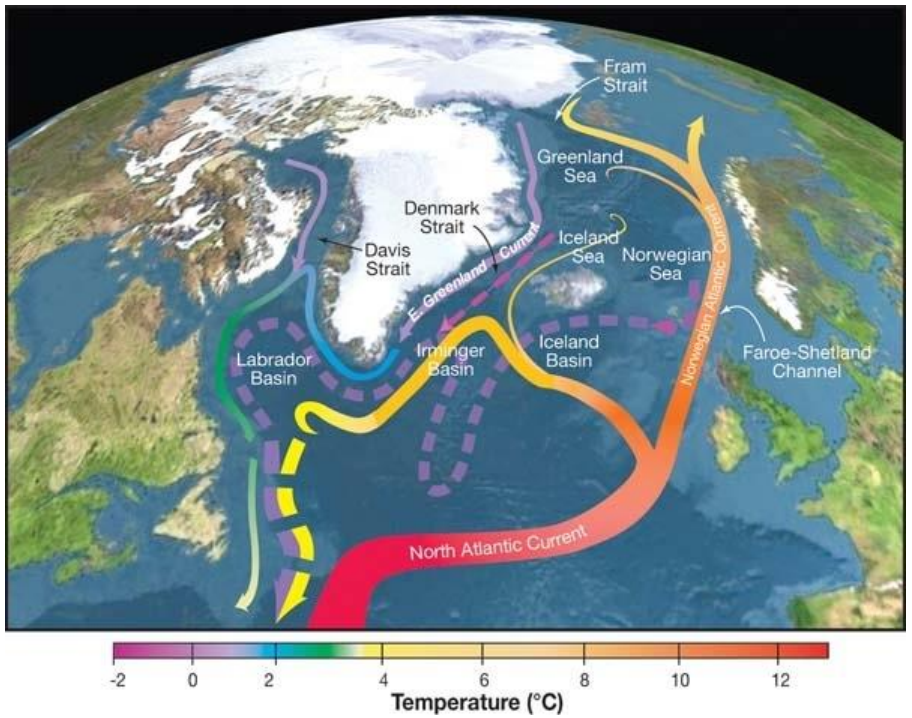
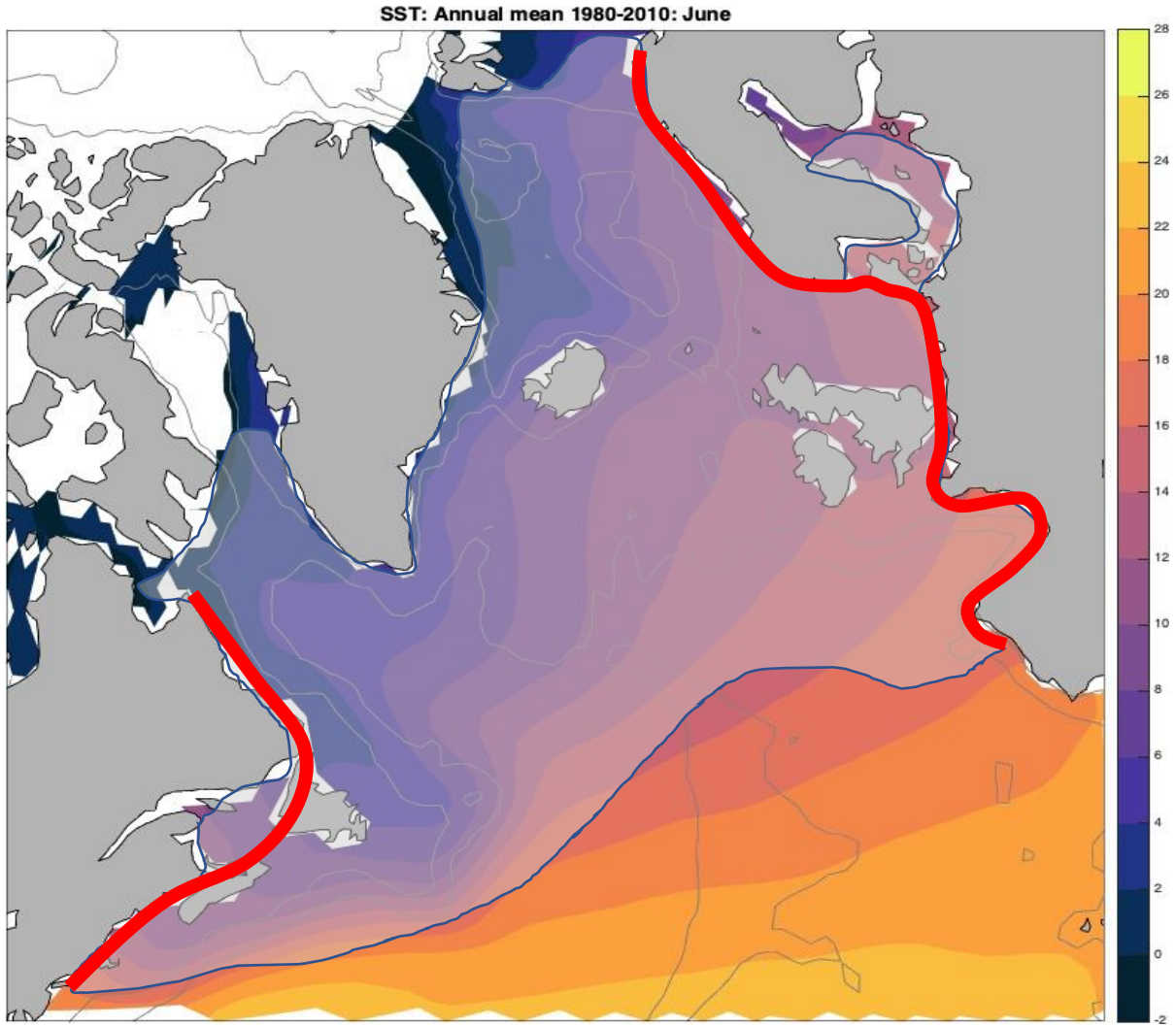
BJERKNES CENTRE for Climate Research



CNL(23)93
Summary of existing and forecasted climate change across the North Atlantic relevant to salmon marine ecology

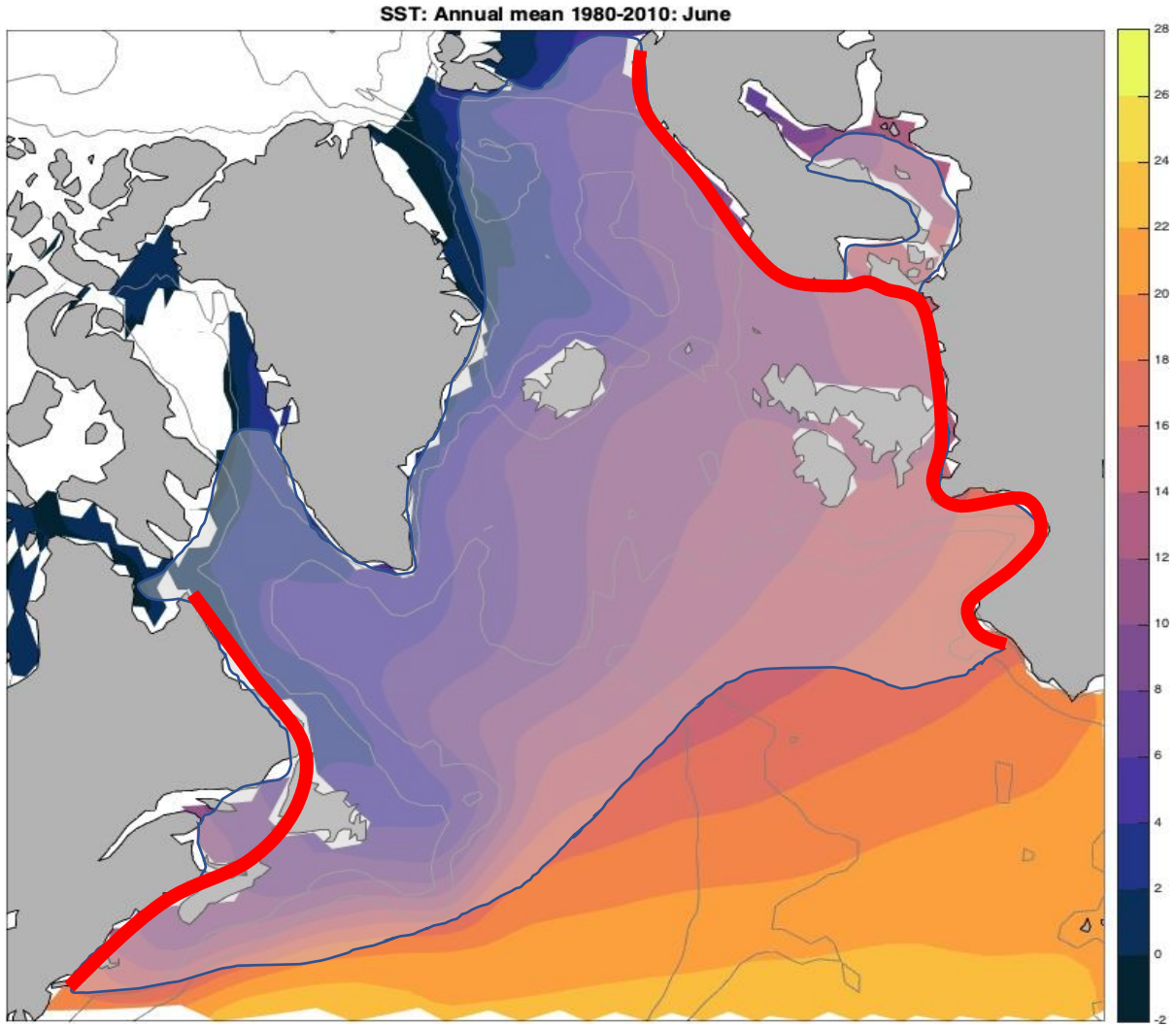
Øystein Skagseth
Institute of Marine Research and Bjerknes Centre for Climate Research, Norway

SST June / Salmon rivers and marine



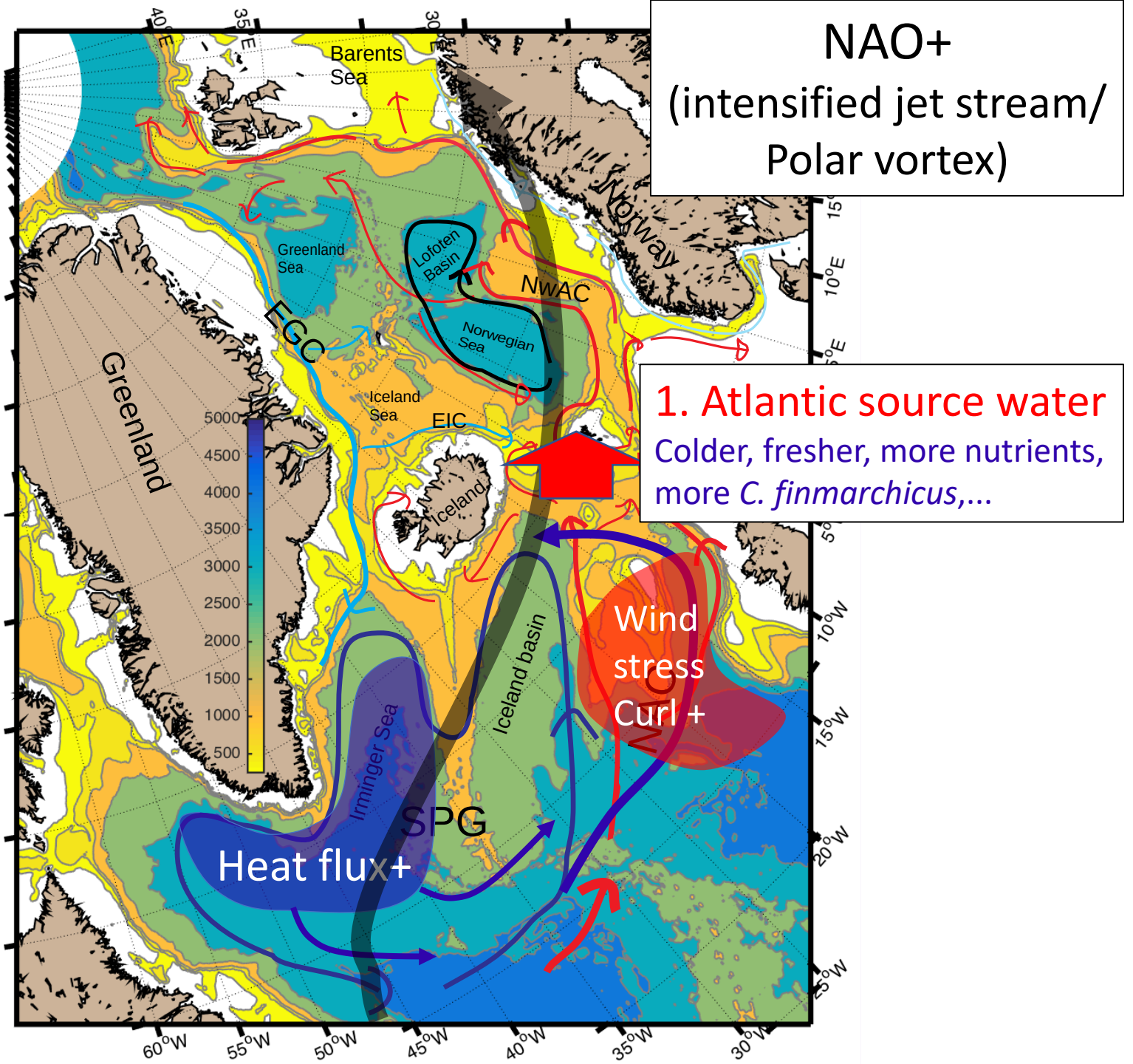
- Salmon span a large temperature range [0-20]^{o}C
- River distribution span a larger region in Europe compared to North America, but comparable in temperature range
- Marine phase cover largely temperate/cold part of North Atlantic

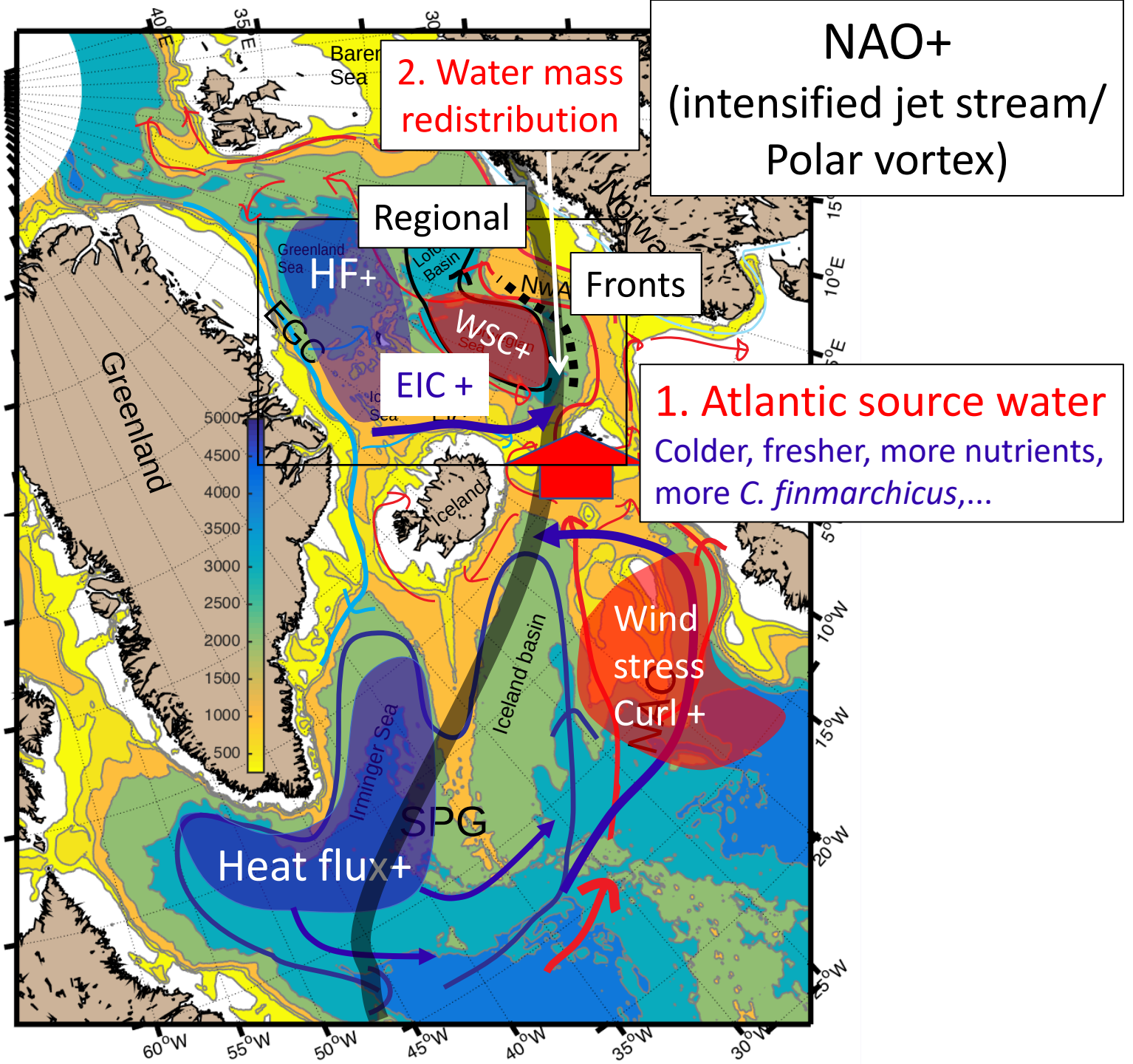
SST June / Salmon rivers and marine

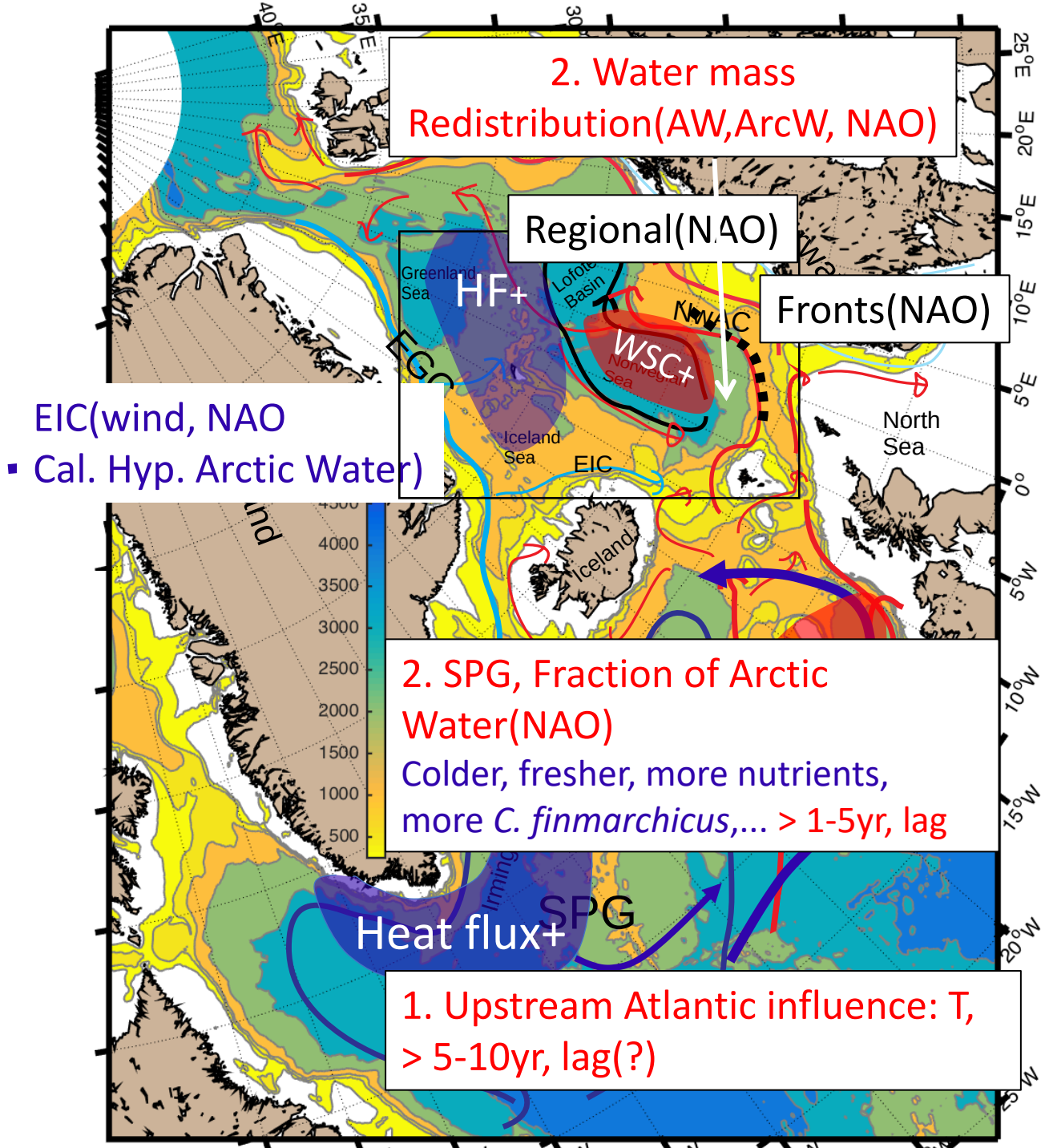


Mills et al. 2013, ”Salmon abundance and productivity declined in a **coherent** manner across major regions of North America, .. points toward potential shift in marine survivorship … “

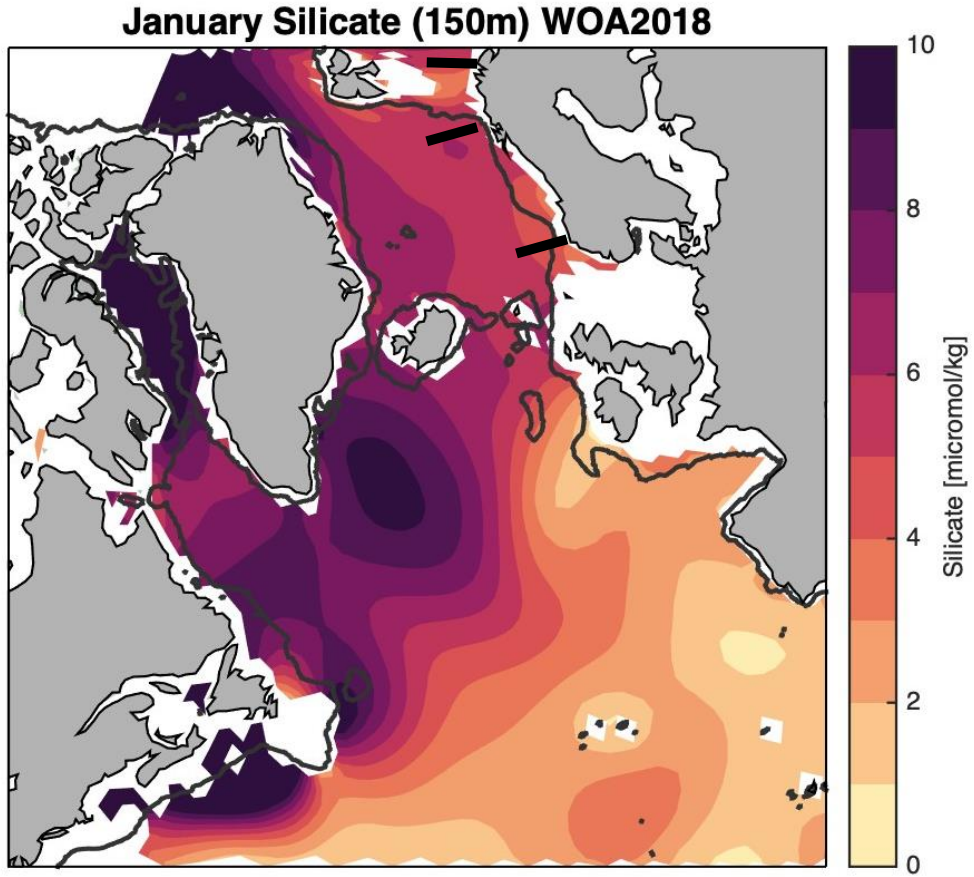
What are the observed change in ocean climate of relevance to salmon in the marine phase, .. and what are the future projections?

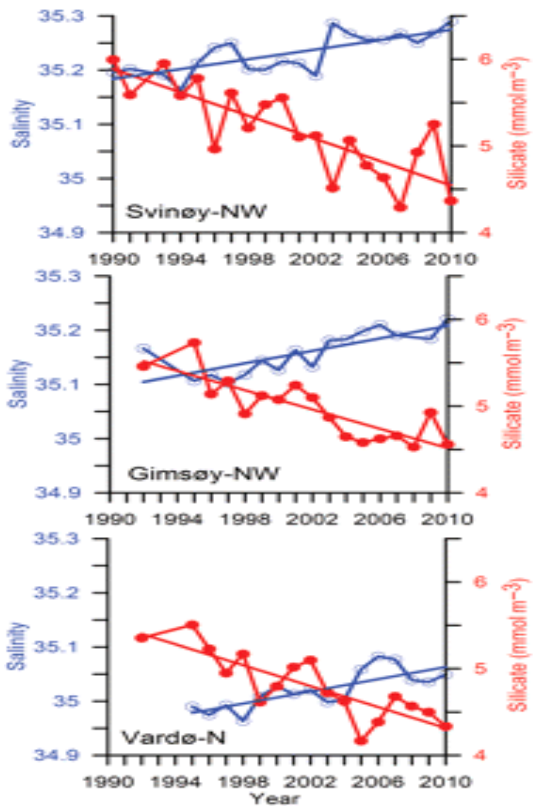

NAO+
(intensified jet stream/
Polar vortex)
1. Atlantic source water
Colder, fresher, more nutrients,
more C. finmarchicus,...
Barents Sea
Greenland Sea
Lofoten Basin
NwAC
Norwegian Sea
EGC
Greenland
Iceland Sea
EIC
Iceland
Norway
Wind stress Curl +
Iceland basin
Irminger Sea
SPG
Heat flux+
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
60°W
55°W
50°W
45°W
40°W
35°W
30°W
10°E
10°W
15°W
20°W
25°W


NAO+
(intensified jet stream/
Polar vortex)
2. Water mass redistribution
Regional
Fronts
1. Atlantic source water
Colder, fresher, more nutrients, more C. finmarchicus,...
Barents Sea
Greenland Sea
Lofoten Basin
HF+
EGC
WSC+
EIC +
Greenland
Iceland
Iceland basin
Irminger Sea
SPG
Heat flux+
Wind stress Curl +
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
60°W
55°W
50°W
45°W
40°W
35°W
30°W
10°E
15°W
20°W
25°W


2. Water mass Redistribution(AW,ArcW, NAO)
Regional(NAO)
Fronts(NAO)
EIC(wind, NAO
Cal. Hyp. Arctic Water)
2. SPG, Fraction of Arctic Water(NAO)
Colder, fresher, more nutrients, more C. finmarchicus,... > 1-5yr, lag
1. Upstream Atlantic influence: T, > 5-10yr, lag(?)
Heat flux+
SPG
HF+
WSC+
EIC
Greenland Sea
Iceland Sea
Norwegian Sea
North Sea
Iceland
4000
3500
3000
2500
2000
1500
1000
500

Circulation changes affect nutrients





Rey 2012: suggested nutrient decline as a potential for bottom up

Winter seesaw between Greenland and northern Europe

North Atlantic Oscillation

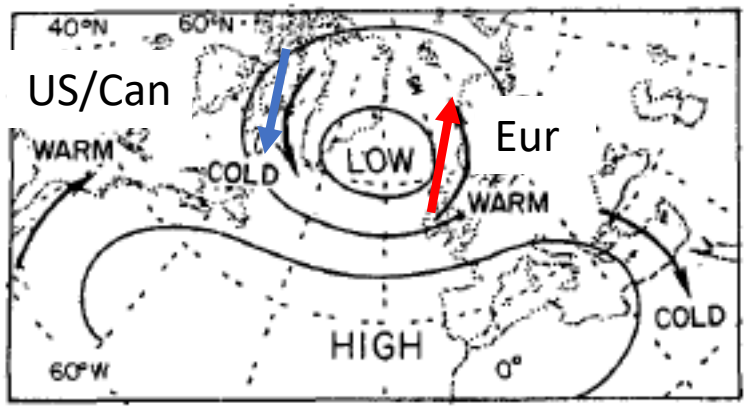
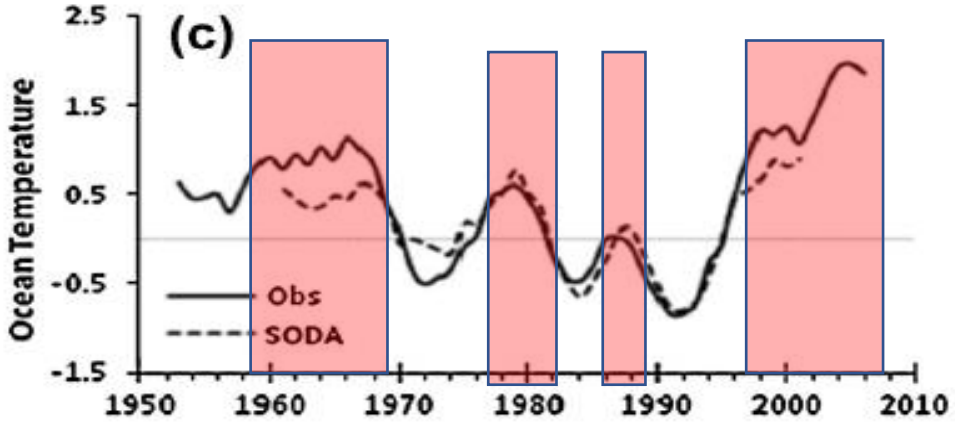


FIG. 1. Idealized relationships between pressure and temperature anomalies associated with the North Atlantic Oscillation.

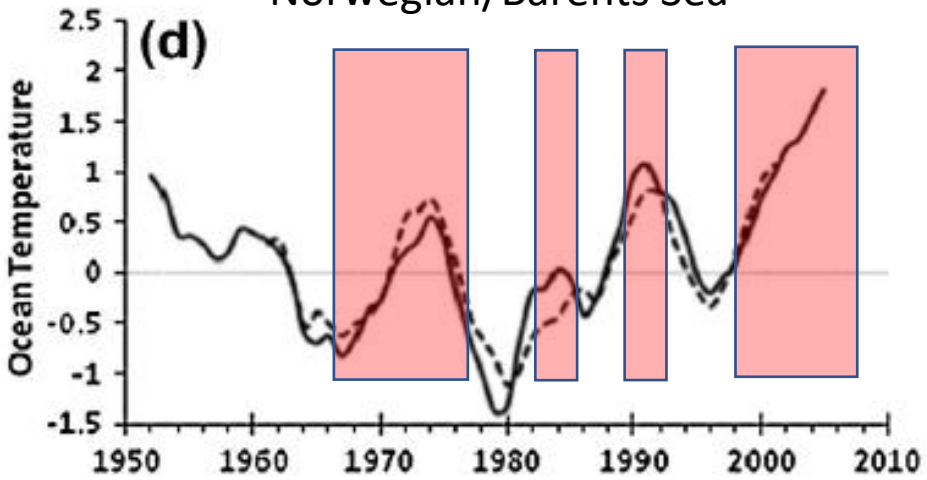
Wallace and Gutzler, 1981

During strong influence of the North Atlantic Oscillation - North America and north European climate vary in opposite phase

Labrador Sea

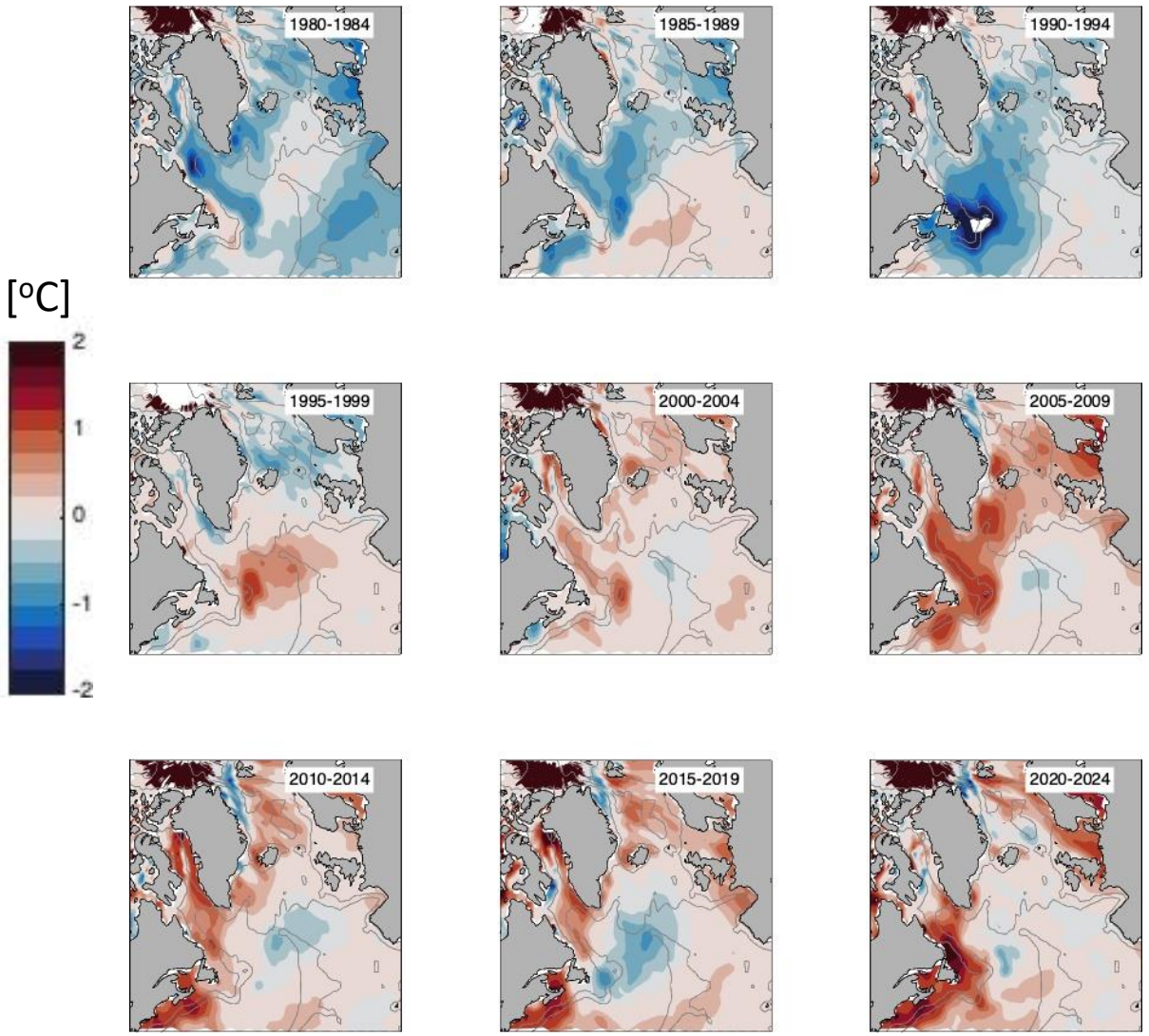


Norwegian/Barents Sea



van Loon and Rogers, 1978
Drinkwater et al, 2013

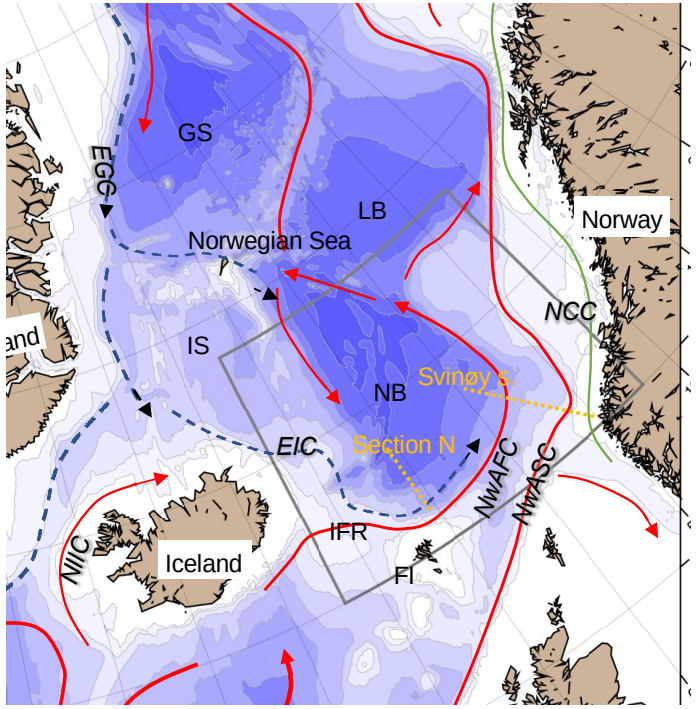
Observed Sea Surface Temperature (July)

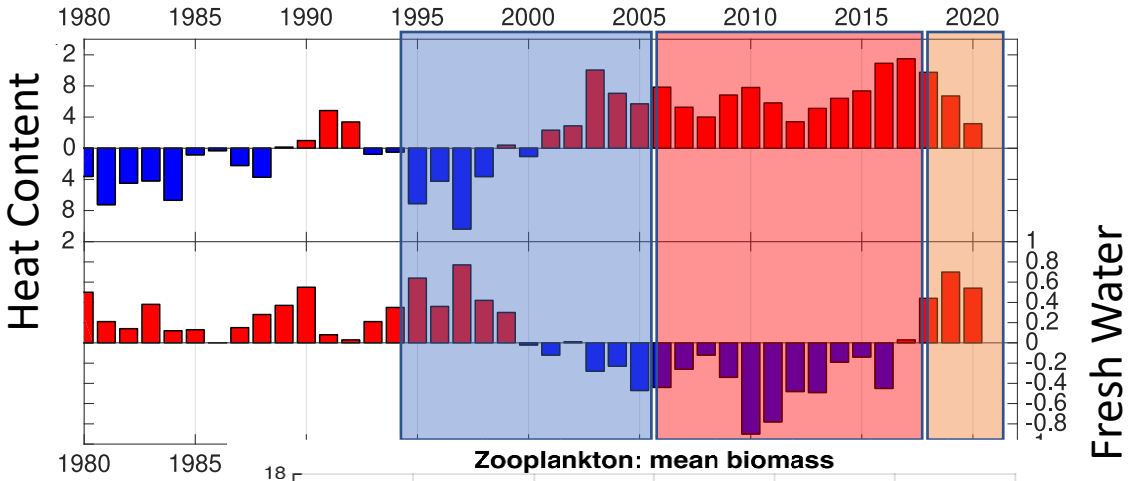


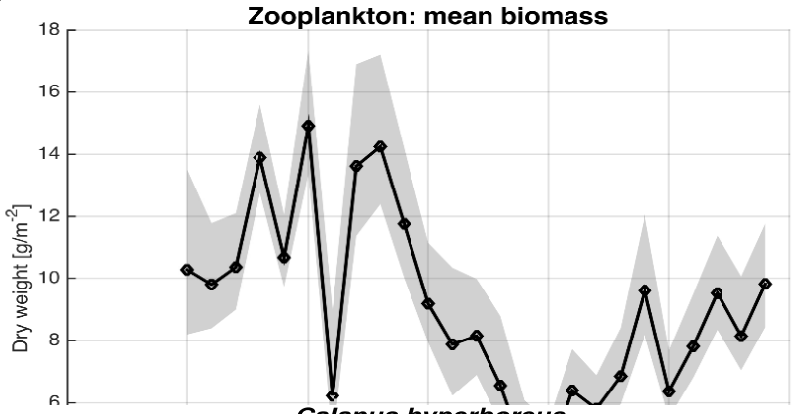
- Generally cold 1980s, warm 2005 onward
- Extreme cooling in Lab shelf until 1995, and also decline in salmon, but salmon has not rebound despite later milder condition
- Spg weakening in 1996 onwards
- Warming in Norwegian Sea peak in 2005-2009, but post smolt salmon growth reduced
- The North-Atlantic “warming hole / “cold blob”

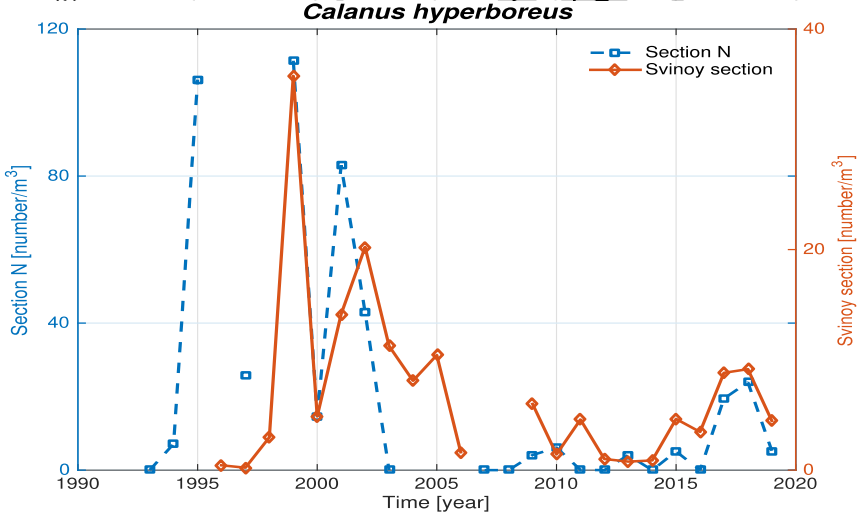
Climate change may trigger changes (in salmon), but recovery does not necessarily follow the same trajectory.

Climate -> zooplankton









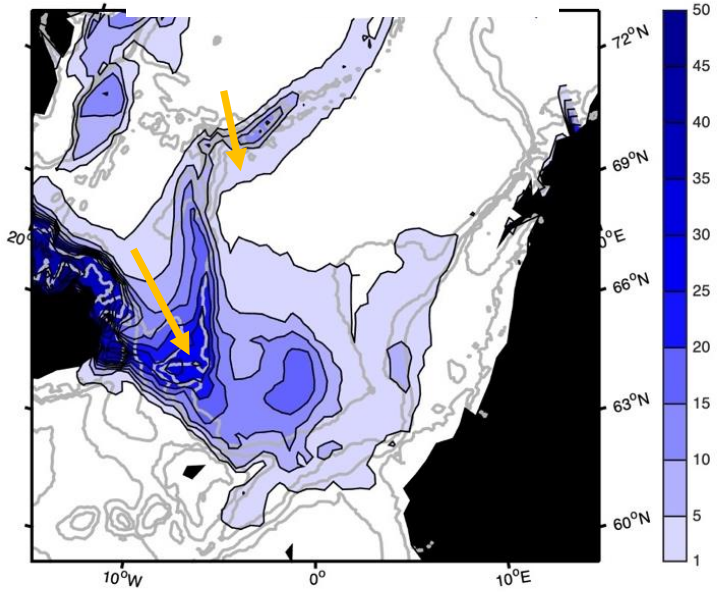
1995-2005: “Arctic” condition; high nutrients, overall high zoopl biomass and Cal. *hyperboreus*

2006-2016: “Atlantic” condition; low nutrients, overall low zoopl biomass and Cal. *hyperboreus*

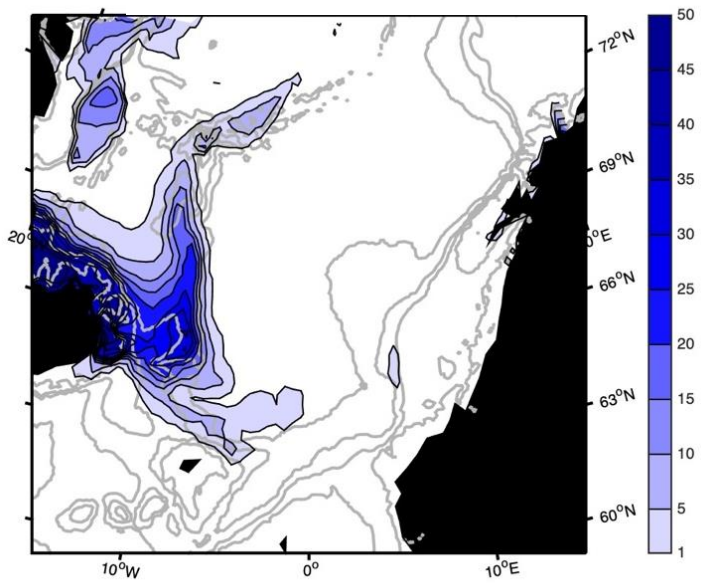
2017-2019: “Arctic but warm” condition; low nutrients, rel increase in zoopl biomass and Cal. *hyperboreus*

Southern Norwegian Sea: Effect of Artic Water from west:
Thickness [m]: S<34.9, 1<T<4, Depth < 300m

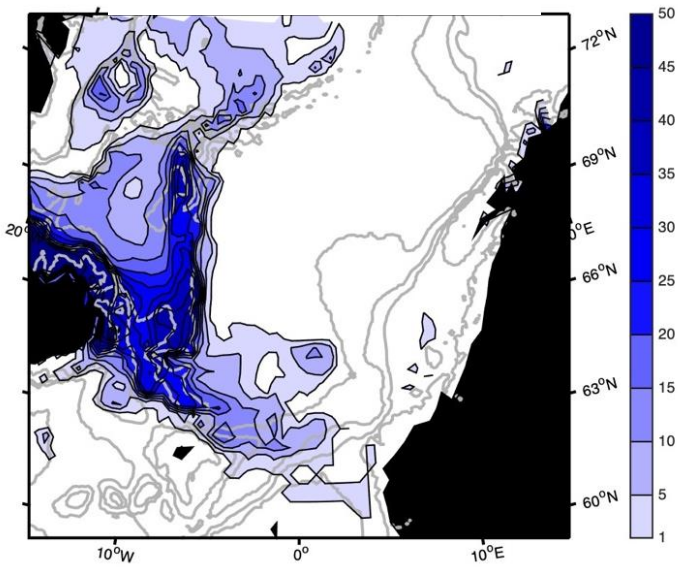
1995-2005



2006-2016



2017-2019

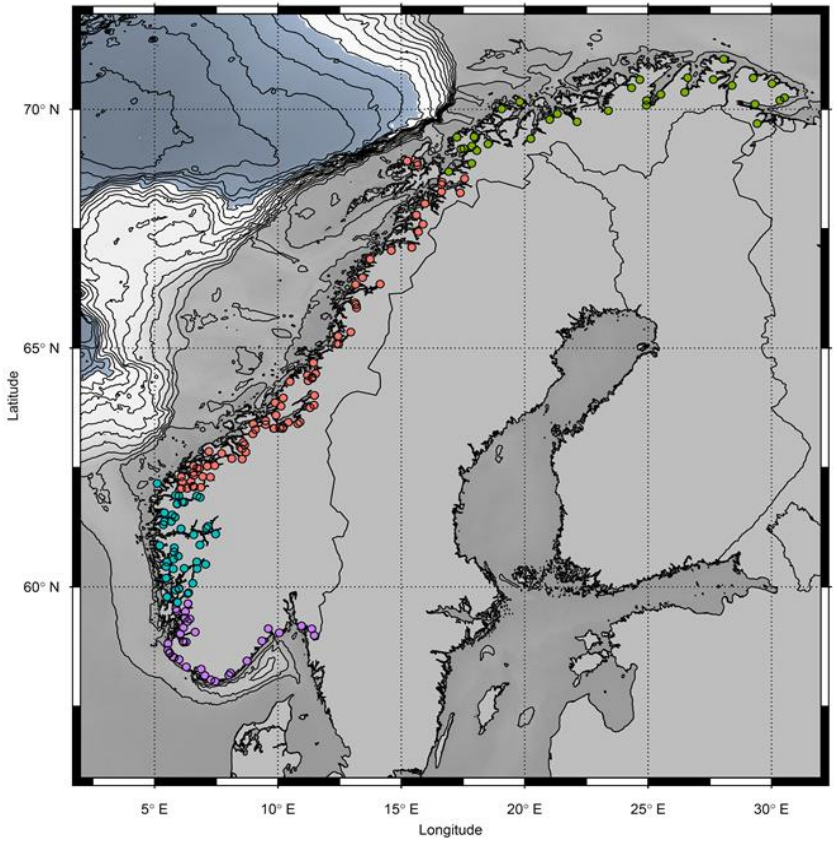


Stefansson 1962: North Icelandic Winter Water
Malmberg 1984;

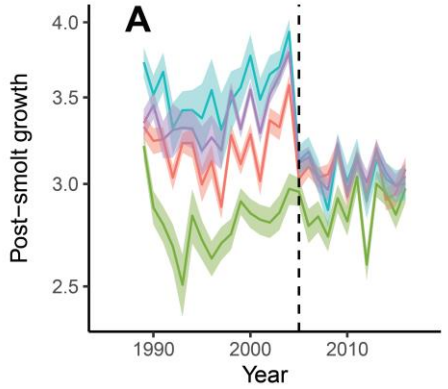
Wiborg 1952: Advection of Arctic zooplankton

growth, vs [environment, prey]

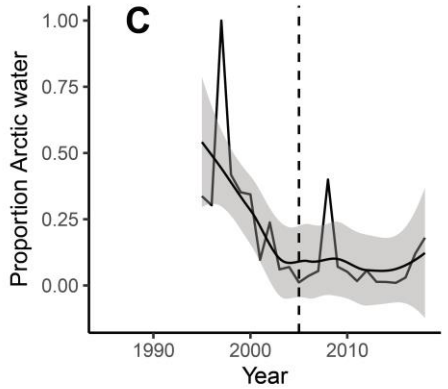
Vollset et al, (2022) Evidence of an ecological regime revealed from the unprecedented reduction in marine growth of Atlantic salmon. *Science reports*



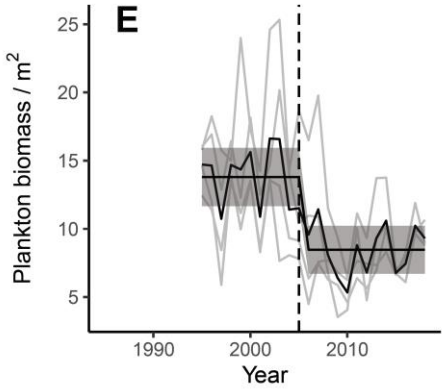
Post-smolth growth



Arctic Water

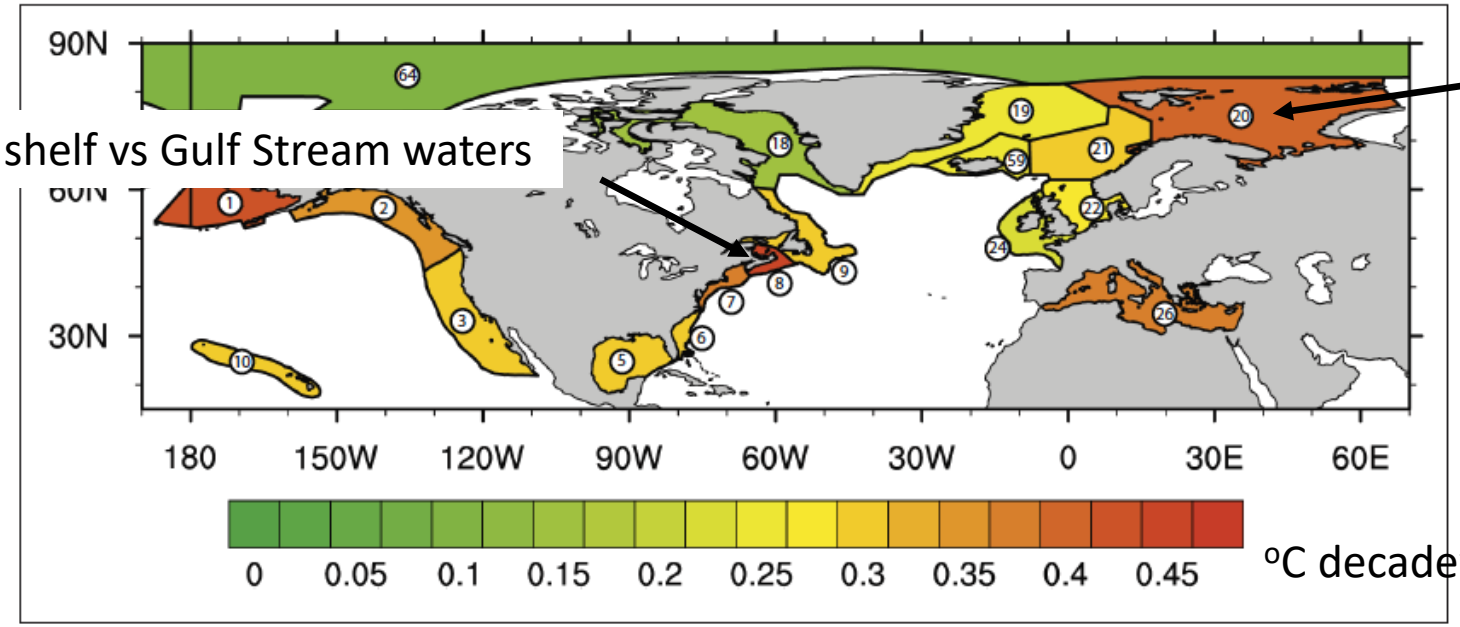


Plankton biomass



Future projections (RCP 8.5): Trends in SST 1976 versus 2099 Large-Marine Ecosystems

Competing Scotian shelf vs Gulf Stream waters



Barents Sea: sea ice retreat

Figure 2: SST trends in Large Marine Ecosystems in the Arctic and around North America and Europe. Colors

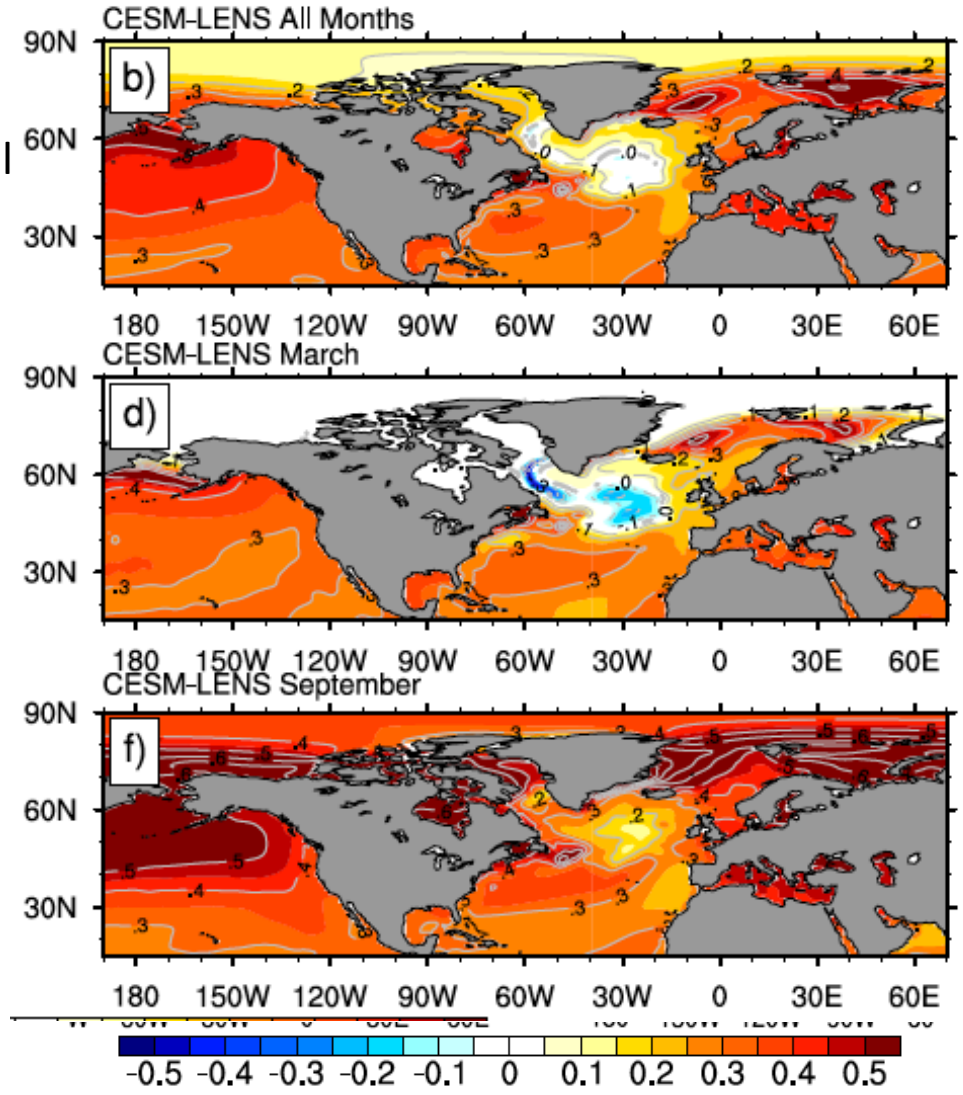
Alexander et al., 2018

Future projections (RCP 8.5): SST 1976 versus 2099

Annual

March

Sept



°C decade^{-1}

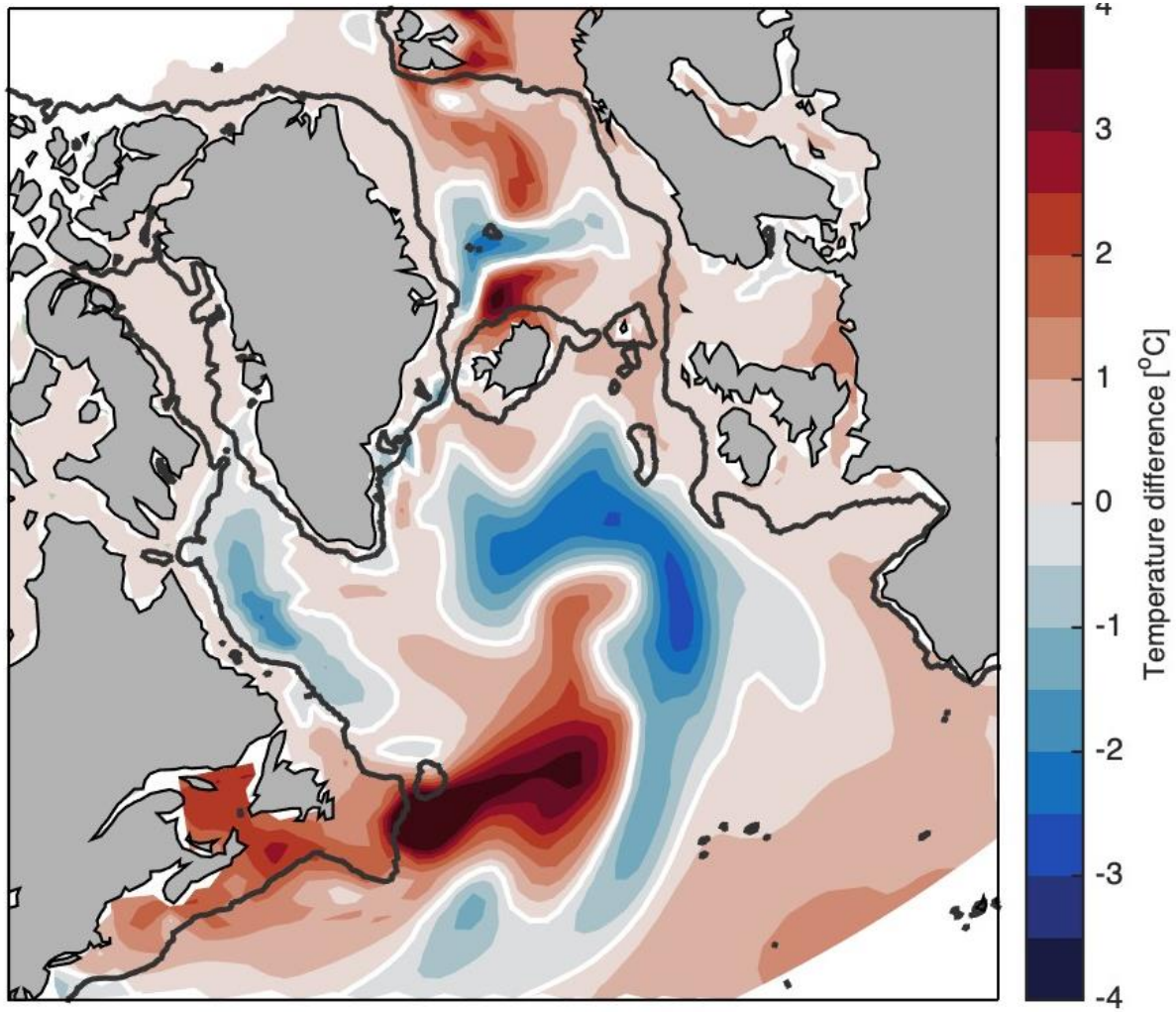
- General warming, upto .5°C decade^{-1}, especially in areas where with sea ice retreat
- increased stability → likely increased primary prod → increase but shift toward smaller zooplankton
- cold blob (mainly winter) in north Atlantic appear a robust feature, mainly winter

Alexander et al., 2018

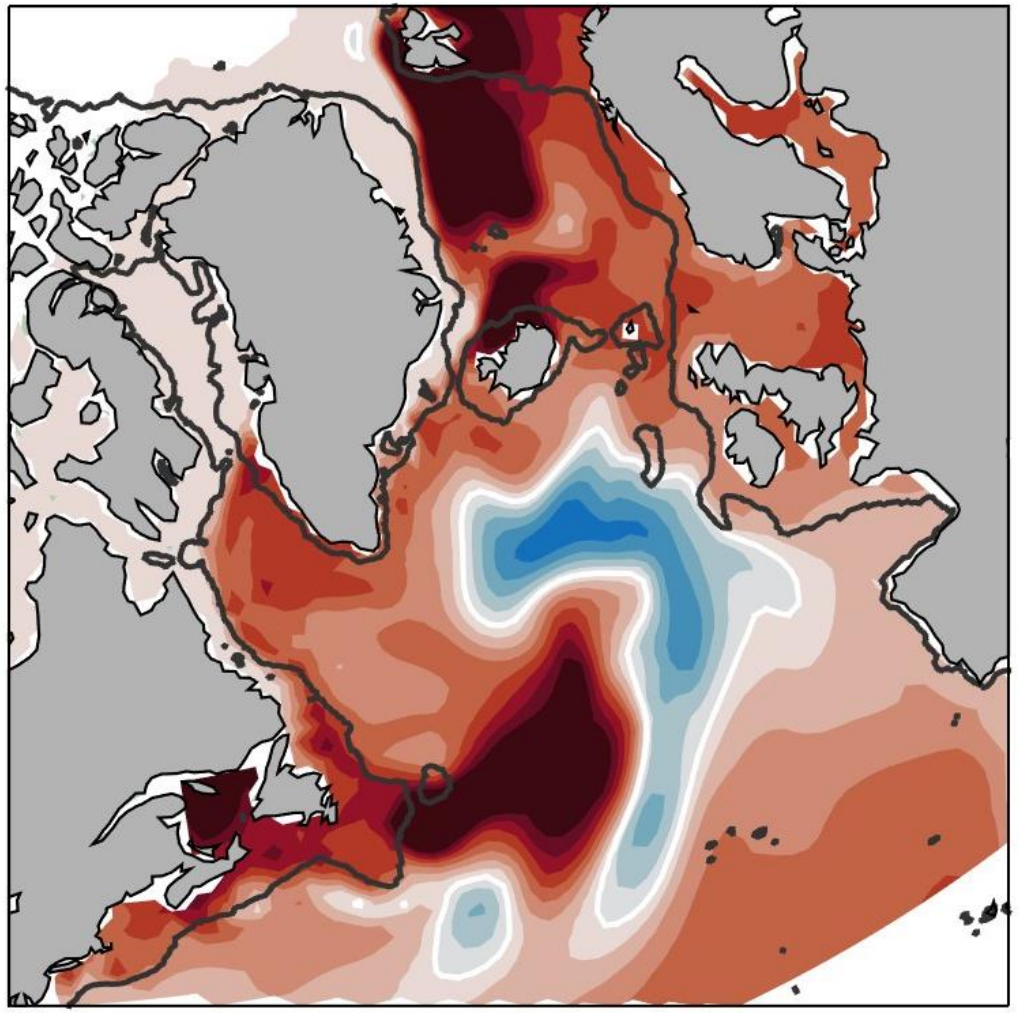
Climate scenario 8.5: highest baseline, emission continue to rise through the 21st century

Future (march) EC-EARTH3, RCP4.5-moderate scenario

Difference: 2050 - present



Difference: 2100 - present



Summary points

- From 1970 (to about 2000) significant relations between 1) three tropic levels- phytoplankton, zooplankton and salmon, and) NE Atl T/ NHT and 3) NAO
- Effect of warming; smaller zoopl, northward shifts (upto 10^{o} lat in Europe)
- 1980-90s cold period Lab/New Foundland, salmon decline, but lack of recovery despite returning climate
- Reduced advection of Arctic zooplankton in Norwegian Sea coincide with decline marine salmon growth about 2007
- SPG changes affect advection of nutrients and zooplankton
- Climate warming → increased upper ocean stability → increased phytopl → smaller zooplankton
- Warming arund 2050 continues through the 21st century. Only exception is the the cold blob of the North Atlantic – related to NAO+.
- Southern salmon population are volunerable to warming, moreso on the European side
- The strong northern warming and reduced sea ice allow salmon to utilize new areas, *already observed aroung Spitzbergen*