The Weak Link in the Fish Food Chain

Cod stock numbers within the North Sea have already been depleted by decades of over fishing. Mathematical modelling now suggests that the North Sea population of cod and other commercial fish stocks could also feel the effects of a warming planet unless they can adapt fast enough.

"Getting fish from the sea to your stomach is big business: Britain consumes £5.65 billion worth of seafood every year. A consistent member of the country's top three seafood staples is cod – of all the cod eaten on the planet, a third of it ends up on British plates. However, cod stocks around Britain's coastlines, particularly in the North Sea, have dwindled in recent decades under the strain of over-fishing.

Strict fishing quotas are now in place to protect the North Sea cod population, with the majority of cod consumed in the UK coming from further afield fisheries like the Barents Sea and the Baltic. However, mathematical modelling suggests that, if global temperatures change in line with current predictions, North Sea cod could face another pressure: the disappearance of a plankton species on which they currently depend.

There is evidence to suggest that a key element in cod population is the abundance of a species of zooplankton called Calanus finmarchicus. Just a few millimetres across, and a pillar of marine food chains, it is thought the larvae of cod and other commercially important fish species rely on them for survival to adulthood.

Mathematical modelling by Pierre Helaouët, a marine numerical ecologist at the Sir Alister Hardy Foundation for Ocean Science (SAHFOS), Plymouth, suggests that Calanus finmarchicus could move northwards by as much as one degree of latitude per decade of the 21st century. Such a migration could drain the North Sea of a species that commercial fish stocks currently rely on.

To come to that conclusion, the first step was to work out just how much Calanus finmarchicus inhabits North Atlantic waters.

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For this, Helaouët used the Continuous Plankton Recorder (CPR) survey which has been managed and maintained by SAHFOS since 1990, but whose data dates back to 1958. The plankton population is sampled using a device attached to the back of commercial marine traffic on over a hundred routes across the North Atlantic. Dragging behind the vessel, at a depth of seven metres, the sampler captures any Calanus finmarchicus it encounters.

Monthly population values for each route are then compiled to give a raw database of species abundance covering an area from 99.5°W to 19.5°E and 29.5°N to 69.5°N. Helaouët used this raw data to compile a grid map of Calanus finmarchicus population over that area, with each square measuring 1° by 1°. He populated the grid with the average population per decade from the 1960s to the 1990s and from 2000 to 2005.

A combination of mathematical modelling and future climate projections was then used to forecast future population numbers. However, it is difficult to model abundance directly. Instead, egg production rate is used as it can be studied in a laboratory. When abundance is high it means that reproduction is high. If a similar grid map of the rate of egg production agreed with the map produced from the CPR, then Helaouët could use egg production as a proxy for abundance from which to predict what the population grid could look like in future.

The rate at which female Calanus finmarchicus produce eggs is dependent upon two key factors: water temperature and food supply. Laboratory experiments, in which

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these two factors were varied, produced a mathematical equation which quantified the relationship between them and egg production. As the food Calanus finmarchicus consumes is plentiful, its supply was fixed at its optimal value to produce an equation for egg production dependent only upon sea temperature.

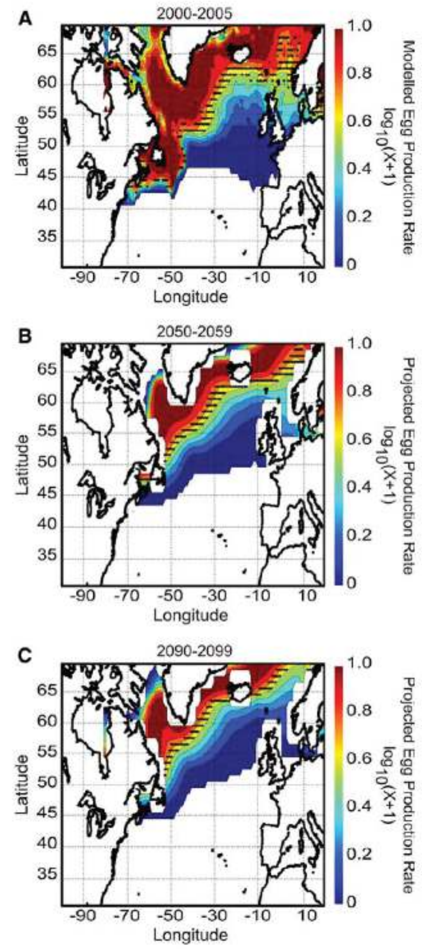
Helaouët then took historical sea temperature data from the Comprehensive Ocean-Atmosphere Data Set (COADS), acquired and managed by the National Oceanographic Data Center (NODC) in the US. The average temperature for each decade since 1960, and the half decade between 2000-2005, were put through the egg production equation to produce a grid map with the same dimensions as the CDR abundance map. There was more than a 70% agreement between the two maps – a strong correlation when natural variation is taken into account.

With the correlation established, Helaouët used predicted values of future sea temperatures to model the effect those changes could have on the North Atlantic Calanus finmarchicus population. The values he took were from a model selected by the Intergovernmental Panel on Climate Change (IPCC) for its global climate projections and take into account likely carbon dioxide levels based on world population predictions up to the year 2100. This data was used to produce maps which forecast egg production rates for the decades 2050-2059 and 2090-2099.

The maps predict a pronounced change in population: Calanus finmarchicus could disappear from the North Sea by the end of the 21st century, moving polewards at a rate of one degree per decade.

Should such a departure take place, it is possible that a knock on effect could be seen in the number of cod and other commercial fish stocks in the North Sea. What is known for sure is that there is a link between Calanus finmarchicus and cod: last time Calanus finmarchicus numbers collapsed in the North Sea that had an impact on the fish. With Helaouët's model suggesting that, if global temperatures rise as predicted, it will become harder and harder for the plankton to remain in the North Sea, cod numbers could be hit again. However, what is unknown is whether cod, or the plankton it relies on, can adapt to the changes or whether a new species can exploit the new conditions.

Changes within ecosystems are nothing new – the natural world is driven by the natural variability in resources. Yet human activity, which many believe to be warming our planet, can accelerate these changes. It remains to be seen whether the plankton and fish species that currently support the big money fishing industry can adapt quickly enough to the changes. Whichever way it pans out, it is mathematics that is giving us a head start when it comes to thinking about the future of North Sea fishing.



TECHNICAL SUPPLEMENT

Egg production rate

The equation for egg production rate, which gives the number of eggs per female Calanus finmarchicus per day, is a power law with five unknown parameters. These parameters were estimated using the technique of non-linear least square regression.

There was a difficulty in accurately forecasting egg production rate as both a function of temperature and food supply because there was insufficient data on the abundance of food – chlorophyll a. Therefore the equation was simplified by setting the food supply to its optimal value.

A correlation check between these two ways of assessing egg production rate showed agreement between 89% and 93% of the time.

Abundance vs egg production

To see the relationship between the two maps, a Pearson coefficient, r, was calculated. For all marine regions r was found to be 0.71 – a greater than 70% agreement between the two. For regions deeper than 50 metres that rose to 0.81.

References

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The IMA would like to thank Dr. Pierre Helaouët, Sir Alister Hardy Foundation for Ocean Science, for his help in the preparation of this document.