CNL(23)94

Current and predicted ecological impacts of climate change to salmon productivity in the North Atlantic, in marine habitats

NASCO Theme-Based Special Session:
Informing a Strategic Approach to Address the Impacts of Climate Change on Wild Atlantic Salmon

Katherine E. Mills[1] and Timothy F. Sheehan[2]
[1] Gulf of Maine Research Institute
[2] NOAA Fisheries

June 6, 2023

Outline

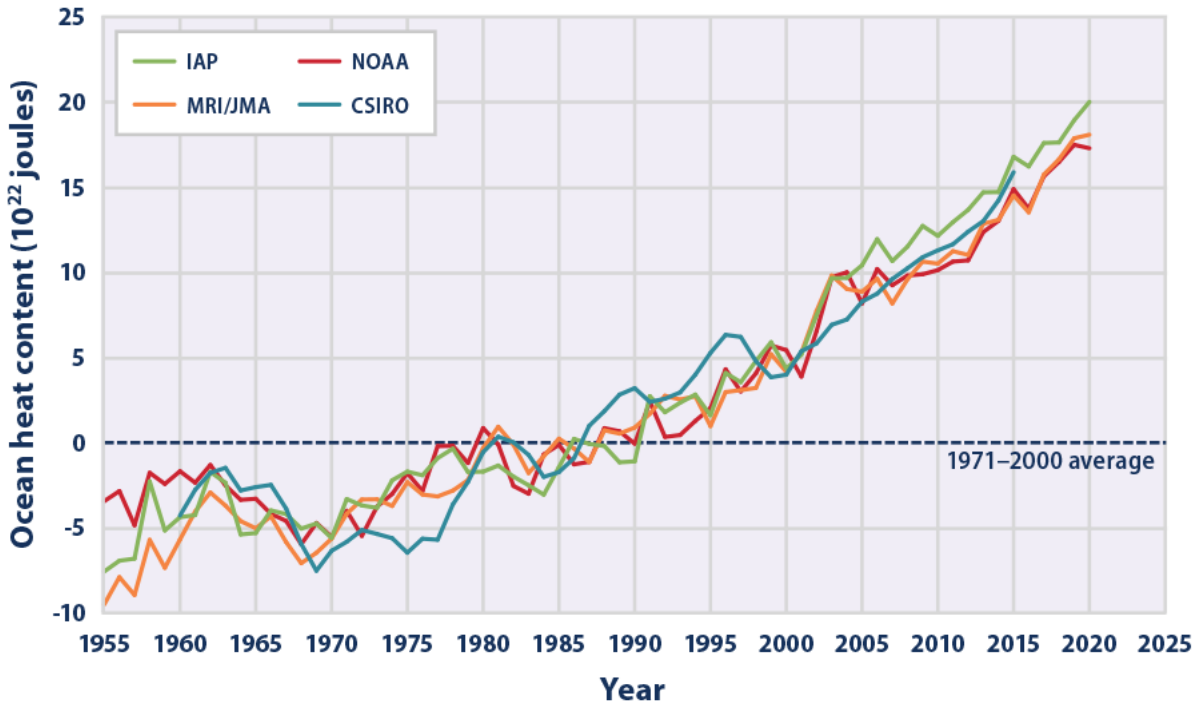
1. Climate change and the oceans
2. Atlantic salmon marine habitats
3. Projected physical changes
4. Ecosystem impacts on Atlantic salmon
5. Climate change impacts of salmon
6. Uncertainties and research needs

Details within CNL23(49)

Climate change and the oceans

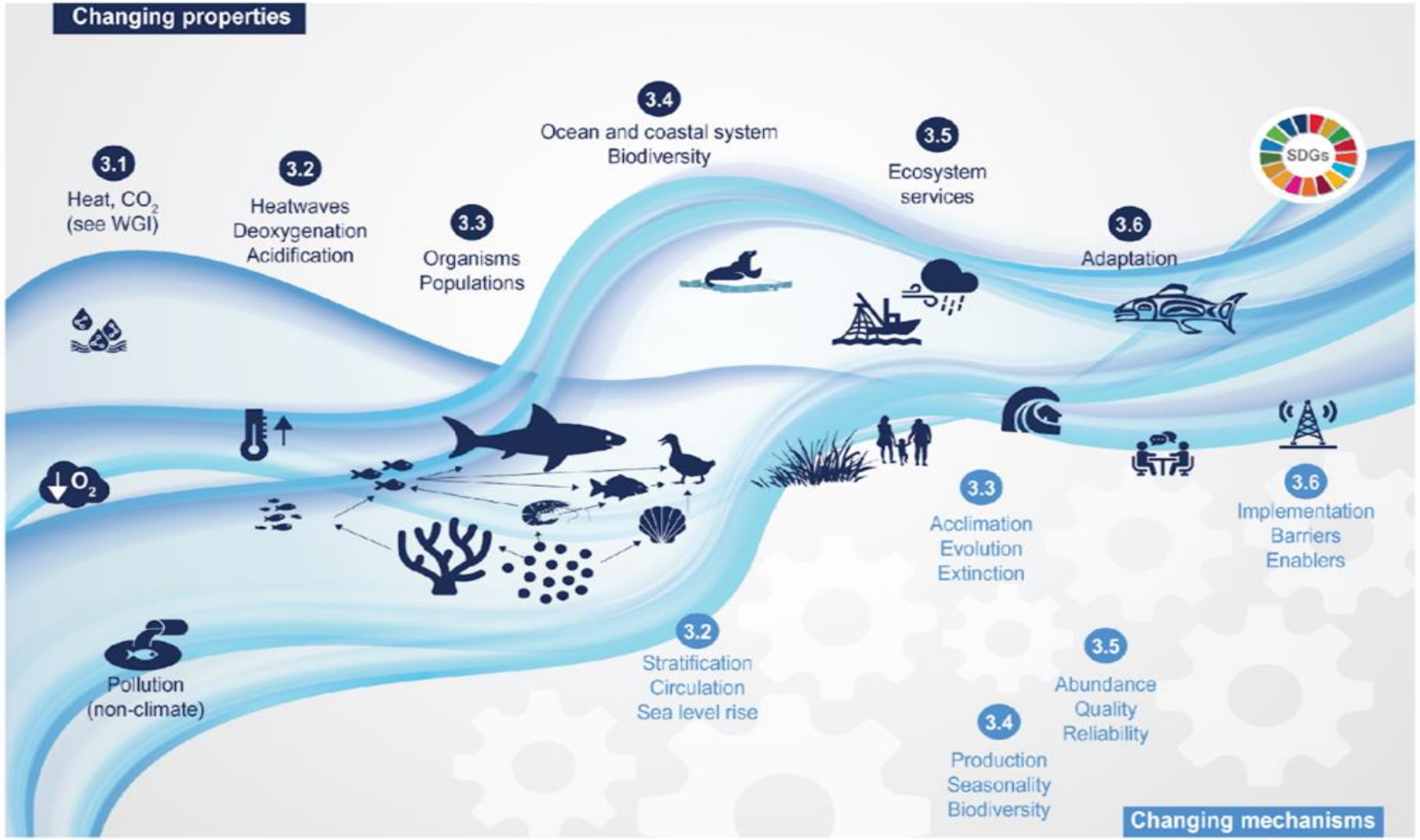
- It is *virtually* certain that the global ocean has warmed unabated since 1970 and has taken up more than 90% of the excess heat in the climate system.
- Since 1993, the rate of ocean warming has more than doubled.
- Marine heatwaves have *very likely* doubled in frequency since 1982 and are increasing in intensity.

(Intergovernmental Panel on Climate Change: Special Report on the Ocean and the Cryosphere 2019)



(US EPA)

Climate change and the oceans



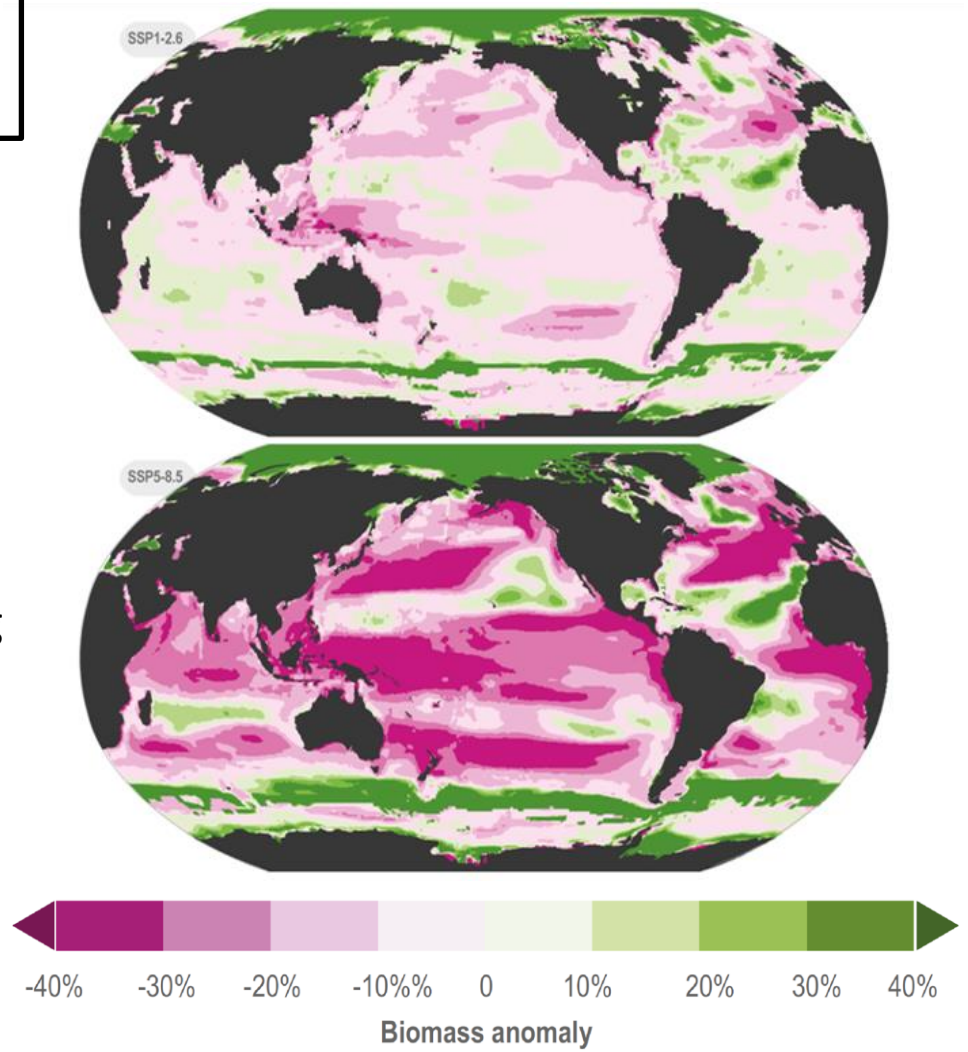
(IPCC's AR6 WG2, Ch. 3)

Climate change and the oceans

Fish Biomass
Projected Change
1990-1999 versus 2090-2099

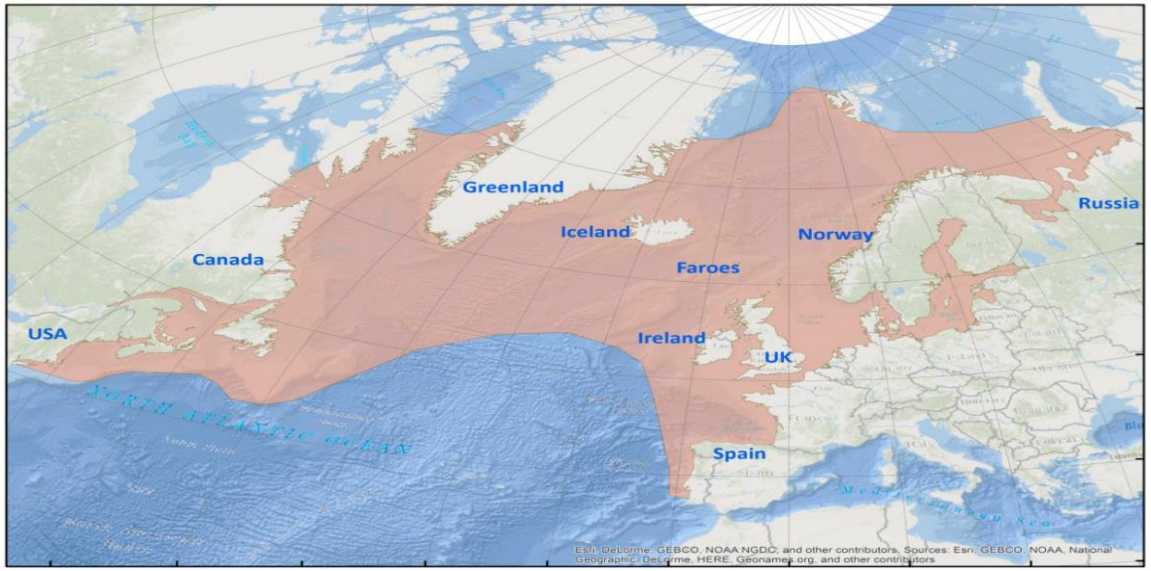
Low warming scenario

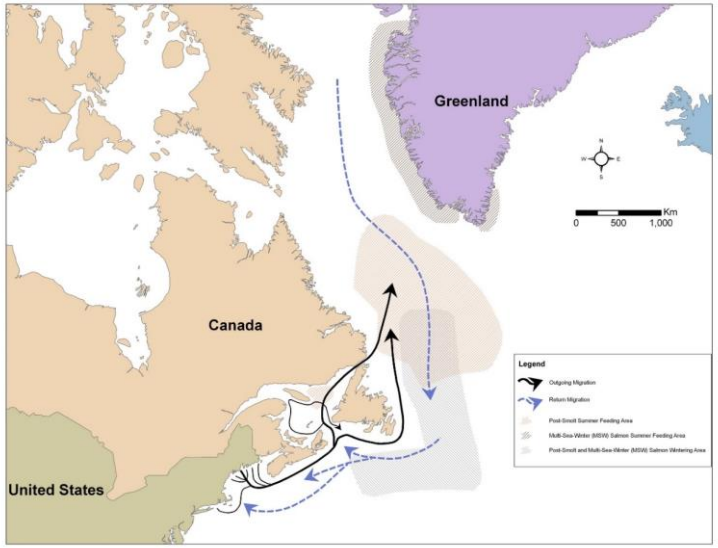
High warming scenario

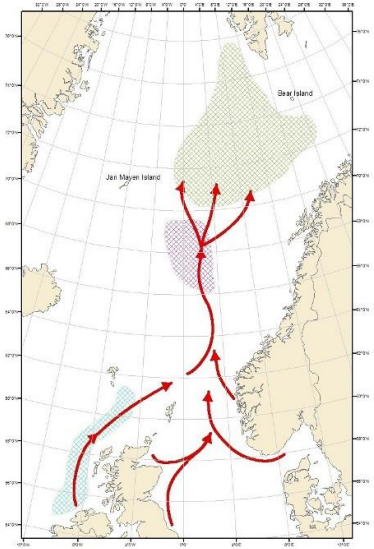


(IPCC's AR6 WG2, Ch. 3)

Atlantic salmon marine habitats

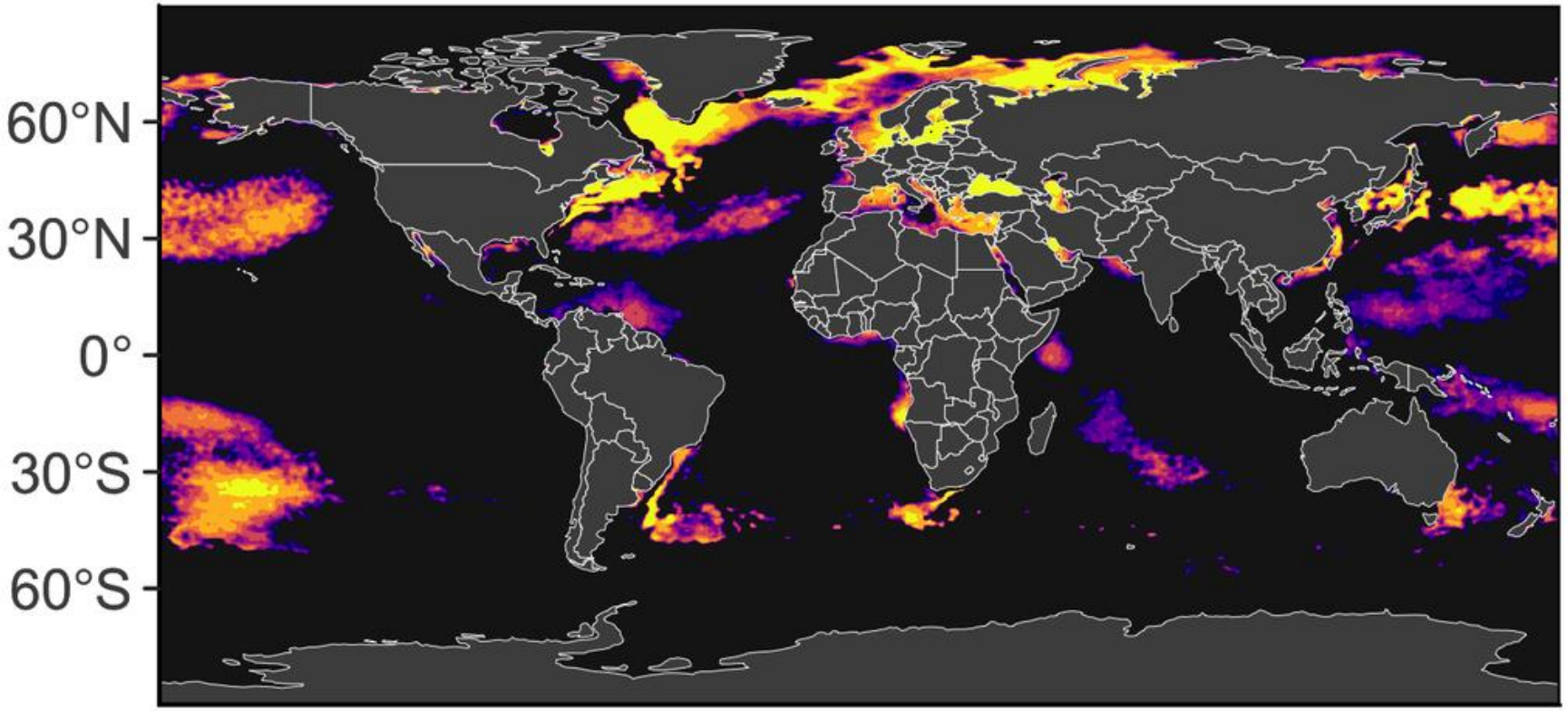






(Ó Maoiléidigh *et al.* 2018; NOAA Fisheries; AST)

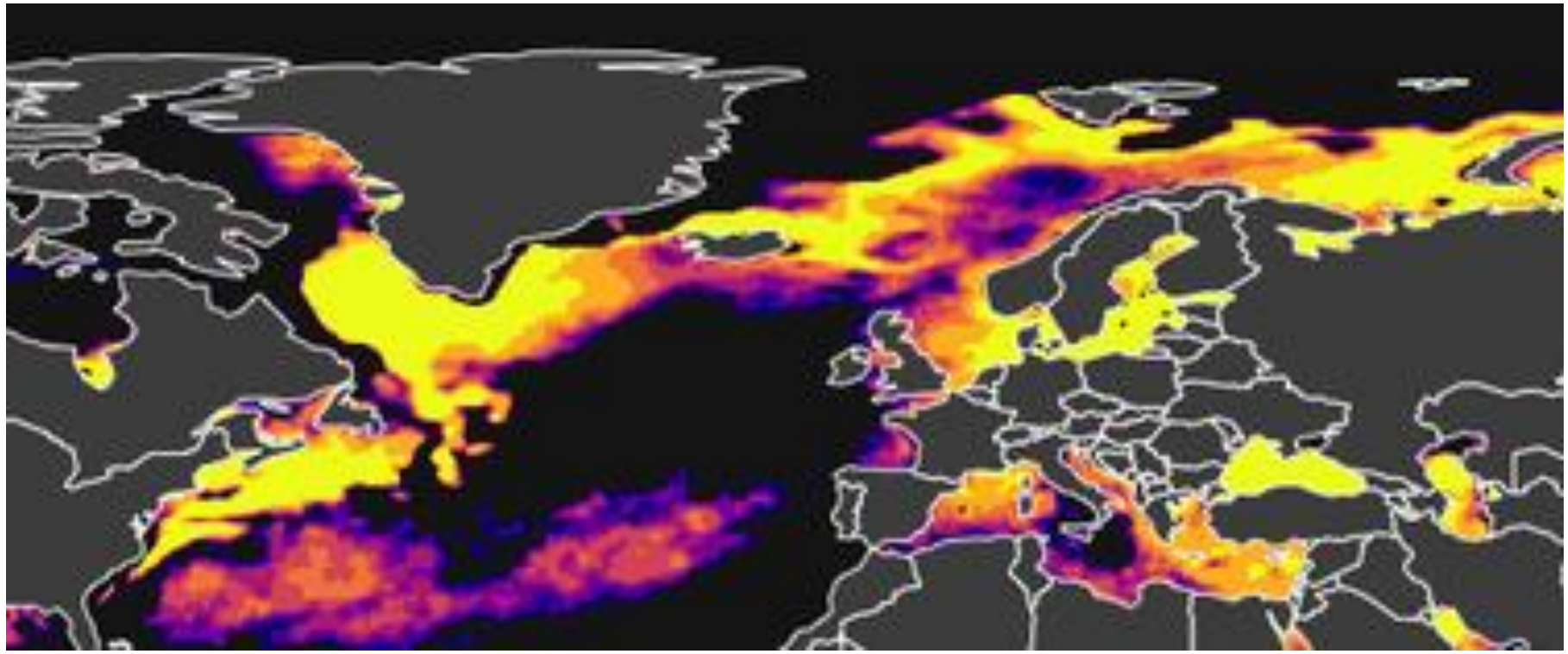
Atlantic salmon marine habitats



Warming Rate Percentile: 1982-2021

80 82.5 85 87.5 90 92.5 95 97.5

Atlantic salmon marine habitats



Warming Rate Percentile: 1982-2021

80 82.5 85 87.5 90 92.5 95 97.5

Physical habitat features

Temperature

- Absolute and seasonal temperatures affects spatiotemporal habitat availability
- Affects spatial distribution, phenology, metabolism

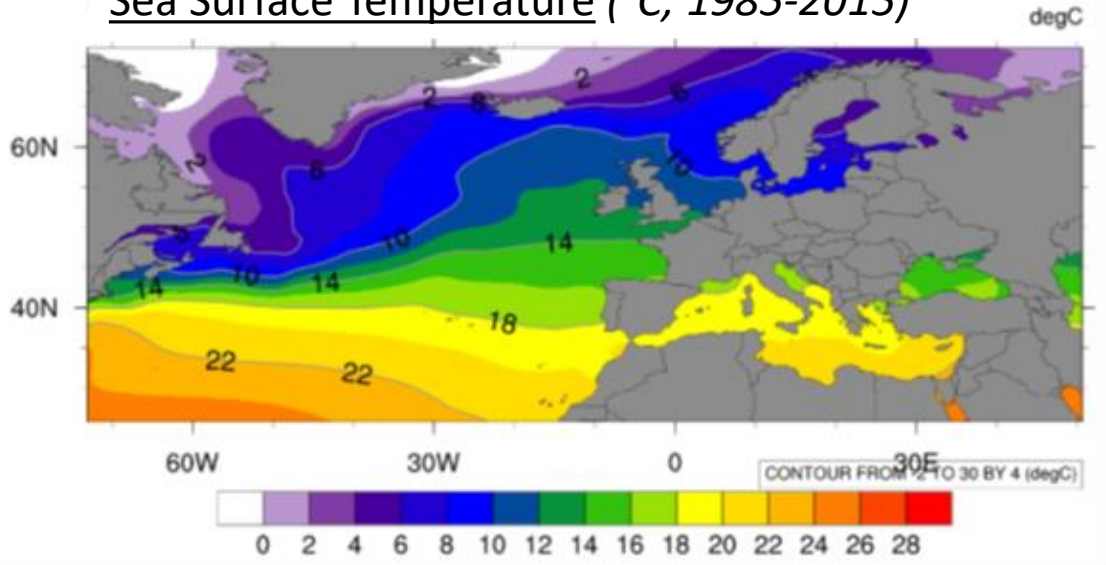
Stratification

- Affected by water masses, salinity, currents etc.
- Affects mixed layer depth, productivity

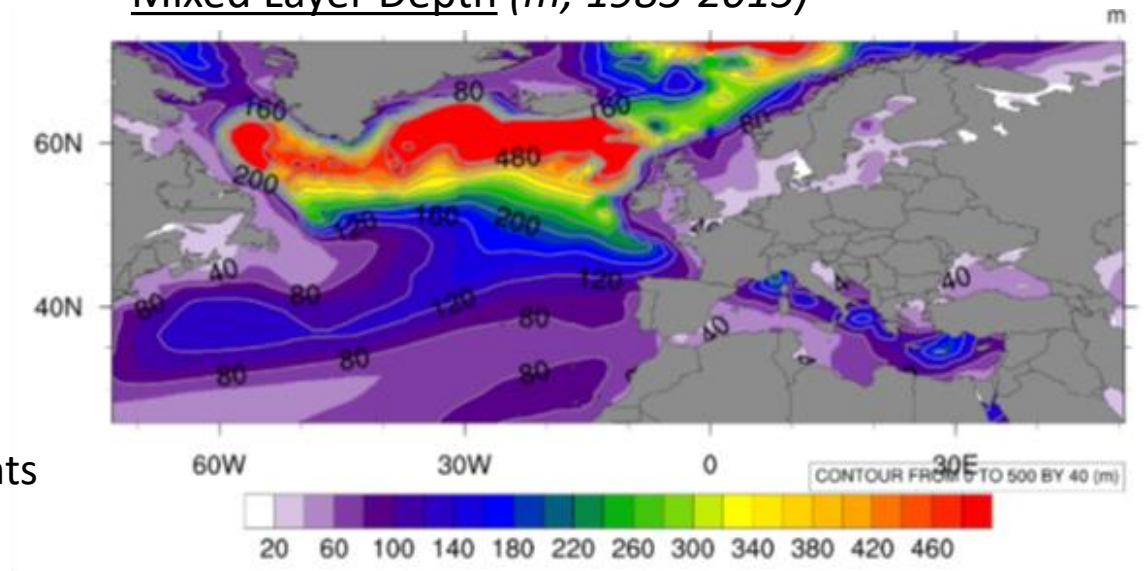
Ocean Currents

- Driven by broad circulation patterns and various environmental conditions
- May affect migration routes, timing, energy requirements

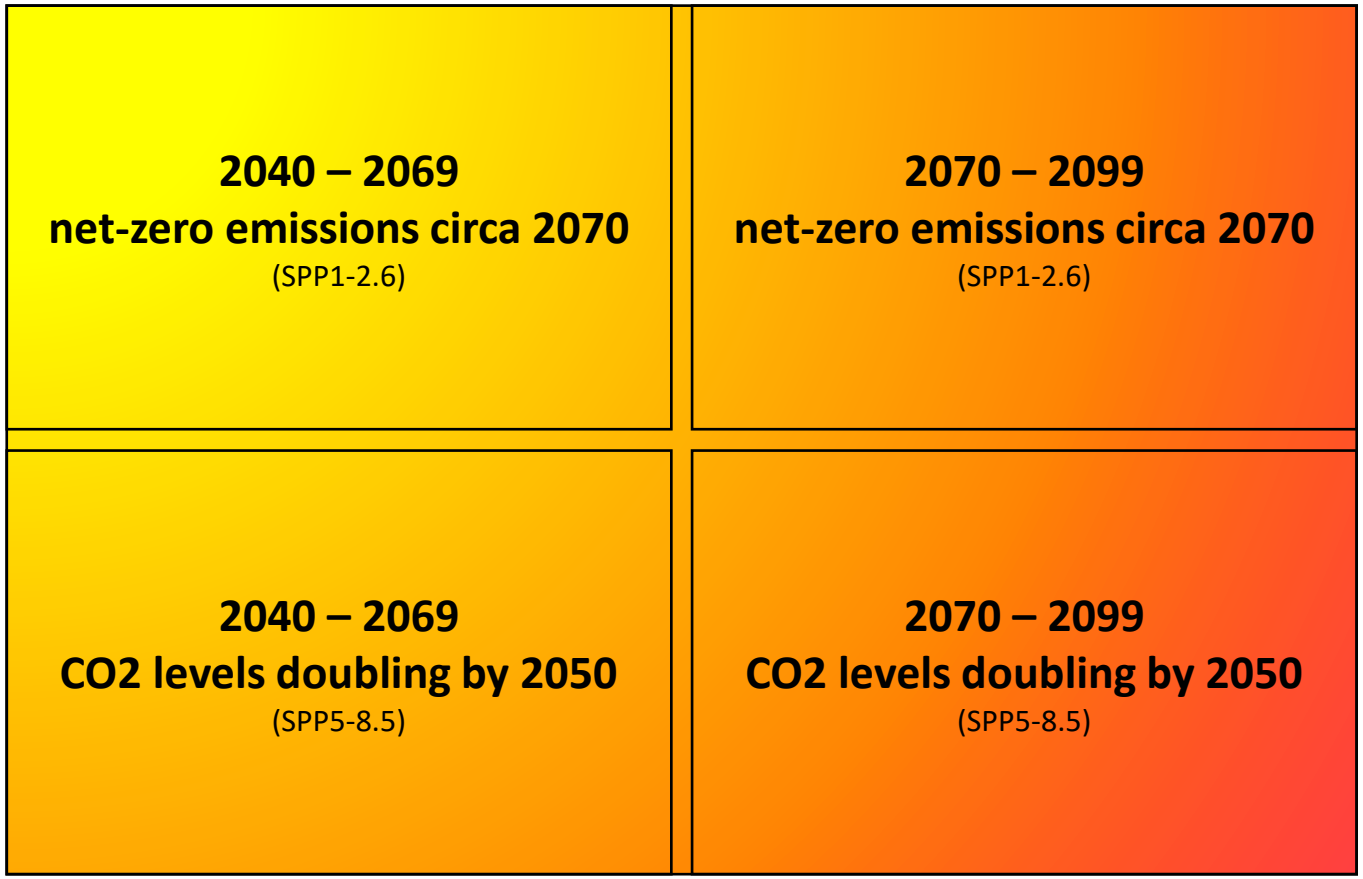
Sea Surface Temperature *(°C; 1985-2015)*



Mixed Layer Depth *(m; 1985-2015)*



Projected physical changes



IPCC scenarios

- Two time periods of consideration
  - 2040-2069
  - 2070-2099

- Two extreme scenarios of greenhouse gas emission trajectories
  - SPP1-2.6 (low warming)
  - SPP5-8.5 (high warming)

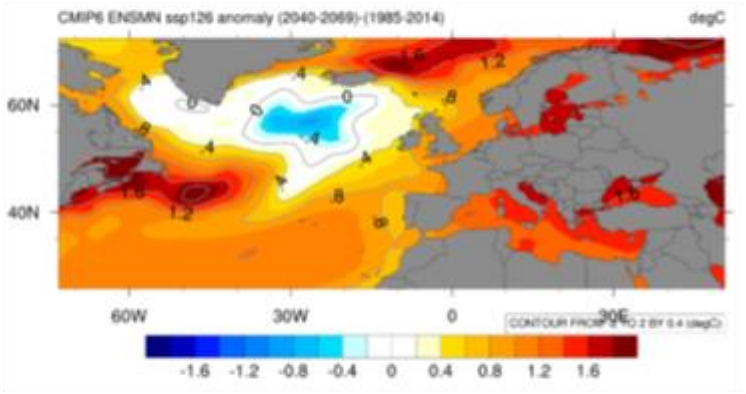
Projected physical changes

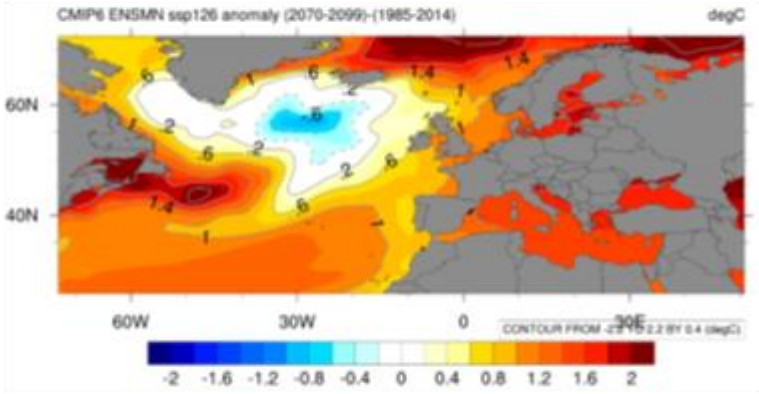
Sea Surface Temperature

2040-2069

2070-2099

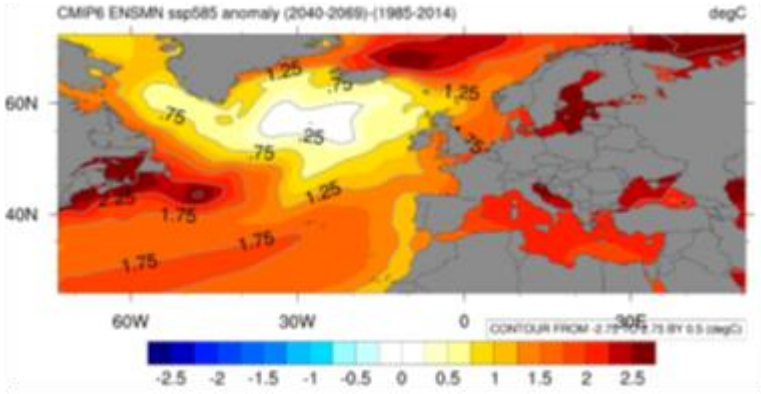
SSP1-2.6

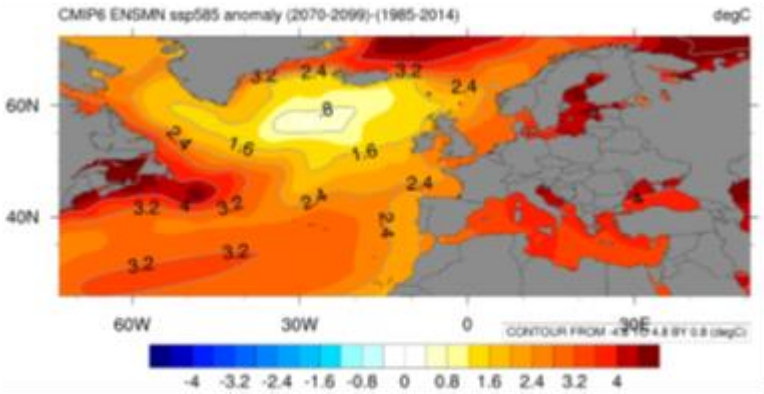




- Strong warming at SE and NE edges
- Cooling in central North Atlantic

SSP5-8.5





- Warming over full range
- Weakest warming in central North Atlantic

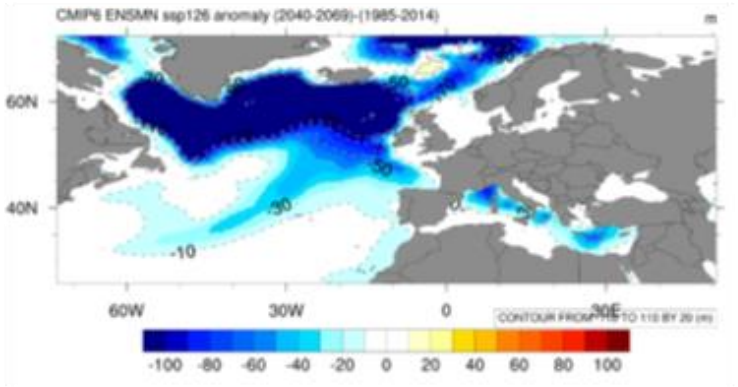
Projected physical changes

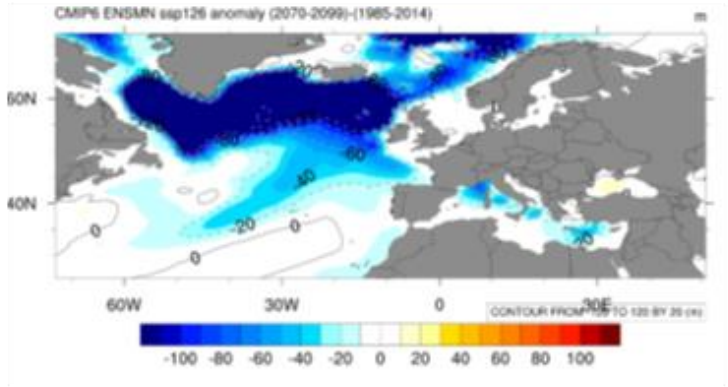
Mixed Layer Depth

2040-2069

2070-2099

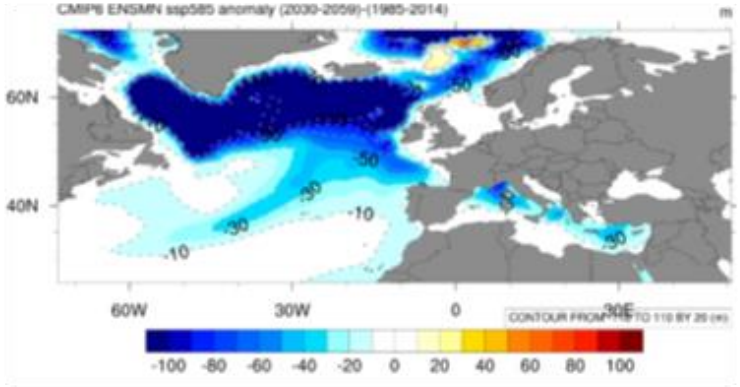
SSP1-2.6

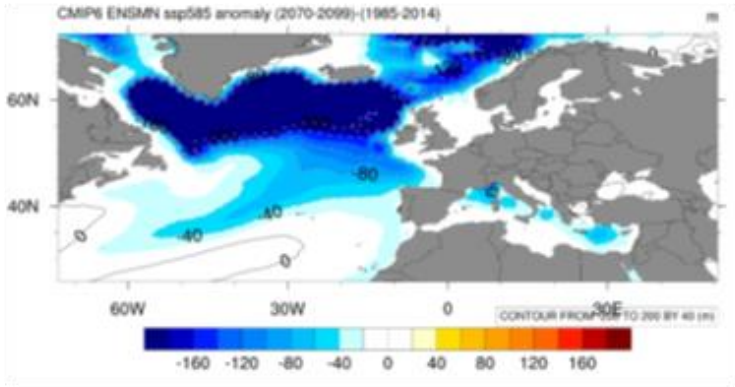




- Shoaling of mixed layer across North Atlantic, Norwegian Sea, Barents Sea

SSP5-8.5

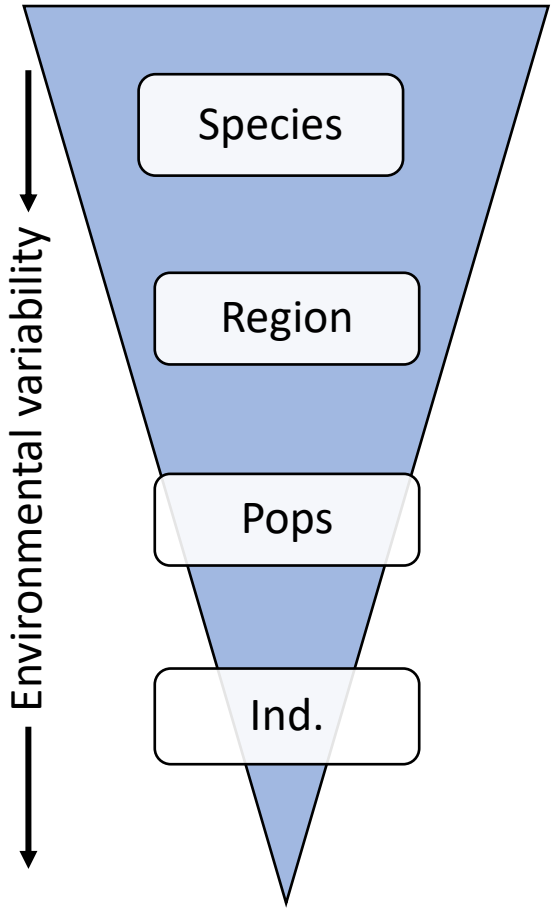




- Same spatial patterns but stronger shoaling effect

Projected physical changes

- Projected changes will influence the entire marine ecosystem
  - *e.g. phytoplankton, zooplankton, prey, predators*
- Salmon have evolved to depend on the ecosystem dynamics historically experienced
  - Species ranges are much wider than population ranges
- Alterations of these spatiotemporal patterns will have direct and indirect influences on salmon dynamics
  - *e.g. growth, maturity, fecundity, survival*

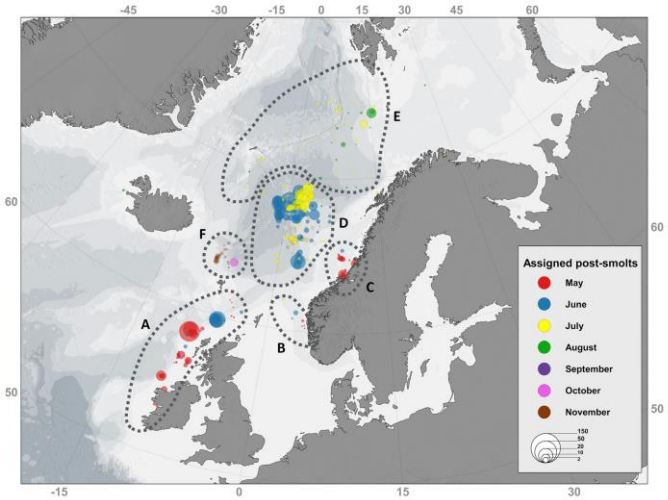


Impacts of ecosystem change on Atlantic salmon

Shift Spatial Distribution

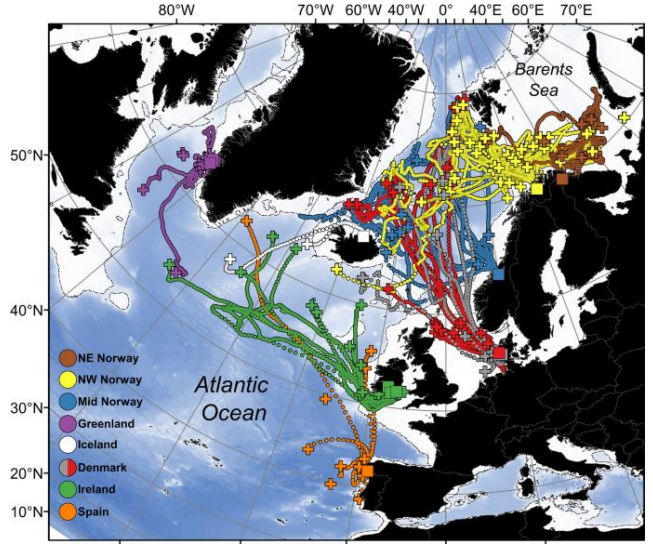
- Temperature and ecosystem conditions shape spatial distribution
  - Potential contraction at southern end of range
  - Possible expansion northward
  - Shift locations of preferred habitats
- New techniques and studies
  - Expand understanding of spatial distributions and migration seasonality
  - Changes or new observations?

Post-smolts



(Gilbey *et al.* 2021)

Kelts



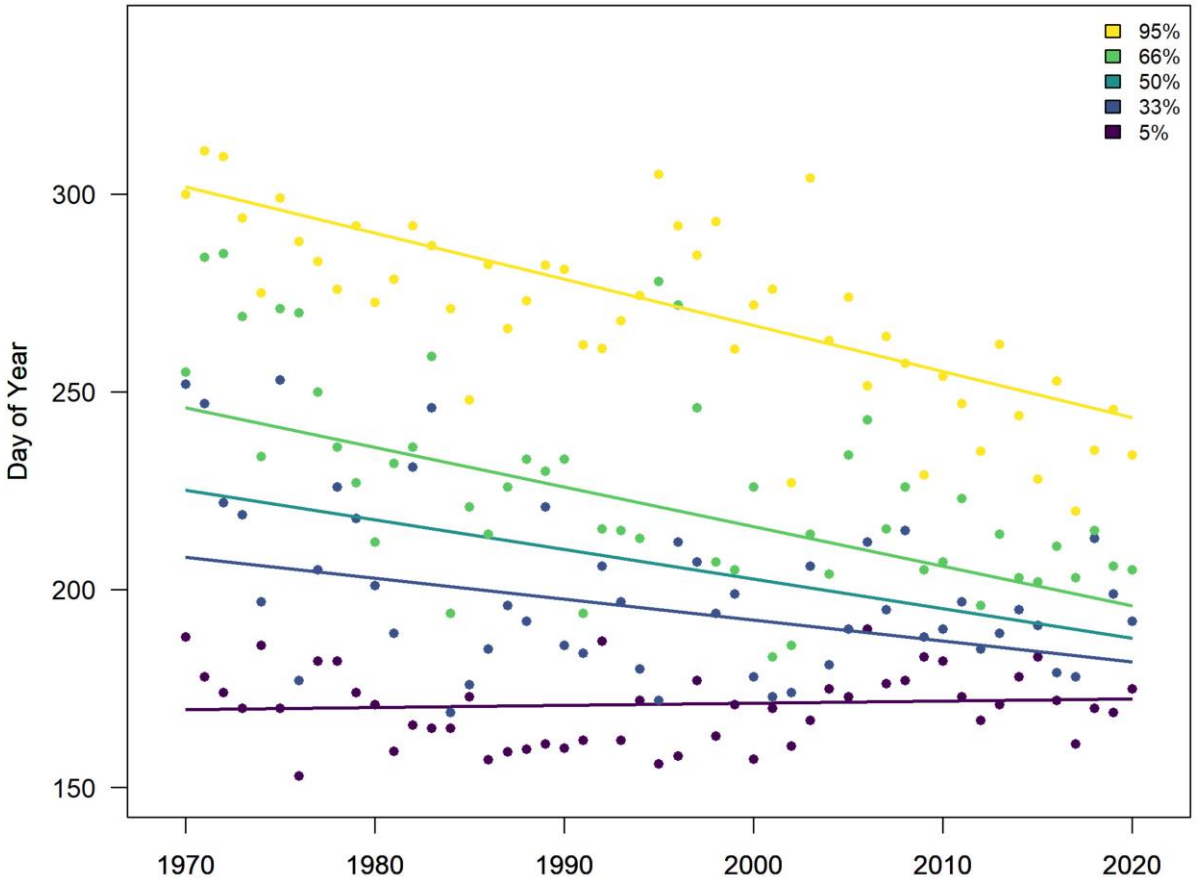
(Rikardsen *et al.* 2021)

Impacts of ecosystem change on Atlantic salmon

Shift Temporal Distribution

- Alter timing of smolt migration
  - Affects prey and ecosystem conditions encountered at ocean entry
- Alter timing of adult return
  - Advances and delays in adult return dates, dependent on river
    - Mostly advances, particularly of late portions resulting in contraction of run
- Alter timing of transition between phases
  - Migration to wintering/feeding grounds earlier/later
  - Differential changes could result in less optimal transitions
- Migration windows allowing all evolved phenotypes to persist are important given changing environmental conditions

Burrishoole catchment (Ireland)



(de Eyto *et al.* 2022)

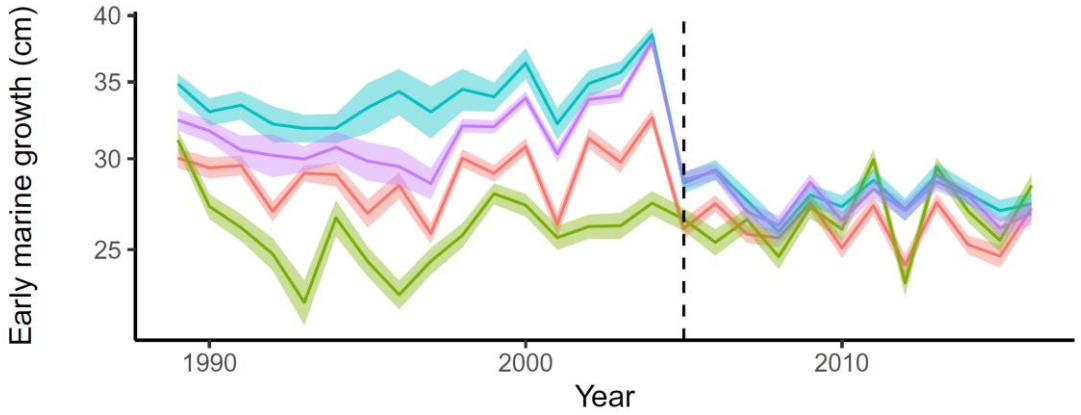
Impacts of ecosystem change on Atlantic salmon

Alter Growth, Maturation and Survival

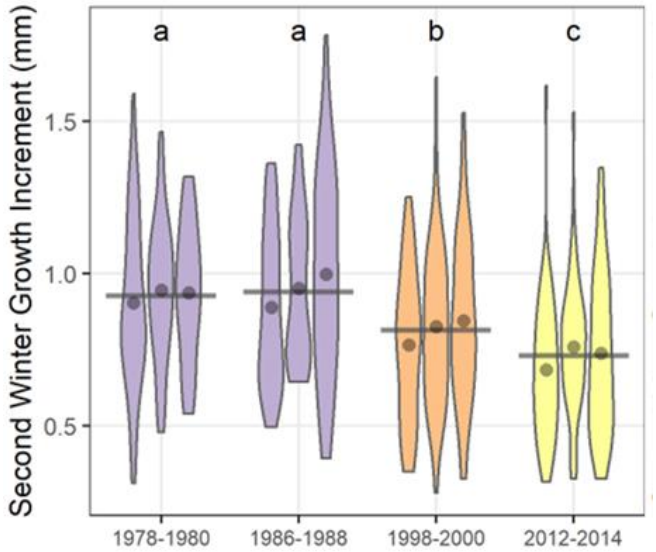
- Increased or reduced metabolic demand
- Increased or reduced growth
  - Early/late phases most tightly linked with survival
  - Consequences for maturation

- Declines in growth observed for different life stages
  - Post-smolt / early marine stages in Europe (Vollset *et al.* 2022)
  - Late-stage (2nd winter) growth for US MSW fish (Barajas *et al.* 2021)

- Ecosystem relationships
  - Need to look beyond temperature to further consider regime shifts and resulting impacts on biological processes



(Vollset *et al.* 2022)

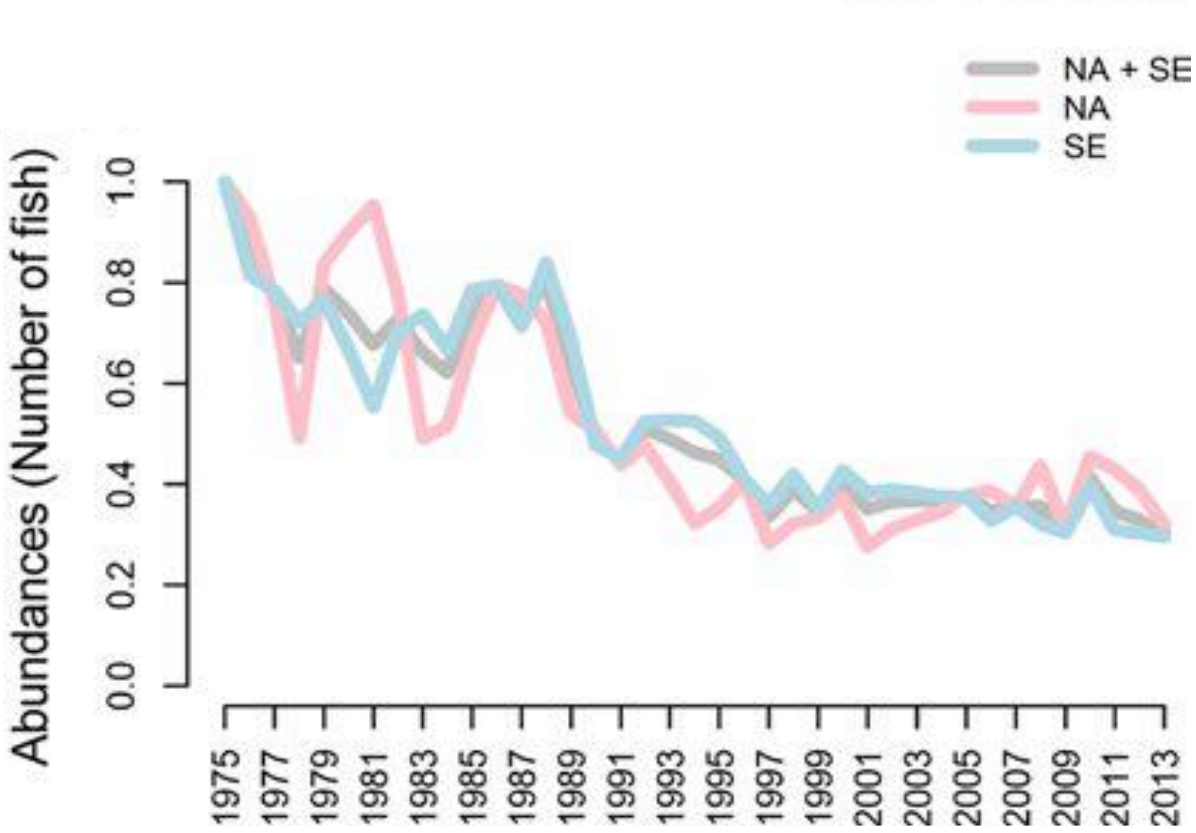


(Barajas *et al.* 2021)

Impacts of ecosystem change on Atlantic salmon

Productivity and Abundance Impacts

- Basin-wide coherence in declines of Atlantic salmon populations
- Greatest declines for population segments that spend more time at sea:
  - Southern extent of range, longer migrations
  - Multi-sea-winter fish



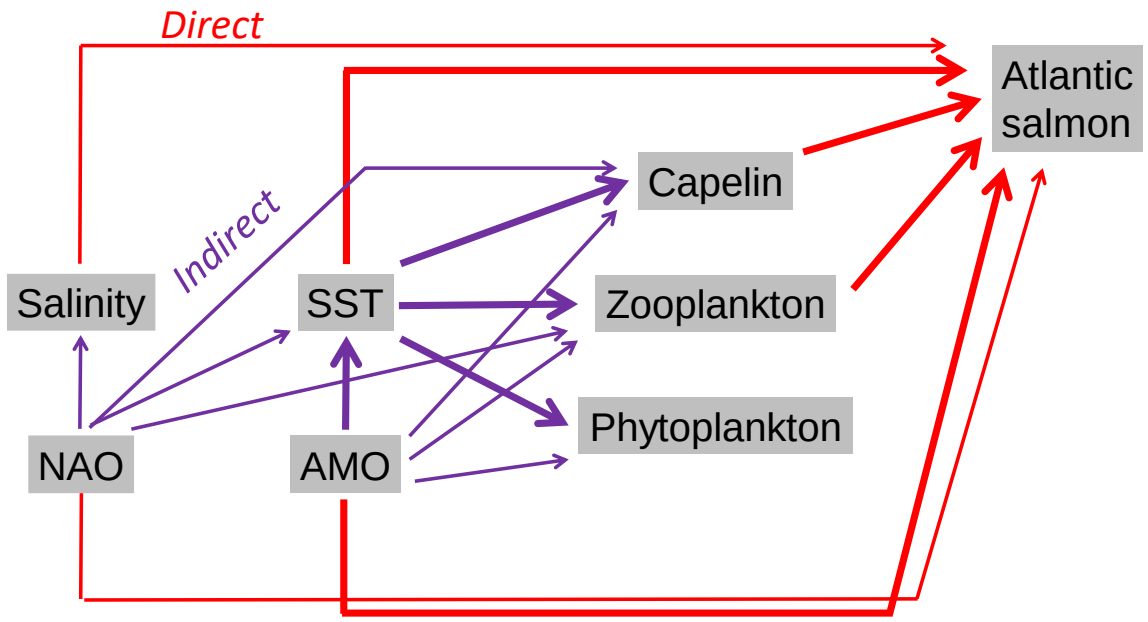
(Olmos *et al.* 2019)

Impacts of ecosystem change on Atlantic salmon

Productivity and Abundance Impacts

- Basin-wide coherence in declines of Atlantic salmon populations
- Greatest declines for population segments that spend more time at sea:
  - Southern extent of range, longer migrations
  - Multi-sea-winter fish

- Direct and indirect relationships to ecosystem conditions

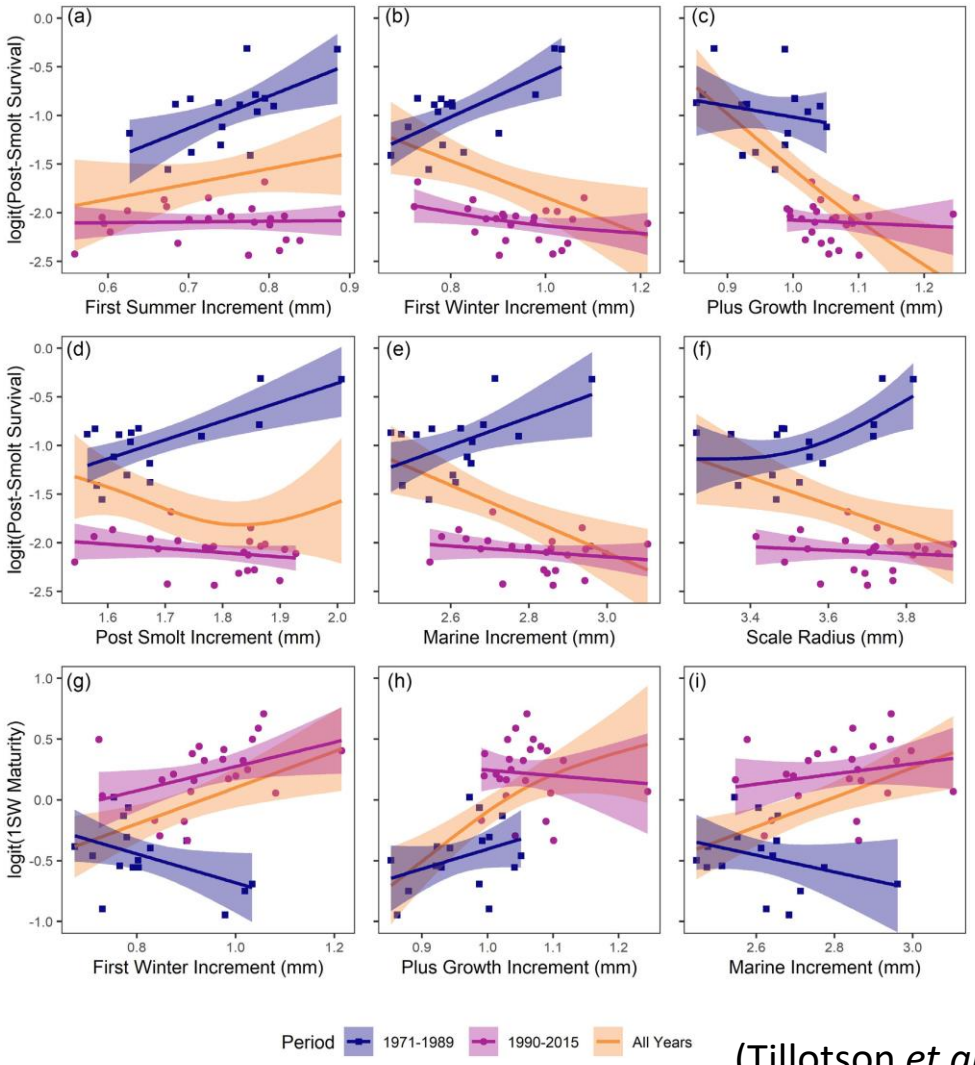


(Mills *et al.* 2013)

Impacts of ecosystem change on Atlantic salmon

Productivity and Abundance Impacts

- Basin-wide coherence in declines of Atlantic salmon populations
- Greatest declines for population segments that spend more time at sea:
  - Southern extent of range, longer migrations
  - Multi-sea-winter fish
- Direct and indirect relationships to ecosystem conditions
- Affected by non-stationary mechanisms (e.g., growth, survival) that change with ecosystem regimes



(Tillotson *et al.* 2021)

Uncertainties and research needs

- Uncertainties in spatio-temporal distribution
  - Where are Atlantic salmon when?
  - How are they using changing ocean habitats?
- Uncertainties in predicting direct, indirect, and cascading impacts of physical changes
- Uncertainties in predicting impacts of differential changes
  - Different areas ocean changing at different rates
  - North Atlantic warming hole
- Tipping points not well characterized
  - Greenland ice sheet melt
  - Large-scale ocean circulation changes (i.e. AMOC slowdown)
- What climate trajectory will we choose?
- Managing for resilience in the context of uncertainty (*e.g. Precautionary Approach*)

Summary

- Projected physical conditions beyond past experiences
- Changing environmental/ecosystem conditions and seasonality (*e.g. temperature, currents, ocean productivity*)
  - Integrated across many biological processes
- Bottom-up and top-down indirect impacts
  - Prey distribution, abundance, energy content
  - Predator distribution, abundance, encounter rates
- Salmon productivity is difficult to forecast with high specificity especially at fine scales
  - Expected increases and decreases
  - Decreases expected in southern areas
- Interactive and cascadingecosystem effects complicate salmon projections
  - Complexity of ecosystem
  - Complexity and uncertainty of the projected changes
  - Complexity of salmon's position within the ecosystem coupled with limited scope of past observations

Thank you and question