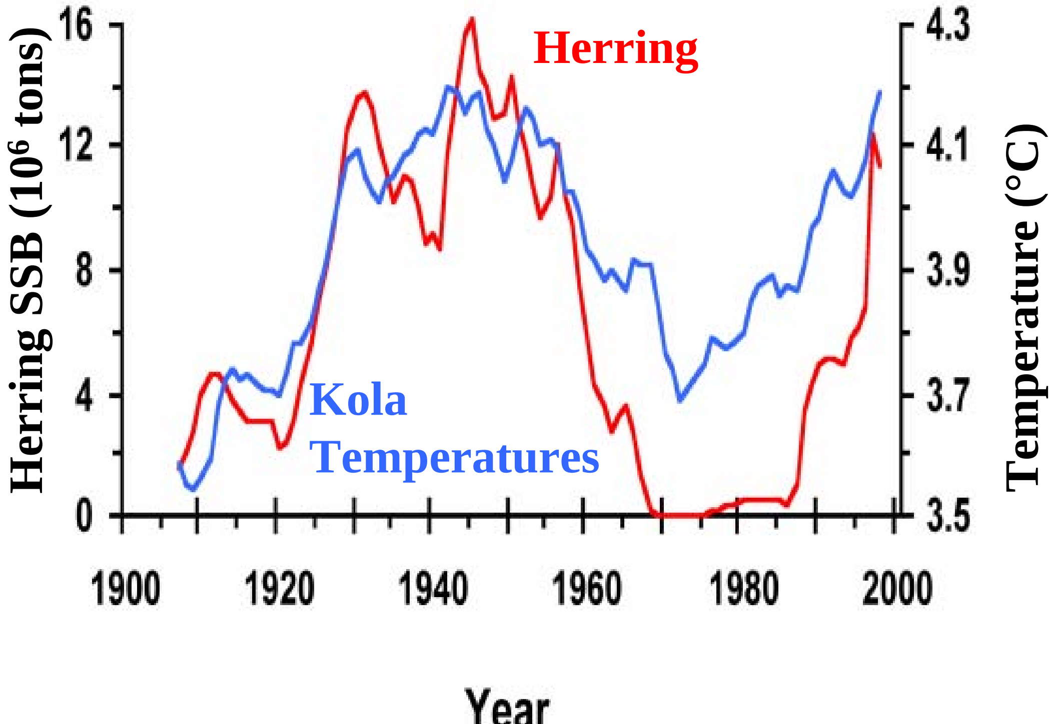


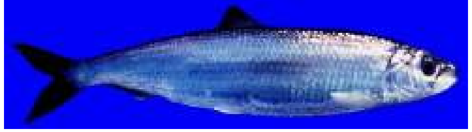


The population of Norwegian spring spawning herring rose dramatically in parallel with the temperatures as recorded in the Kola Section.

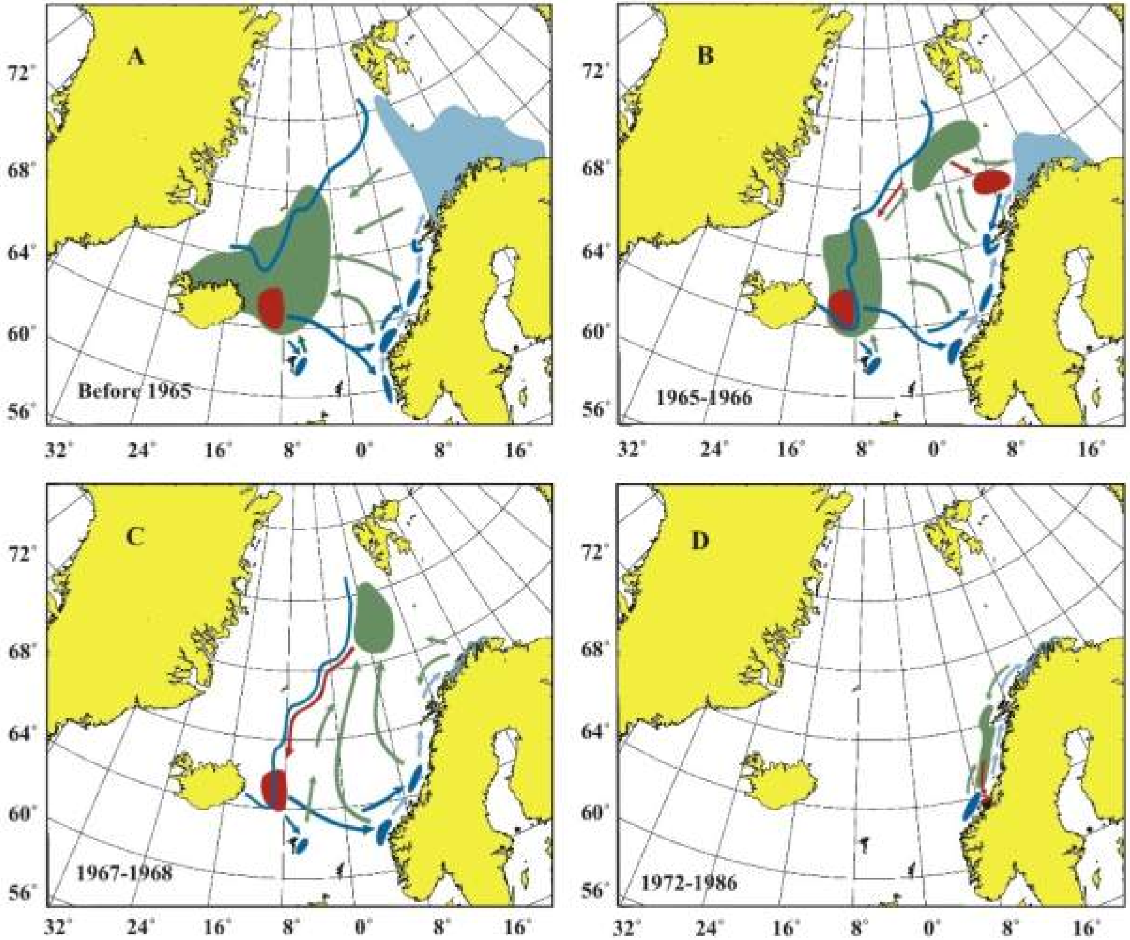
A herring fishery developed along the Murman coast where previously this species was almost unknown.

Toresen and Østvedt, 2000





Atlantic Herring

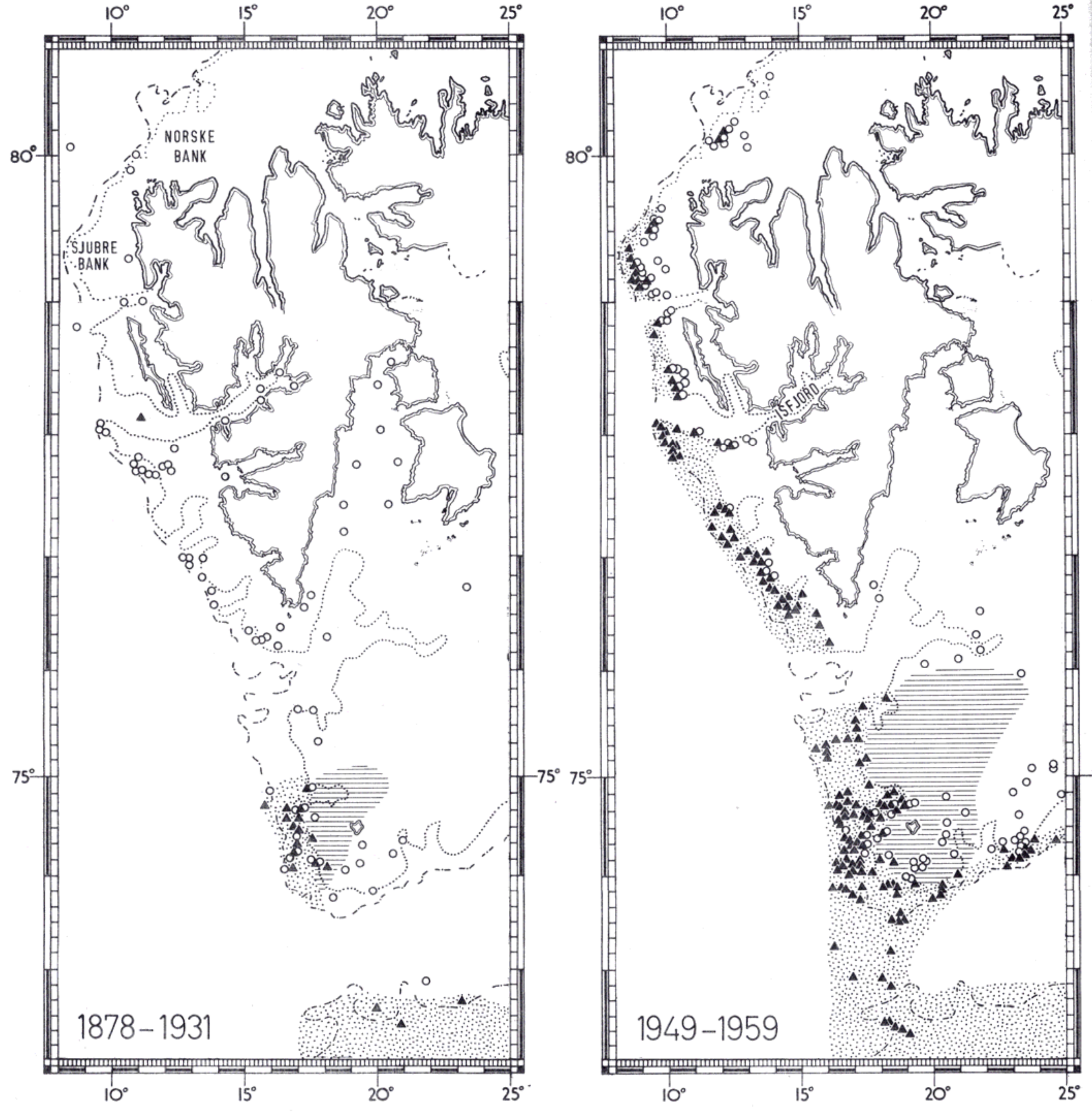


Changes of migration routes, feeding and wintering areas of Norwegian spring spawning herring during the latter half of the twentieth century.

Dark blue: Spawning areas; Light blue: Juvenile areas; Green: Main feeding areas; Blue arrows: Spawning migrations; Green arrows: Feeding migrations; Red arrows: Spawning migrations.

Vilhjalmsson, 1998

Comparison of benthos prior to the 1930s with those of the 1950s indicated that Atlantic species spread northward by approximately 500 km.



Benthic Species

○ **Arctic**

▲ **Atlantic**

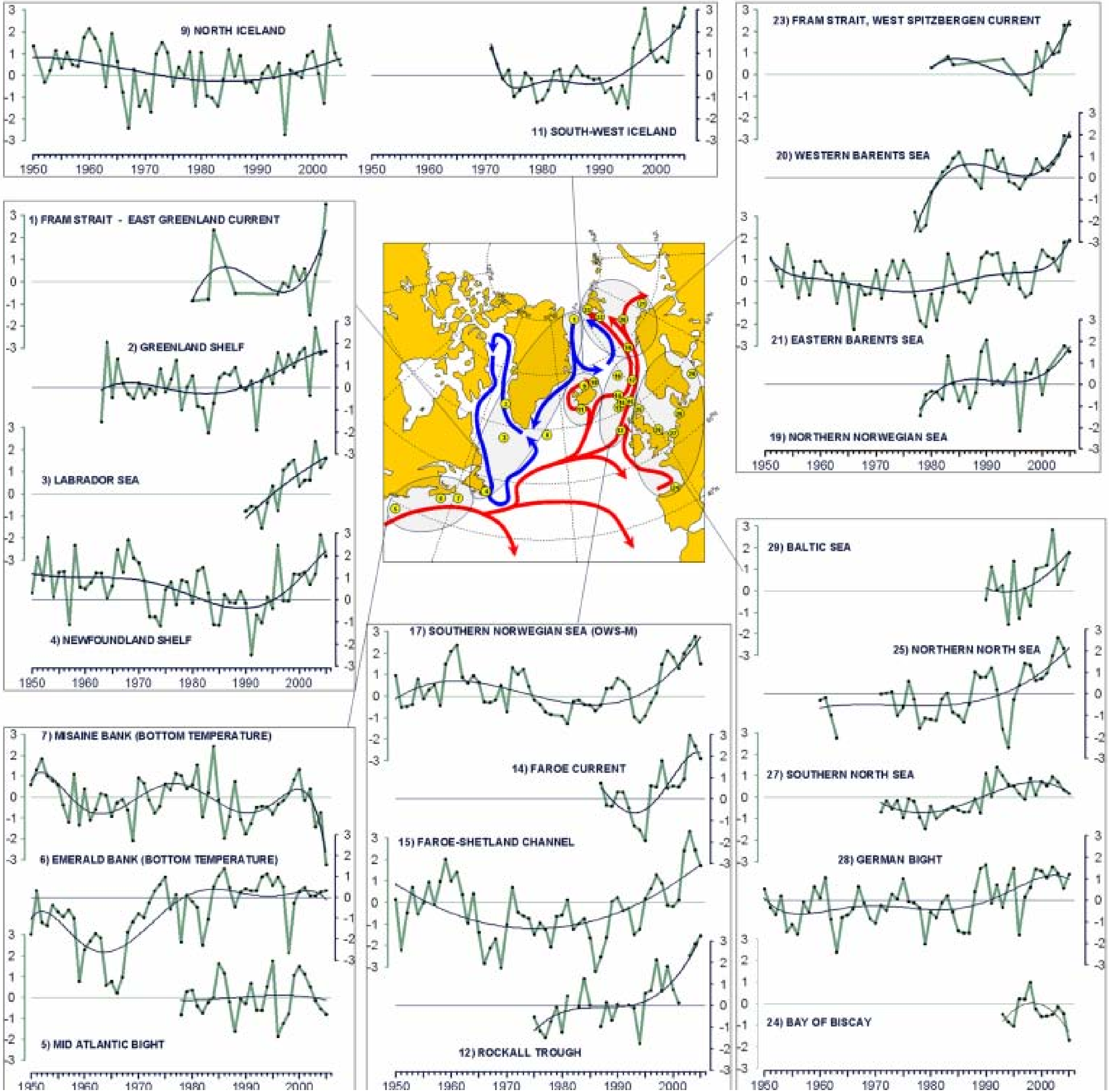
Blacker, 1957

Bottom-Up Response

- Available phytoplankton and zooplankton information suggests that the increased fish production was due to increases in phytoplankton and zooplankton production.
- Increased phytoplankton production was due to a combination of less sea ice, northward spread of Atlantic waters with higher nutrients and faster turnover rates.
- Increased zooplankton production is thought to be due to a combination of higher primary production and faster turnover rates.

Recent Changes

Warming conditions in the boundary currents of the North Atlantic during 1990s and into 2000s.



What are some of the effects of this on ecosystems?

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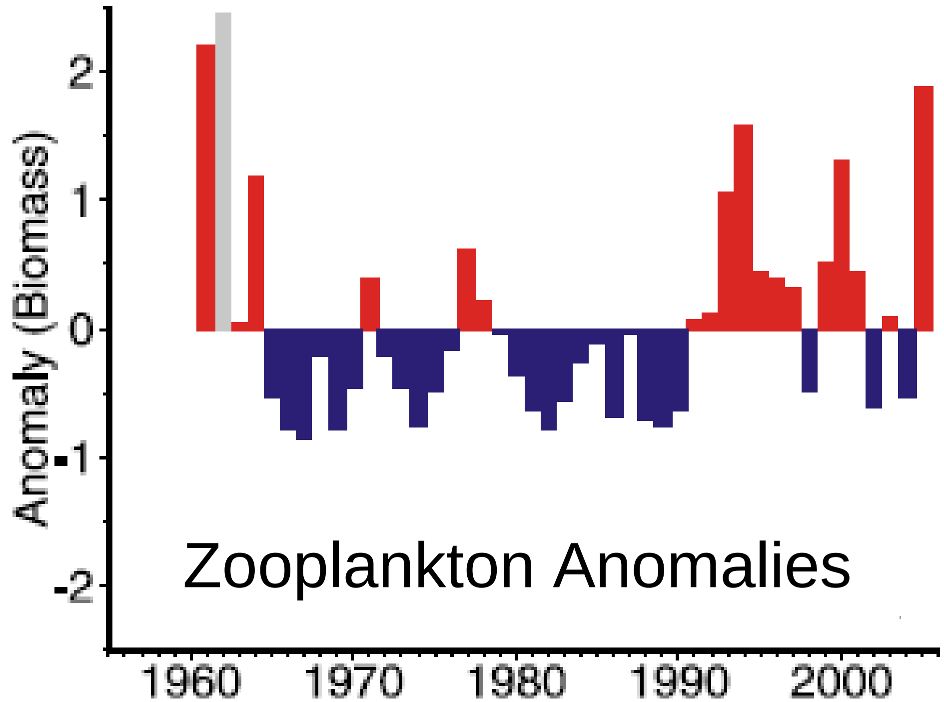
Response to recent warming

Off northern Iceland and in the Barents Sea there has been higher zooplankton biomass accompanying the increase in the Atlantic Water transport to the region.



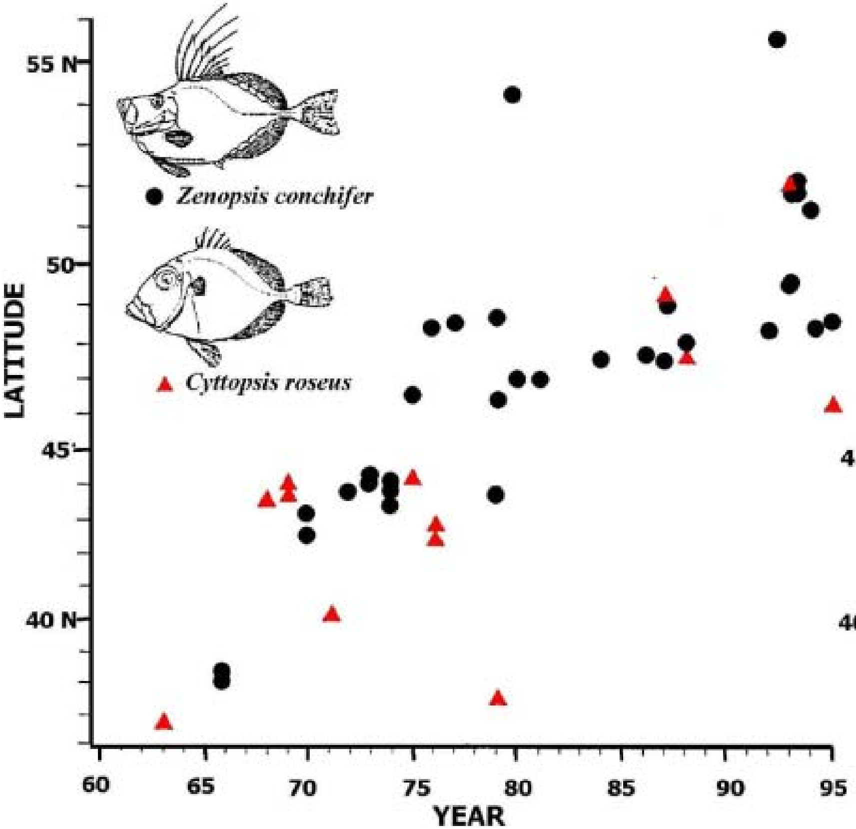
Northern Iceland

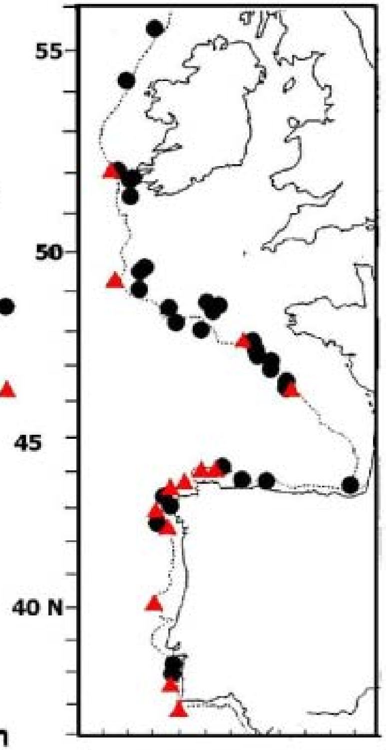
Off the UK there also has been an increase in the relative proportion of temperate versus subarctic zooplankton species due to a northward shift in their centers of distribution.

Response to recent warming

General northward displacement of commercial and non-commercial species of fish.

•In North Sea northward displacement of fish at rate of 7 km per year over 1990s, 7 times faster than on land (Perry, 2004)

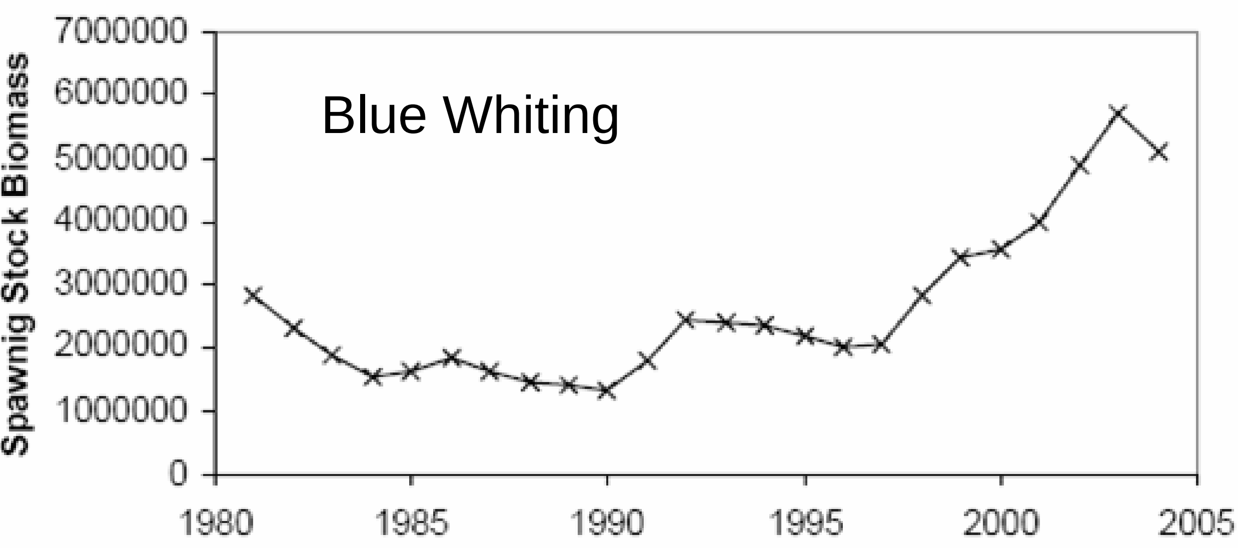




•Acceleration of southern species moving north from Iberian Peninsula to West of Scotland (Quero et al., 1998)

•Increased number of southern visitors to Iceland (Astthorsson, 2006).

Response to recent warming



Blue whiting has increased in abundance and has moved northward to the entrance of the Barents Sea.

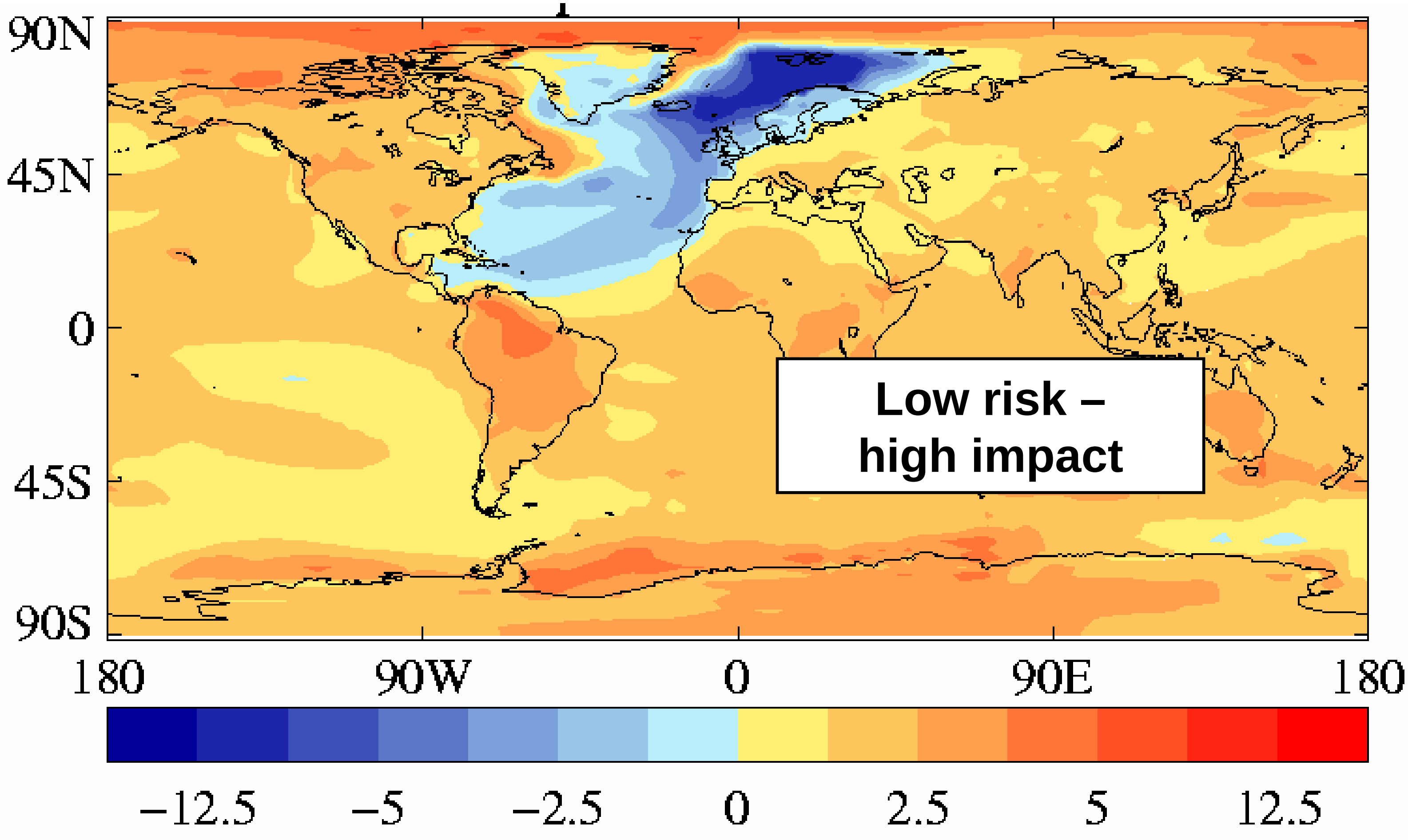
•Northward displacement of spawning sites, e.g. off Norway (Sundby and Nakken, 2004)

•Changes in migration patterns, e.g. Norwegian spring spawning herring have moved back towards Iceland to feed.

Future Changes

Possible effect of shut down of the Atlantic MOC

Changes in air temperatures

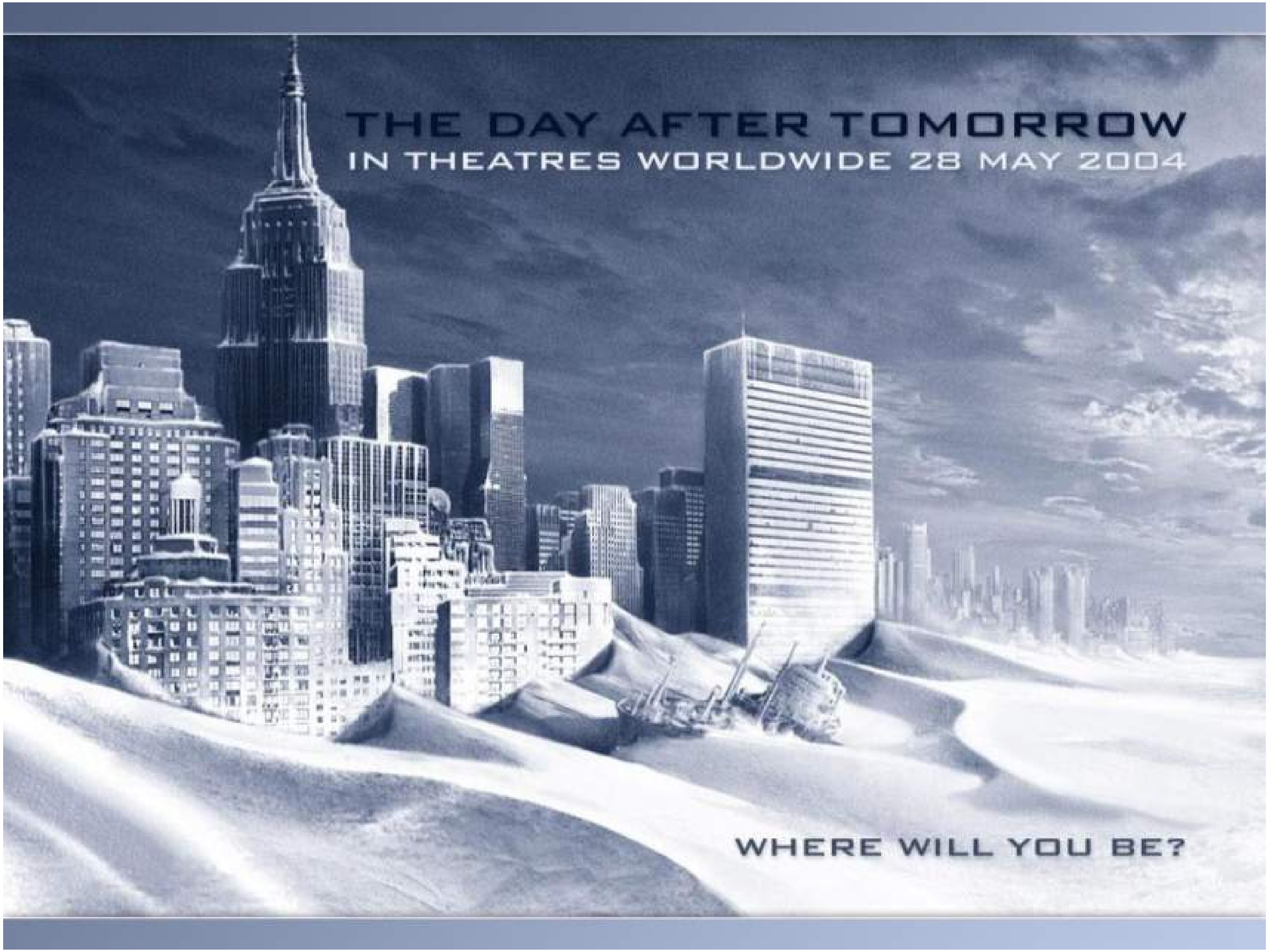


Low risk – high impact

Dramatic consequences for, in particular, the west-Nordic countries

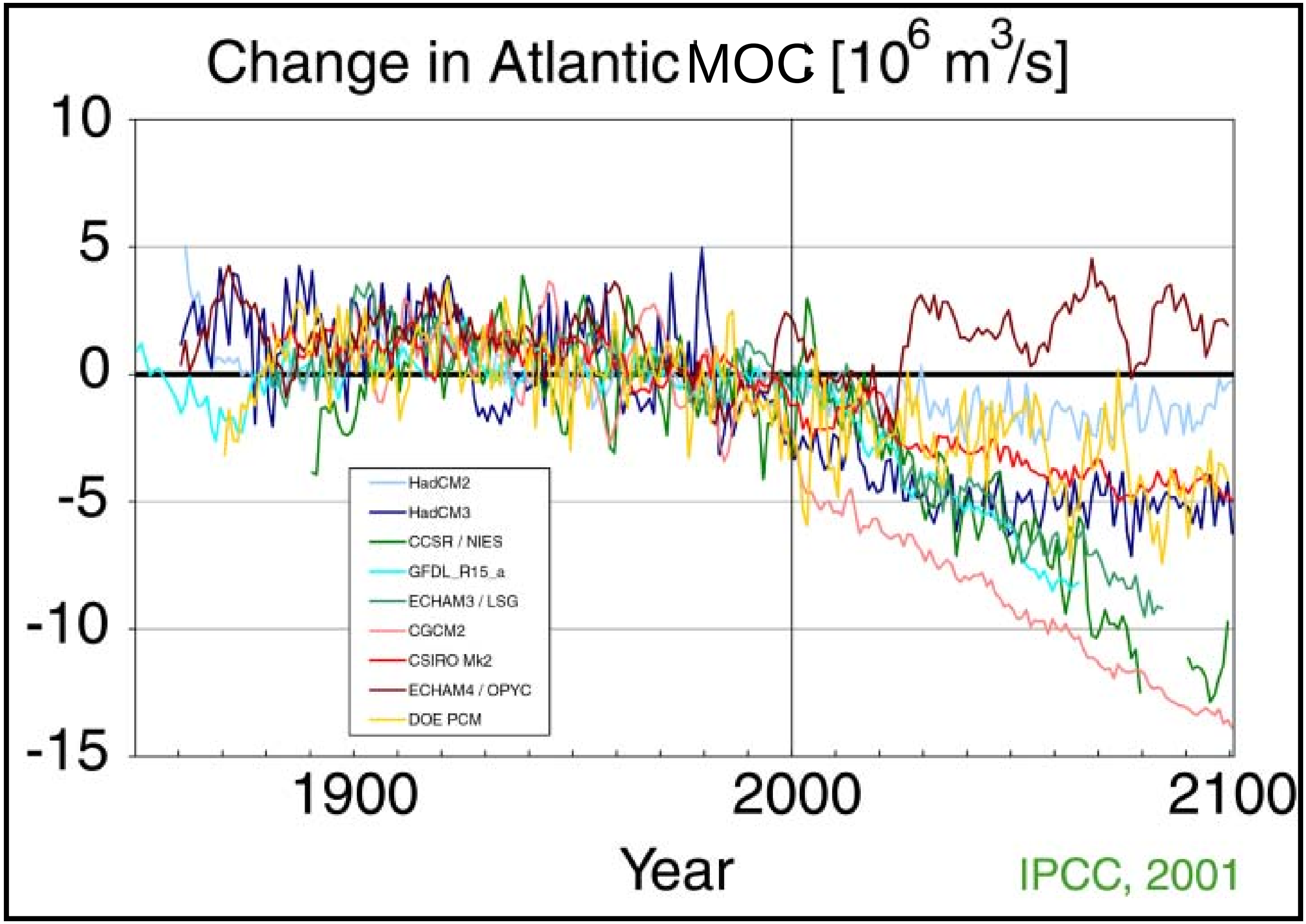
Wood et al. 2003

..but it leads to….

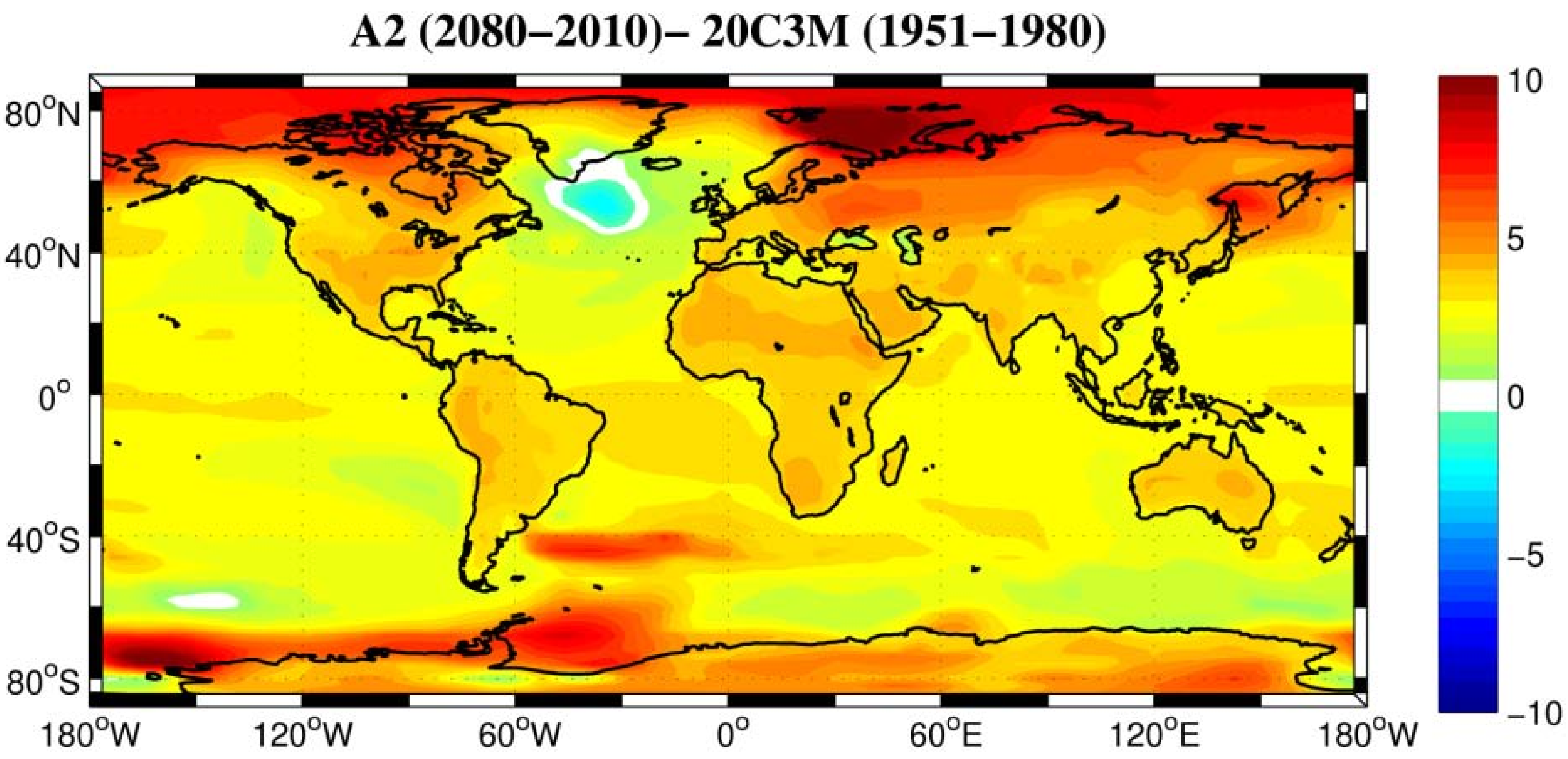


What do the models say about the MOC?

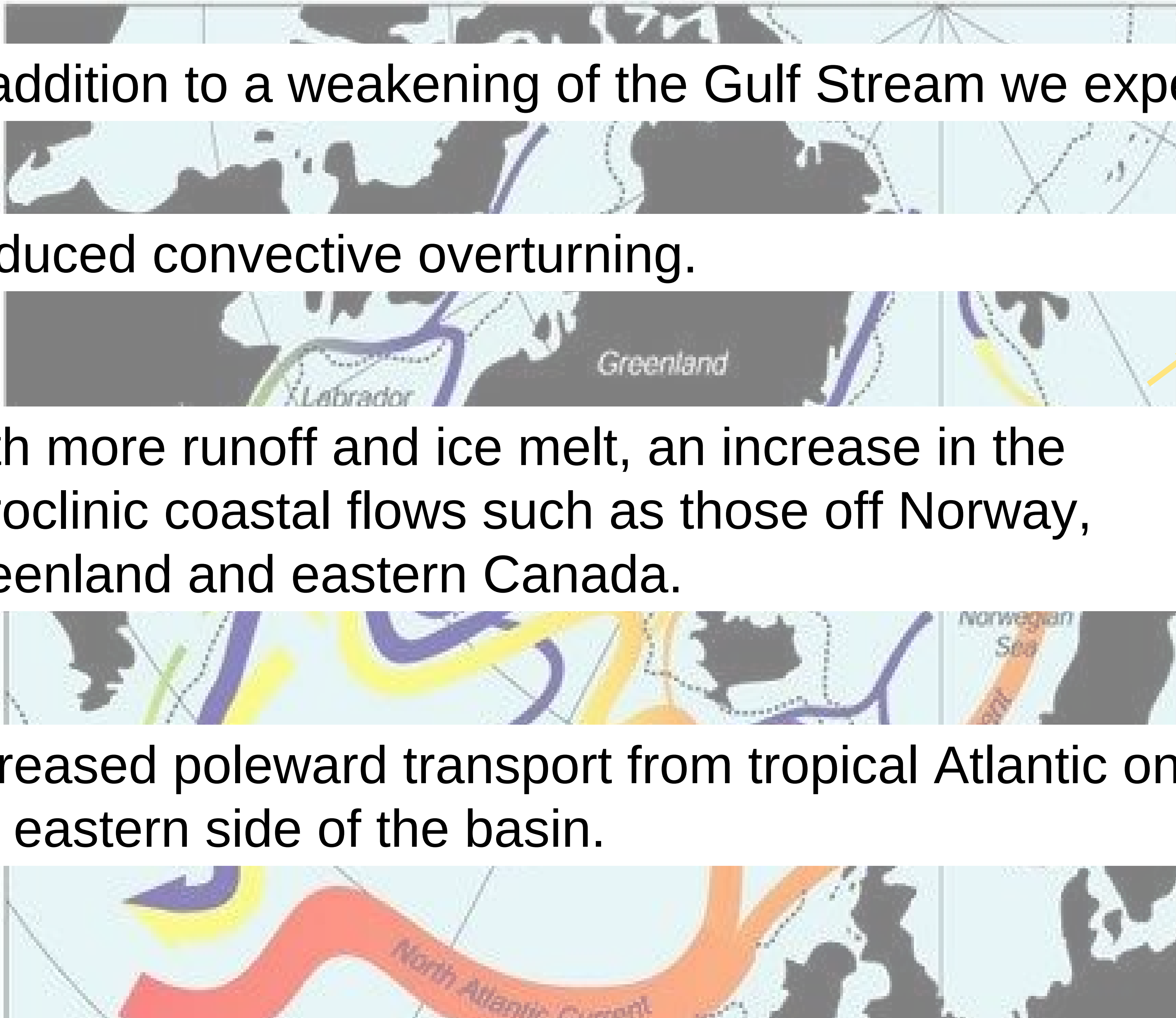
- Most climate models produce 20-30% reduction in the strength of the AMOC
- Large uncertainty
- The associated reduction in the poleward transport of heat is less than the atmospheric warming



Change in surface air temperature in Bergen Climate Model



- Strongest warming at high northern latitudes over land and in winter
- Less warming over ocean and in summer
- The cold anomaly is caused by an eastward shift of the poleward-flowing Atlantic Water



In addition to a weakening of the Gulf Stream we expect:

Reduced convective overturning.

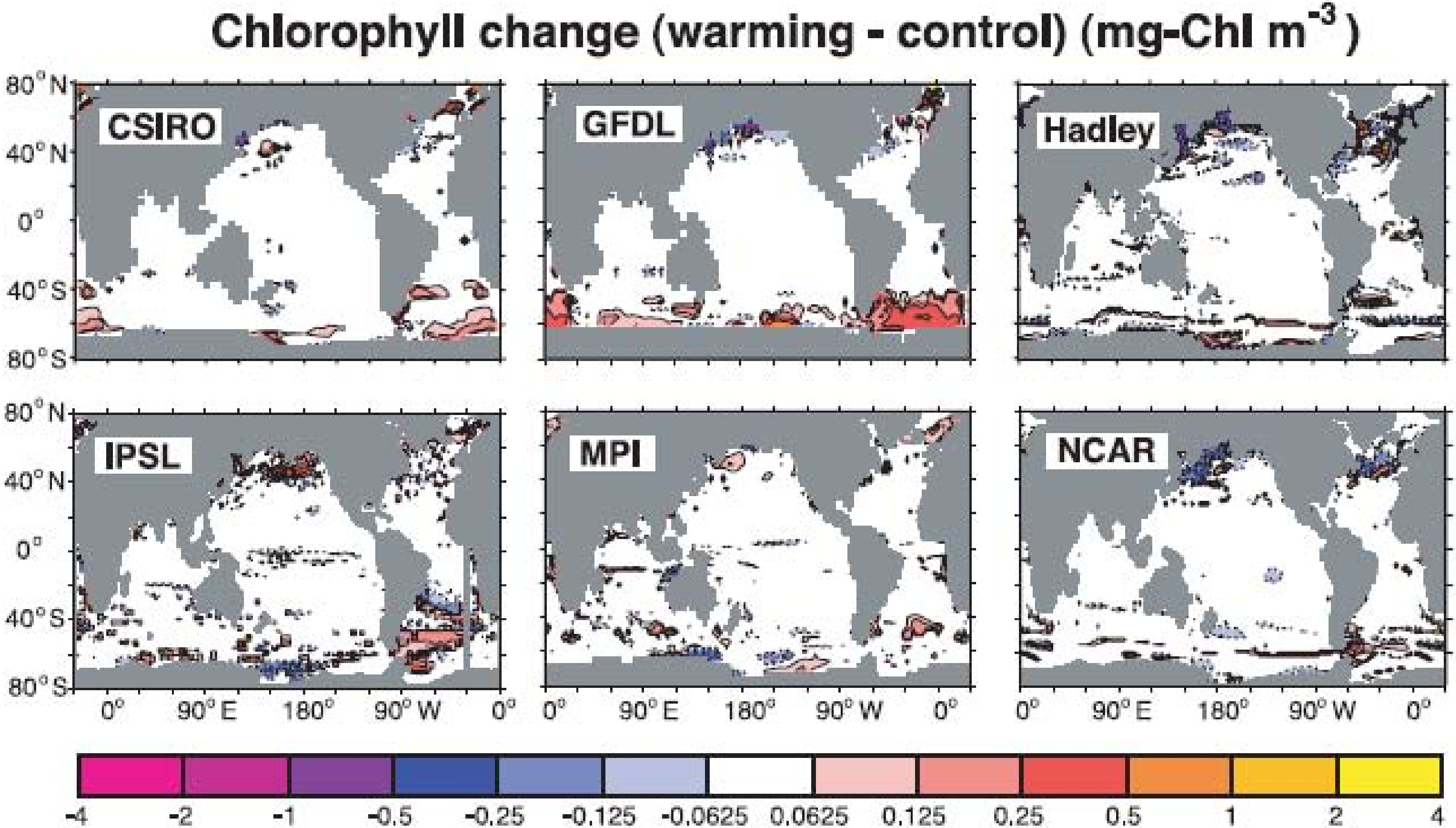
With more runoff and ice melt, an increase in the baroclinic coastal flows such as those off Norway, Greenland and eastern Canada.

Increased poleward transport from tropical Atlantic on the eastern side of the basin.

Ecosystem Response to Climate Change

Under climate change expect:

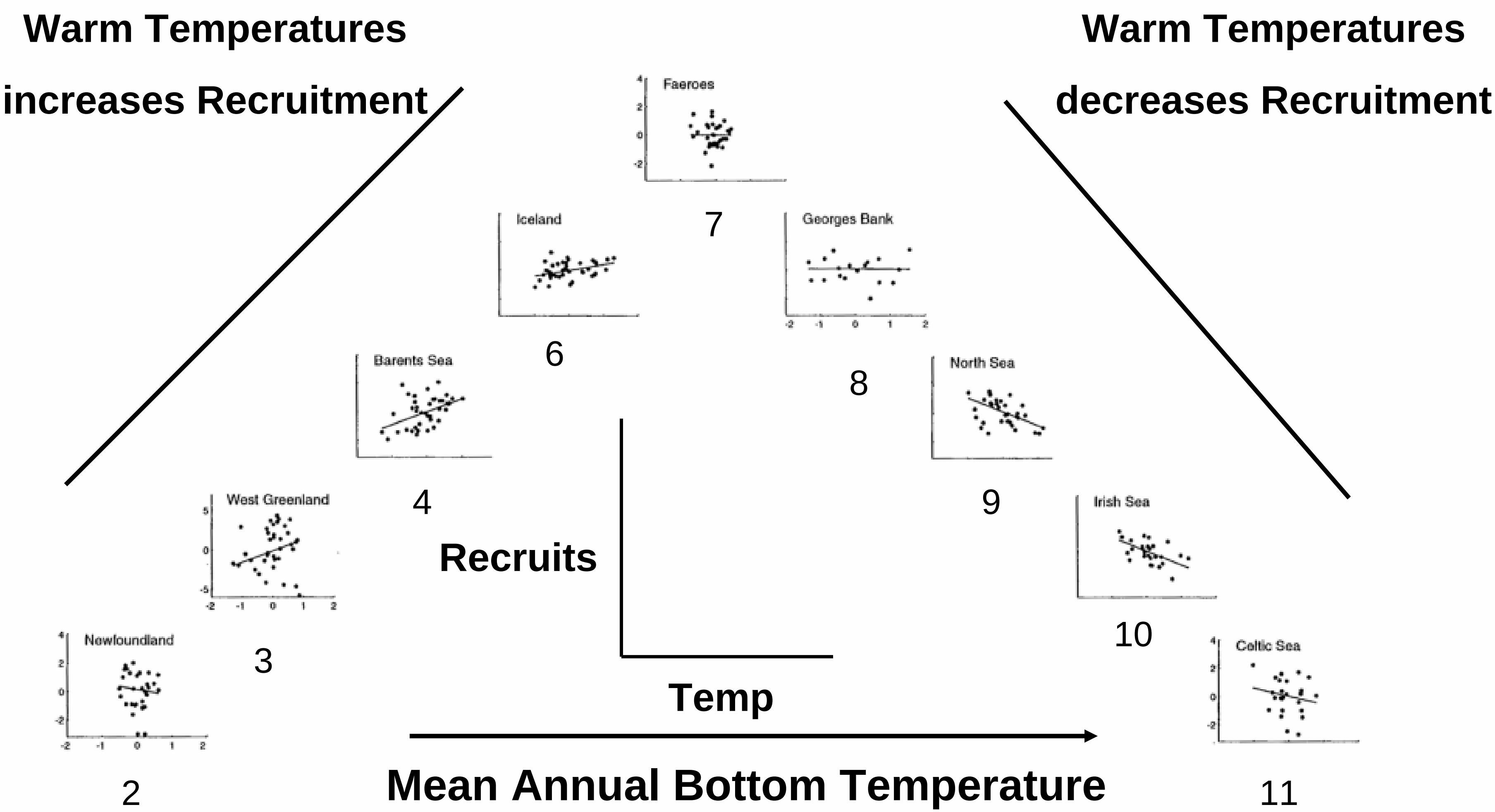
- Increased primary production where seasonal ice disappears and Atlantic Water spreads northward.
- Shift northward of many zooplankton species with increased zooplankton biomass due to faster turnover rates and higher primary production.
- Shift northwards of fish species with resultant changes in community structure and function.
- Increased fish production in northern regions.



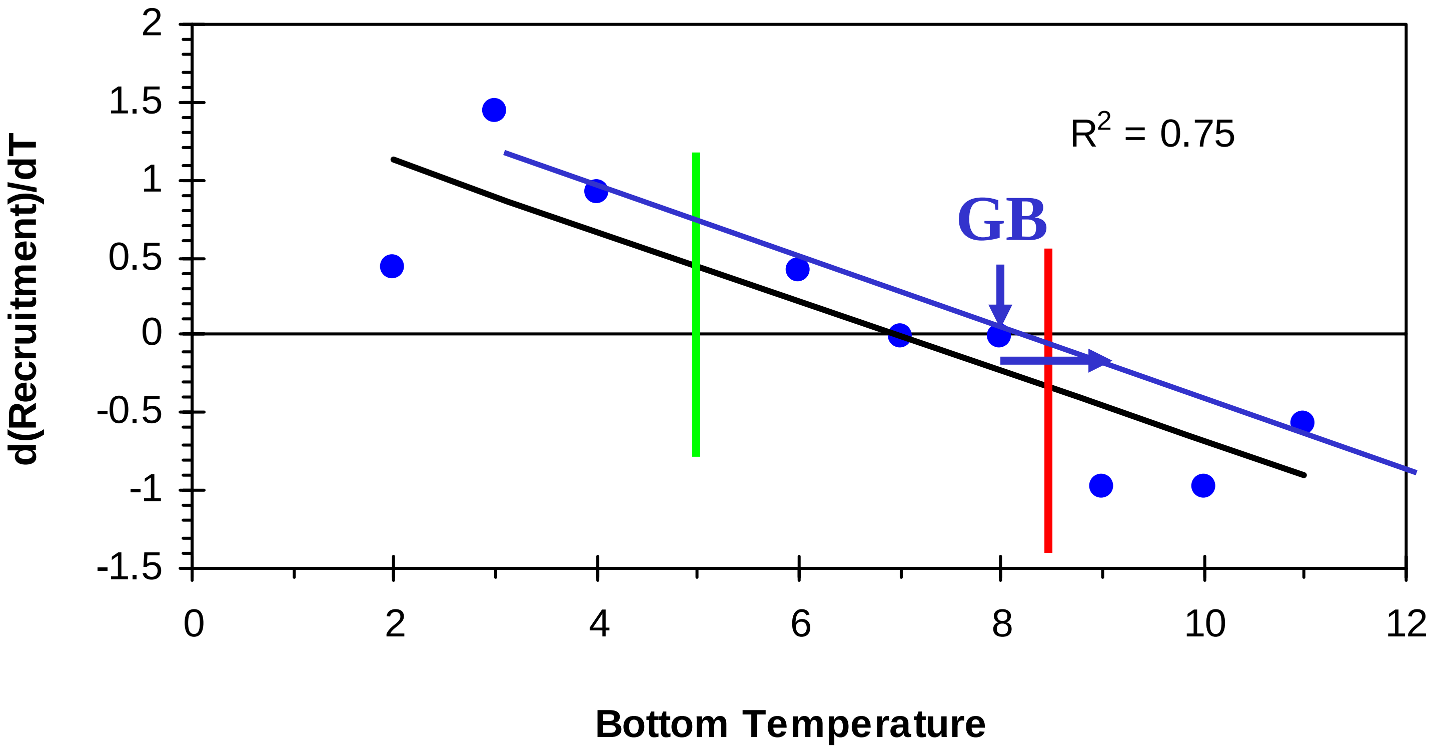
Average of models suggest N. Pacific declines slightly while N. Atlantic increases…but highly uncertain.

Sarmiento 2004

Cod Recruitment and Temperature



Planque and Fredou (1999)



If BT < 5° and T warms stock recruitment generally increase

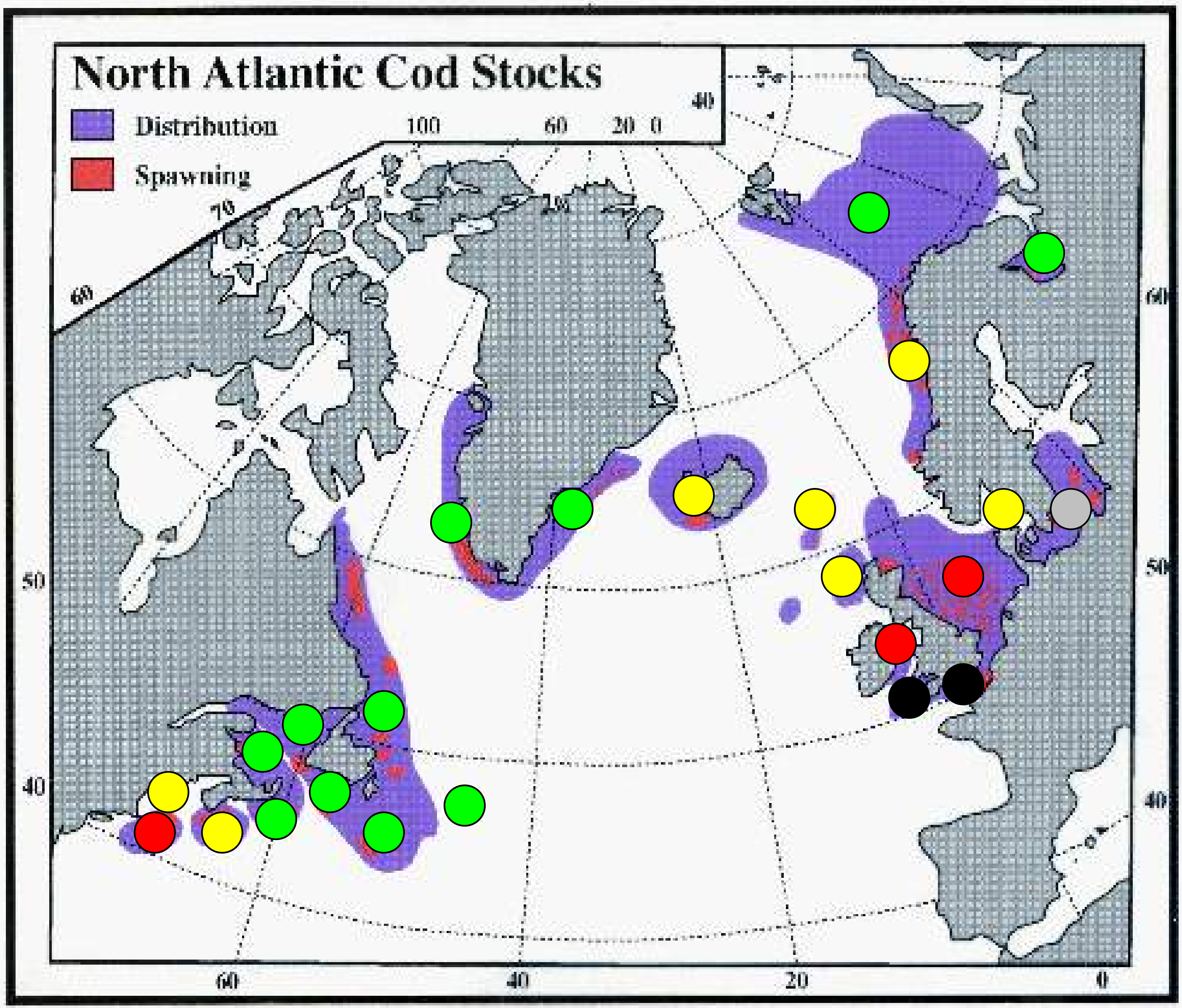
If BT between 5° and 8.5°C little change in recruitment

If BT >8.5°C recruitment generally decreases

If BT 12°C we do not see any cod stocks

Drinkwater 2005

Effect on abundance of 1°C increase



Increase

No change

Decrease

Collapse

?

Drinkwater 2005

Caveats

•Only considered temperature effects on cod.

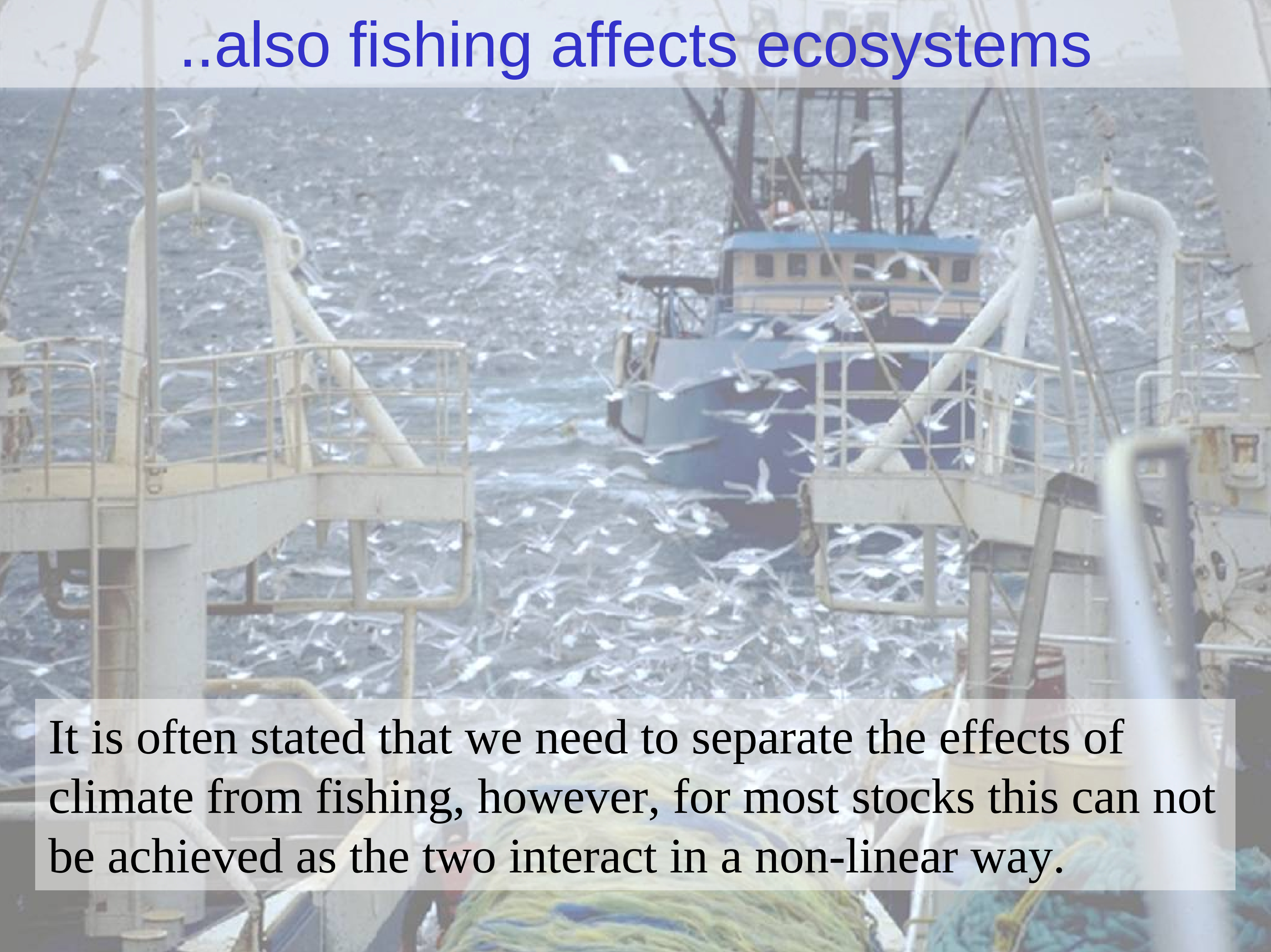
•The temperature will be linked to circulation changes, e.g. to the thermohaline circulation and wind forcing.

•There is high uncertainty in the future temperature scenarios and few regional climate models are available.

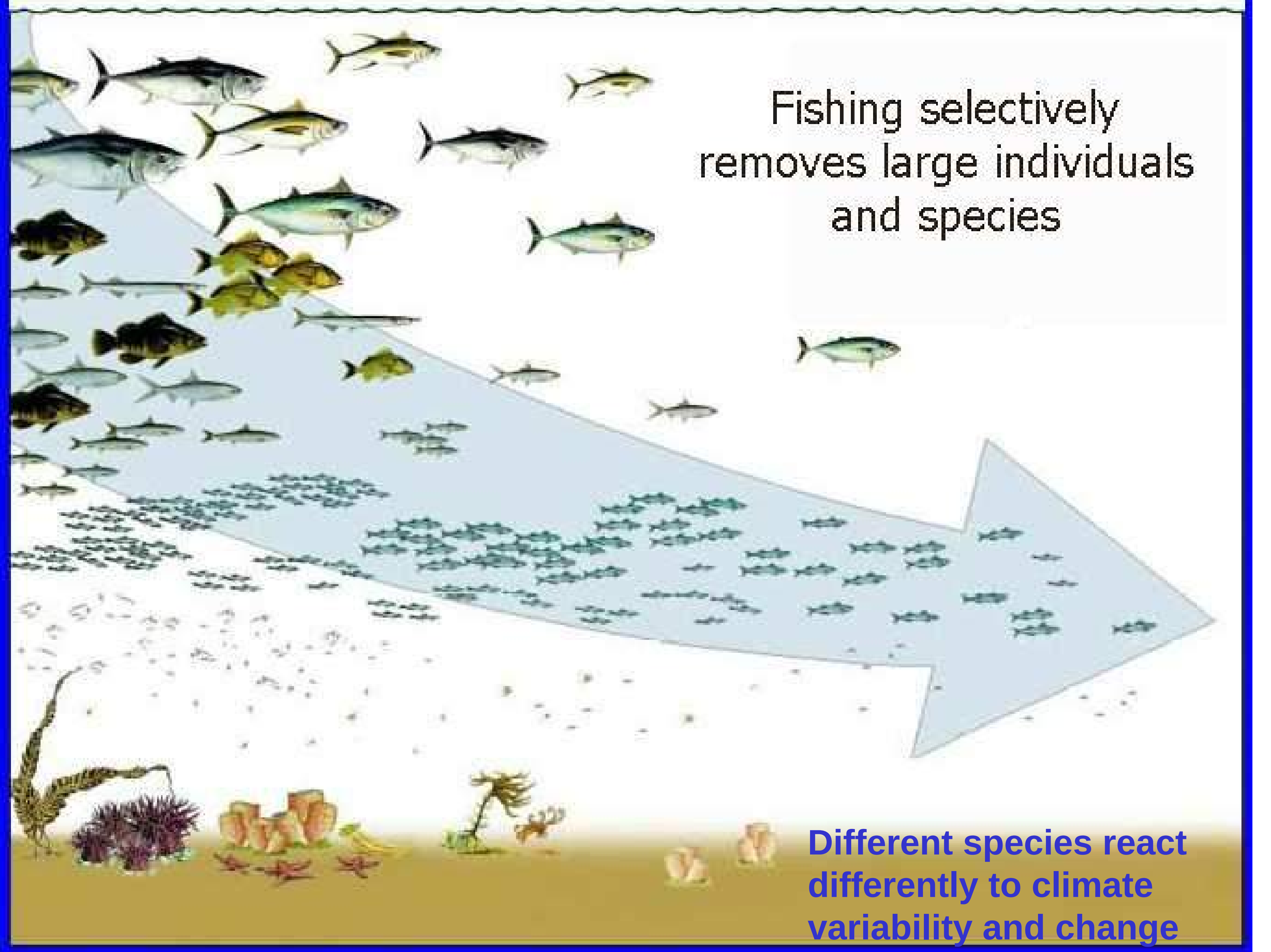
•Cod is not independent of the ecosystem and can not be considered separately, i.e. from its food.

•There is not one answer, but rather a suit of possibilities with varying probabilities and this needs to be conveyed.

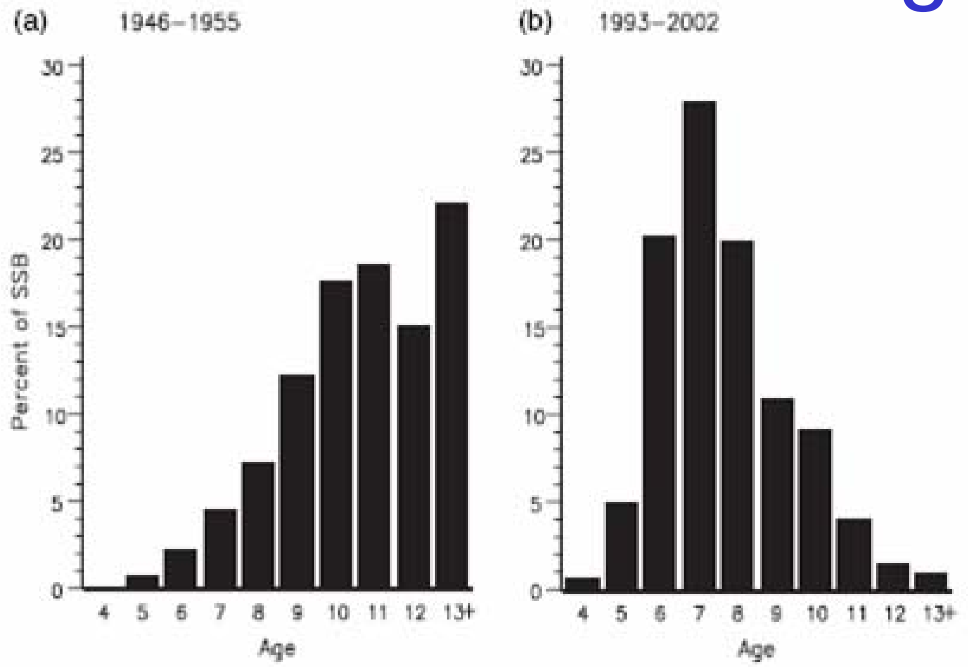
..also fishing affects ecosystems



It is often stated that we need to separate the effects of climate from fishing, however, for most stocks this can not be achieved as the two interact in a non-linear way.

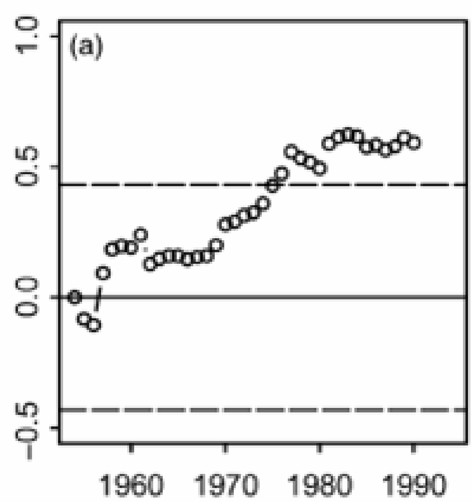

Fishing selectively
removes large individuals
and species
Different species react
differently to climate
variability and change

Fishing increases sensitive to climate change



Ottersen et al. (2006) noted the age structure of Barents Sea cod changed due to fishing. Old spawners have been removed.

Running Correlation Coefficient



They also found correlations between temperature and recruitment increasing and interpreted this as a result of the changing age structure, i.e. an effect of fishing.

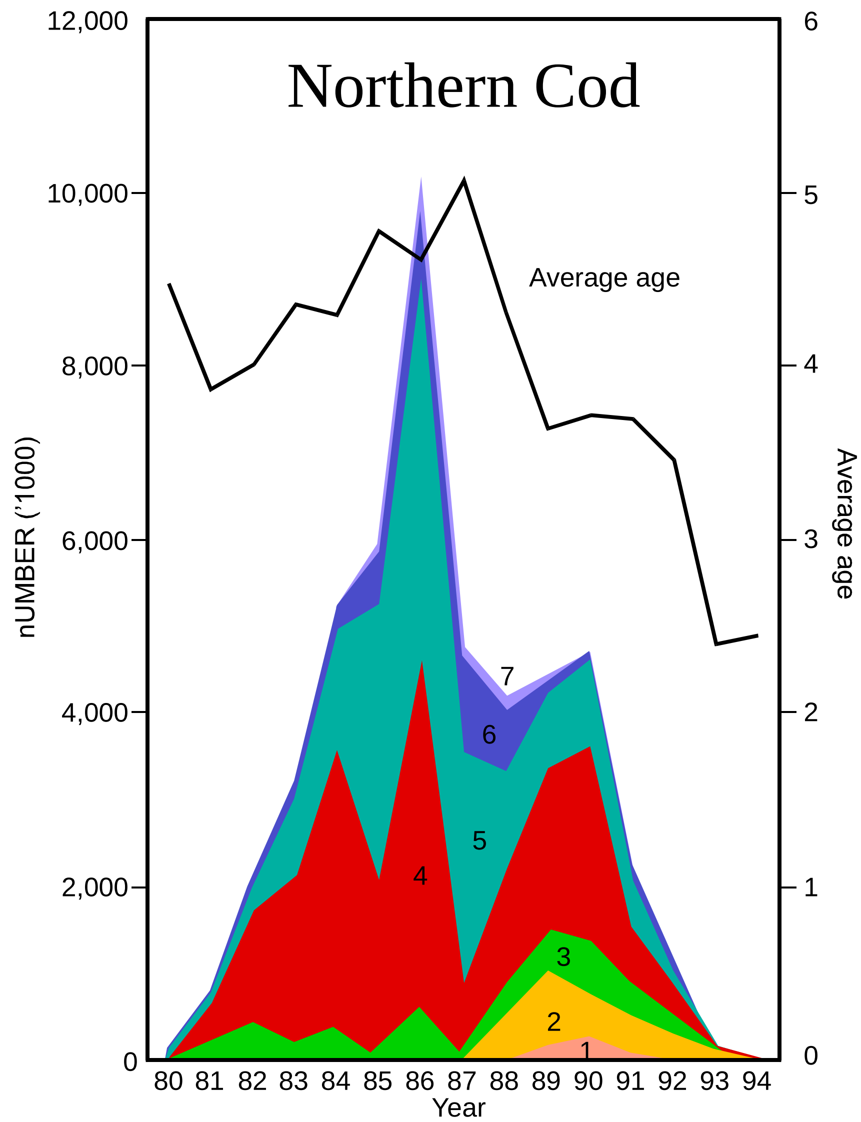
Environment-Fishing Interactions

As condition and size of northern cod declined due to changes in the environment, fishermen dumped small fish in favour of larger fish for which they could obtain a better price ("highgrading")

Dumping peaked in the mid- to late 1980s. This added extra pressure to an already stressed stock.

#s in 1000s

Average Age



(from Kulka, 1999)

Conclusions

1. Boundary currents around the North Atlantic have undergone changes in the past and are expected to undergo significant change under global warming.

2. These changes have, and will in the future, impact the structure and function of their ecosystems with some winners and some losers.

3. Our limited knowledge and the ecosystem complexity make predictions of the future response highly uncertainty but we must respond to society's request for this information.

4. More work on the joint effects of fishing must be undertaken and considered in future effects of global change.

Final Comments

1. While the forcing, as well as the species and their life histories differ between the Pacific and Atlantic, many of the underlying hypotheses are similar.

2. Our aims and goals in terms of understanding the effect of global change on marine ecosystems are similar and we can gain insights by comparing and contrasting climate impacts.


Any Questions?