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Climate change not to blame for cod population decline

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Three decades of increasing temperature were expected to cause cod to decline in the North Sea and Gulf of Maine, but the stocks increased in the former and declined in the latter area. These trends are due to changes in fishing pressure rather than climate change.

In July 2017 the North Sea cod stock gained a sustainable rating from the Marine Stewardship Council following sixteen years of 1lower fishing pressure. Such successes for fisheries management deserve to be celebrated, since they show what can be achieved with regional cooperation and effective control. In contrast however, the Gulf of Maine cod stock has continued to decline and higher temperatures, associated with climate change have been blamed. Both stocks experienced very similar trends in temperature over the past thirty years, but fishing pressure on them followed different trajectories, pointing to overfishing as the more likely principal driver of observed changes. Blaming the wrong primary driver may result in the wrong remedial action being taken. Climate research is often given media prominence, but the scientific community must guard against overemphasising the role of climate. Increasing awareness of climate impacts does not, unfortunately, mean that familiar problems caused by other human pressures on natural resources (such as overfishing, habitat degradation and pollution), have gone away.

In October 2015 Science published a widely cited article[1] and news item[2] that attributed the collapse of the Gulf of Maine cod stock to climate change. This stock is situated close to the warm end of the species' range and it was claimed that sea surface temperatures (SST) in the area had been rising faster than anywhere else on the planet between 2003 and 2014, causing the growth rate of cod to decline and the natural mortality rate to rise. However North Sea cod are thriving at temperatures very similar to those experienced by fish in the Gulf of Maine and with their spawning stock biomass (SSB) at a 35 year high (Figure 1a) have achieved a sustainable rating for the first time in 20 years[3]. A comparison of trends in SST and fishing mortality rate (F y^{-1}) for these two stocks over a 35 year period (1982-2016) implicates fishing, not rising temperatures, as the major cause of observed changes in SSB. Reducing fishing to a sustainable level should therefore be the priority for fisheries management policy, if stocks are to recover.

Warming sea temperatures

Climatological mean (1981-2010) values of SST for both areas are between 10-11 ºC and annual values[4] show similar warming trends (Figure 1b). These are not the warmest areas in which cod occur[5]; there are small stocks west of the British Isles where annual mean temperatures are up to 2 ºC higher (Figure 2). Archaeological evidence that cod stocks persist at higher temperatures has been found in Mesolithic Stone Age Danish kitchen middens from a period (7000-3900 BC) when temperatures in that area were 2-2.5 ºC higher than the present[6]. The middens contained a high proportion of cod.

Fish experience a complex pattern of seasonal and geographical temperature variability, influenced by their vertical and horizontal migratory behaviour. Cod can rapidly change their depth and hence ambient temperature[6]. Processes such as cod growth are non-linear with respect to temperature and to fish size, so that growth at the same annual mean temperature will be different depending on whether the seasonal temperature variability is large or small or whether the fish are large or small[6]. Variation in annual mean SST is inevitably a crude representation of this complex thermal history, but adequate for examining overall trends.

Changes in the cod stocks and in fishing mortality

Stock assessments combine data from commercial and recreational fisheries and research surveys to reconstruct trends in SSB and F. Assessments for the Gulf of Maine and the North Sea[7,8] use very similar age-structured sequential population analysis, although natural mortality (M) is estimated slightly differently.

Both stocks declined for over 20 years from 1982, however the North Sea SSB began a period of rapid increase in 2006 and has returned to the same level as in 1982 (Figure 1a). The Gulf of Maine stock continued to decline and in 2014 was roughly a tenth of its 1982 biomass.

Survival rate (in years) is the inverse of mortality rate (in $years^{-1}$). Total mortality (i.e. F +M) greater than 1 means that the survival rate or life expectancy of an adult cod is less than 1 year. F on fully fished age groups from 1982-2014 averaged 0.86 in Gulf of Maine and 0.87 in the North Sea. In the North Sea F peaked at

just over 1 in 1999 and then declined to 0.35 in 2016 (F+M =0.55, life expectancy of nearly two years), which is considered sustainable (Figure 1c). In the Gulf of Maine F in 2014 was still over three times higher than the sustainable level, with an adult life expectancy of about ten months. The reduced F and increased life expectancy in the North Sea is a sufficient explanation for the increase in SSB and for associated increases in age and size composition since 1999.

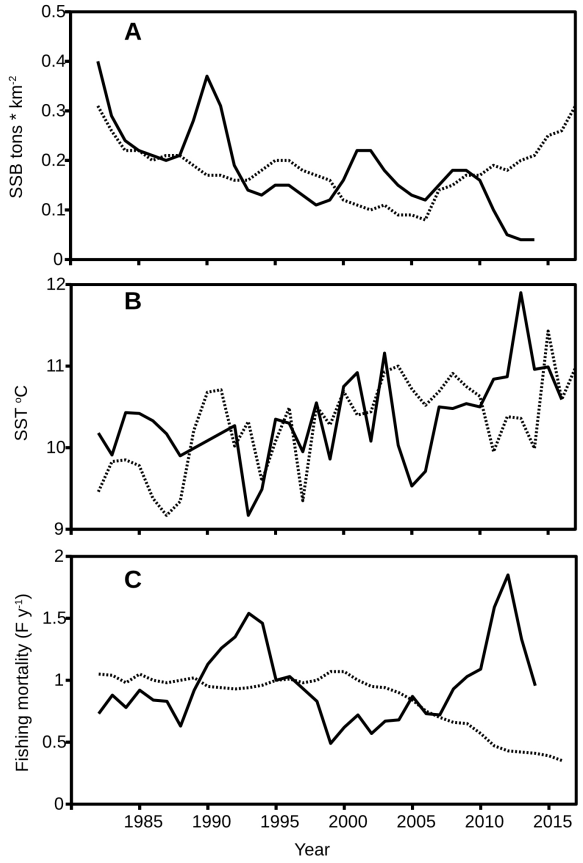

Figure 1 (a) Spawning stock biomass (SSB) of cod in the Gulf of Maine (solid line)[7] and North Sea (dashed line)[8]. (b) Mean annual sea surface temperatures (SST)[4]. (c) Annual adult fishing mortality (F per year). Fishing mortalities for maximum sustainable yield (F_{MSY}) are 0.18 for the Gulf of Maine[7] and 0.31 for the North Sea.[8]

Comparison of the two stocks

Changes in cod stocks can have many interrelated causes, which may not be reducible to binary options (e.g. climate vs fishing) or attributed to a single factor. Nevertheless, the observed changes in SSB of these two stocks are consistent with the expected effects of the levels of F they have been subjected to, whereas the temperature changes in the two areas do not provide a consistent explanation. Fishing kills fish; the process is not in doubt. Temperature affects cod via a number of possible processes, but the evidence that any of these caused the observed changes in SSB in either area is weak [9]. The SSB of North Sea cod increased during a period of declining fishing mortality, despite high temperatures. The decline in SSB in the Gulf of Maine is sufficiently explained by the extremely high F, although that does not exclude lesser effects of temperature related processes.

It is axiomatic that fishing reduces SSB and this effect must be taken into account before seeking to attribute stock decline to other causes. Conversely, a sustained reduction in F is expected to result in increasing SSB and we are now fortunate to have empirical evidence of this from the major North Atlantic cod stocks (NE Arctic[10], Iceland[11] and North Sea).

Does climate change matter for stock management?

The shifting geographic distribution of cod within the North Sea has been attributed to climate change as well as to shifts in the distribution of fishing[6]. Geographic shifts due to continued warming, together with likely future effects on growth and reproduction of cod, affect long-term strategic management and can be modelled using stock projections based on scenarios that include changes in temperature, salinity, stratification, advection and plankton productivity[12]. To date potential effects of rising sea temperature on stock productivity have not been included in the year-to-year stock assessments for the North Sea[8] or in the resultant management advice because at short time scales they are relatively small and uncertain. In the Gulf of Maine on the other hand, comparable temperature change has been blamed for the collapse of the stock, but the methodology used for making this attribution is flawed and the processes (such as geographic shift, natural mortality, growth, reproduction or ecosystem change) remain unclear[1,9].

The evidence and mechanisms for climate effects should be well established and credible, before they influence the management advice[13] and become a dominant part of the public narrative about why a stock is declining. The danger of exaggerating climate effects is that it implies that reduction of F and other potential management actions will have lesser effects. Concern has been expressed[2] that if climate change is viewed as an overwhelming factor causing decline in the Gulf of Maine cod stock then the case for enforcing a recovery strategy, by reducing fishing mortality, may be weakened.

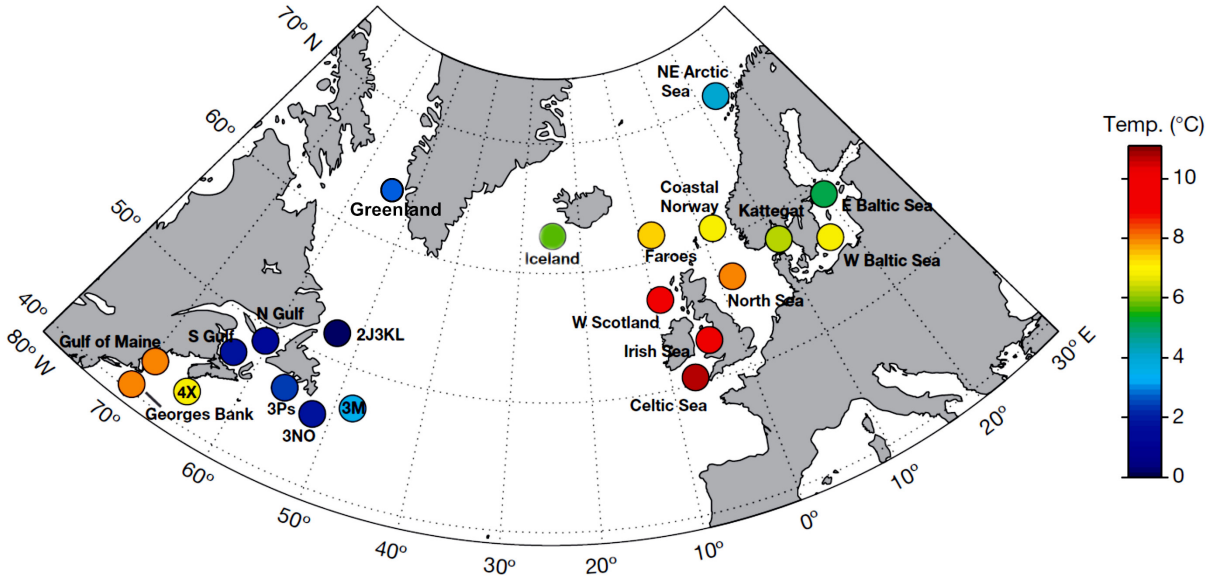

Figure 2 North Atlantic cod stocks with habitat temperatures (redrawn [5])

Improving scientific presentation and management implementation

Poor presentation of projections of climate change impacts makes it difficult for policymakers and managers to judge how much or little weight they should carry. For example a widely cited paper[14] projected a decline in the North Sea cod stock if temperatures rose 1ºC above current levels. A reader would have difficulty in interpreting this projection, since the paper did not specify what the "current level" is. The missing information is from IPCC (2001), which uses a baseline period 1961-90. In the event, the average SST for the North Sea over the period 2000-2015 increased by >1 ºC relative to the 1961-90 baseline and, contrary to the projection, the cod stock doubled in biomass. Although the paper was careful to point out that the projection was uncertain for a number of reasons, one may consider at what point such a level of uncertainty results in projections that are unsuitable for management advice [15].

Fisheries management in the USA is founded on the 1976 Fishery Conservation and Management Magnuson-Stevens Act, with the goal of managing fisheries at their optimal yield. In this it has been successful in many areas, however the fact that the cod stock in the Gulf of Maine has been overfished for so long suggests that regional and local pressures can override National Standards. The North Sea cod stock is managed jointly by Norway and the countries of the EU. Despite criticism over many years that supranational regulation was inefficient and ineffective in bringing overfishing under control, there are now many examples of stocks in European waters being managed sustainably, including the North Sea cod. It would seem from the divergent history of the Gulf of Maine and North Sea cod stocks since 1982 that single-nation management is neither necessary nor sufficient to restrain fishing mortality and achieve sustainable management. Sustainability goals can be achieved by strengthened regional and international cooperation in assessment and management of fisheries, but require agreement on allocation of shares, effective regulatory instruments and acceptance of enforcement measures.

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