Marine ecosystems productivity, climate effects and sustainable fishery

Svein Sundby

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

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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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Spatio-temporal scales the ocean physics

Length scale (km)

Time scale (year)

- Coastal fronts
- Interannual processes
- Decadal (NAO)
- Multidecadal (AMO)
- Global
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
Strong outflow of low saline Arctic water

Strong inflow of high saline Atlantic water

Sundby and Drinkwater (2007)
Spatio-temporal scales the ocean physics

- Coastal fronts
- Interannual processes
- Decadal (NAO)
- Multidecadal (AMO)
- Global
Source: PINRO, Murmansk
Den Atlantiske Multidekadiske Oscillasjonen (AMO) 1873-2000

Sutton and Hodson (2005)
AMO-signalet øker mot Arktis

Johannessen \textit{et al.} (2004) \textit{Tellus}
Atlantic Multidecadal Oscillation Index

Annual $r = 0.64$ (20th Century $r = 0.78$)
Decadal $r = 0.81$ (20th Century $r = 0.94$)
Warming was concentrated in the Northern North Atlantic

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

Temperature [°C]

0,7°C
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

* **Climate projections for 21. century**

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

* Climate effects on aquaculture
The Biggest Global Experiment - Ever!

Human perturbation

Atmospheric CO₂ (ppm)

Thousands of years
Temperatur-utviklingen siden 1850 (IPCC 2007)
IPCC (2007)
ICE EXTENT

IPCC (2007)
High latitude predictions more insecure:

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

Årsmiddel av obs. lavpassfilter av obs.

Langtidsprognose etter Furevik et al. (2002)

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 multidecadal 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)

- Phytoplankton
- Calanus
- Parathemisto
- Polar cod
- Seal
- Cod
- Herring
- Man

Nivå 1
Nivå 2
Nivå 3
Nivå 4
Nivå 5
Phytoplankton

Zooplankton

Planktivore fish, juv. and fish larvae

Larger fish

Sea birds and marine mammals

SALINITY
TEMPERATURE
LIGHT
TURBULENCE

OCEAN CLIMATE

ADVECTION SPREADING VERTICAL MIXING

Microbial loop

Phytoplankton

CARBON and NUTRIENTS

Zooplankton

Individuals

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

Eaten by:

- Euchaeta
- Calanus hyperboreus
- Calanus finmarchicus
- Pseudocalanus
- Microcalanus
- Oithona
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
Overvintringsområde for raudåte
North Sea cod spawning-stock biomass (SSB) and spring/summer abundance of *C. finmarchicus*
Ocean climate + Inflow of Atlantic Water + Ocean climate

Inflow of C. finm. + Inflow of Atlantic Water + Ocean climate

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.

The North Sea

The Barents Sea

NAO+ AMO+

- Inflow of C. finm.-rich NSIW

- Transport of C. finm.

- Local spring prod. of C. finm.

- Local growth conditions for C. finm.

Strong cod recruitment

Poor cod recruitment
The ocean climate conditions in the 1920s were favourable for transport of cod larvae and juveniles from Iceland to Greenland.
The cod spread northwards during the warm period of the 1920s and 1930s.
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)

Start of the new herring period after 17 years of fishing moratorium and the formation of the outstanding 1983 year class

Stock collapse caused by overfishing under a cooling climate

Long-term averaged temperature
Gytedefelter for skrei langs Norskekysten

Spawning in East Finnmark since 2004
Langperiodiske klimavariasjoner skaper forflytninger i gyteområdene for skrei

Sundby and Nakken (2007)
Havklimaet i Barentshavet

Temperature [°C]

0,7°C
All zooplankton species in the northeastern North Atlantic have moved northwards with the increasing temperature.
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).
Climate effects on marine ecosystems vary with the periodicity

- **Interannual to decadal**
  - Local production on lower trophic levels
  - Fish recruitment and year-class strength

- **Multidecadal**
  - Habitat extents of populations
  - Production on higher trophic levels
Vinjefjorden, Nordmøre november 2006
Unni Justsen med 22kg sverdfisk
Figur 3.
Gjennomsnittlig biomasse av norsk vårgytende sild

Antall observasjoner

Figur 4.
Ecosystem responses to climate change

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
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Veksten til lus er styrt av temperaturen i sjøen
Dette er en bakteriesykkdom som kan gi økte problemer ved økt temperatur.
Midlere maksimum/minimum temperatur for Hls kyststasjoner (1 og 10 m dyp)

![Graph showing temperature distribution across different distances from various locations like Flødevigen, Møre, Ingøy, and Russland.]
Minimum og maksimumstemperaturer for Hls kyststasjoner (1m dyp)

Avstand (km)

Temperatur

Minimum middelår
Minimum 1980
Maximum middelåret
Maximum 2003

Minimum middelår
Minimum 1980
Maximum middelåret
Maximum 2003
Maksimumstemperatur for HIs kyststasjoner (1 m dyp)

![Graph showing maximum temperature for HIs coastal stations at 1 m depth.](image-url)
• 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 moderately 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.