Marine ecosystems productivity, climate effects and sustainable fishery

Svein Sundby

Value Creation in the Nordic Countries of the Fisheries and the Aquaculture

Nordic Council, Akureyri 11 – 12 October 2007

HAVFORSKNINGSINSTITUTTET
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Outline

* Climate variability and climate change in the past centuries
* Climate projections for 21. century
* North Atlantic marine ecosystems response to climate variability and its cascading effects on fisheries
* Climate effects on aquaculture

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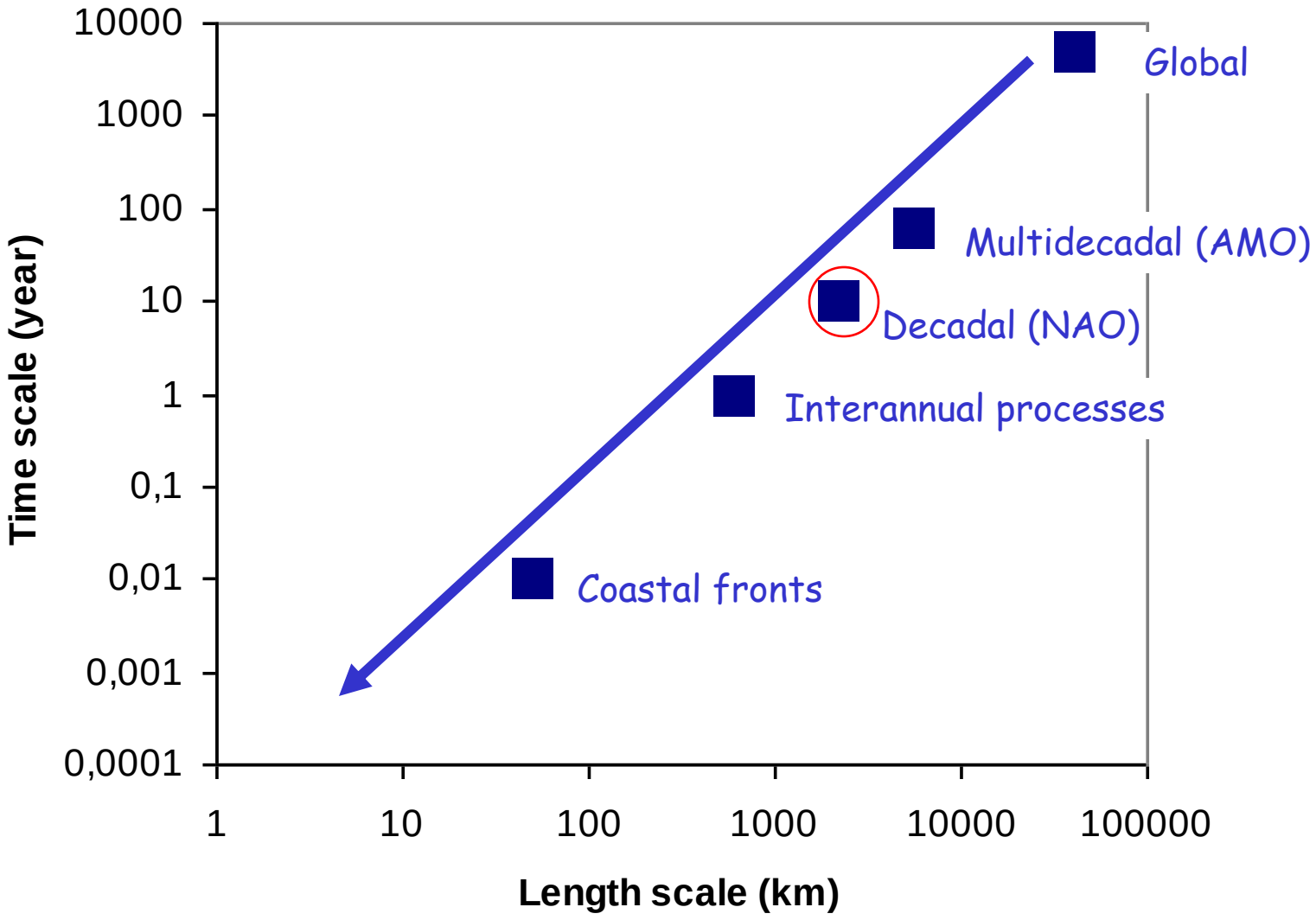
* **Climate variability and climate change in the past centuries**

* **Climate projections for 21. century**

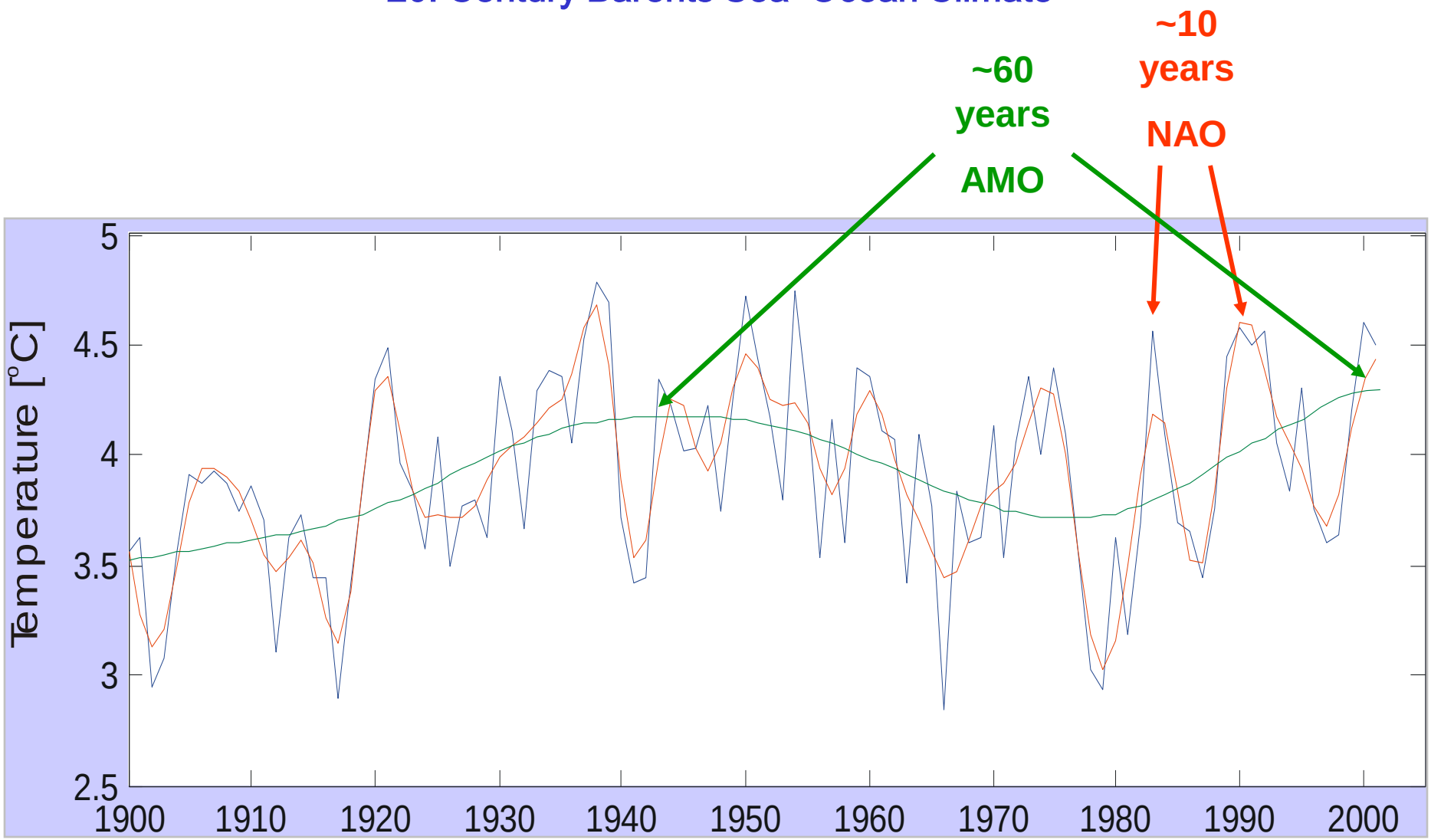
* **North Atlantic marine ecosystems response to climate variability and its cascading effects on fisheries**

* **Climate effects on aquaculture**

Spatio-temporal scales the ocean physics



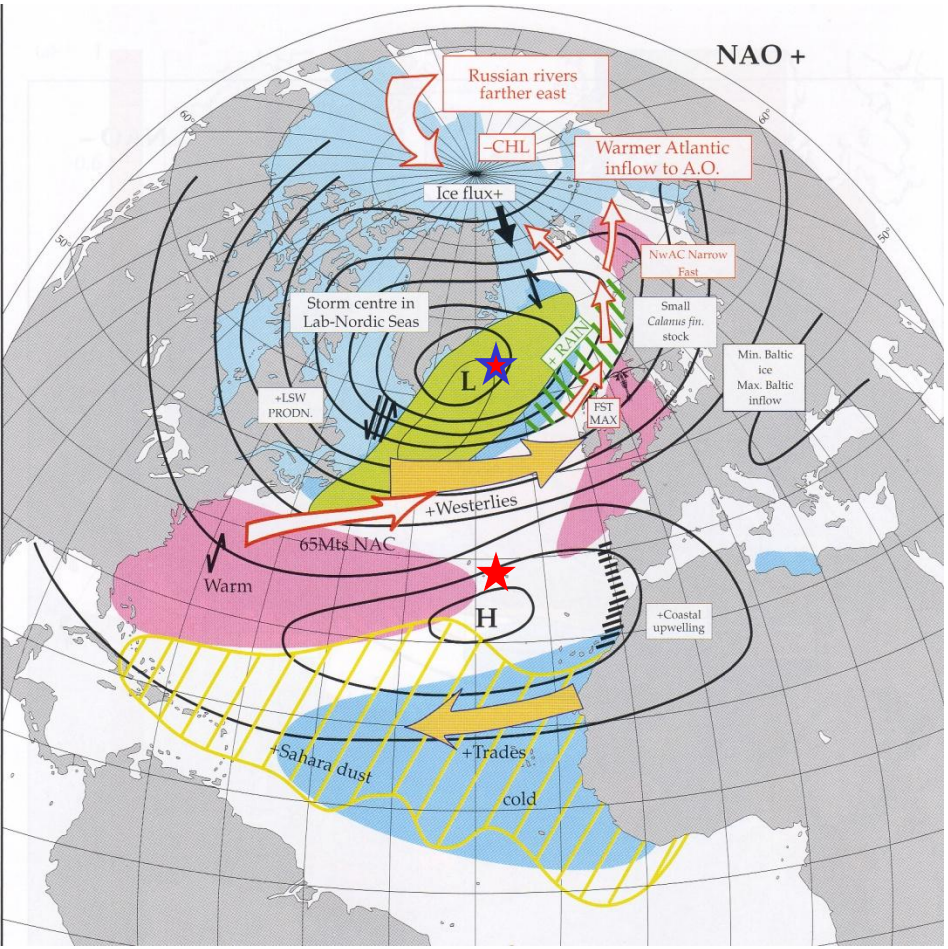
20. Century Barents Sea Ocean Climate

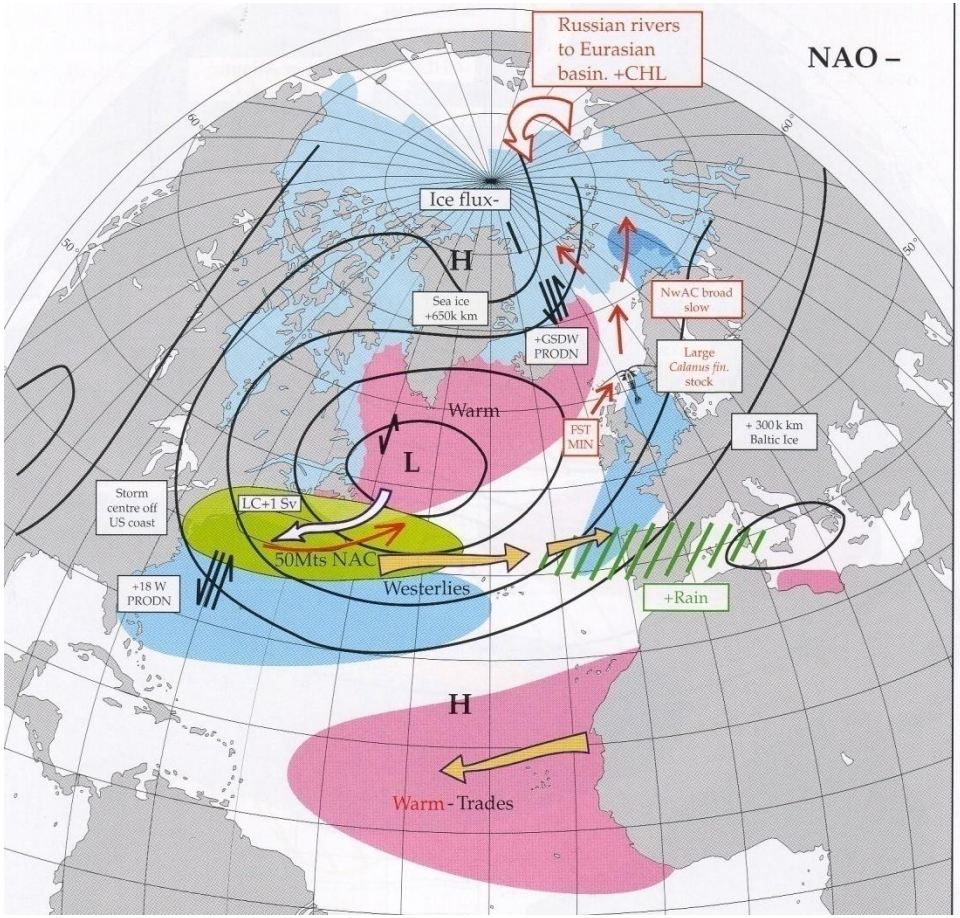


Source : PINRO, Murmansk

The North Atlantic Oscillation (NAO) Index:

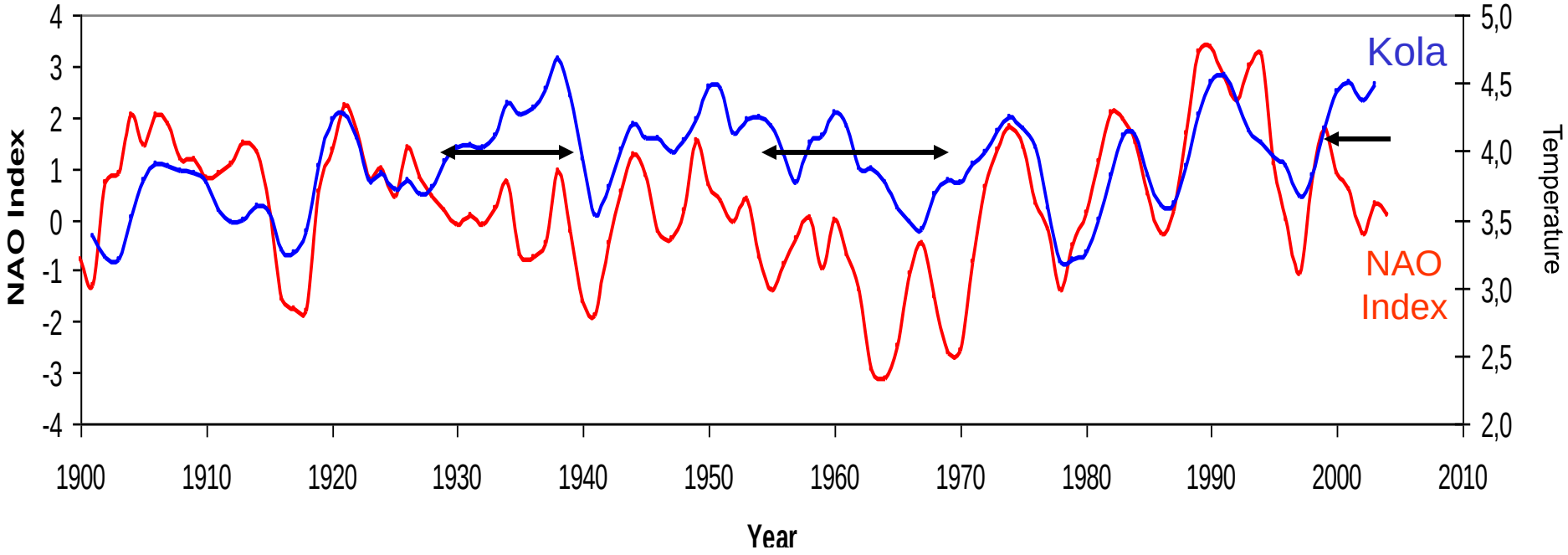
The difference of the normalized sea level pressure between the Azores/Lisbon/Gibraltar and Iceland.



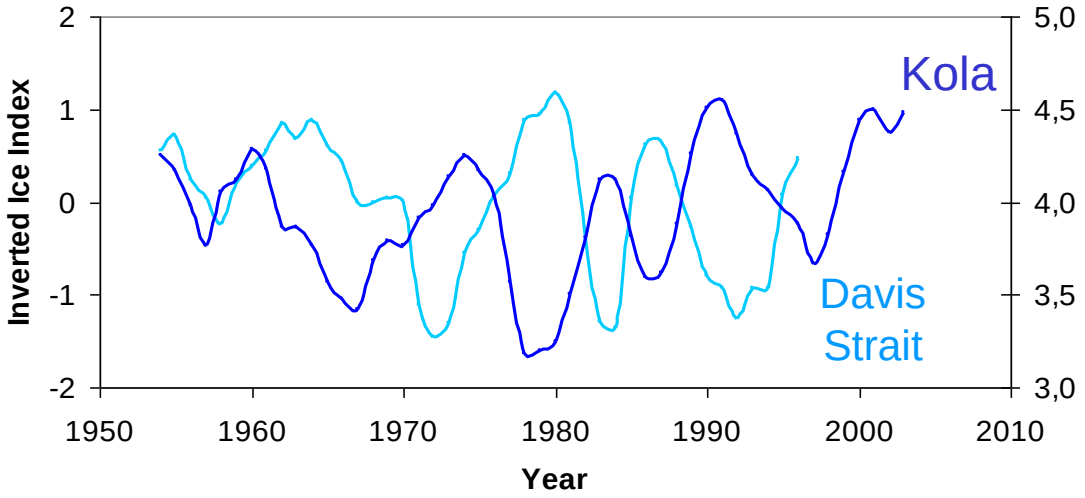


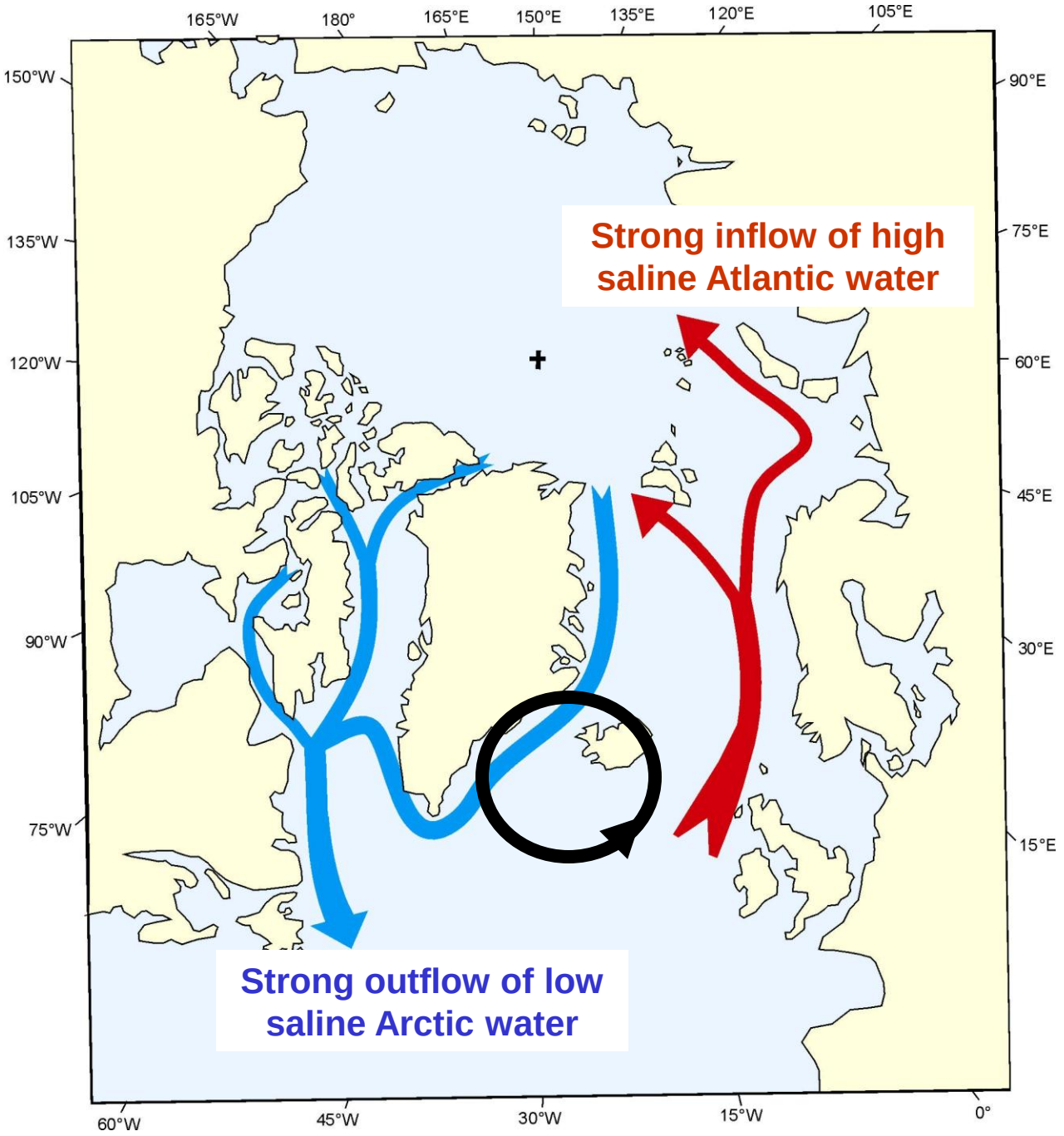
Hurrell and Dickson (2004) In: Marine ecosystems and Climate Variations (Stenseth *et al.* eds.)

Strong decadal-scale signals makes the NAO and Barents Sea ocean climate swinging together



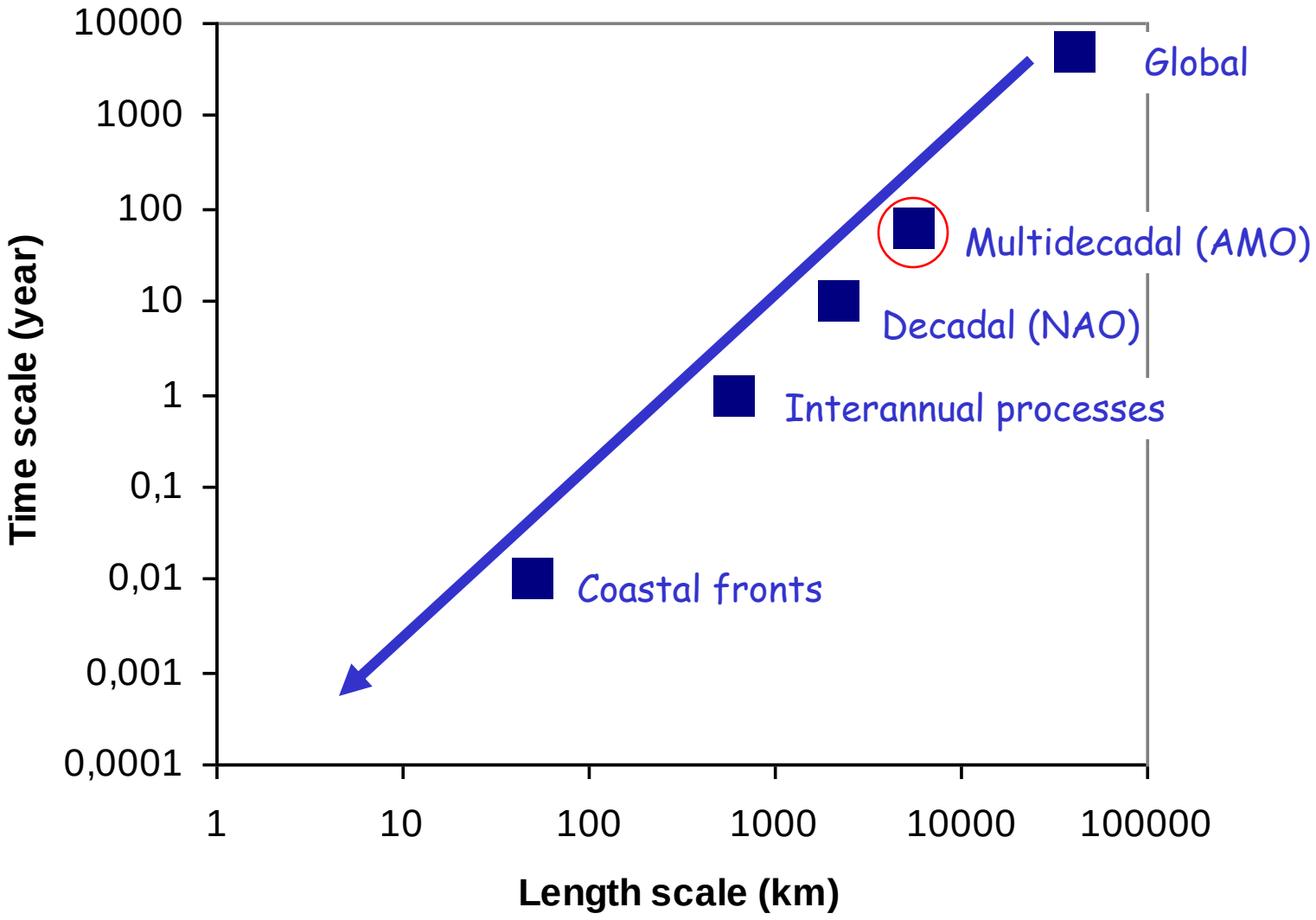
- and the Labrador and Barents Seas playing the seesaw



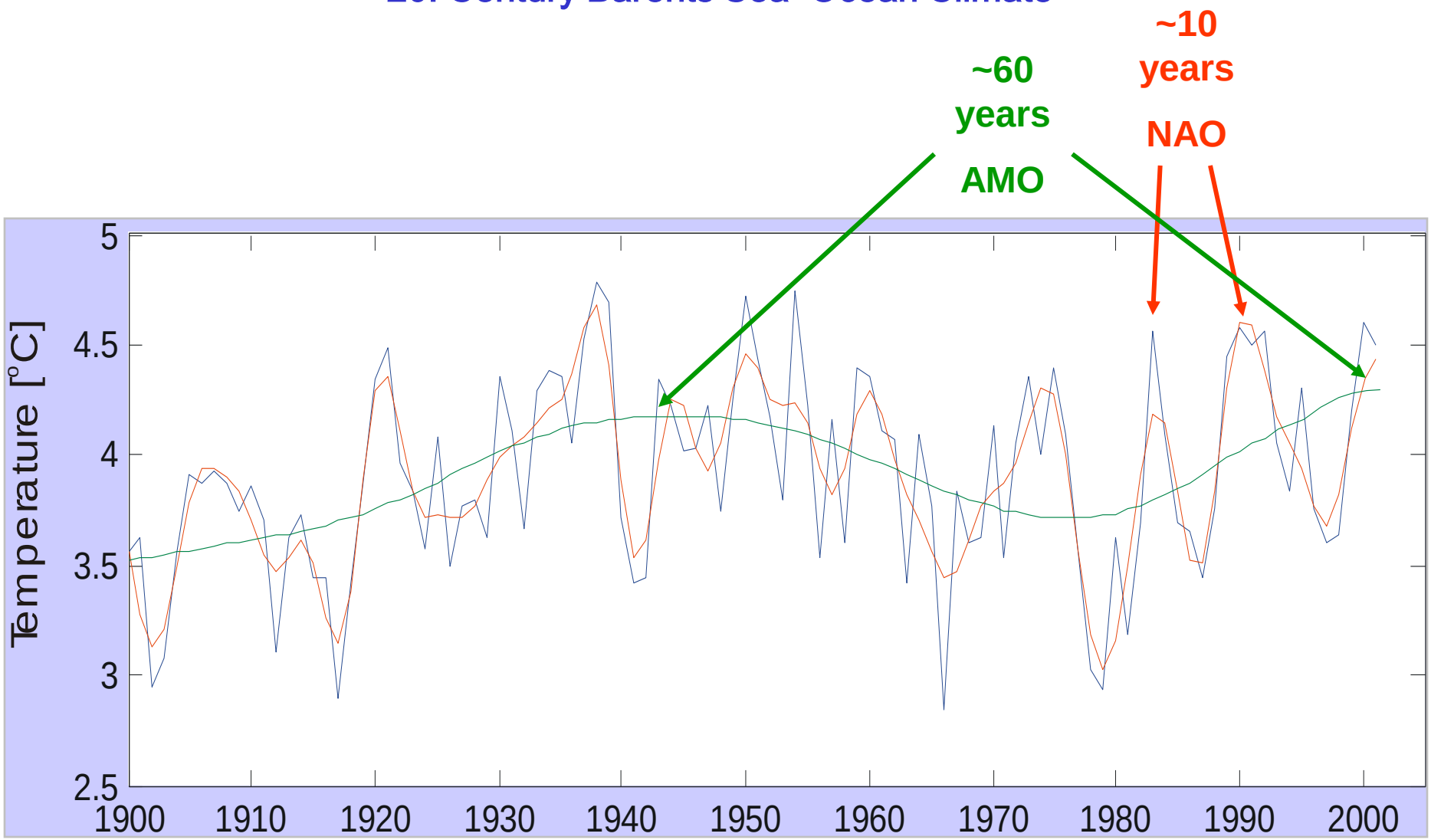


Sundby and Drinkwater (2007)

Spatio-temporal scales the ocean physics

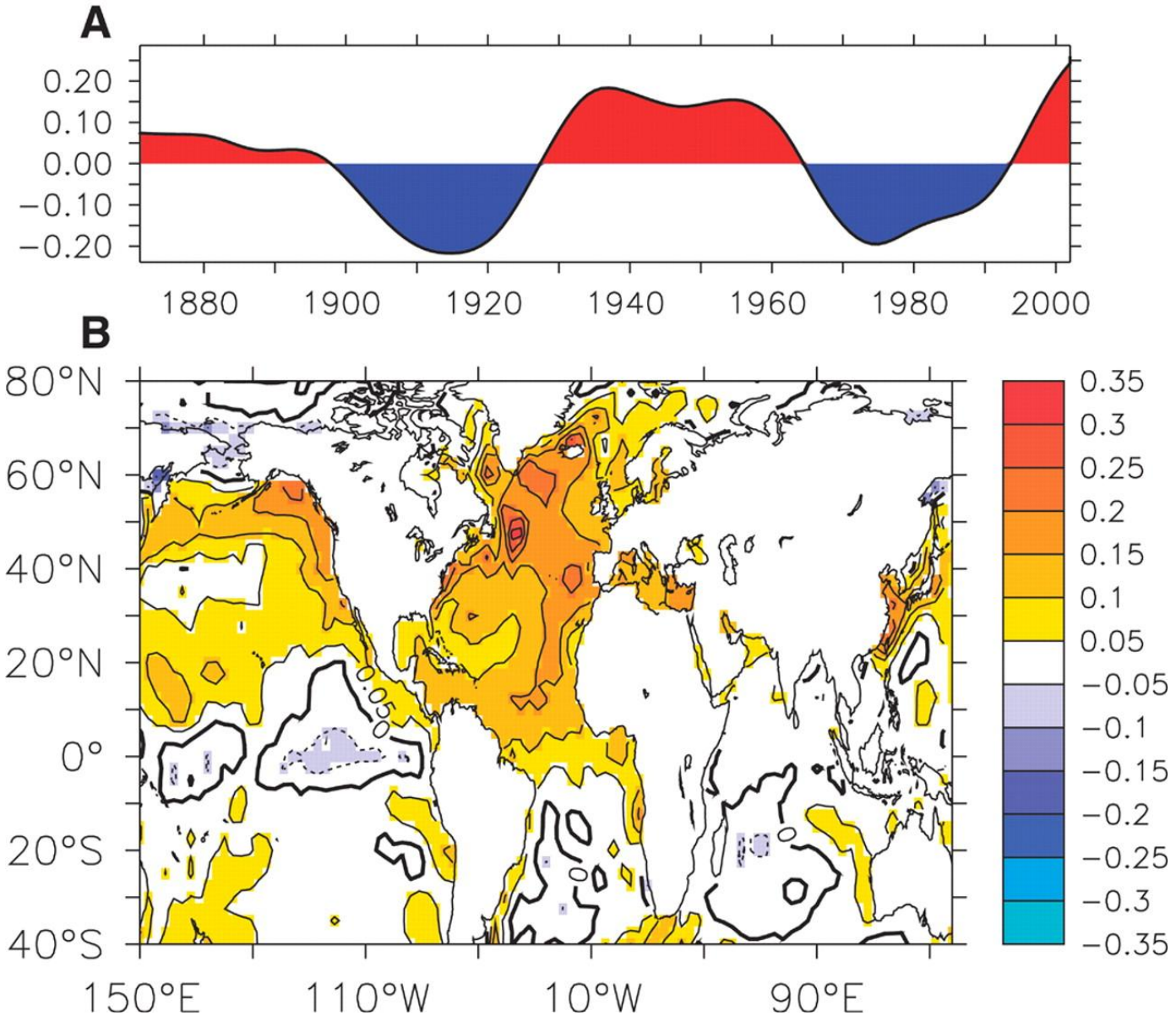


20. Century Barents Sea Ocean Climate



Source : PINRO, Murmansk

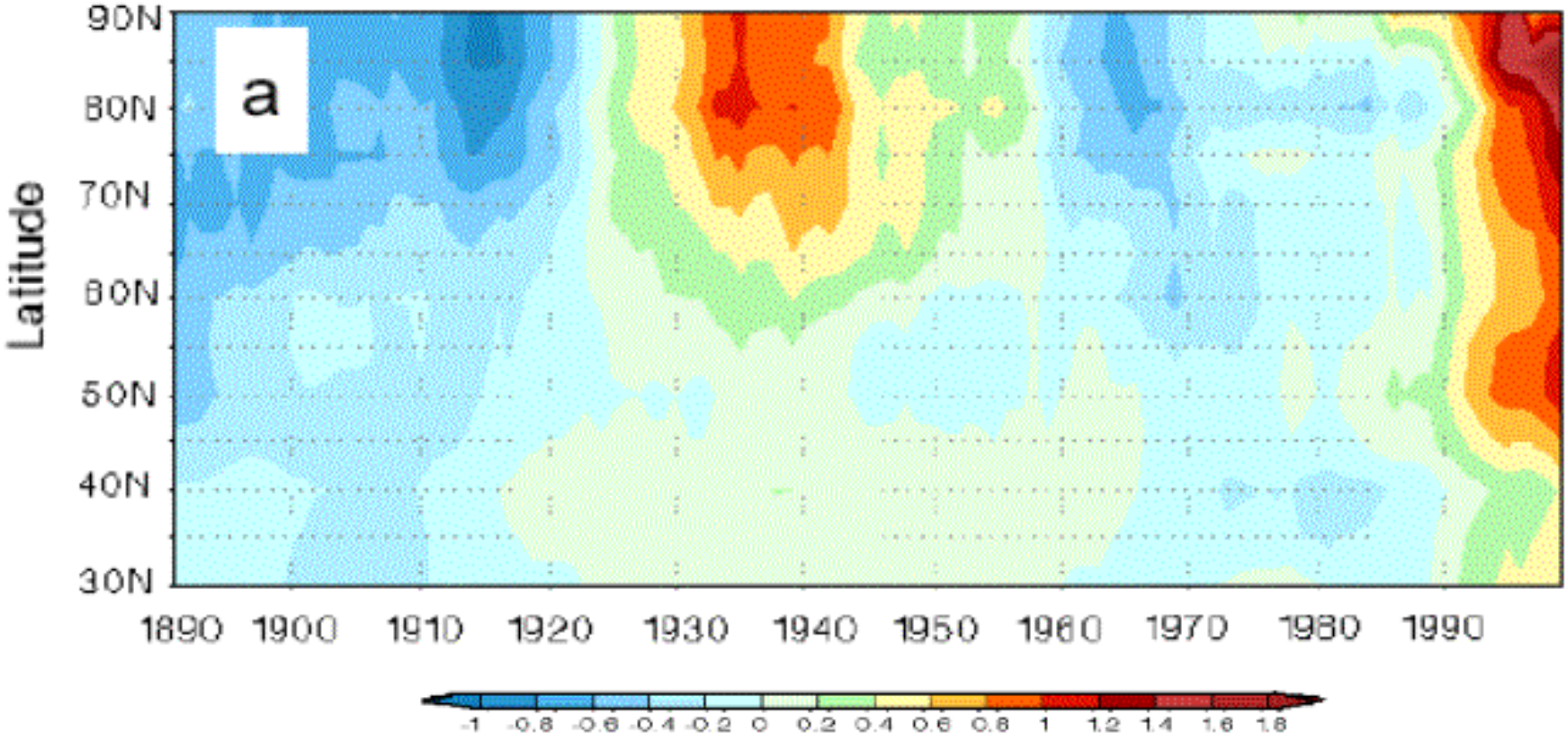
Den Atlantiske Multidekadiske Oscillasjonen (AMO) 1873-2000



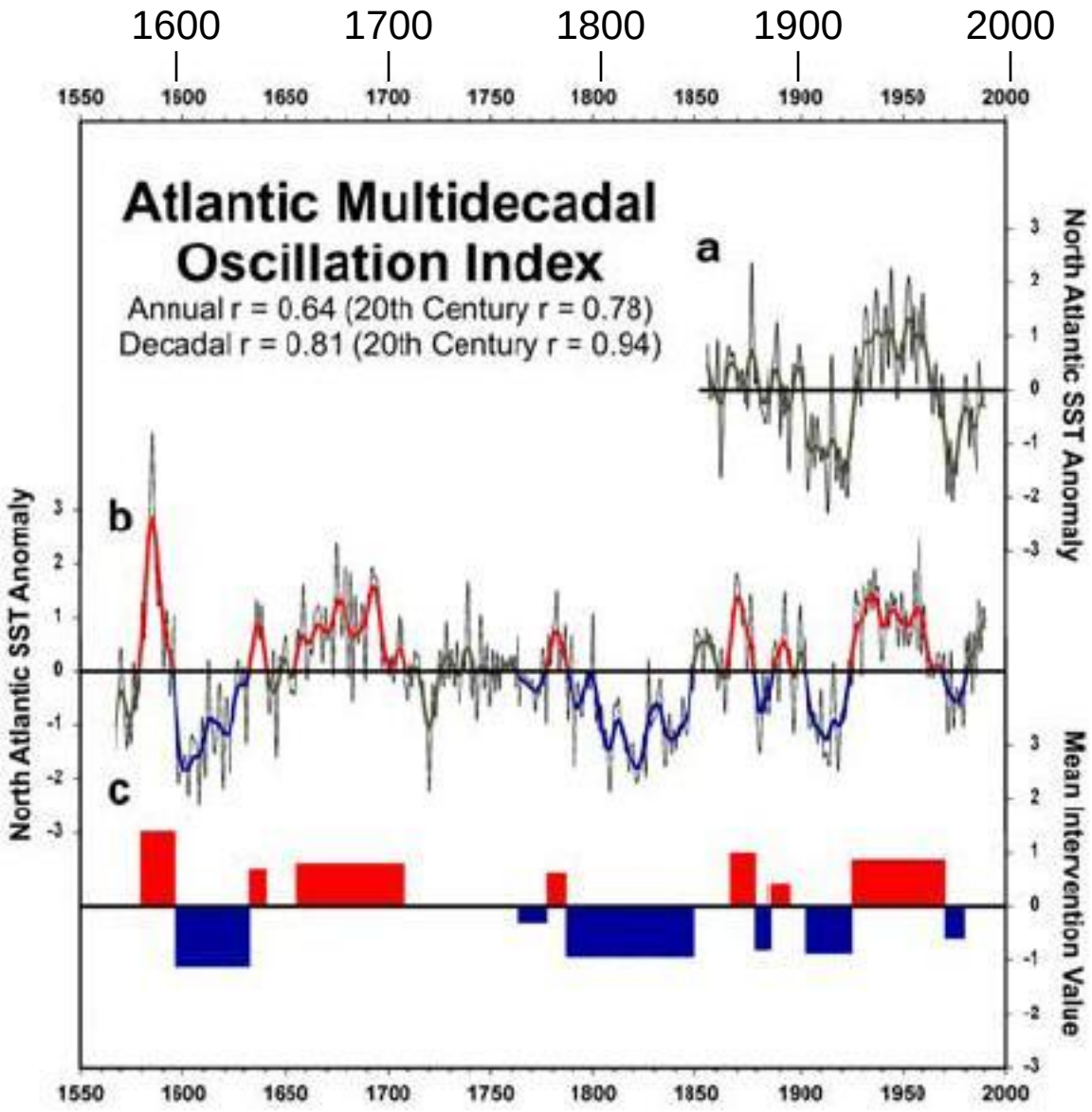
Sutton and Hodson (2005)

Science
AAAS

AMO-signalet øker mot Arktis

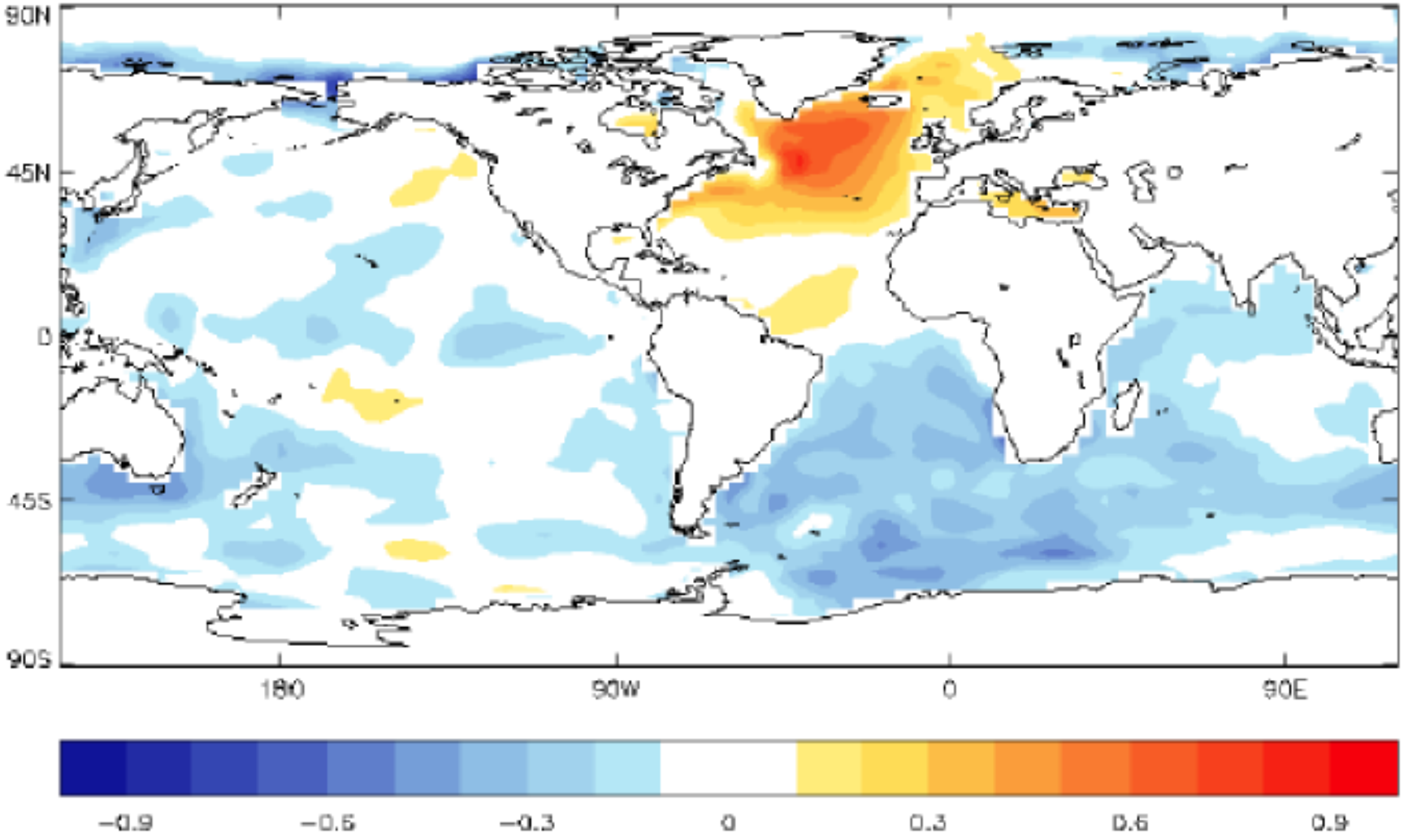


Johannessen *et al.* (2004) Tellus



Gray *et al.* (2004)

Warming was concentrated in the Northern North Atlantic



Sea Surface Temperature Change (1930-60 vs 1961-90)

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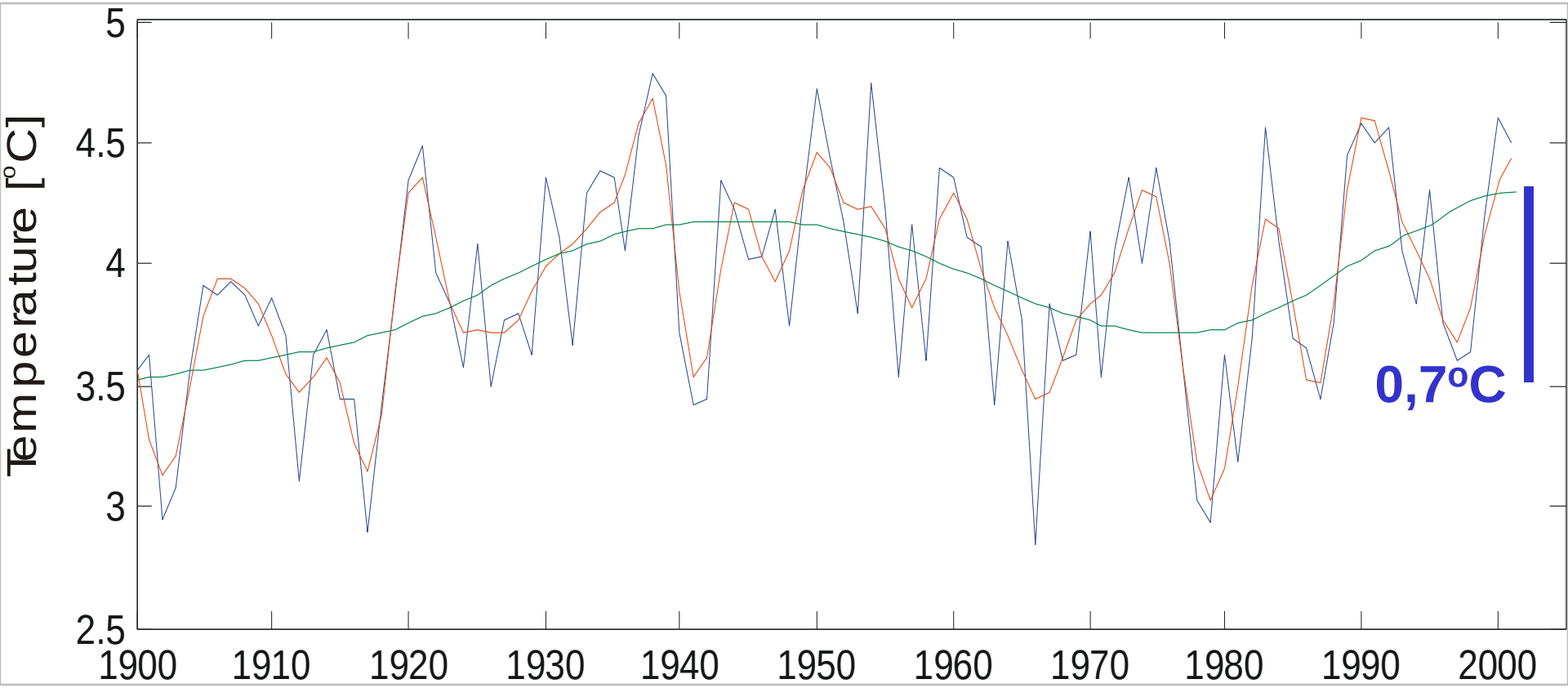
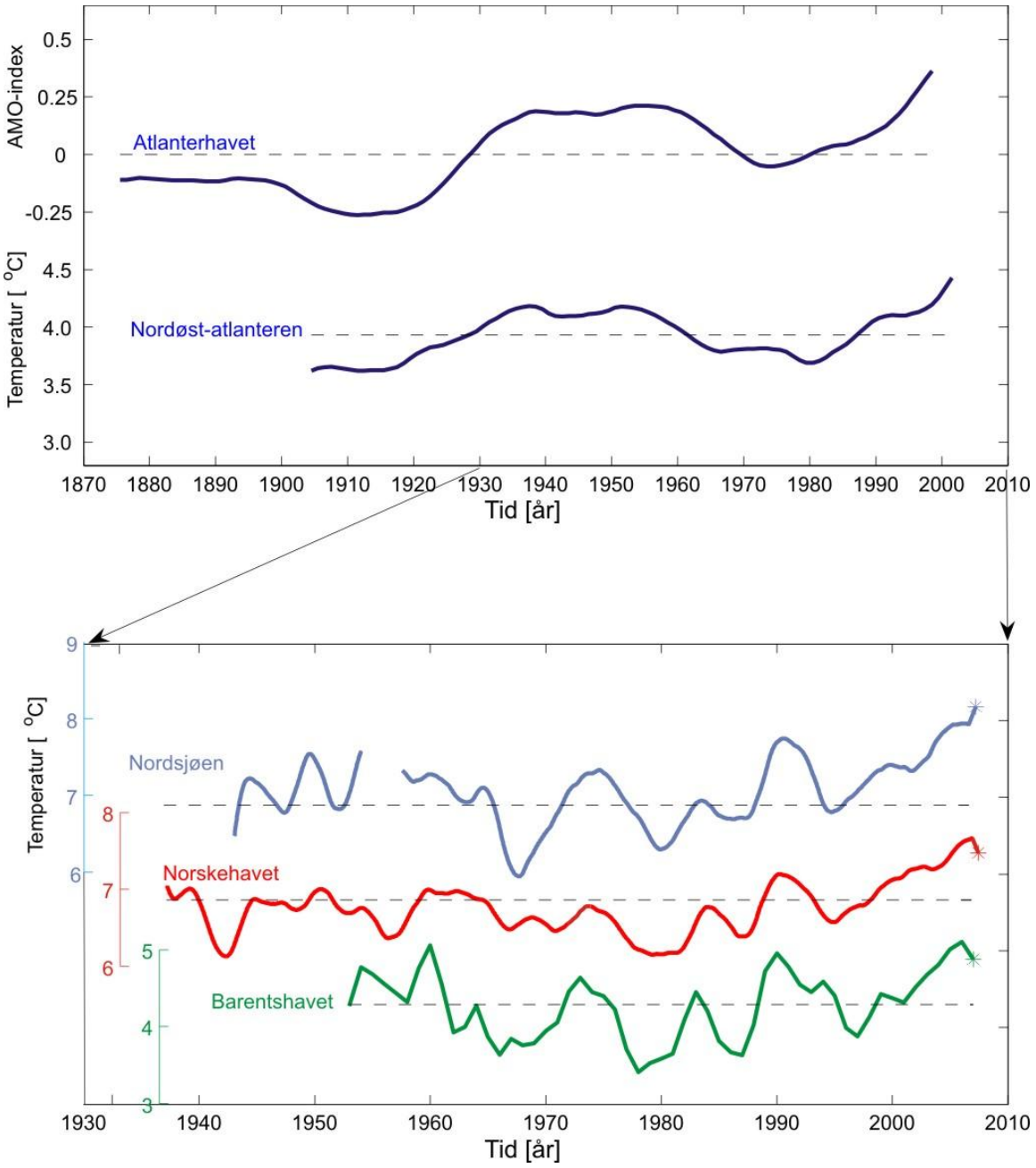
Havklimaet i Barentshavet





From basin-scale to regional-scale climate trends

Is the summit of the multidecadal climate oscillation just passed?

Conclusion

• Natural climate periods influencing marine ecosystems occur from interannual to centennial time scales

• Decadal-scale and multidecadal scale periods are particularly dominant in the northern North Atlantic

• The recent warming of the northern hemisphere since 1960s has uncorrectly been ascribed human-induced global warming

* Climate variability and climate change in the past centuries

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Bjerknes Centre
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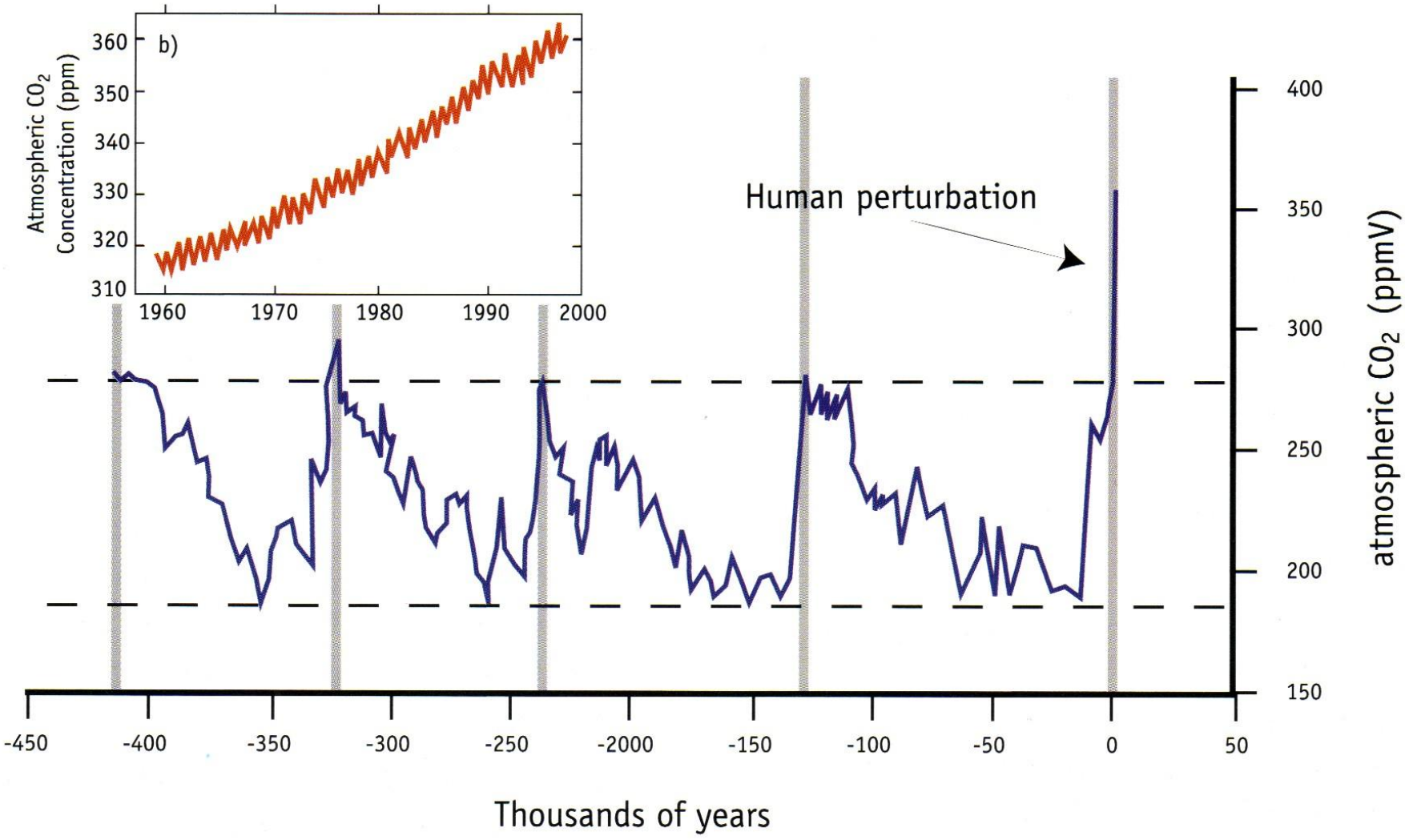
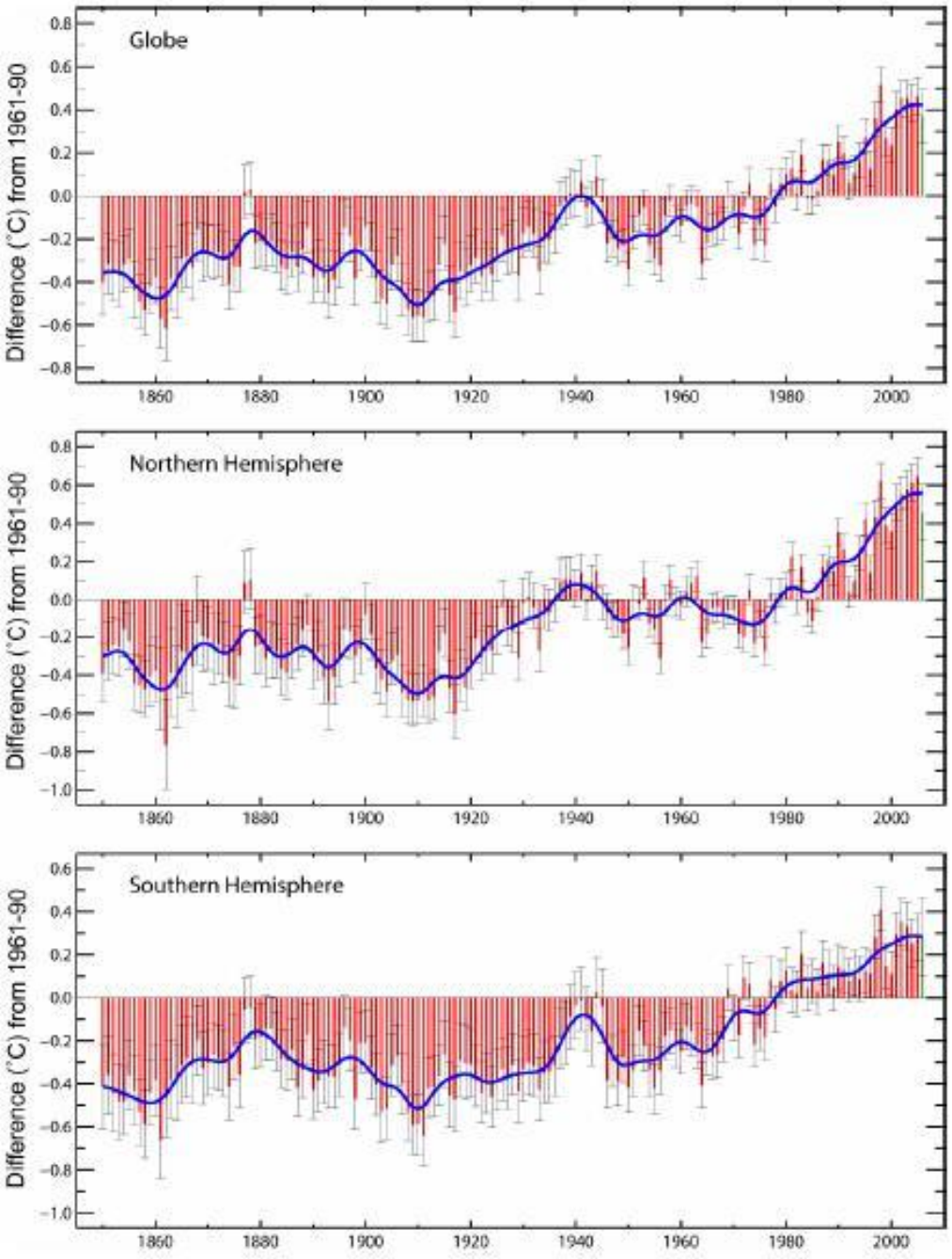
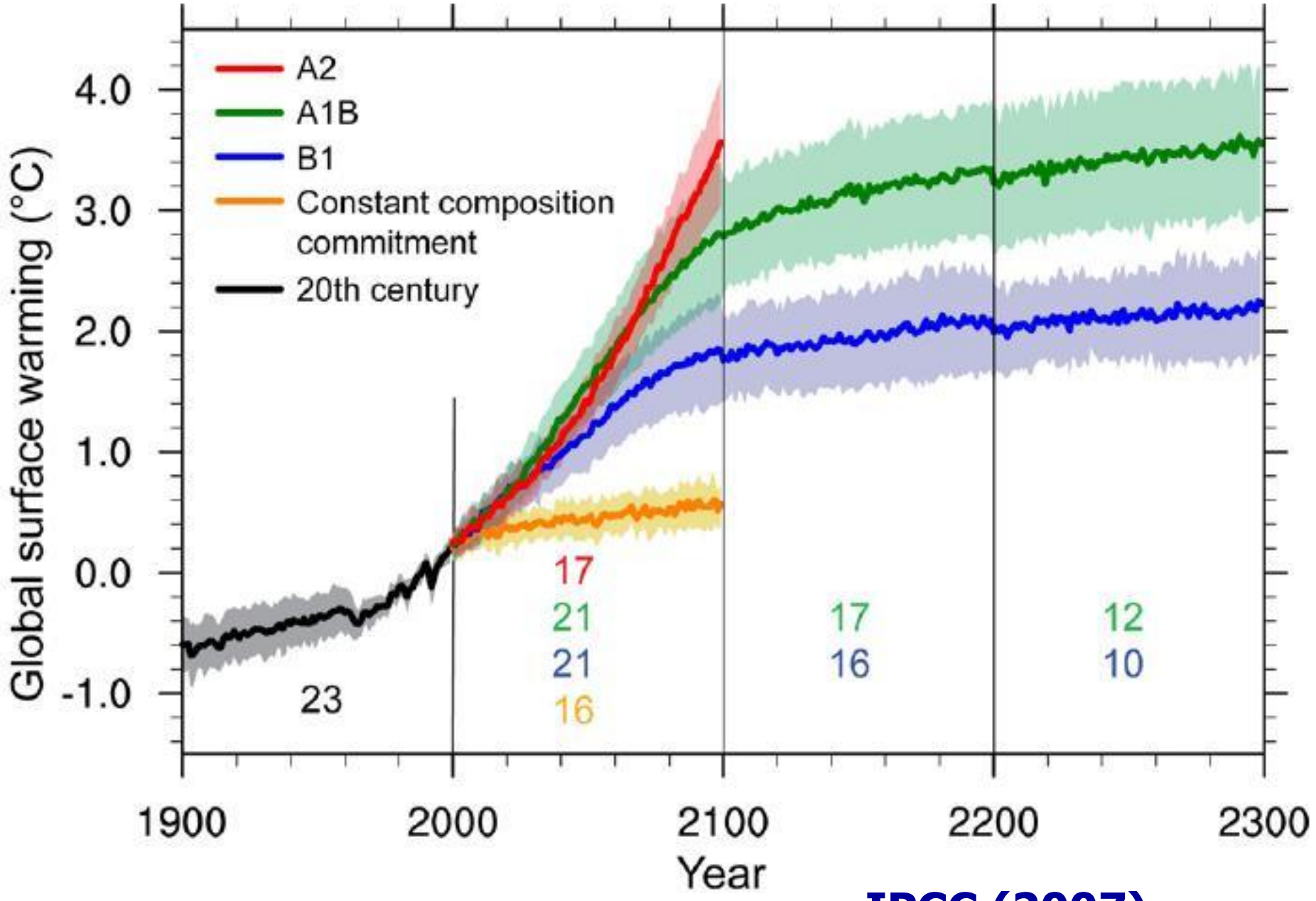
The Biggest Global Experiment - Ever !



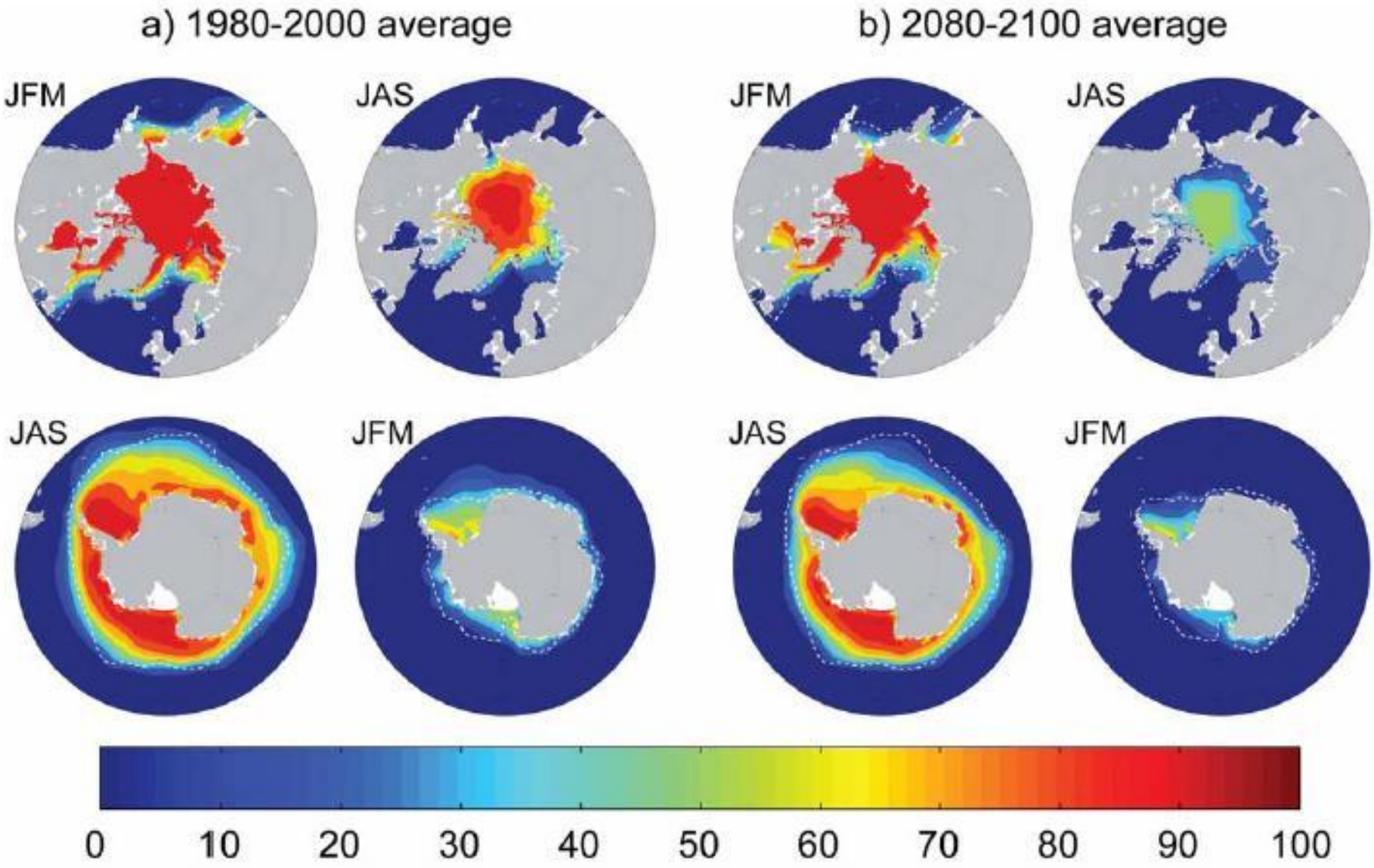
Temperatur-utviklingen siden 1850 (IPCC 2007)




A2
A1B
B1
Constant composition commitment
20th century
Global surface warming (°C)
4.0
3.0
2.0
1.0
0.0
-1.0
1900
2000
2100
2200
2300
Year
23
17
21
21
16
17
16
12
10

IPCC (2007)

ICE EXTENT



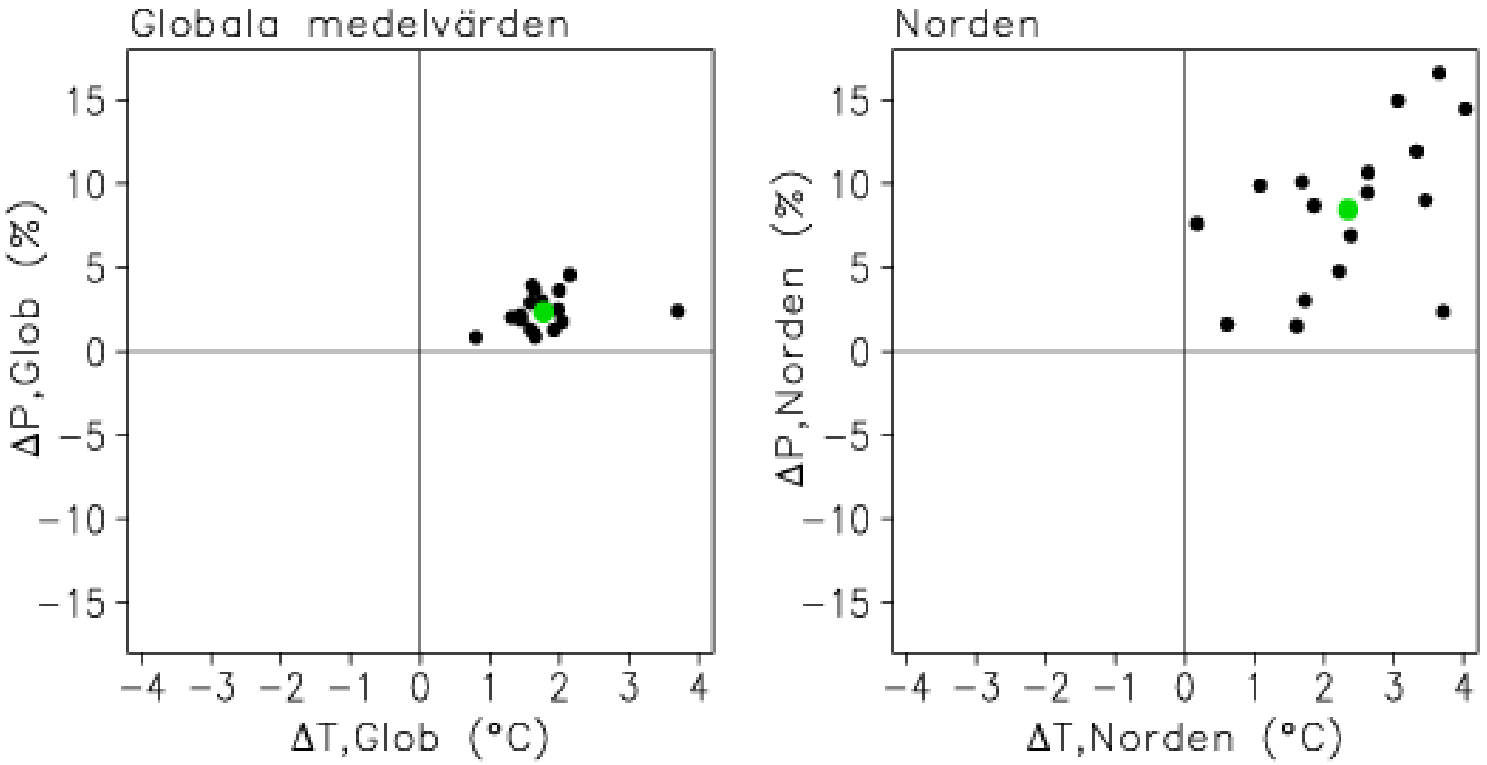
IPCC (2007)

High latitude predictions more insecure:

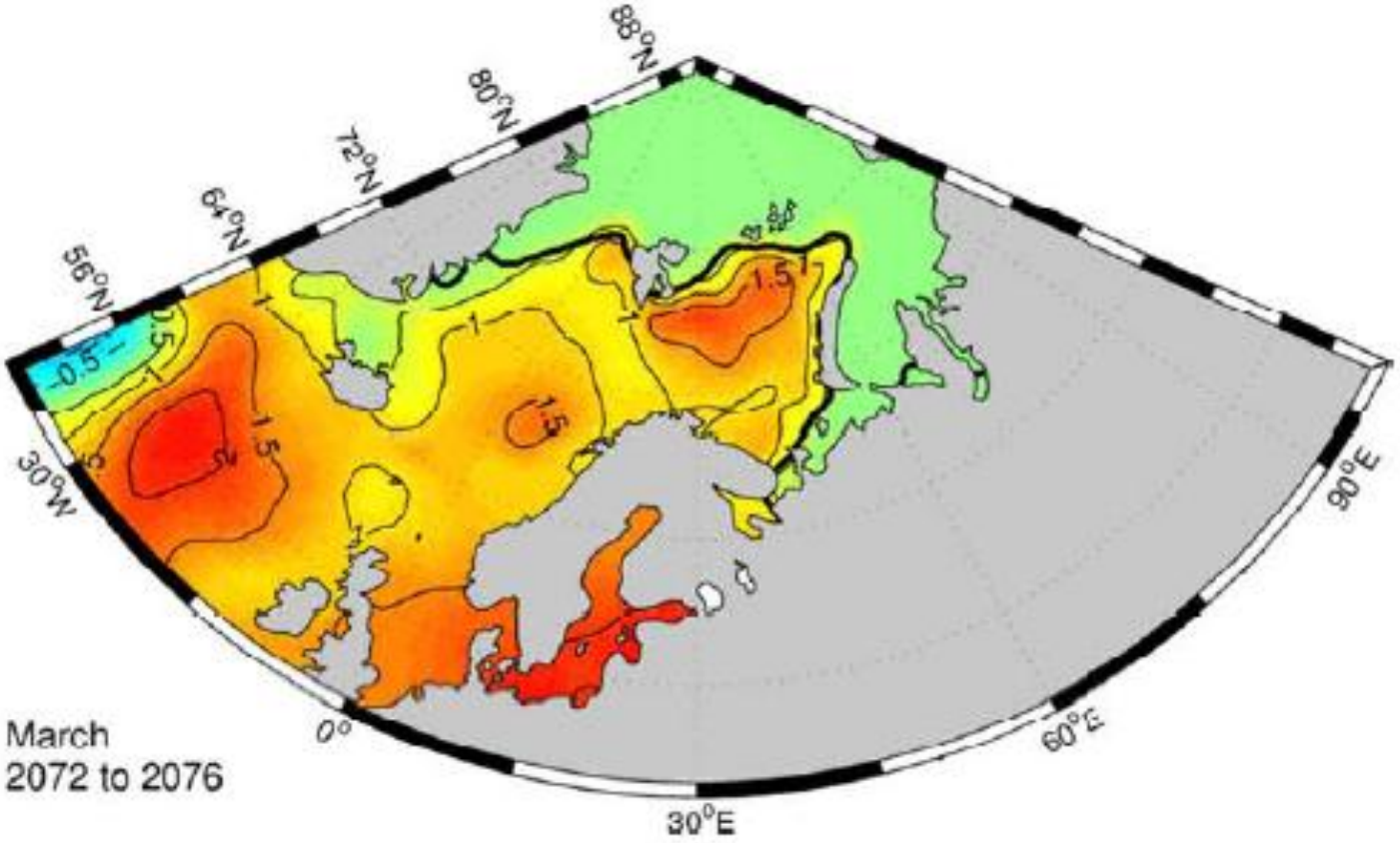
Bjerknes Centre
for Climate Research

Global changes vs. regional (Nordic/High lat.)

(doubled CO2, Räisänen)



Predicted increase of sea temperature in the northeastern North Atlantic is 1,0 –2,0 °C over the next 70 years

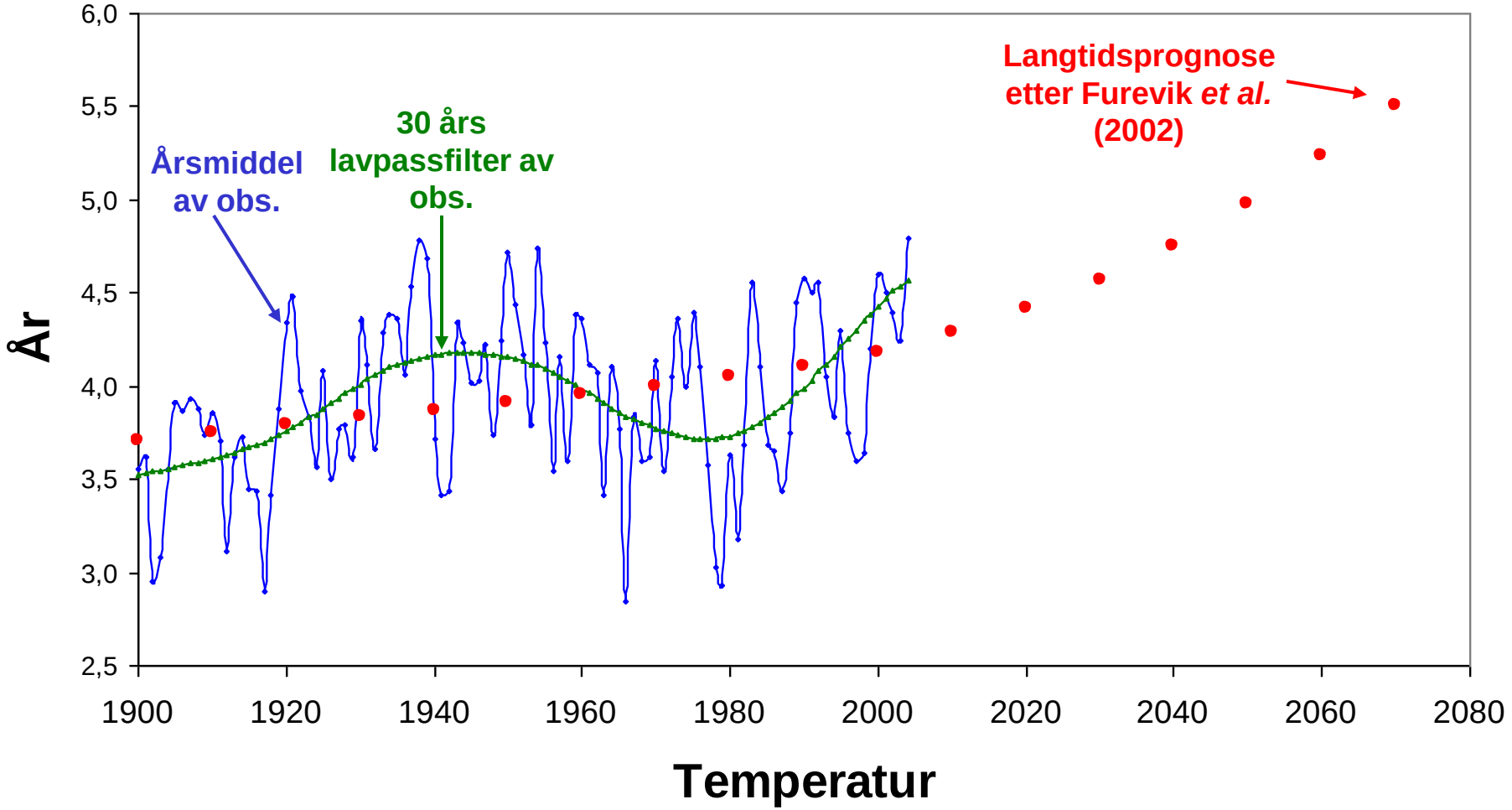


Bjerknes Centre for Climate Research

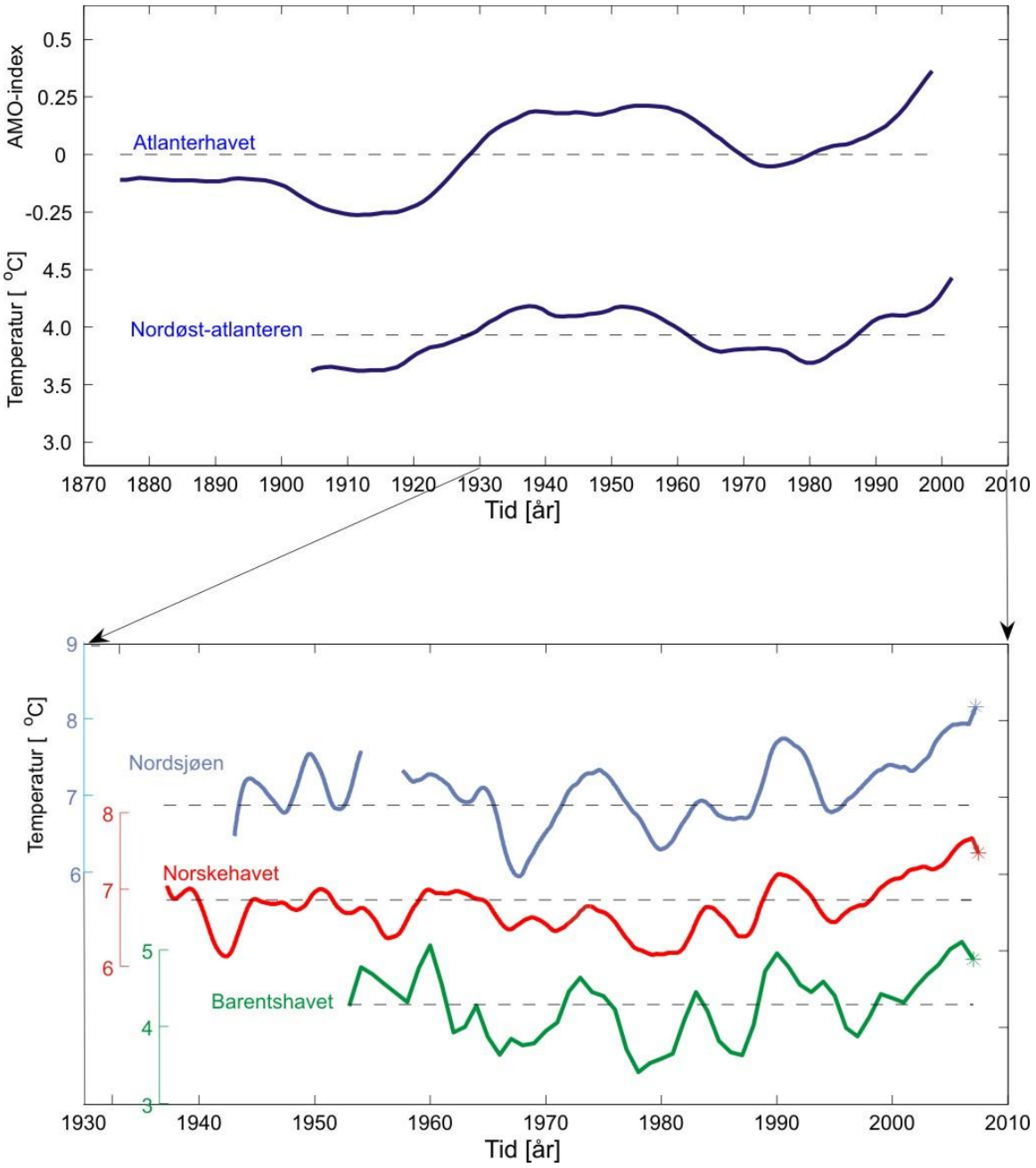
Norwegian Meteorological Institute met.no

Furevik *et al*. (2002)

Sjøtemperaturen i det østlige Barentshavet (Kolasnittet) – observasjoner i det 20.århundret og langtidsprognose fram mot 2080



Sundby (2007)



From basin-scale to regional-scale climate trends

Is the summit of the multidecadal climate oscillation just passed?

Conclusion

- Human-induced global warming during 20. century has been small compared to the projected changes during 21. century

- If the natural multidecdal climate signal continues as during the 20.century we might experience a considerable reduction in the warming of the northern hemisphere, or even a moderate cooling over the coming 20 years followed by a very large warming towards the mid 21. century

- Natural climate variability will be small compared to the human-induced climate signal in the second half of 21. century

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BARENTS SEA FOOD WEB
(Simplified)

Man

Parathemisto

Polar cod

Phytoplankton

Calanus

Seal

Capelin

Krill

Cod

Herring

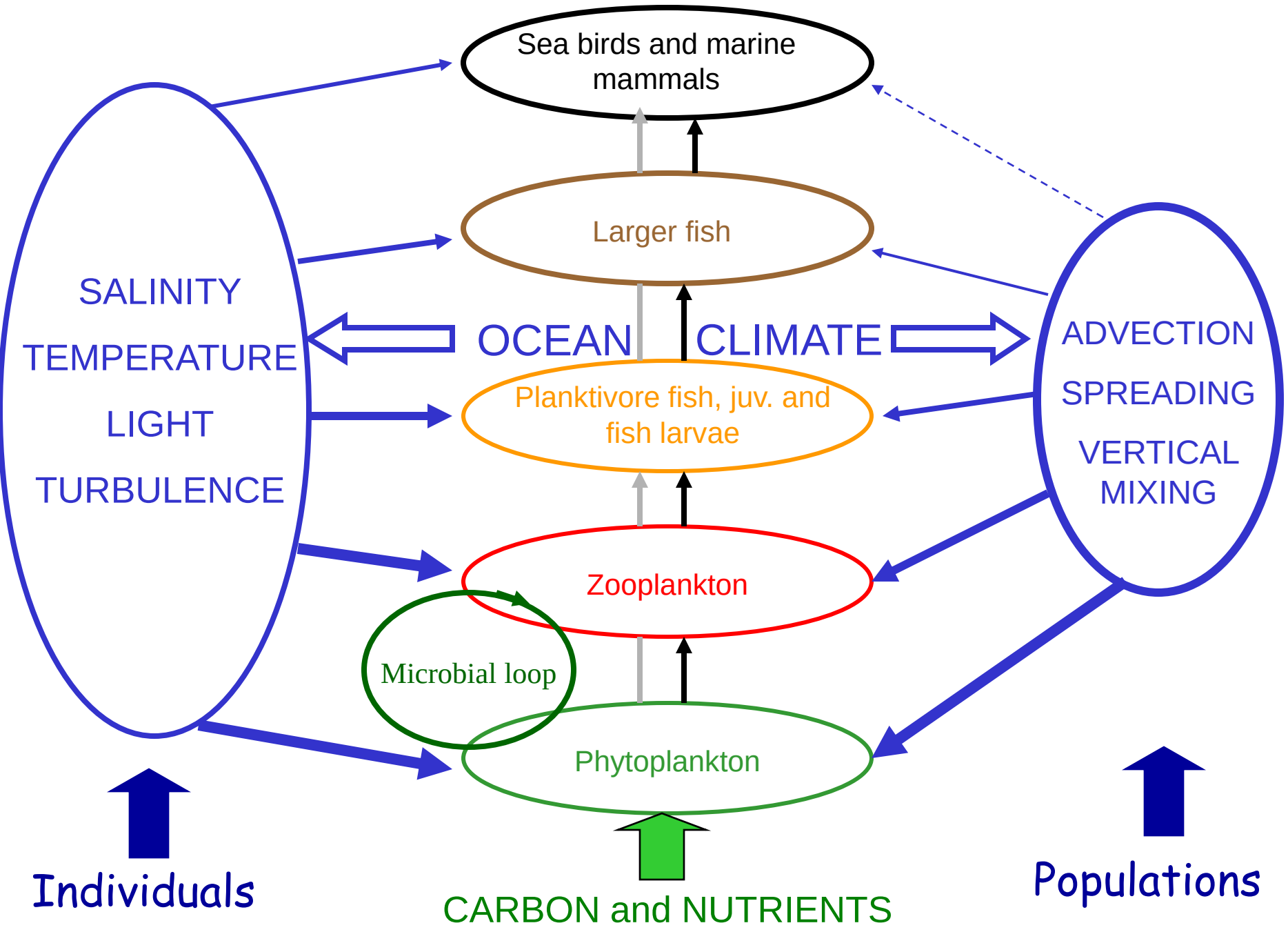
Nivå 1

Nivå 2

Nivå 3

Nivå 4

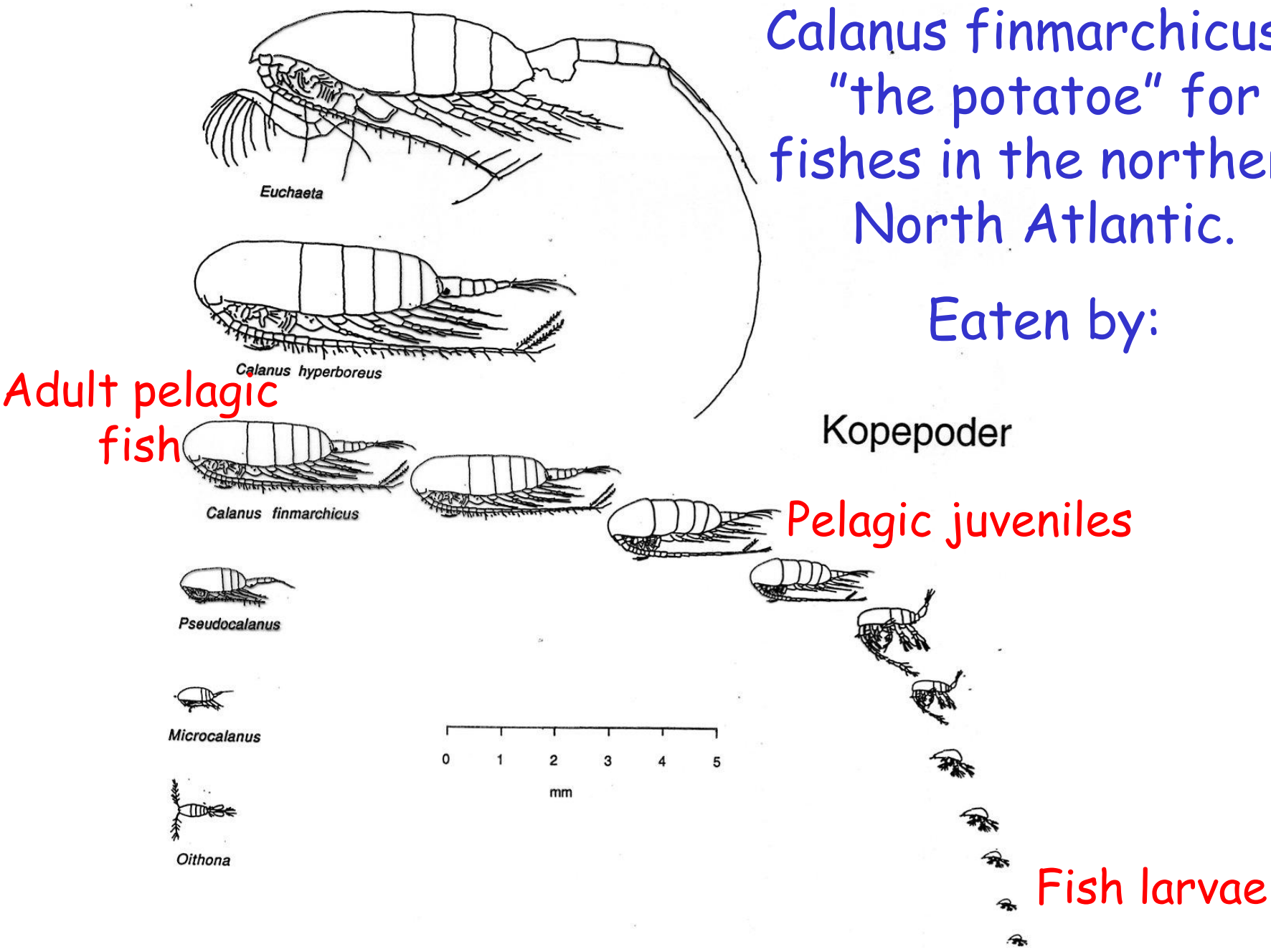
Nivå 5


Sea birds and marine mammals
Larger fish
SALINITY
TEMPERATURE
LIGHT
TURBULENCE
OCEAN
CLIMATE
ADVECTION
SPREADING
VERTICAL MIXING
Planktivore fish, juv. and fish larvae
Zooplankton
Microbial loop
Phytoplankton
Individuals
CARBON and NUTRIENTS
Populations

Calanus finmarchicus – a key player in marine ecosystem of the northern North Atlantic

Calanus finmarchicus – "the potatoe" for fishes in the northern North Atlantic.

Eaten by:

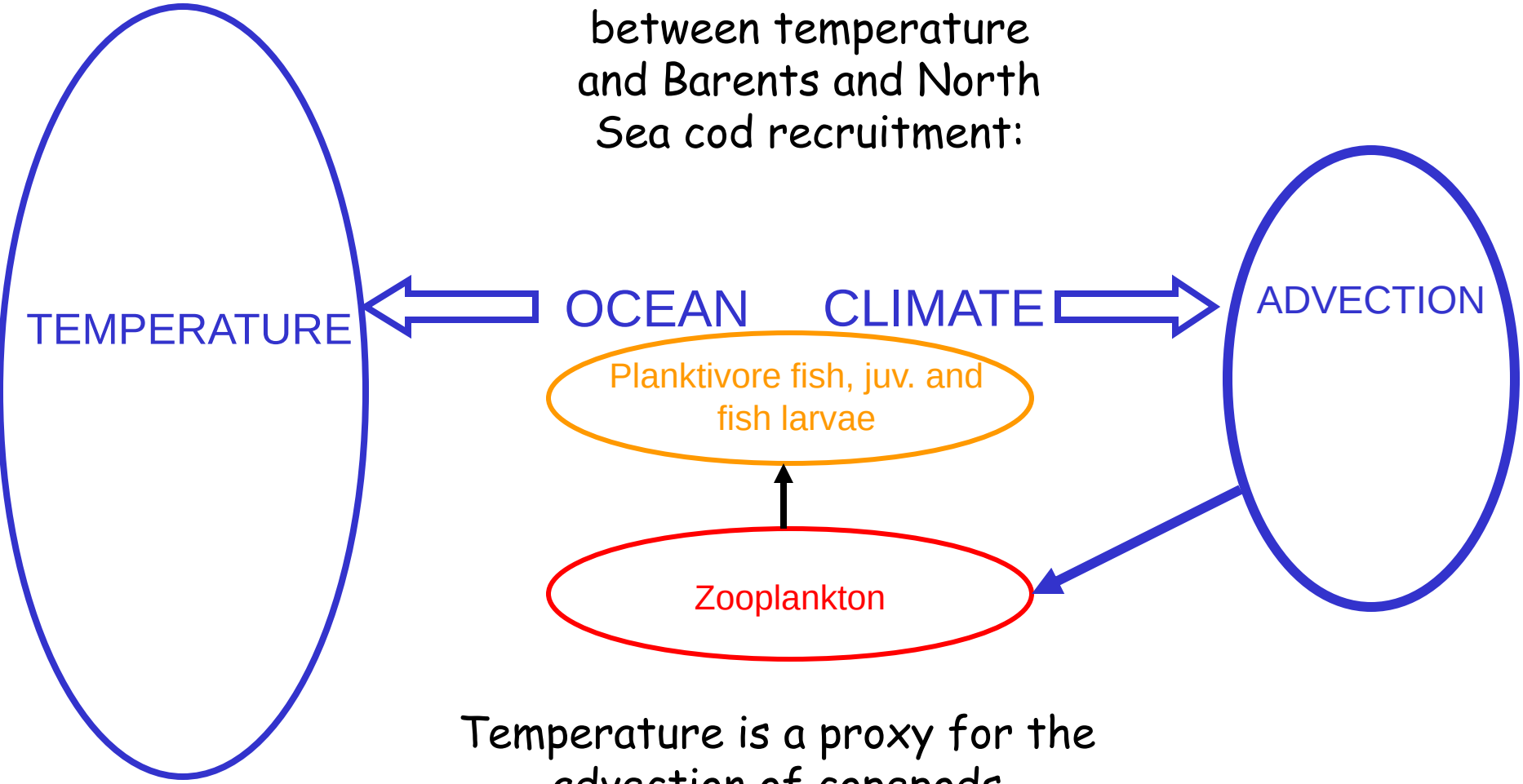


Adult pelagic fish

Pelagic juveniles

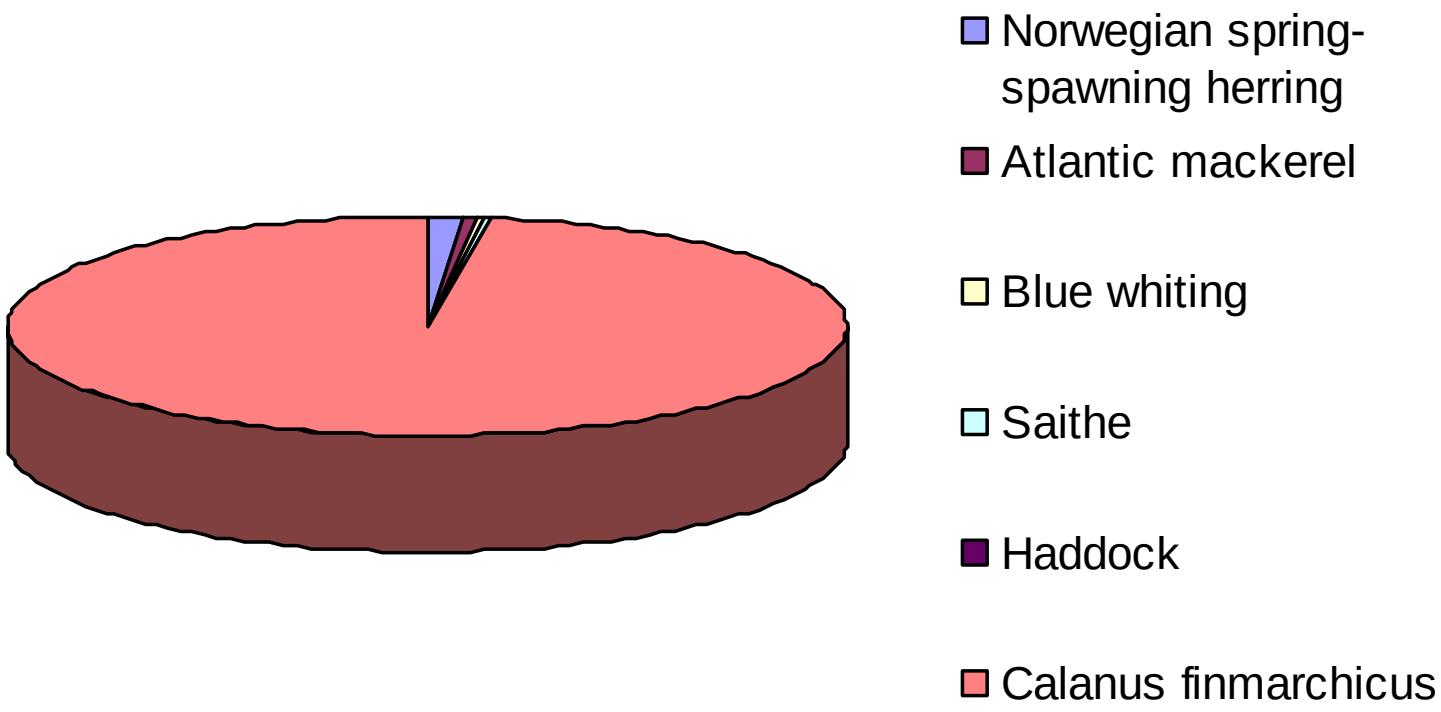
Fish larvae

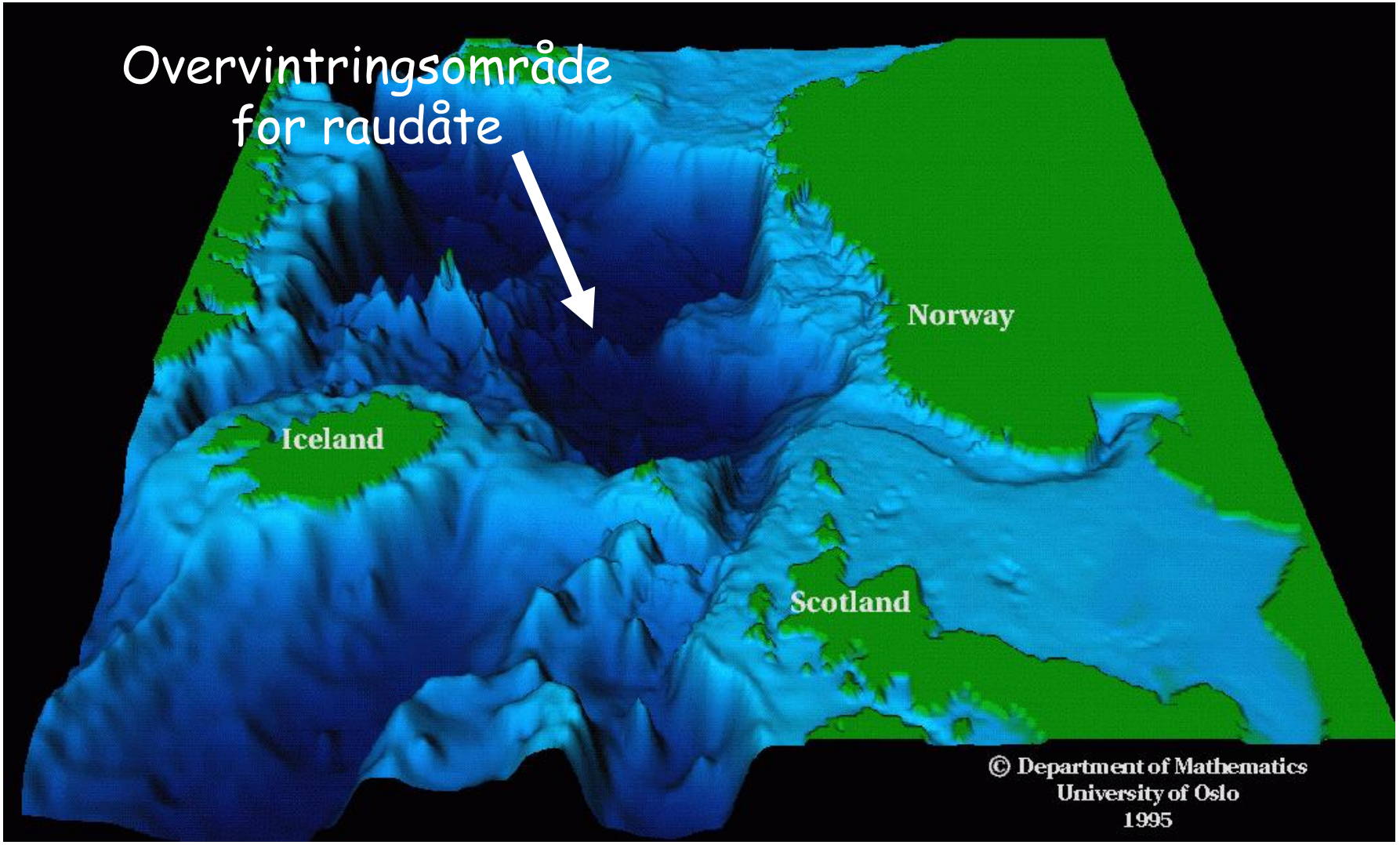
The mechanistic link between temperature and Barents and North Sea cod recruitment:



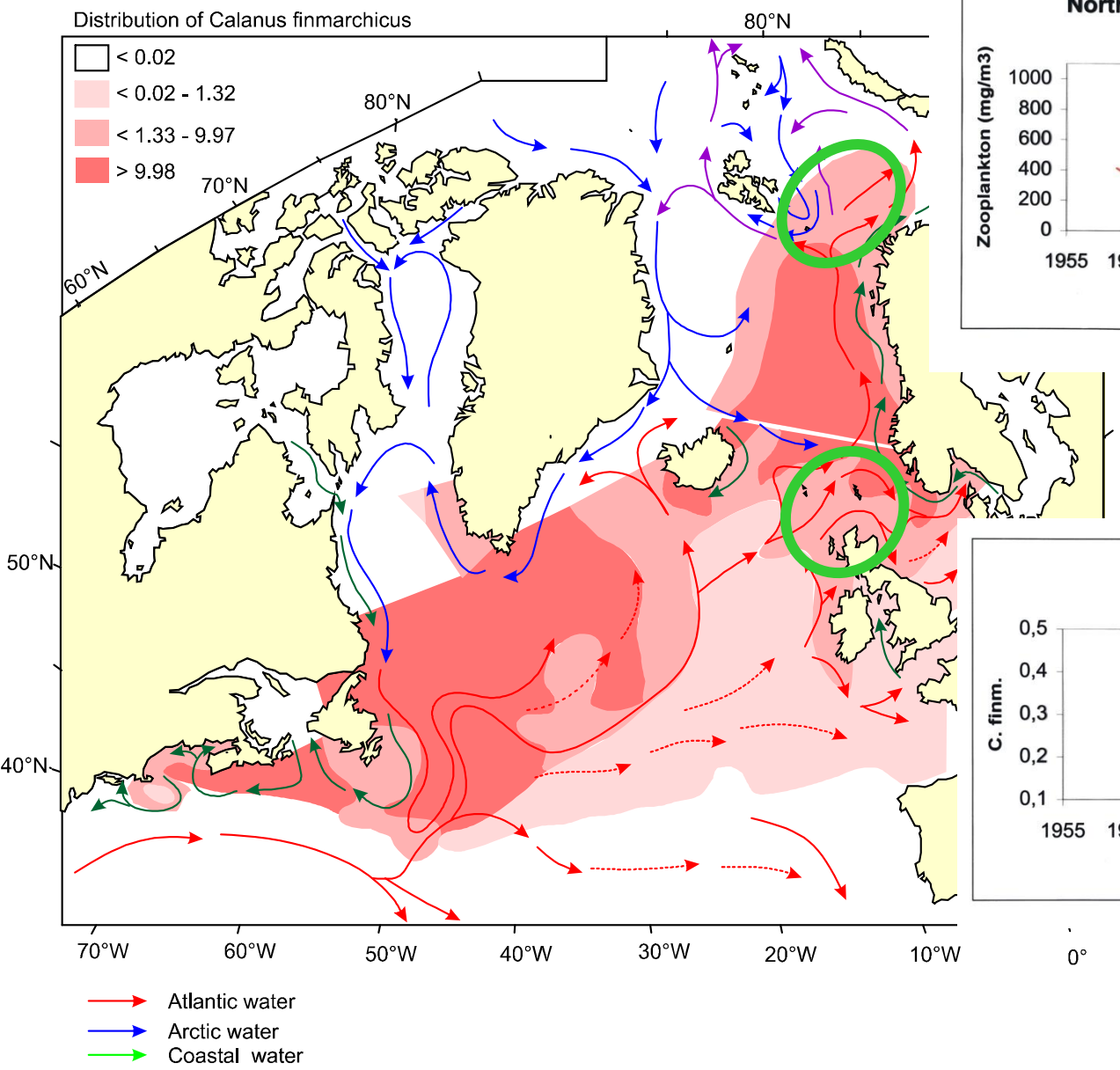
Temperature is a proxy for the advection of copepods

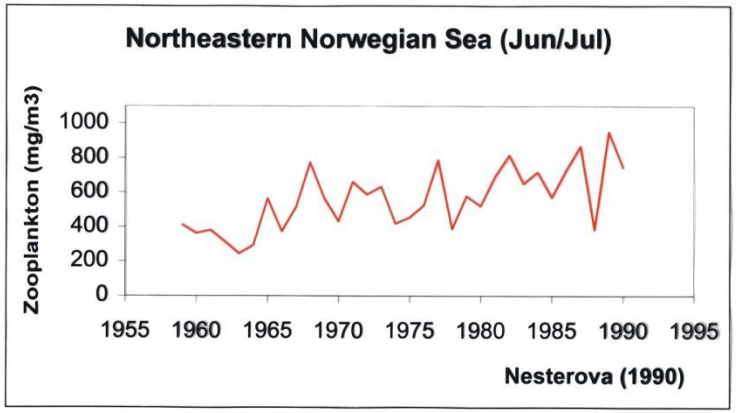
Biomass of *Calanus finmarchicus* and the most important fish stocks in the Nordic

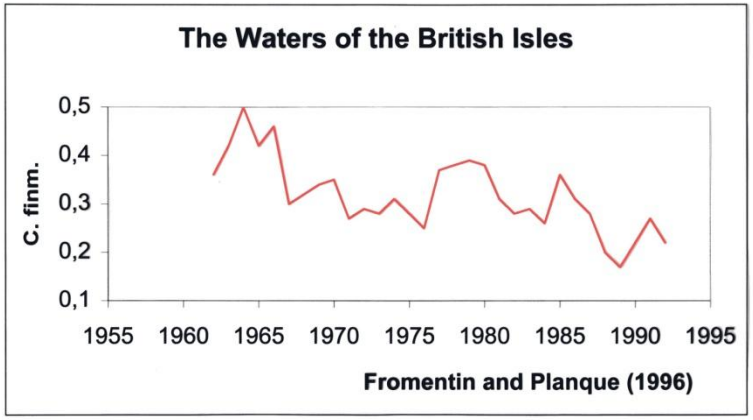


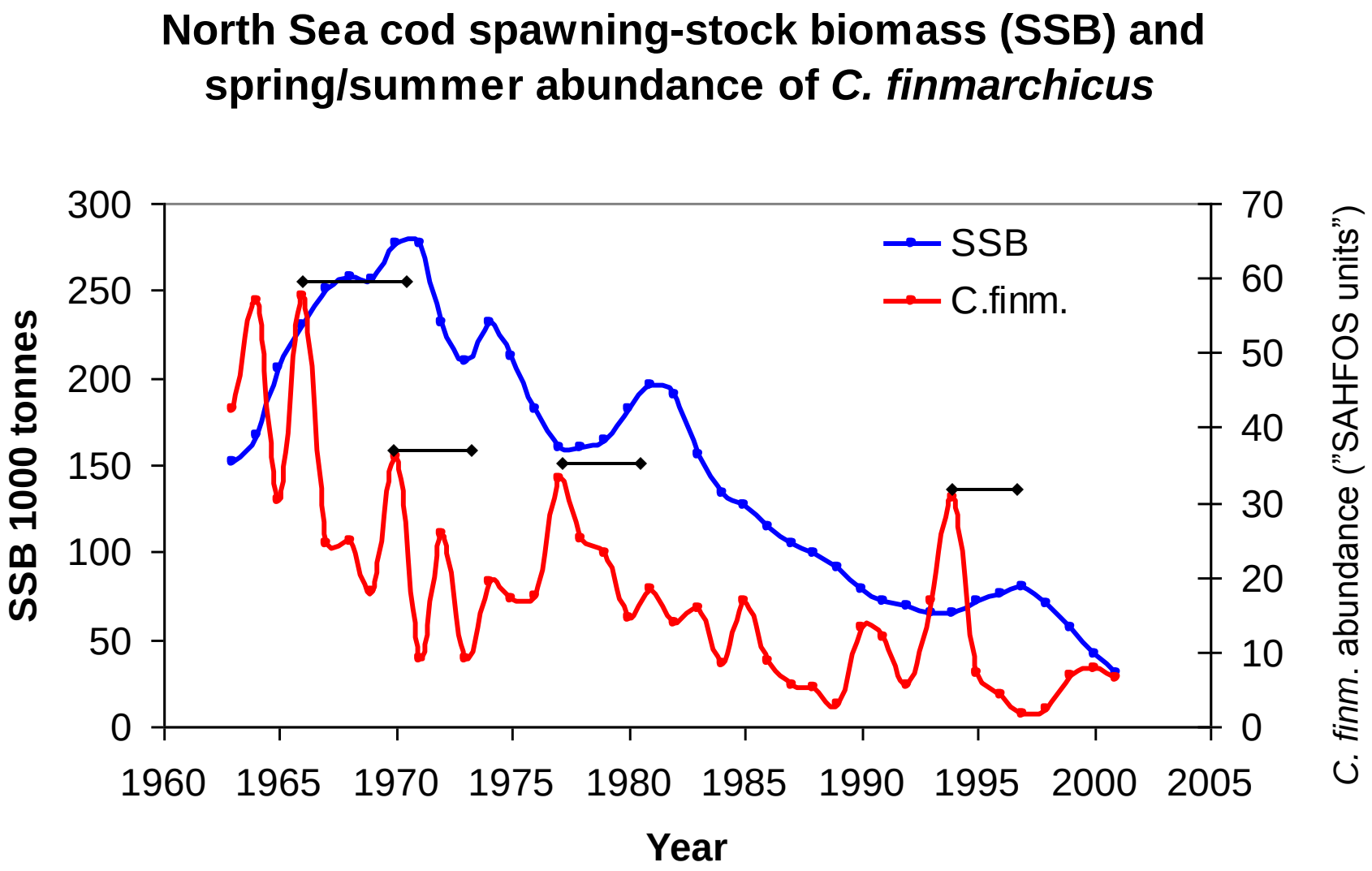


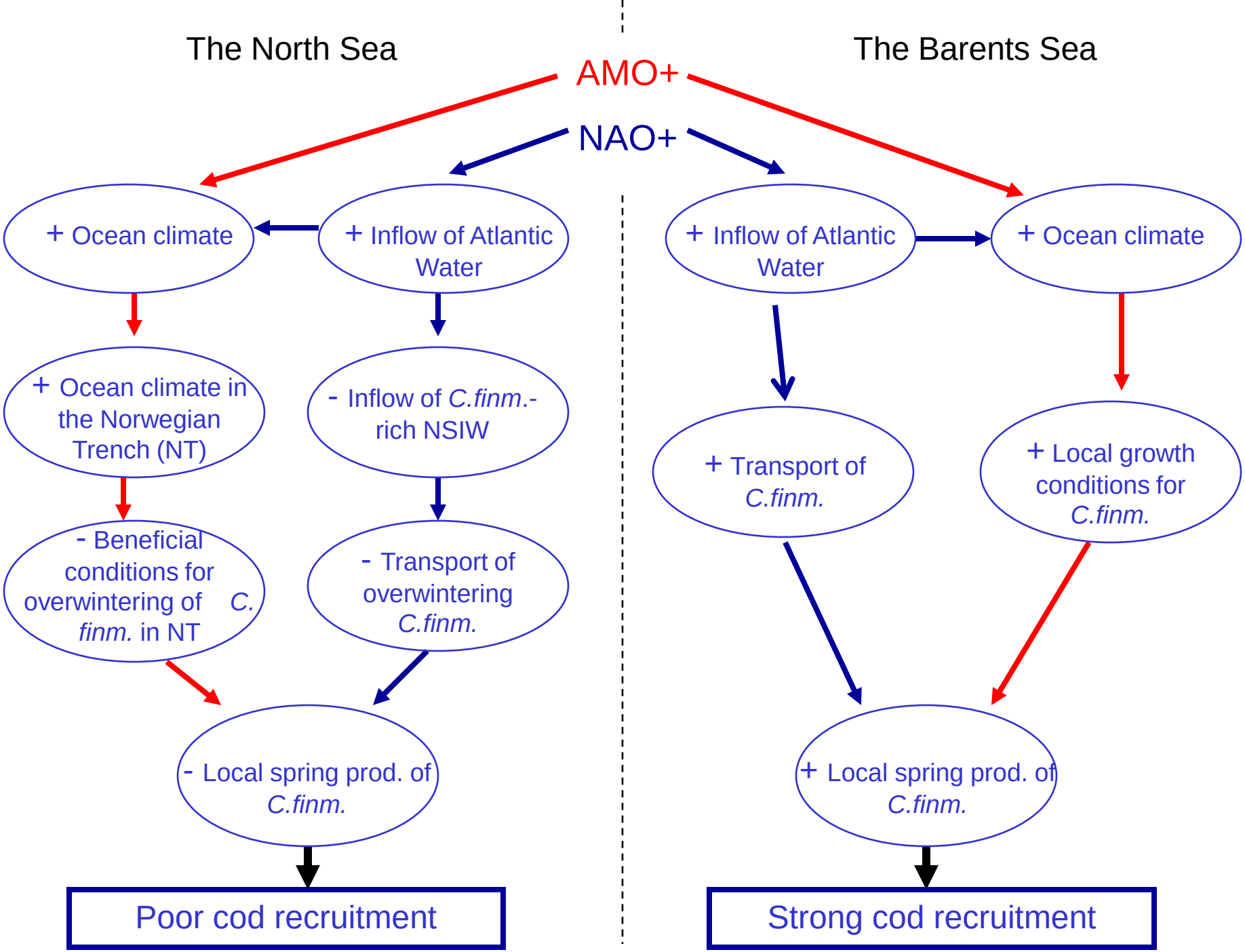
Gjevik *et al.* (1995)

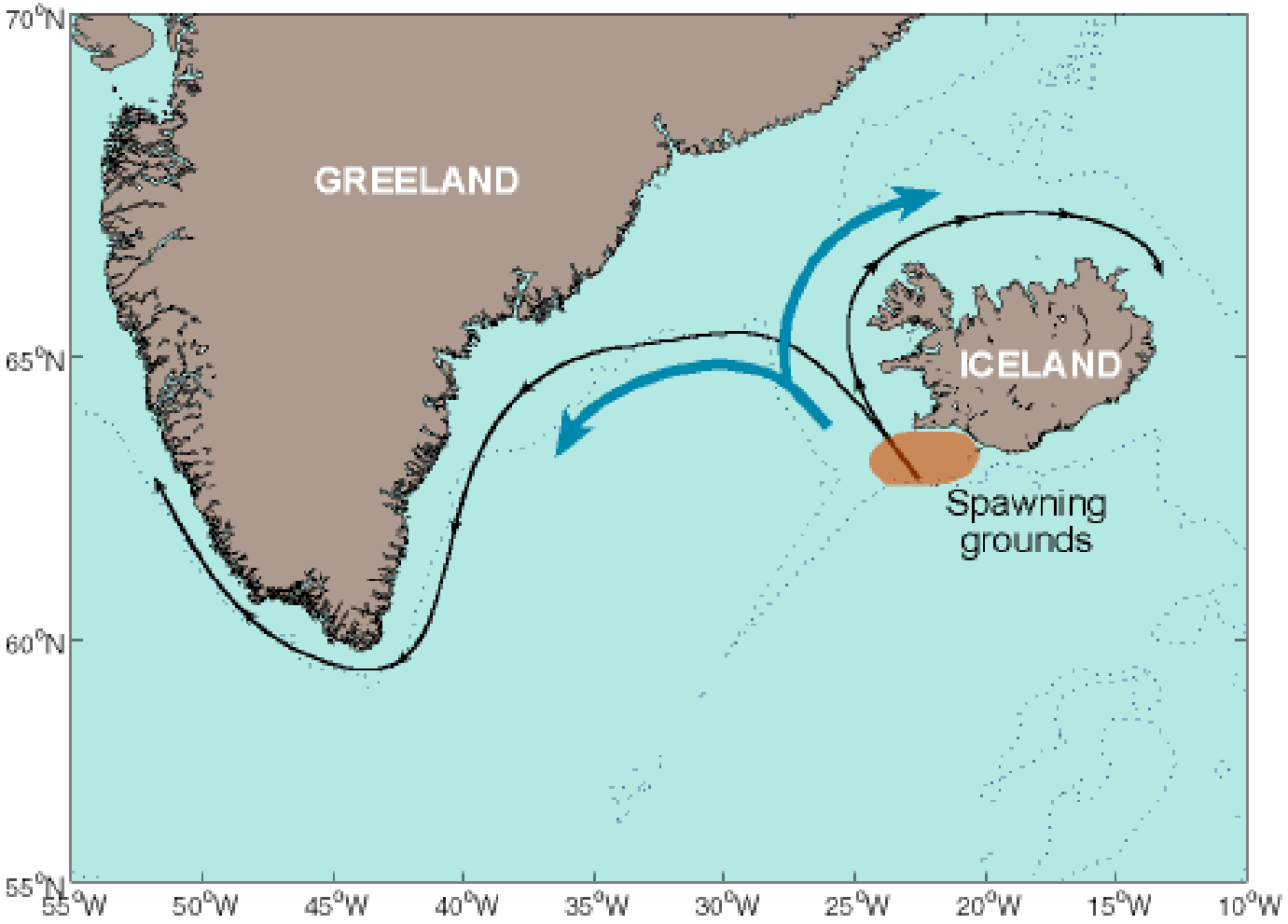

Distribution of Calanus finmarchicus
< 0.02
< 0.02 - 1.32
< 1.33 - 9.97
> 9.98
80°N
80°N
70°N
60°N
50°N
40°N
70°W
60°W
50°W
40°W
30°W
20°W
10°W
0°
Atlantic water
Arctic water
Coastal water


Northeastern Norwegian Sea (Jun/Jul)
Zooplankton (mg/m3)
1000
800
600
400
200
0
1955
1960
1965
1970
1975
1980
1985
1990
1995
Nesterova (1990)


The Waters of the British Isles
C. finm.
0,5
0,4
0,3
0,2
0,1
1955
1960
1965
1970
1975
1980
1985
1990
1995
Fromentin and Planque (1996)

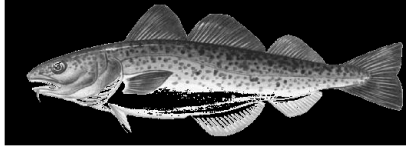

North Sea cod spawning-stock biomass (SSB) and spring/summer abundance of C. finmarchicus
SSB 1000 tonnes
300
250
200
150
100
50
0
70
60
50
40
30
20
10
0
C. finm. abundance ("SAHFOS units")
SSB
C.finm.
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year

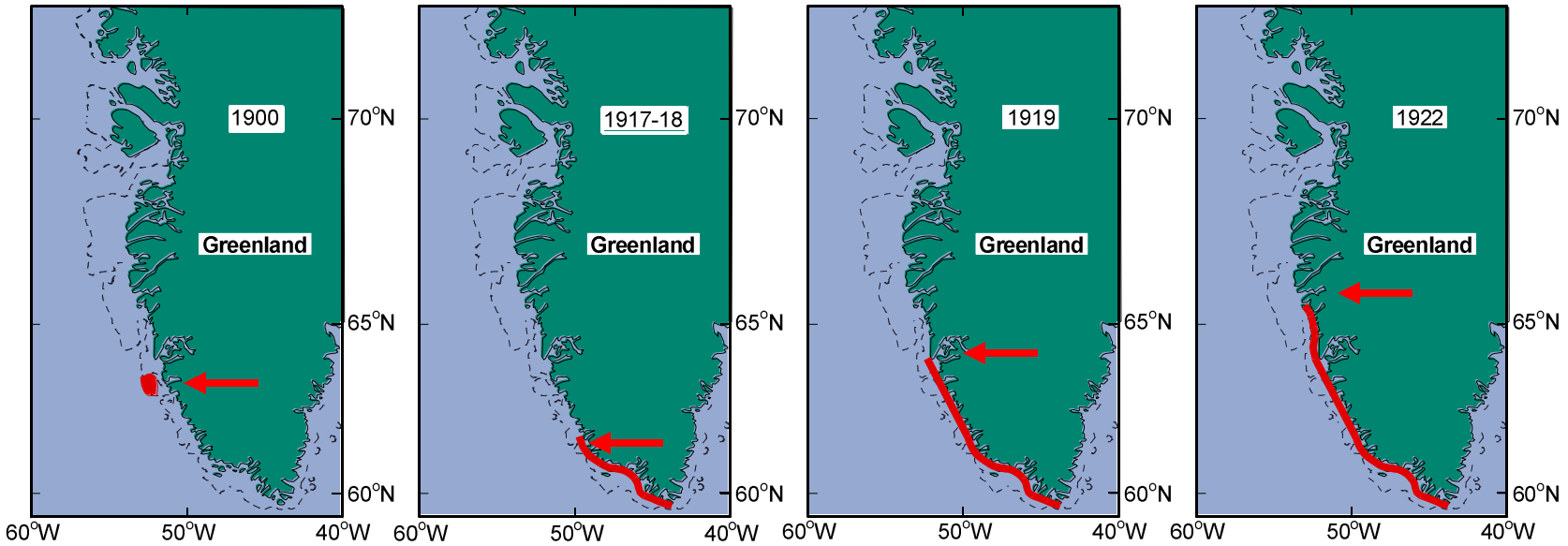

The North Sea
The Barents Sea
AMO+
NAO+
+ Ocean climate
+ Inflow of Atlantic Water
+ Inflow of Atlantic Water
+ Ocean climate
+ Ocean climate in the Norwegian Trench (NT)
- Inflow of C.finm.-rich NSIW
+ Transport of C.finm.
+ Local growth conditions for C.finm.
- Beneficial conditions for overwintering of C. finm. in NT
- Transport of overwintering C.finm.
- Local spring prod. of C.finm.
+ Local spring prod. of C.finm.
Poor cod recruitment
Strong cod recruitment

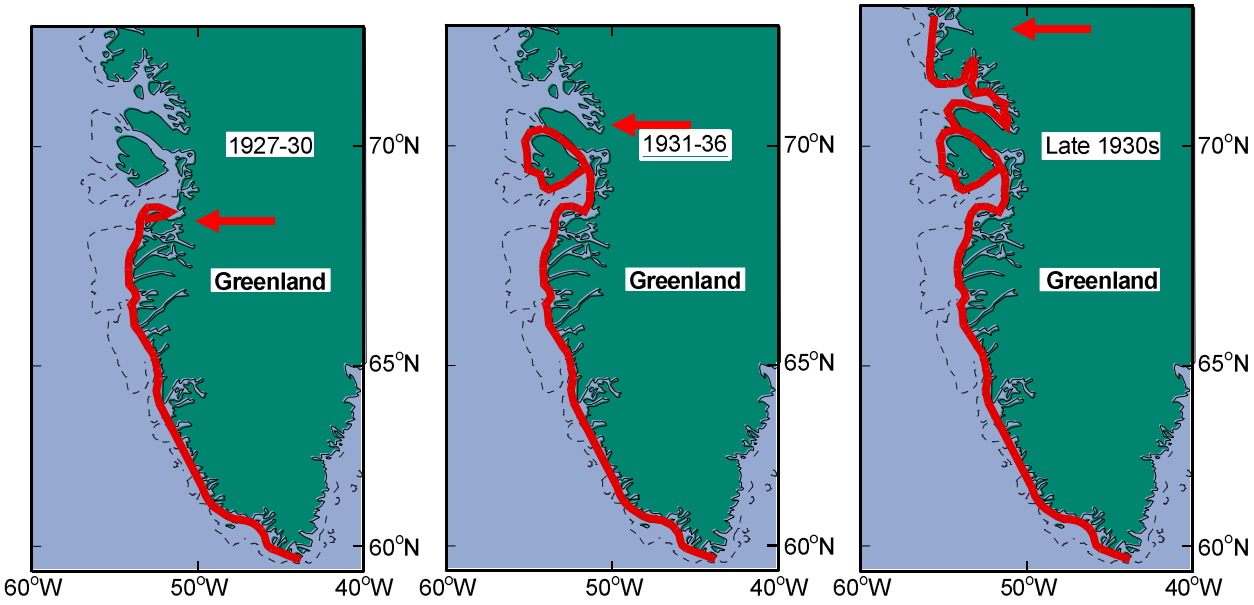


The ocean climate conditions in the 1920s were favourable for transport of cod larvae and juveniles from Icealnd to Greenland

The cod spread northwards during the warm period of the 1920s and 1930s







Hansen (1940)

Vedel Tåning (1953) Long Term Changes in Hydrography and Fluctuations in Fish Stocks

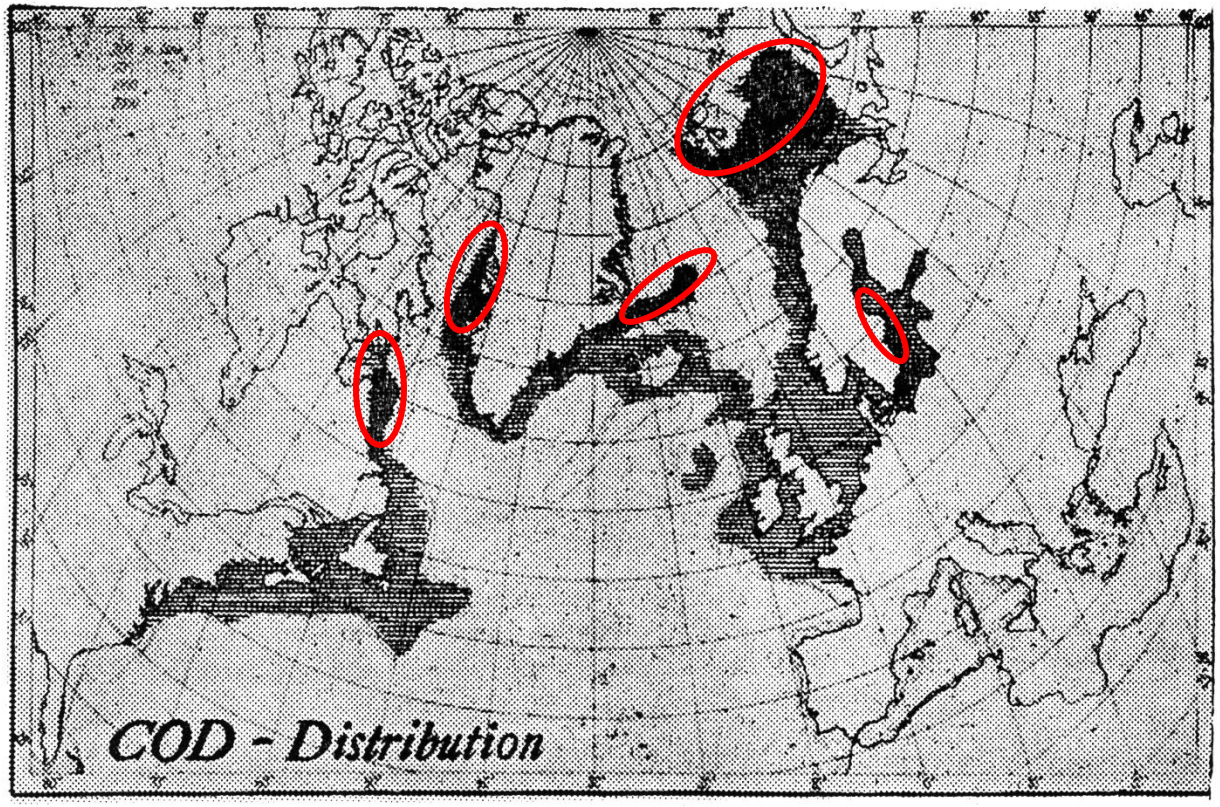
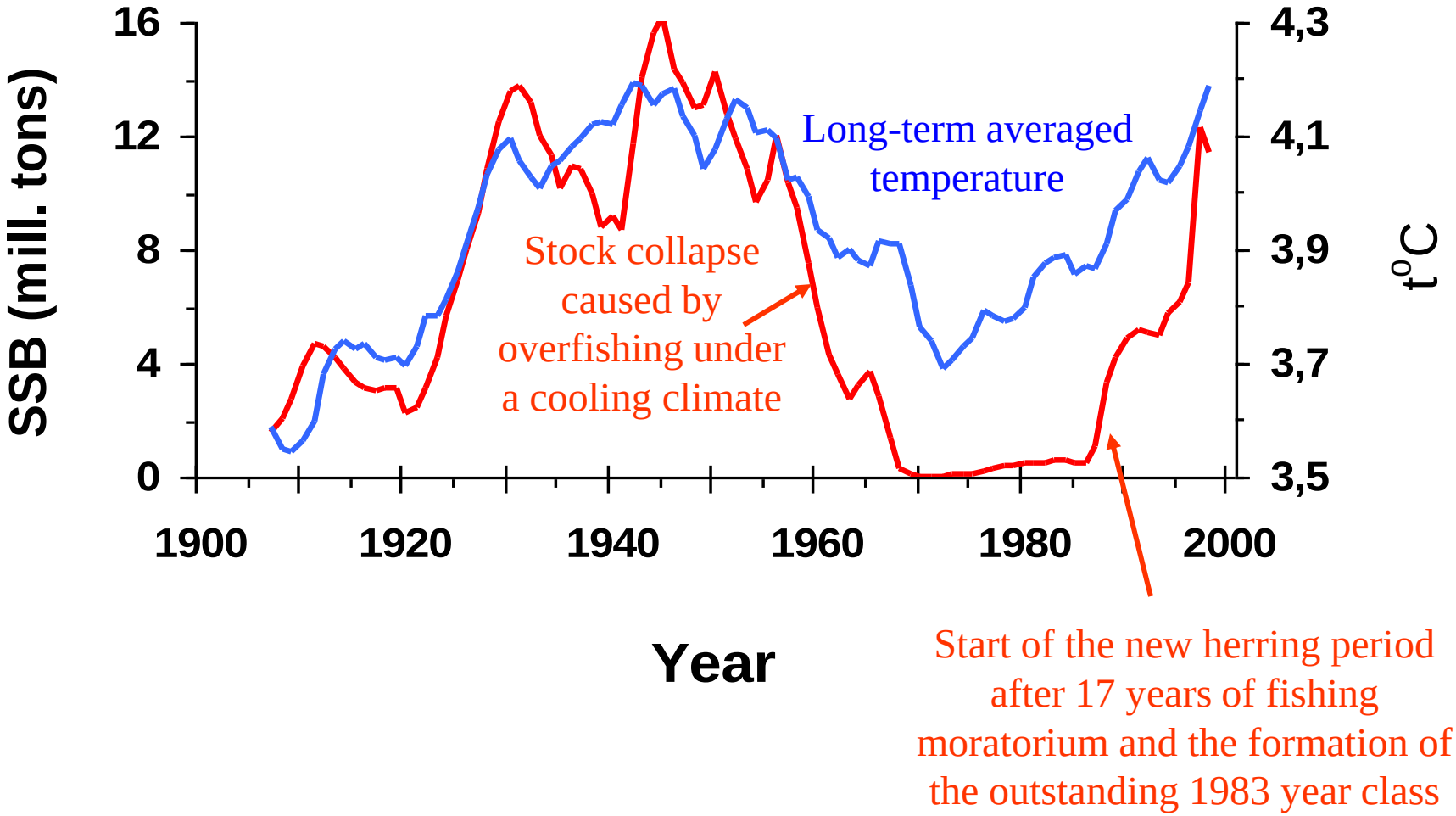


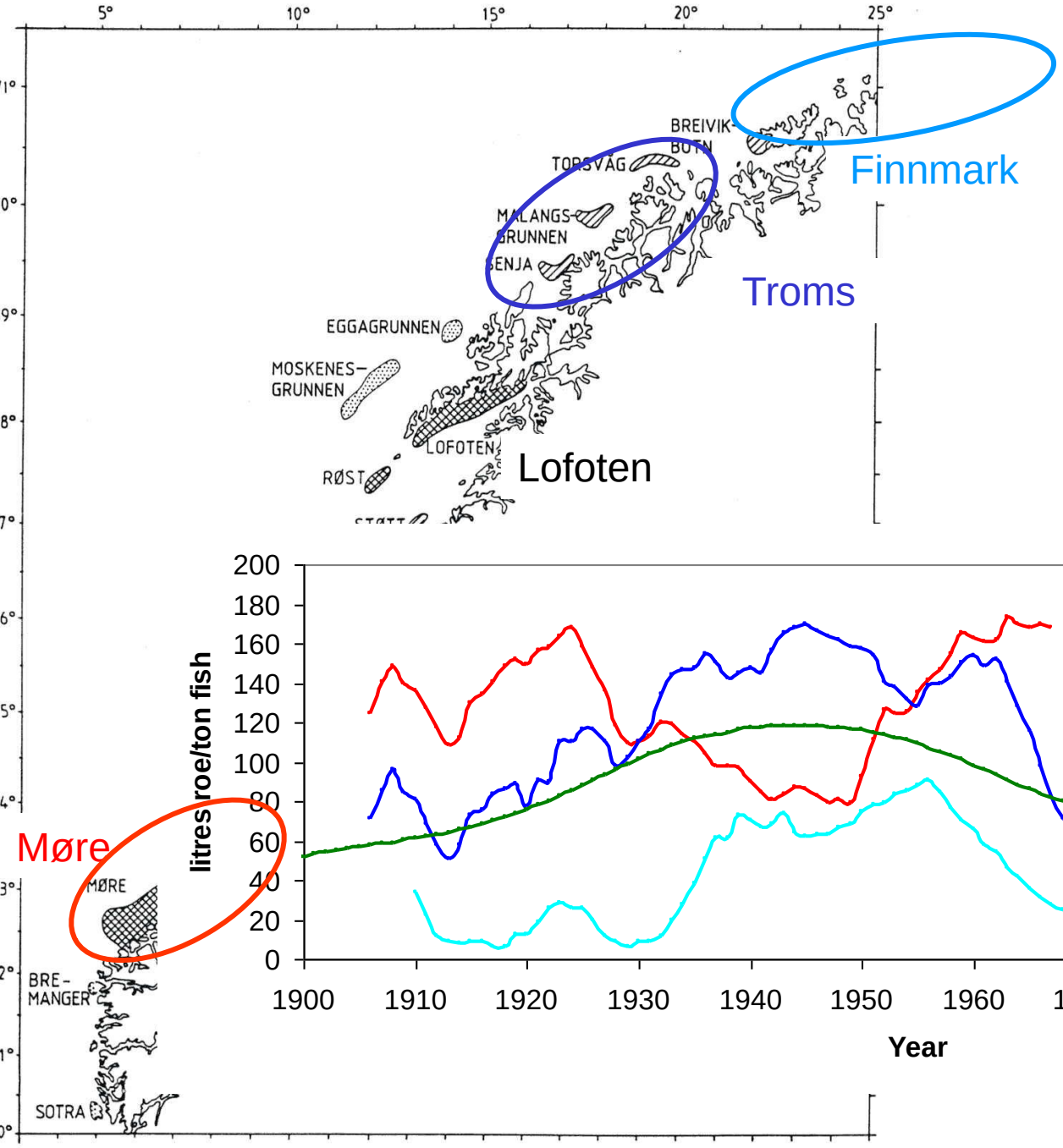
Fig. 1. Rough sketch of distribution of cod in the North Atlantic. Double hatching indicates areas where density of cod approximately has increased in recent time.

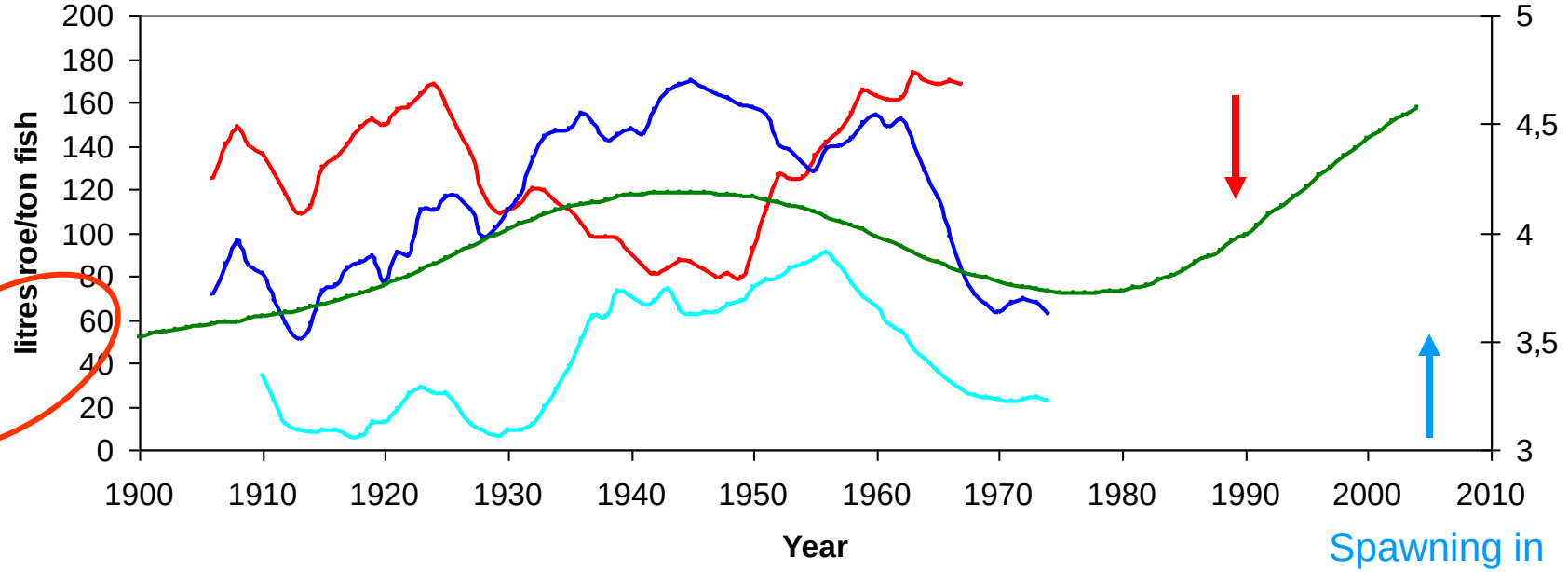
Spawning stock biomass (SSB) of Norwegian spring-spawning herring and the longterm-averaged temperature (the AMO signal)

(Toresen og Østvedt 2000)

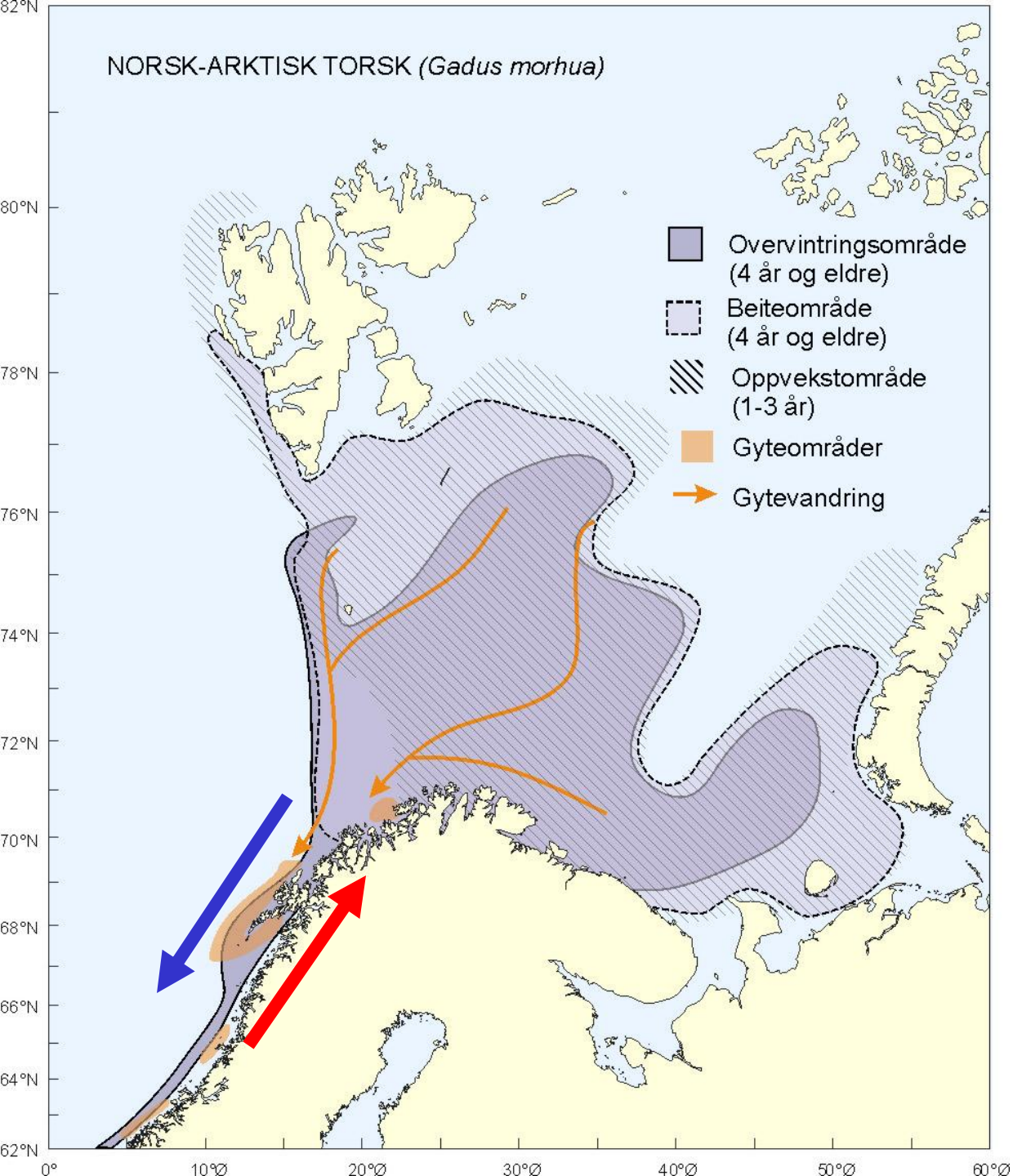


Gytefelter for skrei langs Norskekysten





Spawning in East Finnmark since 2004

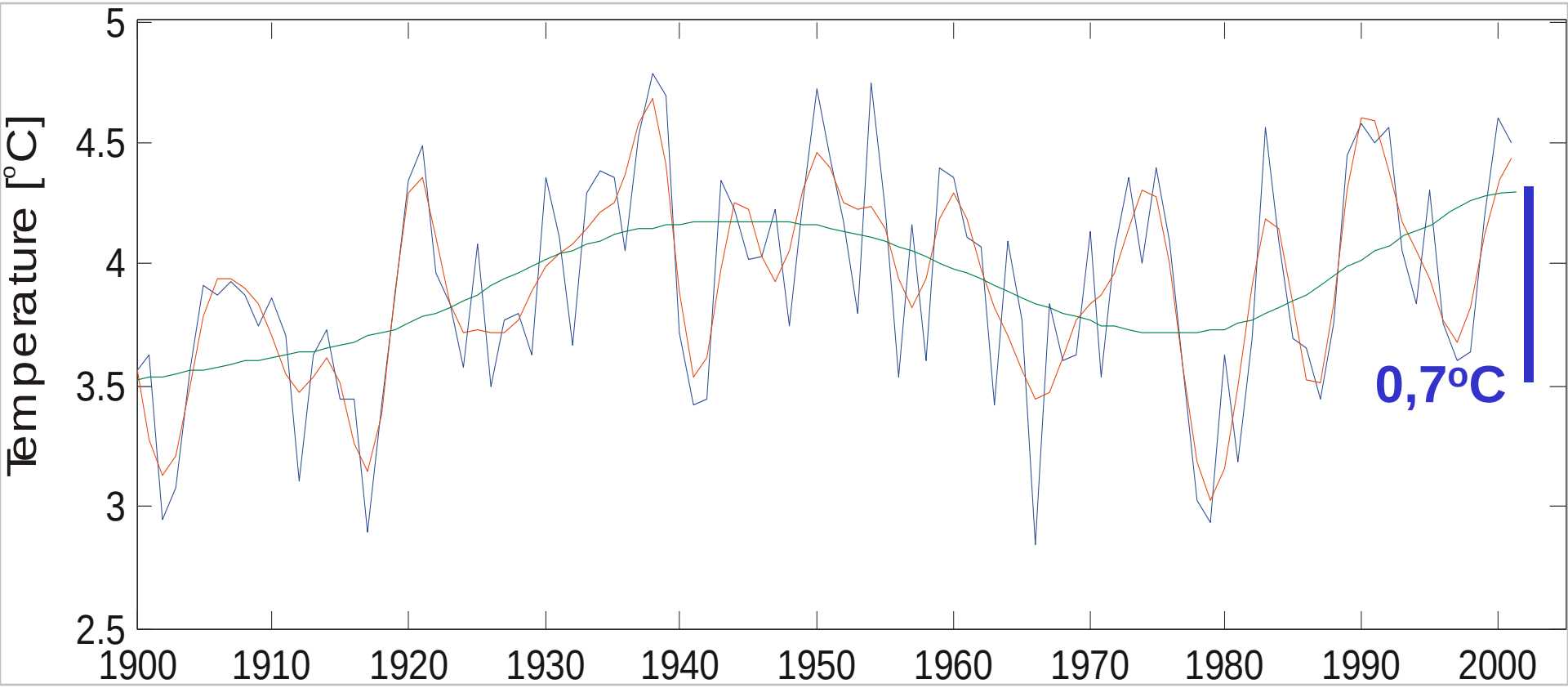


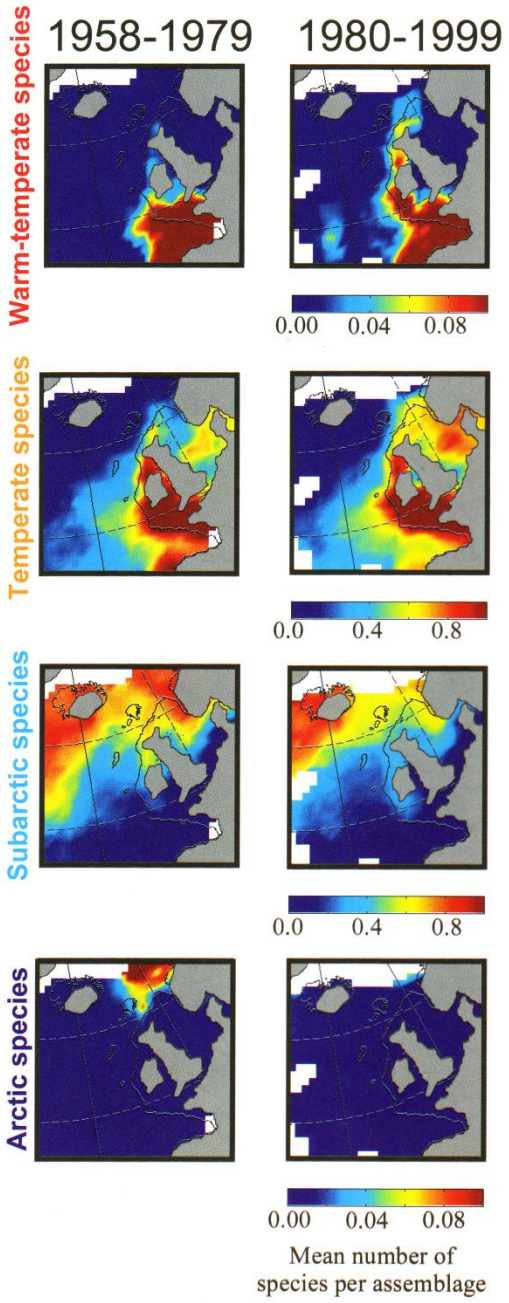
Langperiodiske klimavariasjoner skaper forflytninger i gyteområdene for skrei

Sundby and Nakken (2007)

Bjerknes Centre
for Climate Research

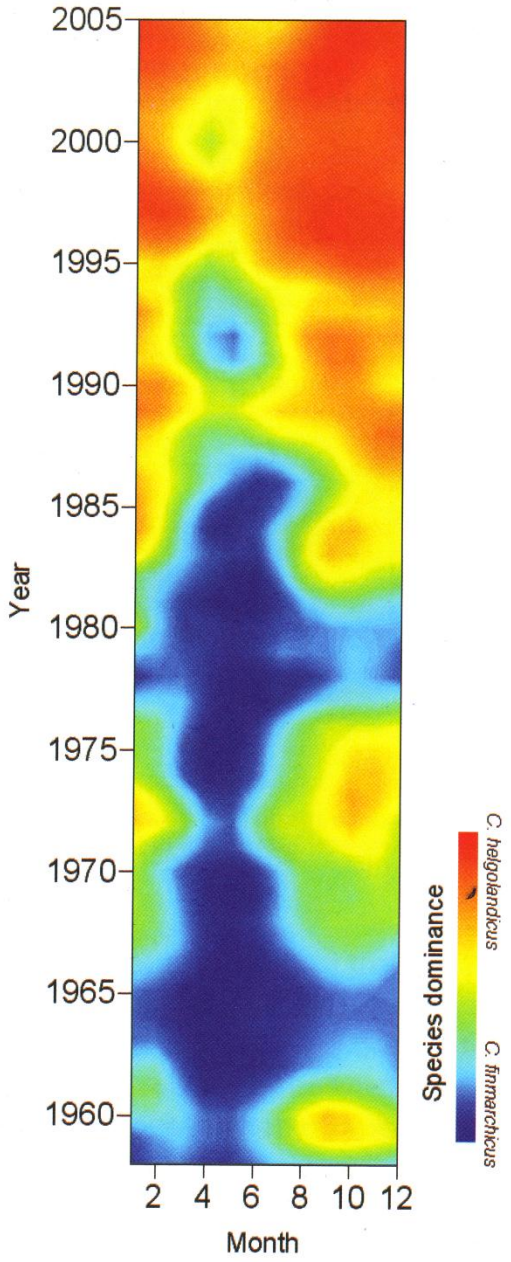
Havklimaet i Barentshavet





All zooplankton species in the northeastern North Atlantic have moved northwards with the increasing temperature

SAHFOS (2007)



The change in species composition between *C. finmarchicus* and *C. helgolandicus* in the northern North Sea

SAHFOS (2007)

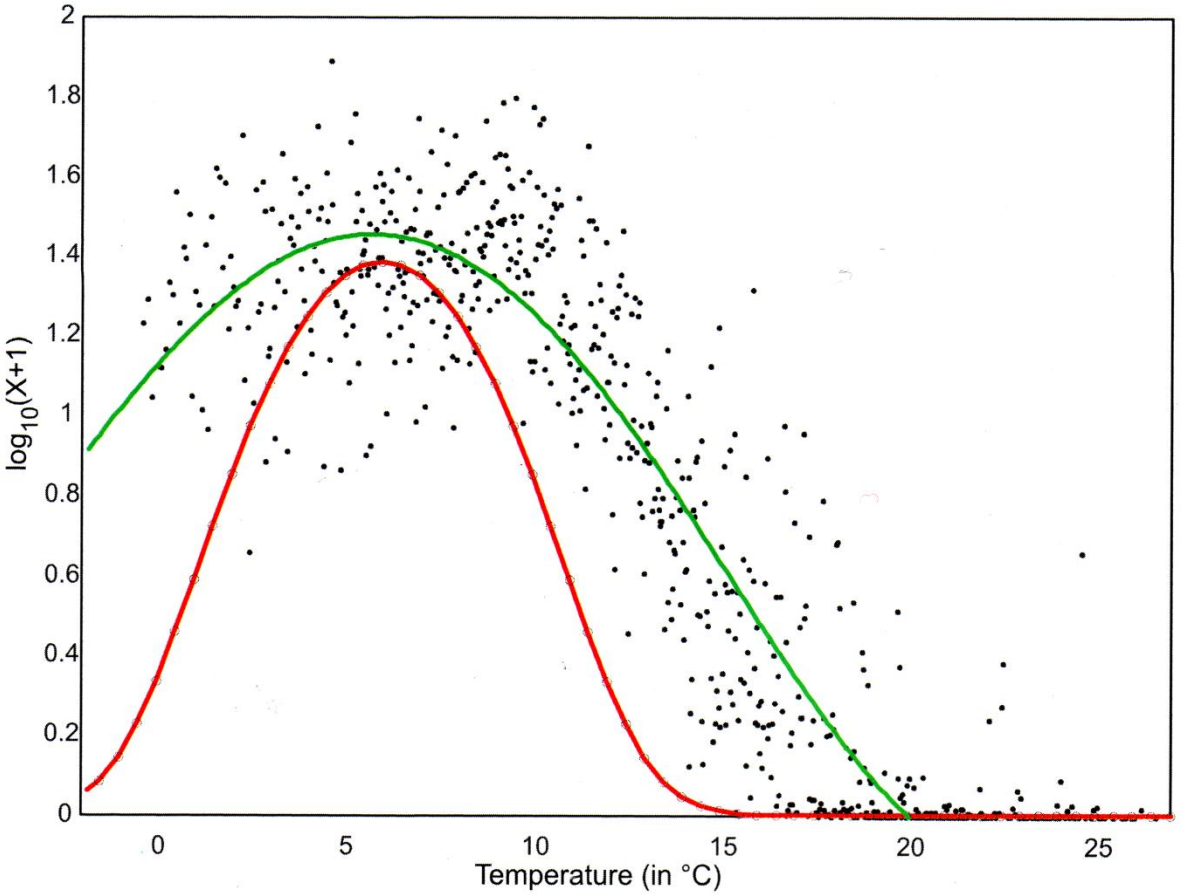
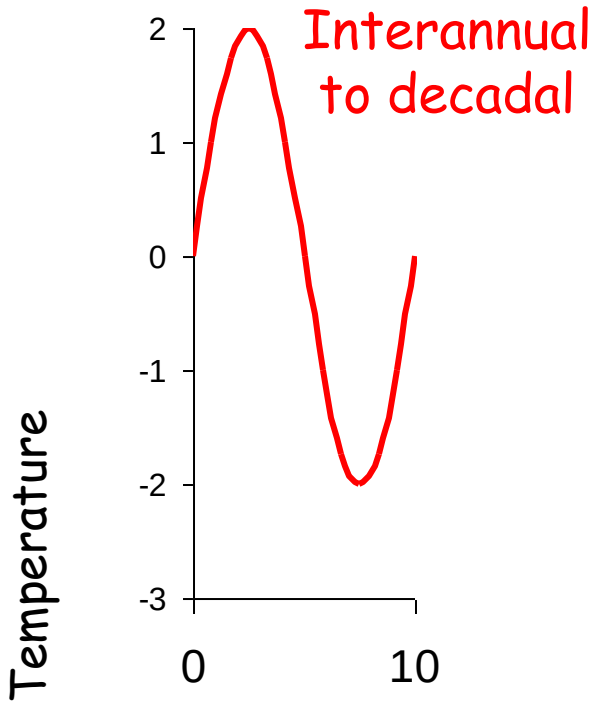


Fig. 10-c. Predicting curve of Eggs Production Rate for *C. finmarchicus* (red, in eggs.female-1.day-1) and abundance of *C. finmarchicus* in the North Atlantic Ocean. A fitting curve is superimposed (green).

SAHFOS (2007)

Climate effects on marine ecosystems vary with the periodicity

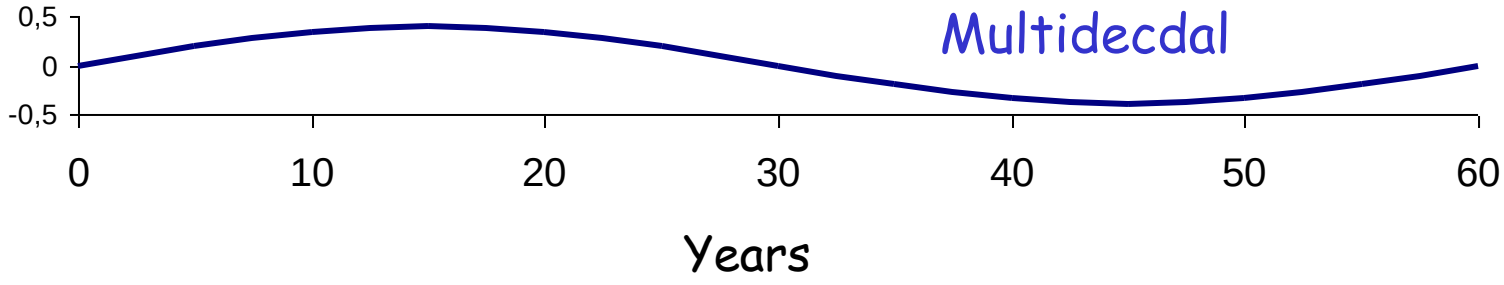


•Local production on lower trophic levels

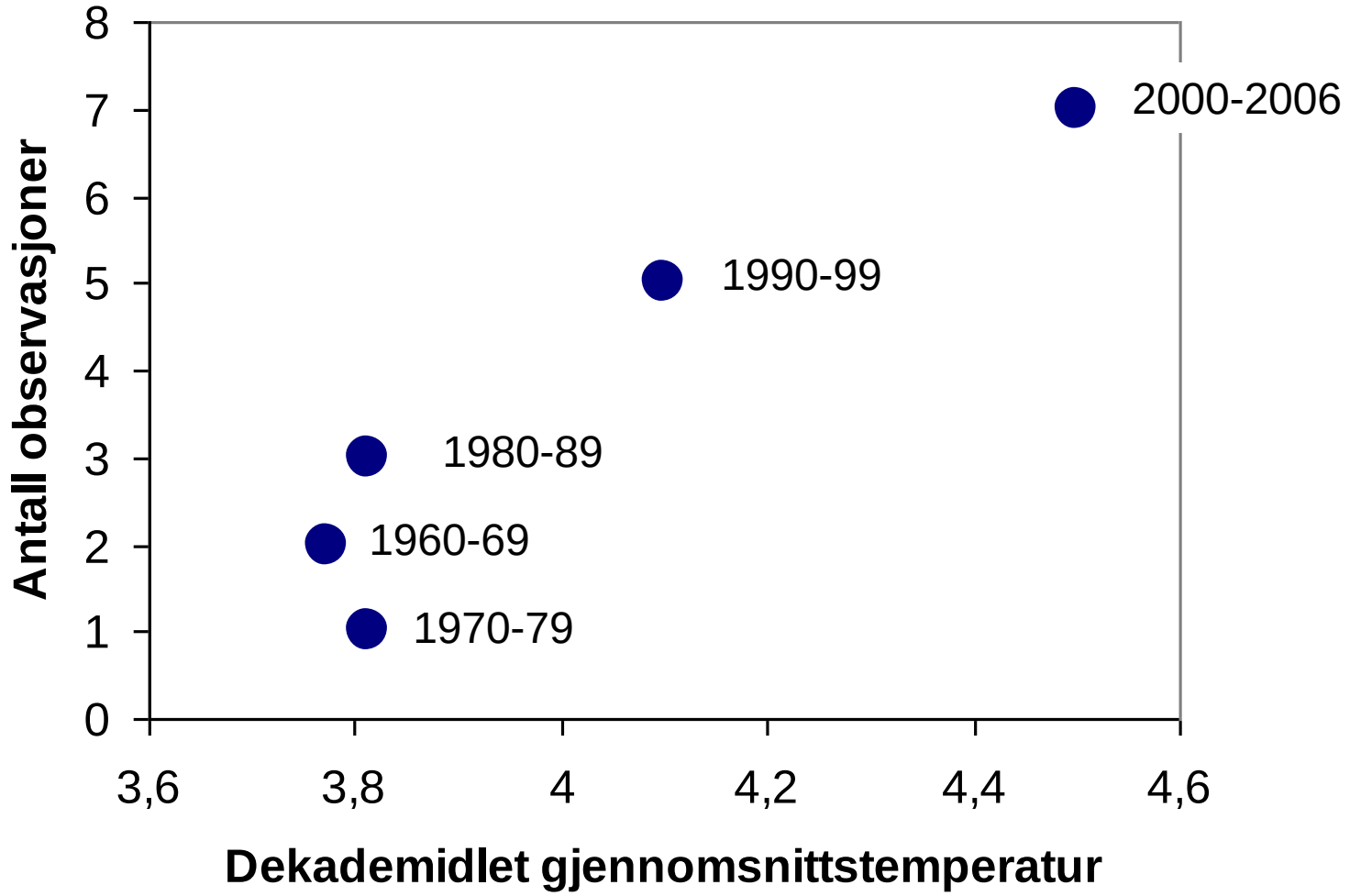
• Fish recruitment and year-class strength

•Habitat extents of populations

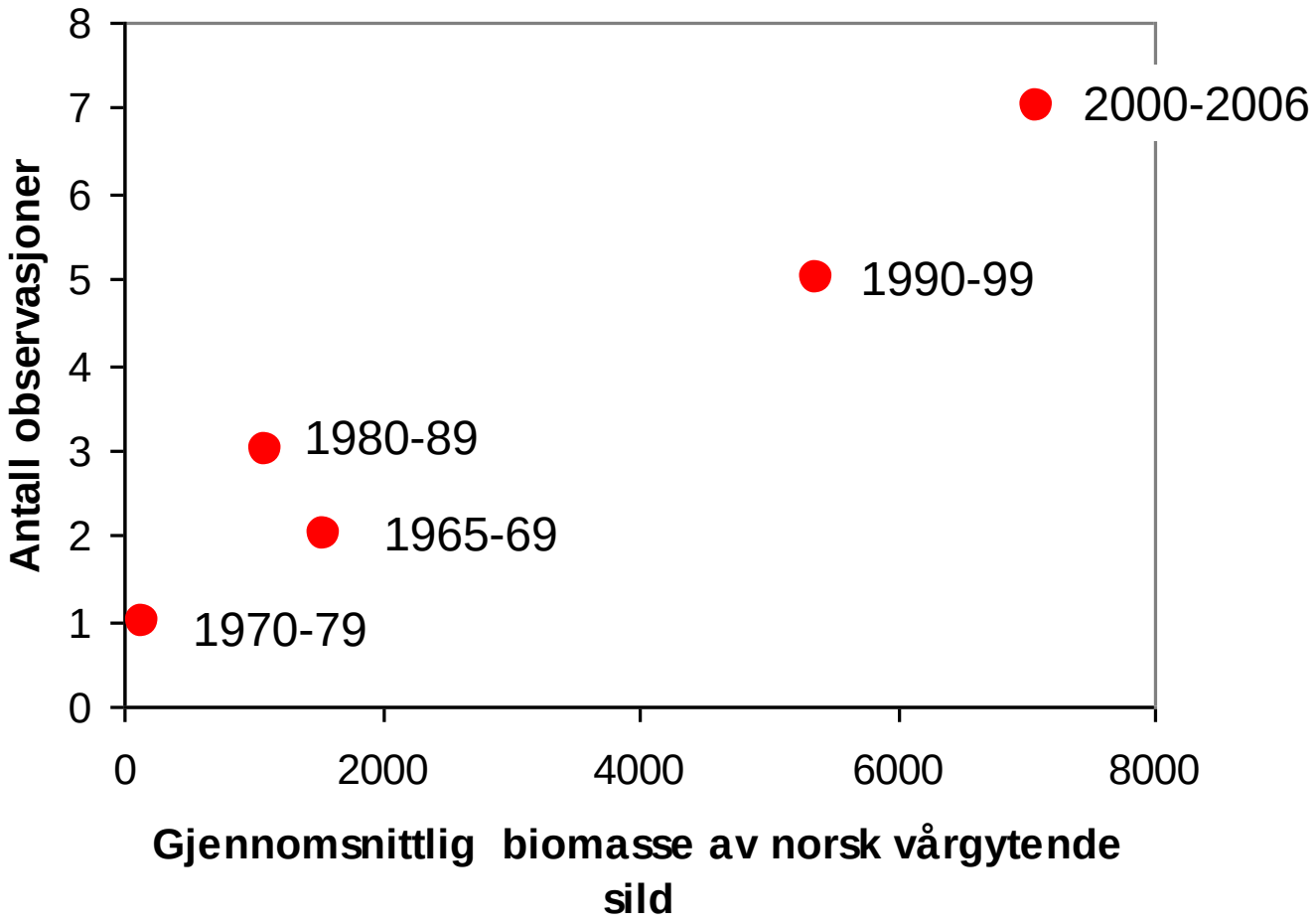
• Production on higher trophic levels



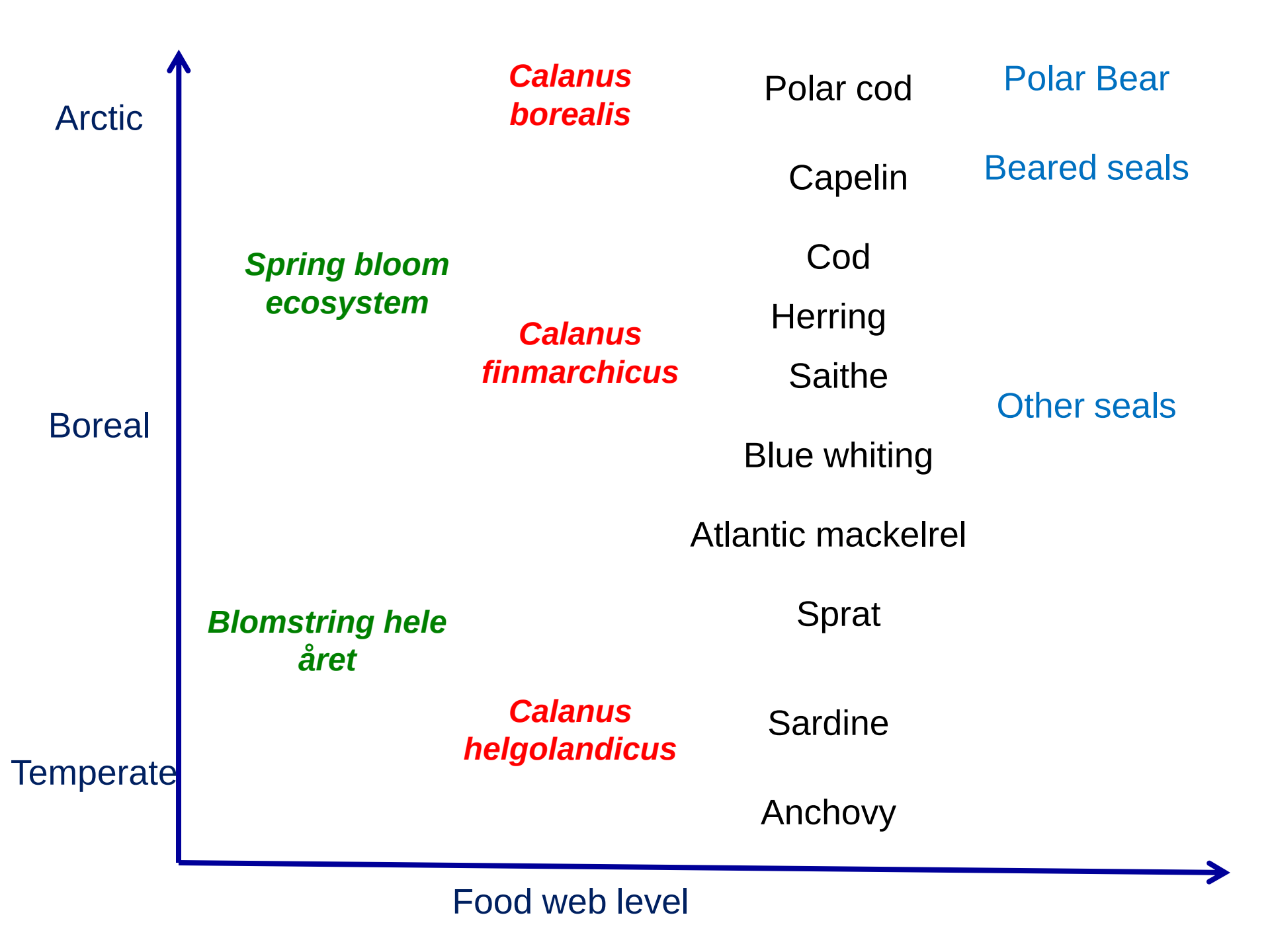

Vinjefjorden, Nordmøre november 2006
Unni Justsen med 22kg sverdfisk

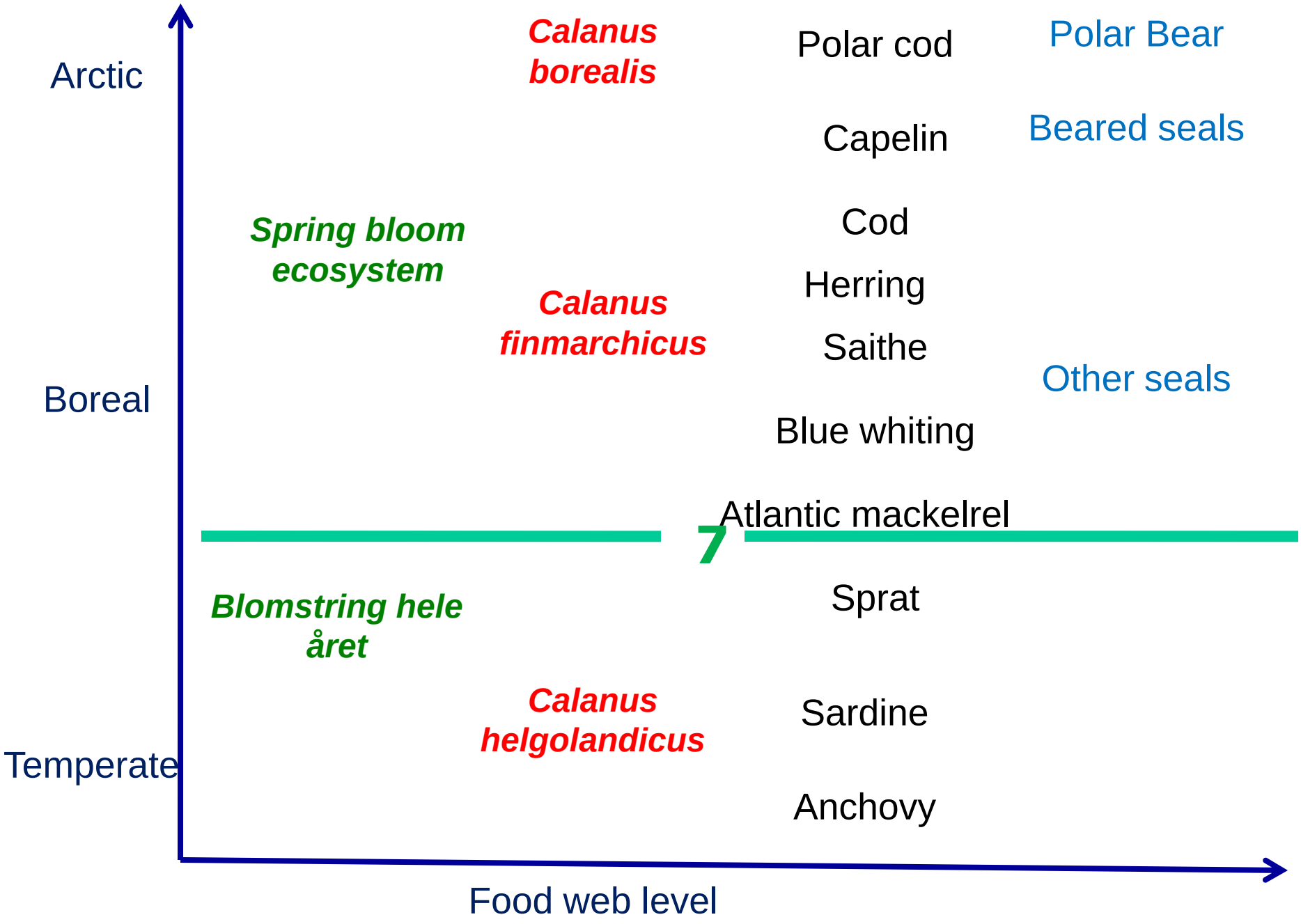

Antall observasjoner
8
7
6
5
4
3
2
1
0
2000-2006
1990-99
1980-89
1960-69
1970-79
3,6
3,8
4
4,2
4,4
4,6
Dekademidlet gjennomsnittstemperatur

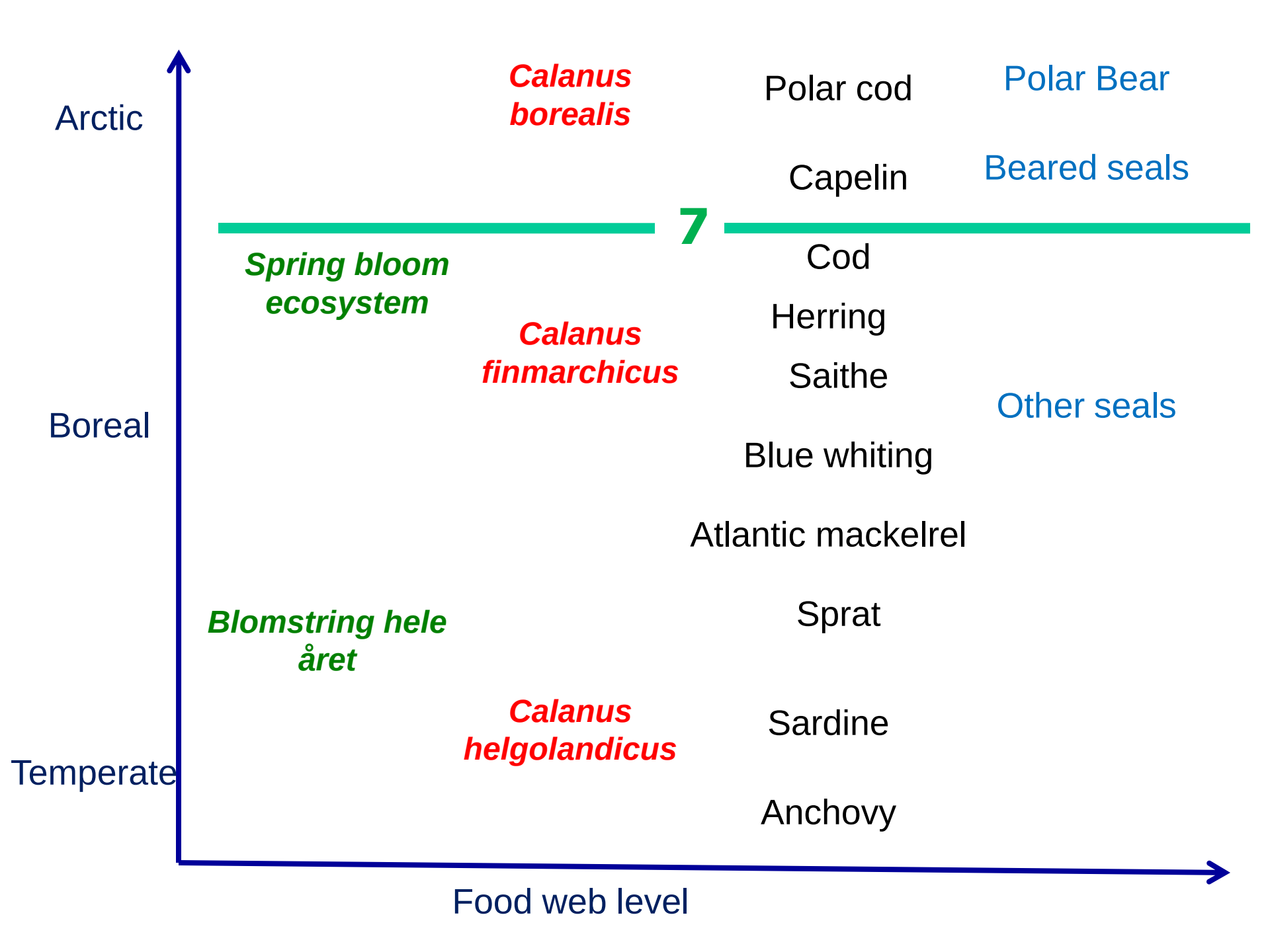
Figur 3.


Antall observasjoner
0
1
2
3
4
5
6
7
8
0
2000
4000
6000
8000
Gjennomsnittlig biomasse av norsk vårgytende sild
1970-79
1965-69
1980-89
1990-99
2000-2006

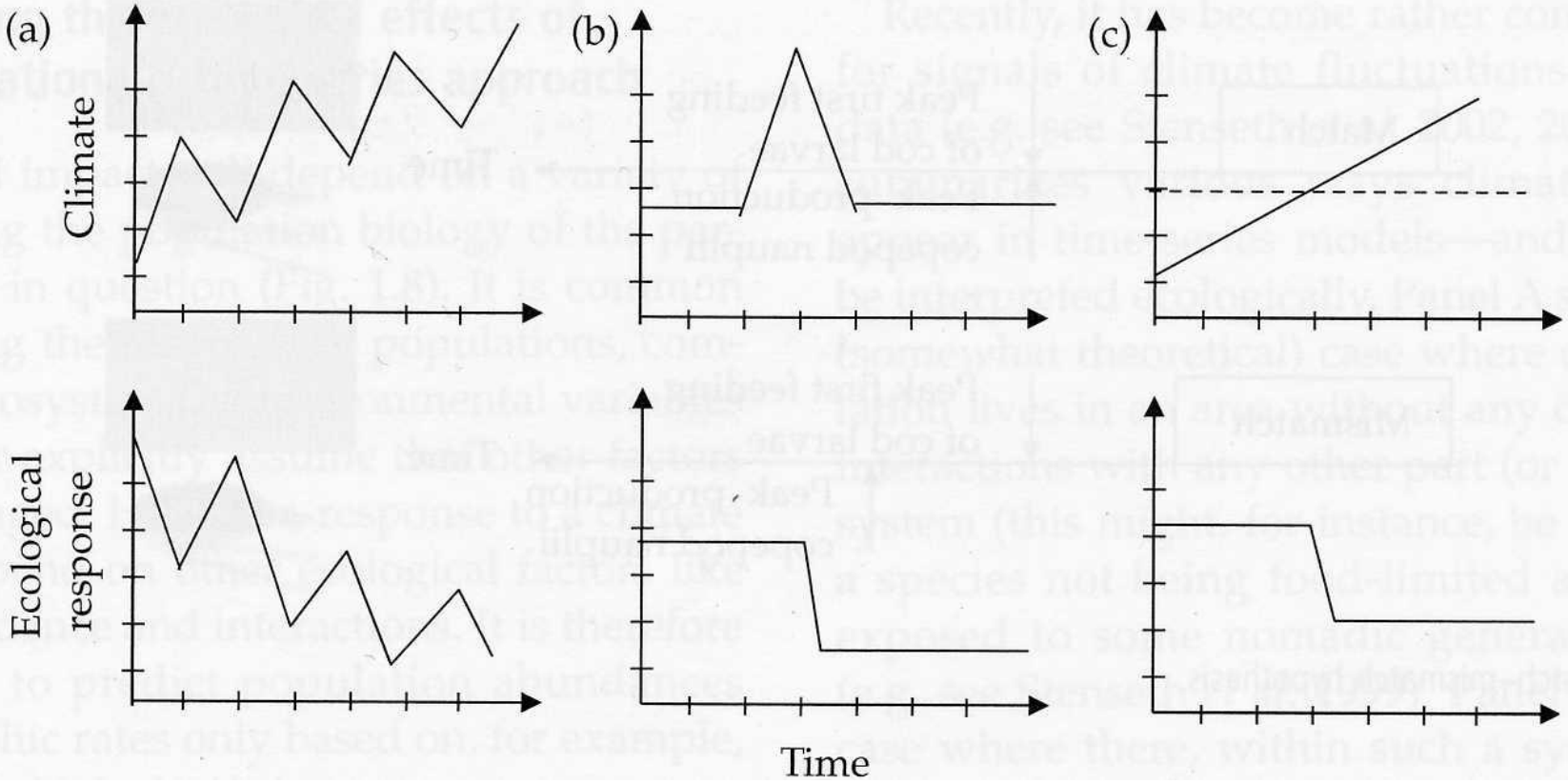
Figur 4.


Arctic
Boreal
Temperate
Food web level
Calanus borealis
Spring bloom ecosystem
Calanus finmarchicus
Blomstring hele året
Calanus helgolandicus
Polar cod
Capelin
Cod
Herring
Saithe
Blue whiting
Atlantic mackelrel
Sprat
Sardine
Anchovy
Polar Bear
Beared seals
Other seals


Arctic
Boreal
Temperate
Food web level
Calanus borealis
Spring bloom ecosystem
Calanus finmarchicus
Blomstring hele året
Calanus helgolandicus
Polar cod
Capelin
Cod
Herring
Saithe
Blue whiting
Atlantic mackelrel
Sprat
Sardine
Anchovy
Polar Bear
Beared seals
Other seals
7


Arctic
Boreal
Temperate
Food web level
Calanus borealis
Calanus finmarchicus
Calanus helgolandicus
Spring bloom ecosystem
Blomstring hele året
7
Polar cod
Capelin
Cod
Herring
Saithe
Blue whiting
Atlantic mackelrel
Sprat
Sardine
Anchovy
Polar Bear
Beared seals
Other seals

Ecosystem responses to climate change



Linear response | Non-linear respons 1 | Non-linear respons 2

Ottersen et al. (2004)

Conclusions

There are large variability in trophic transfer rates from the primary producers to fish in the various marine ecosystems and at various time periods

- This is because of different trophic structures among marine ecosystems and because of the influence of climate variability
- There are strong couplings between zooplankton, particularly copepods, production and fish production
- Hence, assessment of zooplankton should be an integral part of ecosystem-based fisheries assessment
- The long-term climate periodicity is strongly influencing the abundances of the key zooplankton

* Climate variability and climate change in the past centuries

* Climate projections for 21. century

* North Atlantic marine ecosystems response to climate variability and its cascading effects on fisheries

* **Climate effects on aquaculture**

Veksten til lus er styrt av temperaturen i sjøen

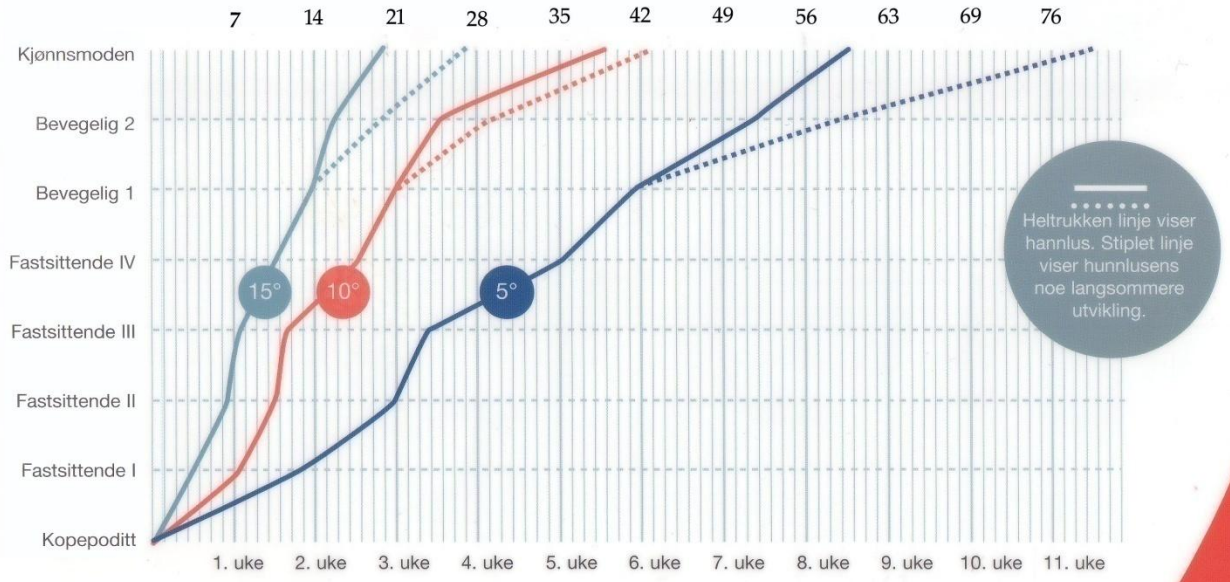
LAKSELUS

- Tre bevegelige stadier på fisken
- Mørk brun farge
- Ingen sugeskål
- Kjønnsmoden hunn 8-12 mm
- Hunnlus større enn hannlus
- Oval form, bakparten mindre enn 50% av full lengde
- Laksefisk som eneste vertsorganisme

SKOTTELUS

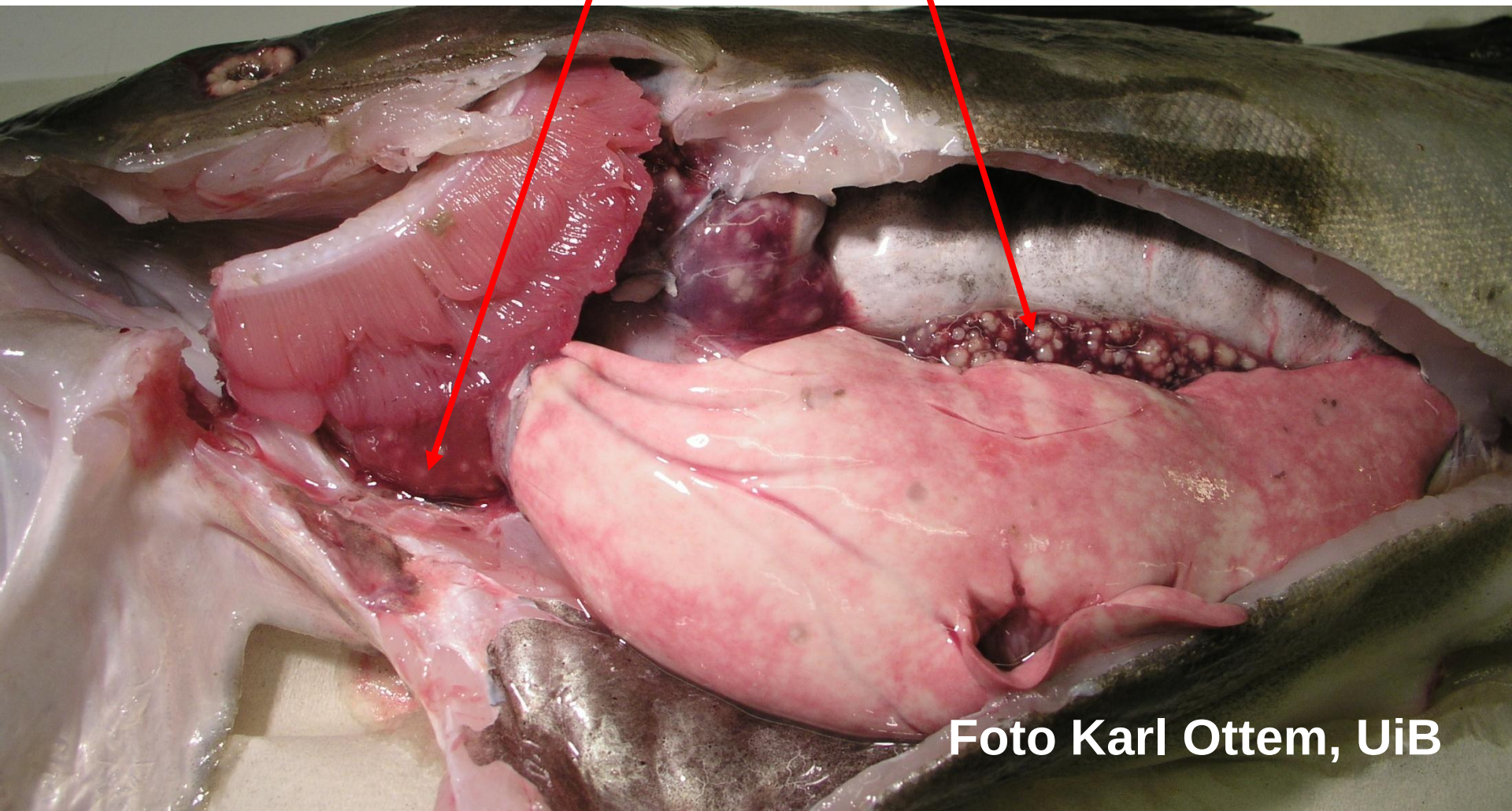
- Ett bevegelig stadium på fisken
- Lys brun farge
- To sugeskåler
- Kjønnsmoden hunn 5-6 mm
- Liten størrelsesforskjell mellom hunn- og hannlus
- Avlang form, bakparten ca. 50% av lengden
- Finnes på flere fiskeslag (laks, torsk, sei, sild)
- Har tre dager kortere livssyklus ved 10° C enn lakselusa

ANSLAGSVIS UTVIKLINGSHASTIGHET FOR LAKSELUS VED 5°, 10° OG 15° C



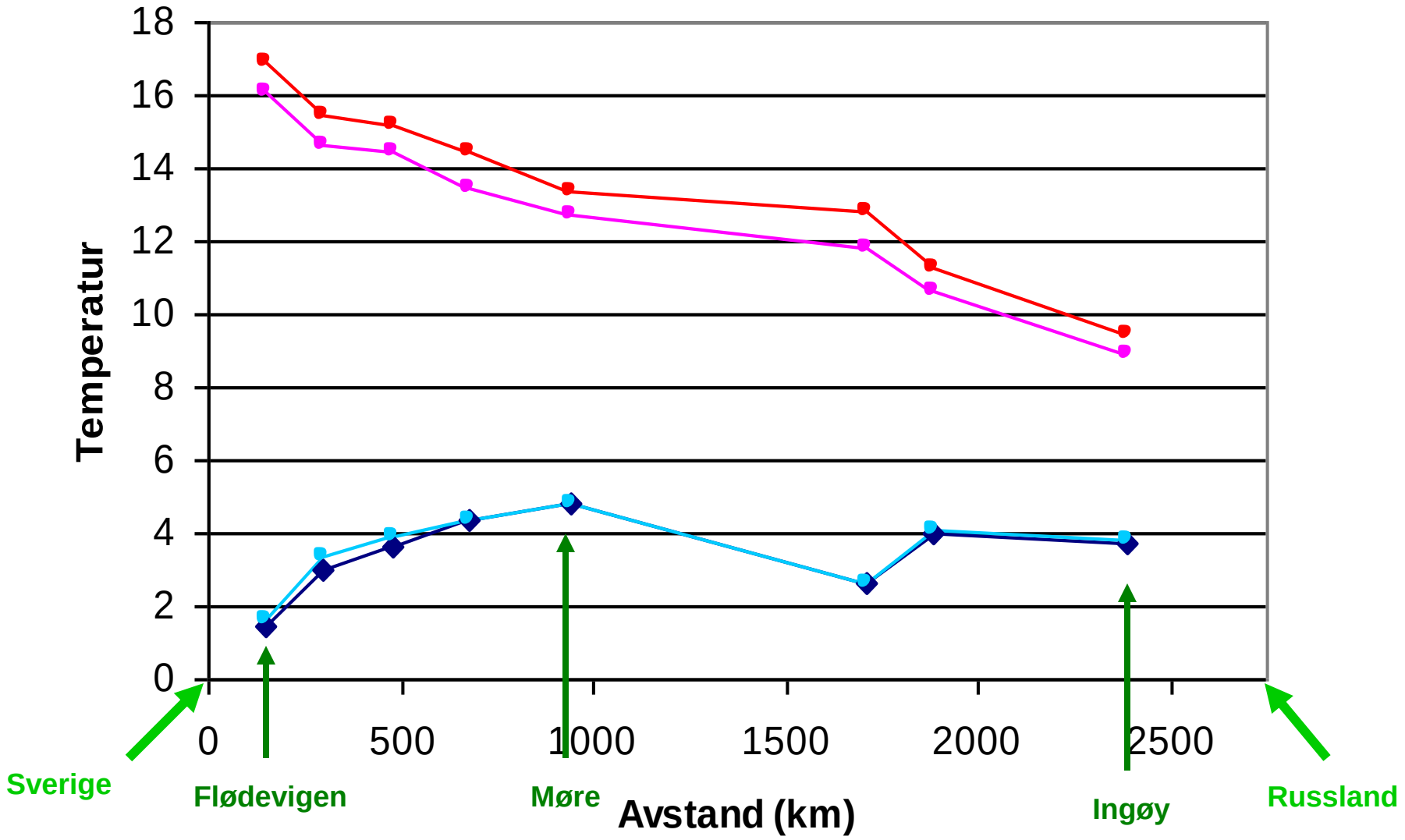
SKRETTING

Dette er en bakteriesykdom som kan gi økte problemer ved økt temperatur

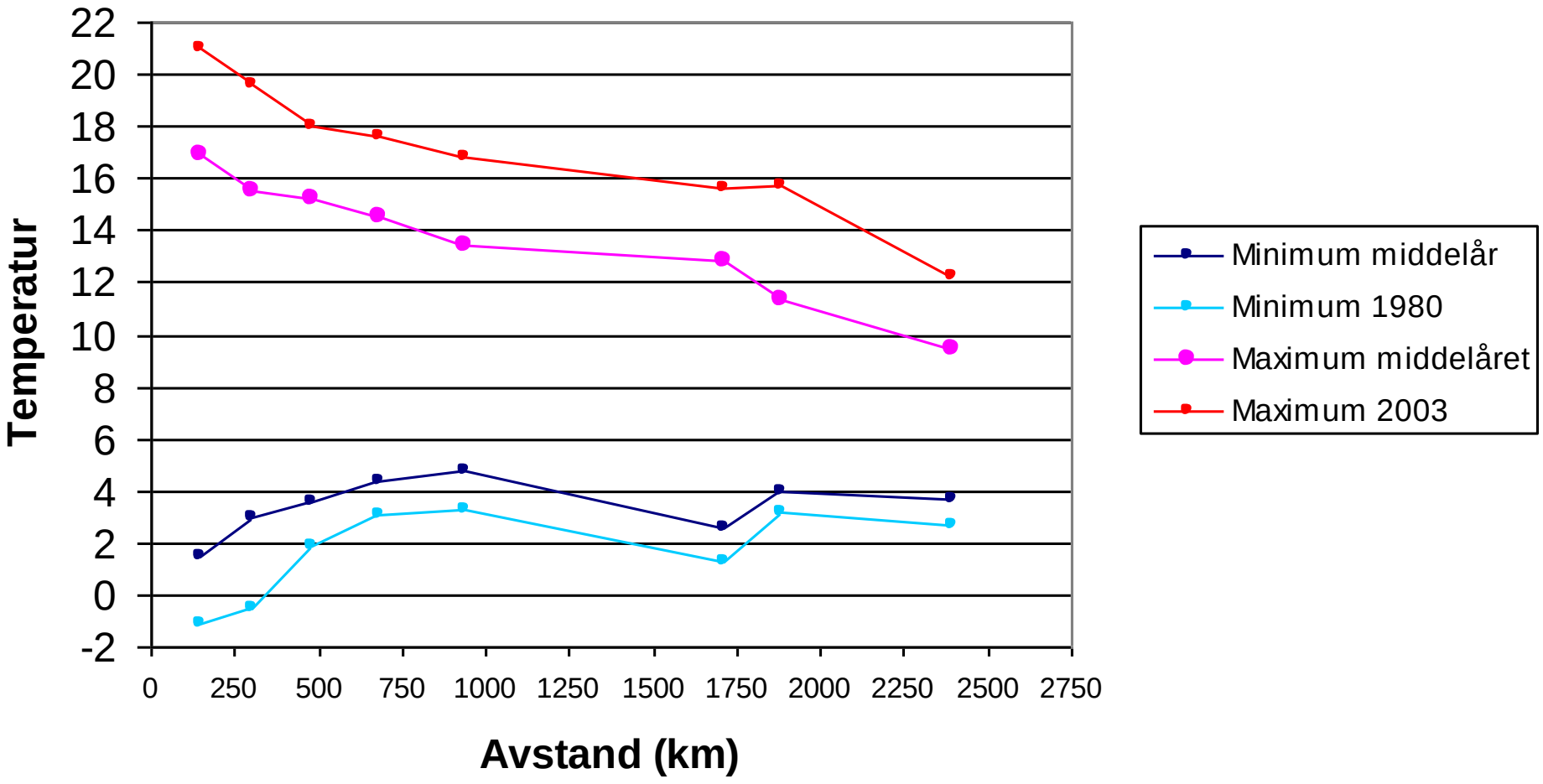


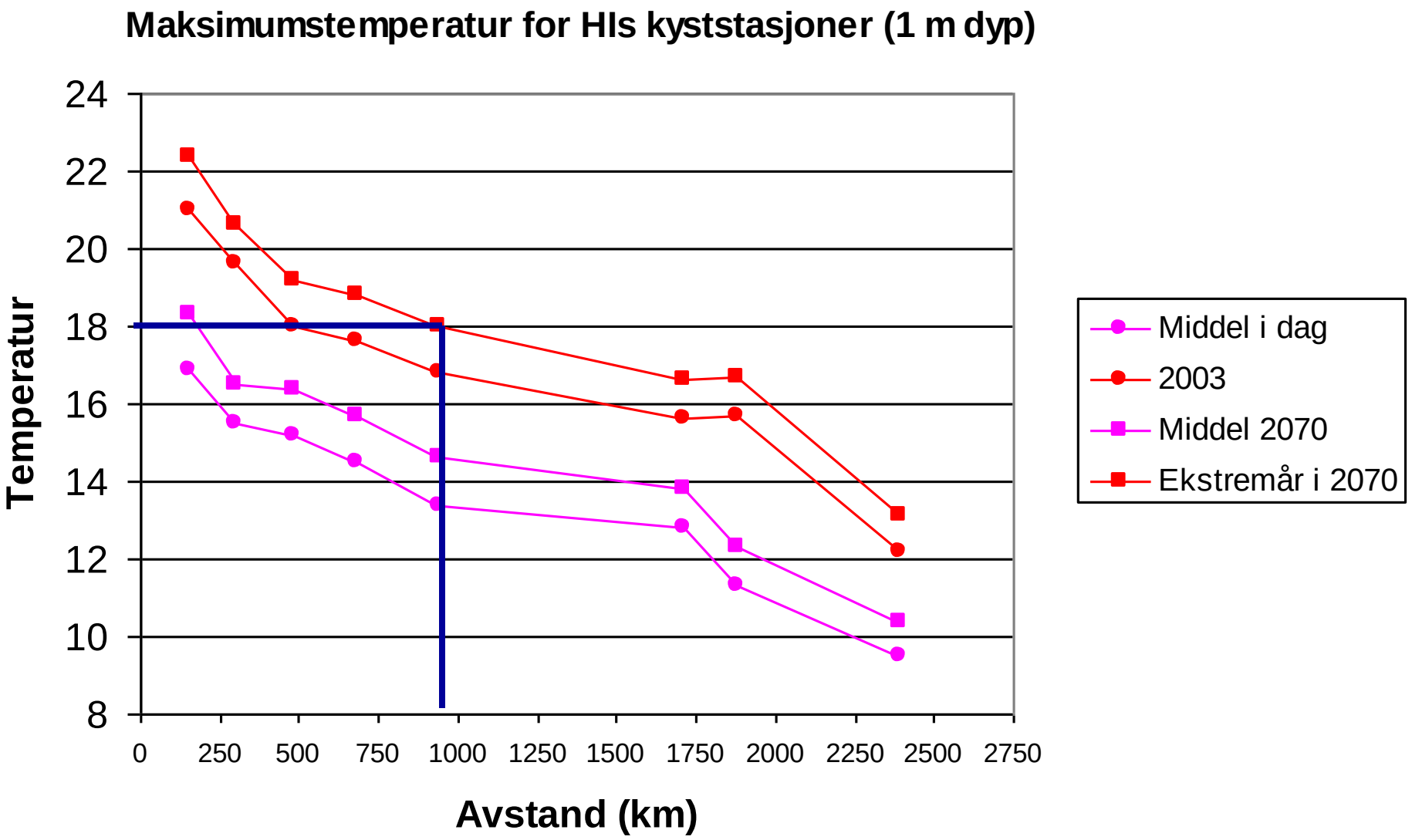
Possible Changes in Fish Distribution

Midlere maksimum/minimum temperatur for HIs kyststasjoner (1 og 10 m dyp)



Minimum og maksimumstemperaturer for Hls kyststasjoner (1m dyp)




Maksimumstemperatur for HIs kyststasjoner (1 m dyp)
Temperatur
24
22
20
18
16
14
12
10
8
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
Avstand (km)
Middel i dag
2003
Middel 2070
Ekstremår i 2070

Conclusion

- New types of diseases are appearing on farmed fish as temperature increases

- Along the Norwegian coast the optimal region for salmon farming has been along the west coast from Hordaland to Møre because of the highest winter temperatures and the moderatly high summer temperature.

- Under future climate change the optimal region for salmon farming will be displaced northwards along the coast towards Nordland because of too high summer temperatures along the Hordaland-Møre coast.