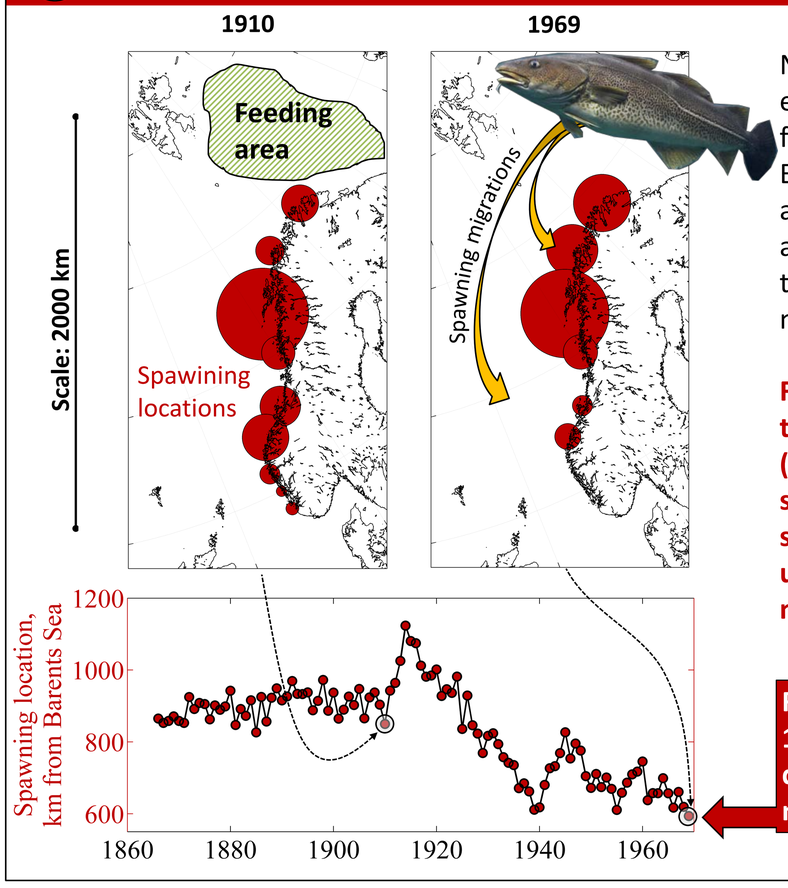
Trait-changes in a fish population as evolutionary response to fisheries

Anders Frugård Opdal, Christian Jørgensen and Øyvind Fiksen. *University of Bergen and Hjort Centre for Marine Ecosystem Dynamics, Bergen, Norway*

1. Before 1930, the Northeast Arctic cod spawned up to 2000 km south of their feeding grounds in the Barents Sea. Today the range is less than half
2. From simulation experiments we find that offspring survival could be 3-4 orders of magnitude higher in the most southern spawning grounds compared to those in the north.
3. Several drivers and processes can influence how far south a female should spawn, but age and size appear to be essential.
4. Using a state dependent bio-energetic model we calculated optimal energy allocation for different ages, body lengths and energy stores
5. For large individuals there is a huge benefit for performing longer southbound migrations., compared to that for smaller fish.
6. This is likely why population age structure explain nearly 60 % of the temporal variation in spawning ground location of Northeast Arctic cod.

1 Spawning ground distribution has shifted north

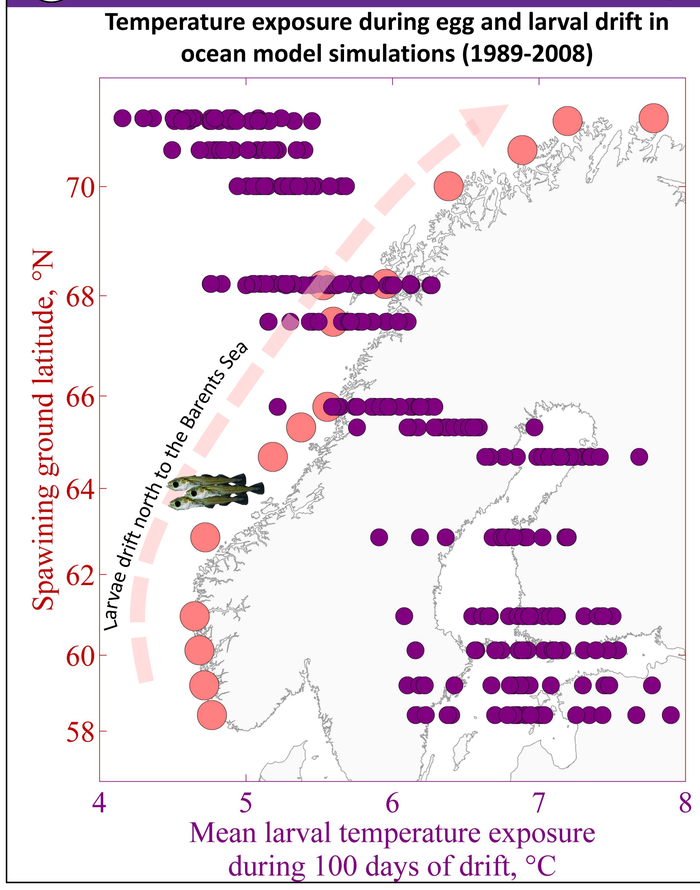


Northeast Arctic cod undertake extensive spawning migrations from their feeding areas in the Barents Sea to spawning grounds along the Norwegian coast. Eggs and larvae are transported back to the Barents Sea by northbound currents.

From coastal fisheries data at the spawning grounds of NA cod (1866-1969) it is evident that spawning has shifted north. This strongly suggest that NA cod are undertaking shorter spawning migrations

Records were discontinued in 1969. Today, spawning distribution is likely further north.

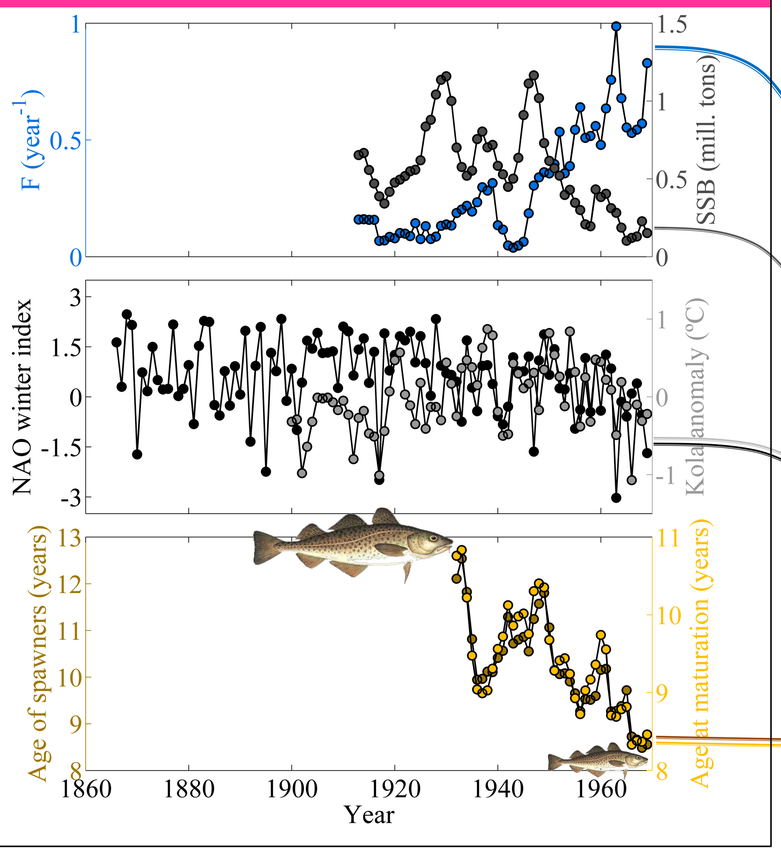
2 What are the benefits of spawning migration?



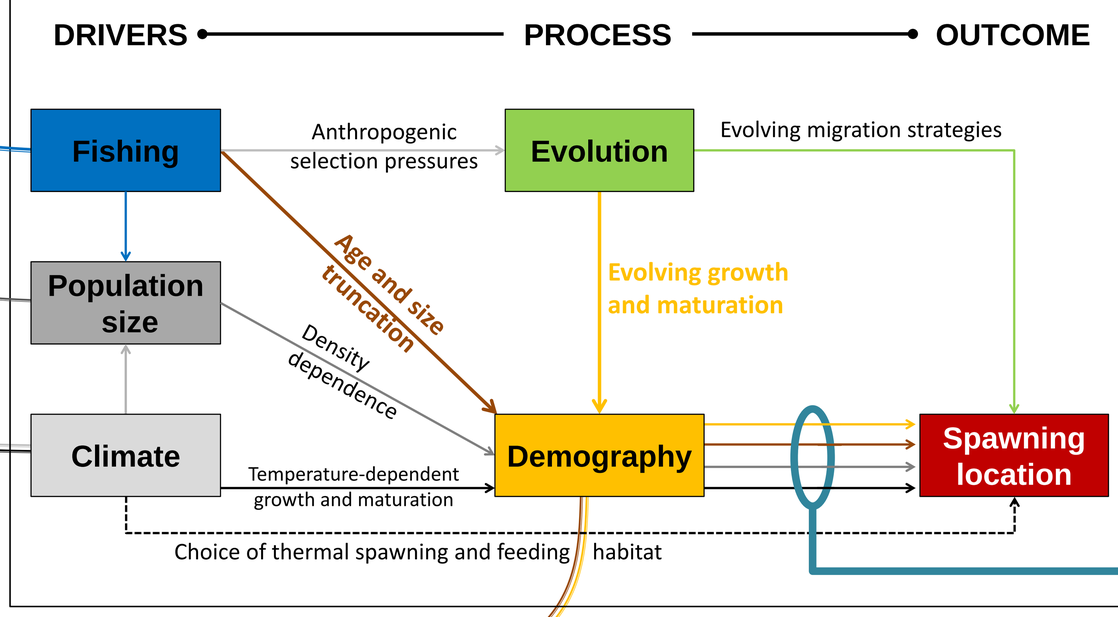
Using an IBM model of fish egg and larval behaviour coupled to a general ocean model, we released eggs at 15 different spawning ground along the Norwegian coast. We followed their northbound drift trajectories back to the nursery and feeding grounds in Barents Sea and recorded temperature exposure.

Assuming temperature-dependent growth, larval survival is 3-4 orders of magnitude higher when spawned in the south compared to the north.

Observations



3 What could change spawning ground distribution?



Demography directly affects spawning location.

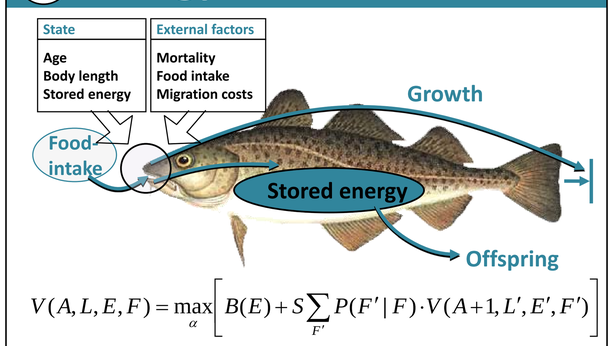
Demography may be influenced by the physical climate through phenotypic plasticity, by density dependence, by fishing-induced truncation of the stock's age distribution, or through fishing-induced evolution of life history parameters.

Population size, fishery and climate indices have NO direct effect on spawning location.

Observed change

Proposed mechanism

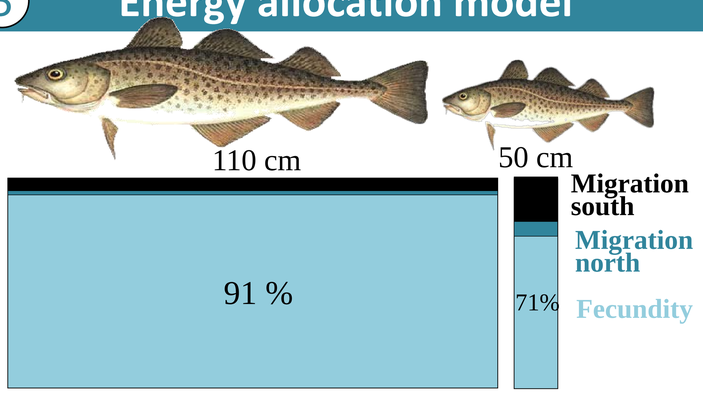
4 Energy allocation model



$$V(A,L,E,F) = \max_{\alpha}\left[B(E) + S\sum_{F'} P(F' \mid F)\cdot V(A+1,L',E',F') \right]$$

Using a dynamic state bio-energetic model, we can calculate evolutionary optimal migration distances for all state combinations (age, body length and energy stores).

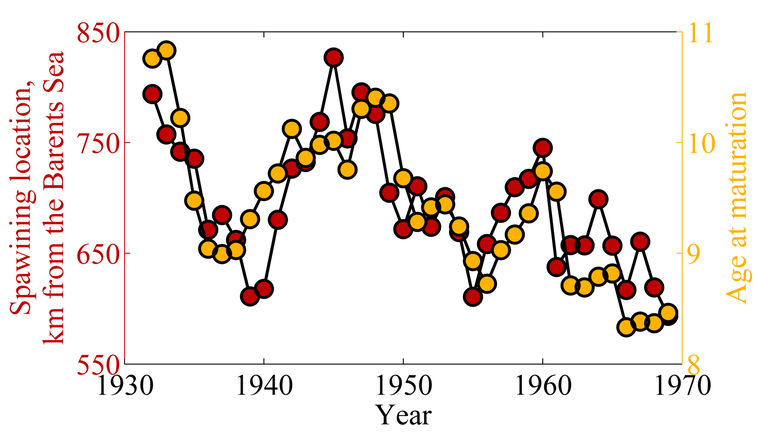
5 Energy allocation model



Area is proportional to energy storage capacity for a large (110 cm) and small (50 cm) cod. Relative cost of migration decreases with size, leaving more energy available for reproduction.

If offspring survival is higher at southern spawning grounds, evolutionary optimal migration distance should be longer for older and larger individuals

6 Conclusion



Variation in age at maturation, or age of spawning stock, explain ca 60 % of the variation in spawning ground location (R^2=0.58). We suggest this is due to a combination of altered demography and evolution of spawning strategies, both driven by fishery

References

Jørgensen, C., E. S. Dunlop, A. F. Opdal, and Ø. Fiksen. 2008. The evolution of spawning migrations: state dependence and fishing-induced changes. *Ecology* **89**:3436-3448.

Opdal, A. F., and C. Jørgensen. 2015. Long term change in a behavioural trait: truncated spawning distribution and demography in Northeast Arctic cod. *Global Change Biology* **21**:1521-1530.

Opdal, A. F., F. B. Vikebø, and Ø. Fiksen. 2011. Parental migration, climate and thermal exposure of larvae: spawning in southern regions gives Northeast Arctic cod a warm start. *Marine Ecology-Progress Series* **439**:255-262.