"OUR UNDERSTANDING OF THE EFFECTS OF TEMPERATURE ON THE LIFE HISTORY OF COD FAR EXCEEDS THAT OF OTHER ENVIRONMENTAL VARIABLES."

"AS WELL AS GROWING MORE QUICKLY IN WARMER WATER, COD ALSO BECOME SEXUALLY MATURE FASTER."

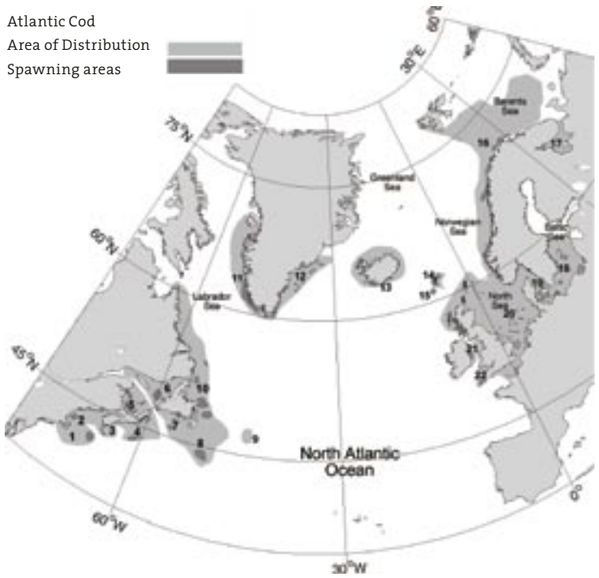
Cod stocks: winners and losers in the climate change sweepstakes

By Ken Drinkwater

Climate scientists have developed numerical models called Global Circulation Models (GCMs) to predict the response to global warming. These models forecast significant warming throughout the globe – under higher levels of greenhouse gases – with the greatest warming in the subarctic and arctic regions. These atmospheric changes will impact the ocean with anticipated effects on water properties, the circulation and ultimately, the marine plants and animals that make up the marine ecosystem.

The increasing uncertainties in understanding the impacts of climate change on marine ecosystems have caused many to shy away from predicting possible ecosystem changes. But politicians, fisheries managers, and increasingly the public are demanding answers of scientists about the most likely outcome from warmer temperatures. Given the implications of the predictions of GCMs, future planning must include, or at the very least, acknowledge the possibility of climate change and its ramifications. It is vital, therefore, that we as knowledgeable scientists provide such information while at the same time stressing the uncertainty of our predictions.

Fig. 1. The present distribution of Atlantic cod stocks.



1	Georges Bank	9	Flemish Cap	16	North East Arctic
2	Gulf of Maine	10	Northern Newfoundland/ Southern Labrador	17	White Sea
3	Western Scotian Shelf	11	West Greenland	18	Baltic Sea
4	Eastern Scotian Gulf	12	East Greenland	19	Kattegat
5	Southern Gulf of St. Lawrence	13	Iceland	20	North Sea- West Scotland -English Channel
6	Northern Gulf of St. Lawrence	14	Faroe Plateau	21	Irish Sea
7	Southern Newfoundland	15	Faroe Bank	22	Celtic Sea
8	Grand Bank				

Cod grow and mature faster in warmer water

The speed at which cod grow is very dependent on water temperature. Average bottom temperatures account for 90% of the observed difference in growth rates between different cod stocks in the North Atlantic Ocean. In addition, year-to-year changes in ocean temperatures also account for annual differences in growth rates within most cod stocks. Temperature also affects the condition of the cod, with heavier fish at a given length being generally found in warmer waters. In a nutshell, warmer temperatures mean that cod grow faster (Fig. 2).

As well as growing more quickly in warmer water, cod also become sexually mature faster. For every 2°C temperature increase, the time it takes a cod to become sexually mature is reduced by approximately 1 year. Higher temperatures also typically result in earlier spawning.

The number of young cod that survive and eventually grow big enough to be caught by the fishery is called recruitment. Recruitment tends to increase with increasing temperatures, for cod living in colder waters at the northern extent of their range (bottom temperatures less than 5°C). At the southern limits of their range recruitment tends to decrease in warmer waters (above 8.5°C). Temperature tends to have no effect on recruitment for cod living in the mid-range of bottom temperatures.

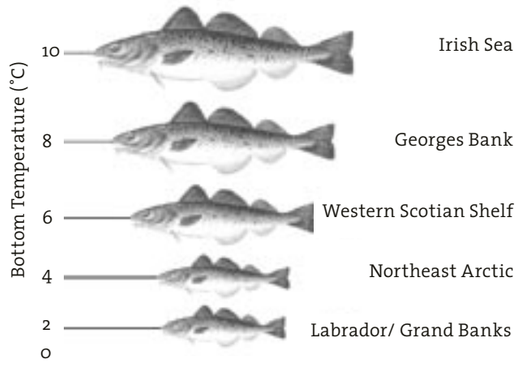


Fig. 2. The relative size of a 4-year old cod as a result of bottom temperature.

Most fish species or stocks tend to prefer to inhabit waters within a specific temperature range, therefore with long-term warming more cod will be found further north. For example, in response to the dramatic warming during the 1920s and 1930s off West Greenland, cod gradually spread northward by 1200 km in less than 20 years. Cod retreated southward in the 1970s as water temperatures declined.

Cod stock responses to warming temperatures

Multi-model scenarios suggest 2°–4°C temperature increases in most regions occupied by cod by 2100, with a maximum of 6°C in the Barents Sea. What will be the impact on the cod stocks throughout the North Atlantic? Such predictions are made based upon several assumptions.

First, present cod stocks are not observed to occupy waters with annual mean bottom temperatures greater than 12°C. This may be due to too high metabolic costs, lack of ability to successfully compete with warmer-water species, or reduced survival of their eggs and larvae. Regardless of the reason, if future bottom temperatures warm beyond 12°C in the future, the assumption is that the cod will disappear.

Second, the observed temperature-recruitment relationship can be converted into a change in recruitment as a function of temperature change. For stocks whose bottom temperatures increase but remain below 5°C, recruitment is predicted to increase. For stocks whose bottom temperatures exceed 8.5°C, recruitment will decrease. At temperatures between these two values, there would be little change in recruitment rate. For example, Georges Bank cod presently inhabit bottom waters of approximately 8°C and temperature changes do not effect recruitment. However, if bottom temperatures there increased by just one degree, it is expected that warmer temperatures would cause a decrease in recruitment. Under further warming, the stock would decline.

Both of the assumptions above leave lead to the following predictions (Fig. 3).

With a sustained 1°C change, several of the southern cod stocks become stressed and those in the Celtic Sea and the English Channel would eventually disappear. Stocks in the Irish Sea, the southern North Sea, and Georges Bank would decline owing to decreasing recruitment. On the other hand the cold-water stocks, such as those off eastern Canada, Greenland, and in the Barents Sea would benefit from increased recruitment. Recruitment levels of the remaining stocks would not change appreciably.

"IF TEMPERATURES INCREASED BY 3°C, THE KATTEGAT AND NORTH SEA STOCKS WOULD LIKELY DISAPPEAR."

If temperatures increased to 2°C above present day values, the Irish Sea stock would disappear, the Georges Bank and North Sea stocks would continue to decline and the stocks in the Kattegat, off West Scotland and the Faroes would begin to decline owing to decreasing recruitment. Those stocks that increased under a 1°C increase would continue to increase, with the exception perhaps of the Flemish Cap stock whose recruitment would level off. Other stocks would not see any change in recruitment.

If temperatures increased by 3°C, the Kattegat and North Sea stocks would likely disappear. The southernmost stocks in the western Atlantic (Georges Bank, the Gulf of Maine, and the Browns Bank/Bay of Fundy) would all be in decline. Icelandic stocks would begin to show signs of declining recruitment, as would the Faroes and West Scotland stocks on the eastern side of the Atlantic. The recruitment of the Barents Sea stocks would level off, as would the southern Grand Banks stocks but most of the Canadian stocks, as well as those off West Greenland and in the Kara Sea, would continue to improve. For a 4°C temperature

Top photo by Paul Kay

"MULTI–MODEL SCENARIOS SUGGEST 2- 4° C TEMPERATURE INCREASES IN MOST REGIONS OCCUPIED BY COD BY 2001"

"IF FISHING REDUCES PRESENT COD STOCKS TO MINIMAL LEVELS, THERE MAY NOT BE ENOUGH COD TO EXPAND AND DRIVE THE PREDICTED INCREASED PRODUCTION".

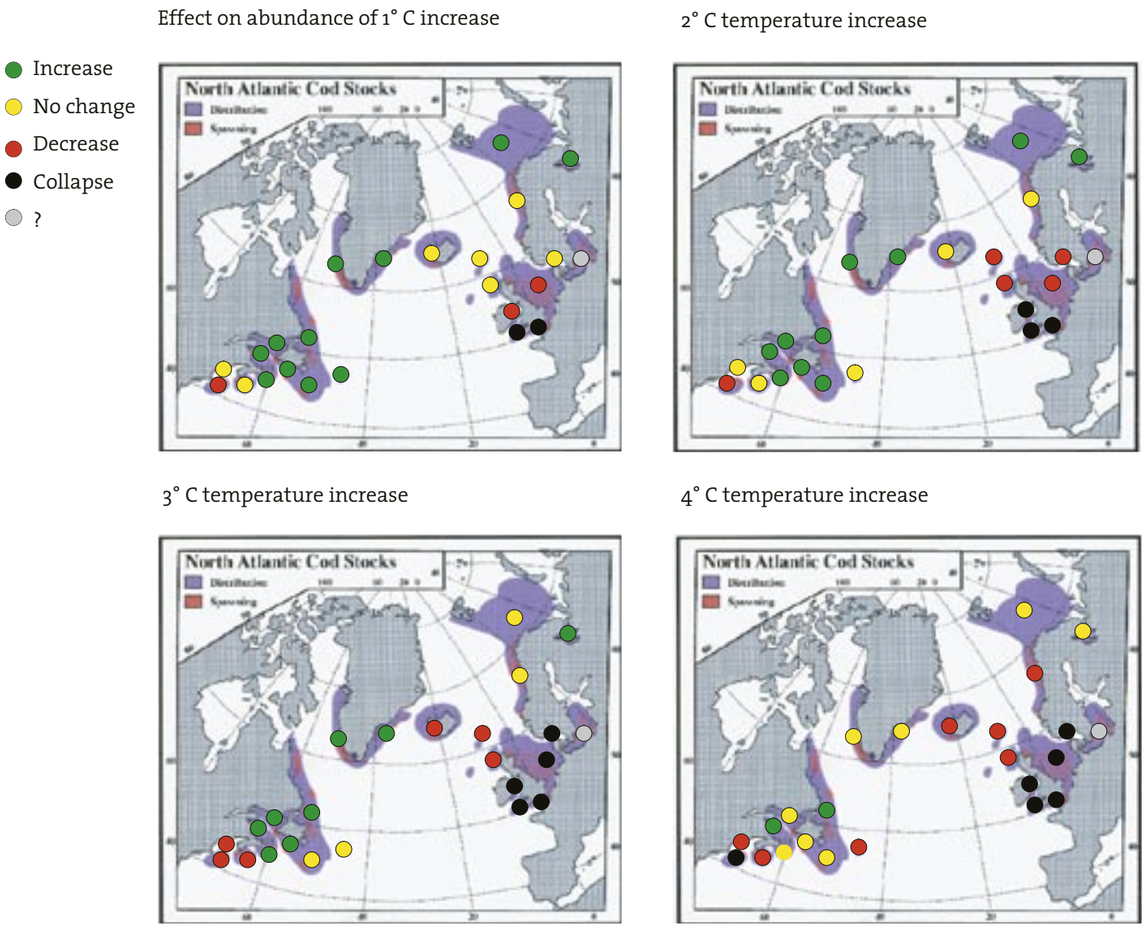


Fig. 3. The expected changes in the abundance of the cod stocks with 1°C, 2°C, 3°C and 4°C temperature increases.

"WITH A SUSTAINED 1°C CHANGE, SEVERAL OF THE SOUTHERN COD STOCKS BECOME STRESSED AND THOSE IN THE CELTIC SEA AND THE ENGLISH CHANNEL WOULD EVENTUALLY DISAPPEAR."

change, the Georges Bank stock is likely to disappear. The Norwegian coastal cod stocks would begin to see declining recruitment along with the Flemish Cap stock. The recruitment of the eastern Scotian Shelf, northern Gulf of St. Lawrence, southern Newfoundland, Greenland, and the Kara Sea stocks would no longer increase. Only in the southern Gulf of St. Lawrence and southern Labrador/northern Newfoundland stocks would the recruitment continue to increase.

Other changes

Future warming will also lead to cod spreading farther north (Fig. 4). They might occupy the entire Labrador Shelf, as they did during the warm period of the 1950s and 1960s, and perhaps even extend further northward along the Baffin Island Shelf. They are also expected to occupy the West Greenland coast north to Disko Island as in the 1930s, as well as the East Greenland coast as far north as Denmark Strait. More cod will be found north of Iceland, and in the Barents Sea they will spread east and north. They will also spread northward along western Svalbard. Cod may even extend to the northern Kara Sea, if only to migrate there in summer.

Earlier migration to the summer feeding and spawning areas will occur as well as a later return to the overwintering grounds. In areas where seasonal ice will disappear, migration might cease altogether. For regions where temperatures increase but mean bottom temperatures do not exceed 12°C, cod production should increase. Coupled with the northward extension, the overall production of Atlantic cod should increase, even with the potential disappearance of some of the southern stocks. The increase in production results from improved growth rates and higher recruitment. Also, since mortality is generally linked to growth rates, survival of the young fish should increase with the higher growth rates. Spawning locations will extend northward and spawning will occur earlier. With faster growth rates, the age of maturity is likely to decrease.

Conclusion

Fishing will continue to play a strong, and in some cases, a dominant role on fish abundance, distribution and growth and thus any projections will depend very much upon future fishing intensity. If fishing reduces present cod stocks to minimal levels, there may not be enough cod to expand and drive the predicted increased production, certainly not to the extent that could potentially occur given reduced fishing. Also, the expanding and increasing cod production may be reduced quickly through fishing, thereby limiting the production increase and the extent of the geographic expansion. The predictions of cod impacts will also depend on the changes to other parts of the ecosystem. These include changes to the primary (phytoplankton growth) and secondary production (zooplankton growth) in the North Atlantic and, more specifically, the specific food for larval and juvenile cod – such as *Calanus finmarchicus* – and, for adults, food such as capelin.

While many of the predictions of possible changes to the Atlantic cod under future warming are supported by past observations, the actual response still remains uncertain. However, with the rapid increase in modelling capabilities, the development of coupled regional models, and improved understanding of the physics, the biology, and the effects of fishing, hopefully in the near future the public, the politicians, and the fisheries managers can look forward to more accurate predictions of responses to global change, not only of Atlantic cod but also of other fish species and the ecosystem as a whole.

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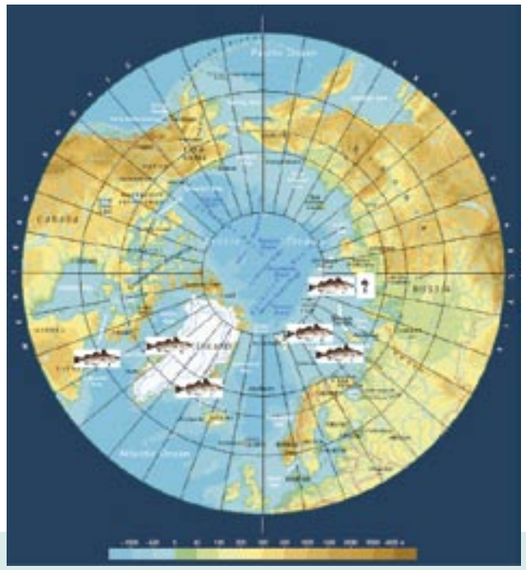

Fig. 4. The possible northward expansion of Atlantic cod. The fish indicate areas where expansion will likely occur.