

Introduction

The North Sea cod spawning biomass (SSB) and recruitment of one year-old cod to the fishery (*Gadus morhua*) have fallen markedly since the 1980s (Fig 1) and the most likely cause of this decline is thought to be depletion of the stock by a high fishing mortality ($F=0.7-0.9$) leading to a drop in the egg supply. There is also evidence, however, that recruitment may have been affected by recent increases in seawater temperature. This poster addresses the question at what stage of the life history, and how, this could occur.

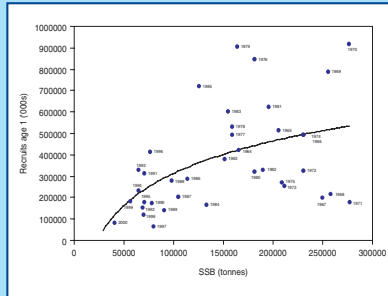


Figure 1: The relationship between the spawning stock biomass (SSB) and the recruitment of 1-group cod in the North Sea (ICES data).

Material and methods

Estimates and indices of abundance of young cod have been compared at different stages of development to identify whether there have been any significant changes in mortality over time that could correlate with changes in the environment, such as water temperature. The main spawning of cod in the North Sea is in February. The 0-group (fish under a year old) cod are initially pelagic and begin to settle out of the plankton to become demersal in habit at 5 months and they start to recruit to the fishery as one year-old fish.

- The annual egg production was estimated assuming that fecundity averaged 600 eggs per gram body weight. This was applied to the ICES estimates of cod SSB, assuming 50% of the adult stock was female. The abundance of 5 month and one year-old cod was derived from multispecies virtual population analysis (MSVPA). Catch per unit effort (CPUE) in numbers of cod caught per hour on the annual August/September North Sea English Groundfish Surveys (EGFS) provided an index of the relative abundance of 9 month old cod and also provided fish length data for the period 1977-1999, enabling mean length to be calculated.
- The mortality rate of pelagic 0-group cod up until around the start of settlement was derived from the \log_e of annual egg production minus the \log_e of the abundance of 5 month old cod. The mortality rate of 0-groups from the start of settlement to the end of the demersal phase was derived from the \log_e of the abundance of 5 month old cod minus the \log_e of the abundance of one year-old cod, based on MSVPA data.
- North Sea temperature data from a variety of sources was subjected to principal component analysis. The principal component TEMPSTRAT represents the average temperature differential between the near-surface and near-bottom temperatures in summer.

Results

Figures 2 and 3 show that the abundance of 5 month and 9 month old cod appeared to be largely independent of annual egg production.

The abundance of 5 month old pelagic 0-group cod did not significantly decline over time (Figure 4) whereas the recruitment of one year-olds did ($P=0.001$).

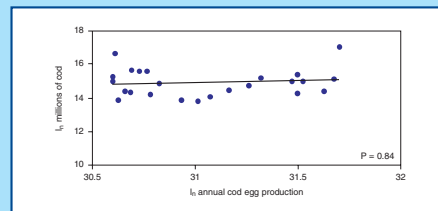


Figure 2: The relation between the abundance of 5 month old cod (MSVPA data) and annual egg production of North Sea cod for the period 1977-1999.

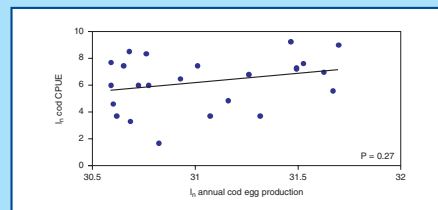


Figure 3: The relation between the CPUE of 9 month old cod (EGFS data) and annual egg production of North Sea cod for the period 1977-1999.

Summer surface water temperatures in the North Sea rose by on average 0.1°C a year from 1977 to 1999. Figure 5 shows that the associated increase in temperature stratification (TEMPSTRAT) of the water column appeared to create conditions that favoured the survival of pelagic 0-group cod, but were detrimental to the survival of cod from around the time they settled out and became demersal in habit.

Not only did the mortality rate of the older 0-group cod increase during warm years, the growth rate also declined (Figure 6).

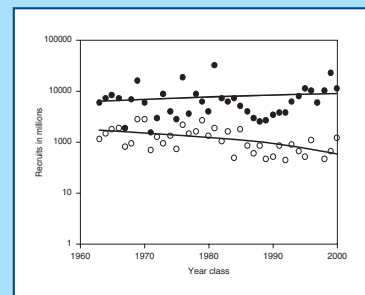


Figure 4: Trends over time in the abundance of 5 month old cod (●) and the abundance of cod recruits aged one year (○) (MSVPA data).

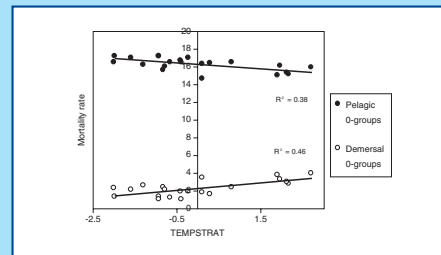


Figure 5: The mortality rate (MSVPA data) of 0-group cod from the egg phase up until the age of 5 months (covering the pelagic phase of development) and the mortality rate of 0-group cod from 5 months up until the age of one year (the settlement and the demersal phase) in relation to TEMPSTRAT, the principal component representing the intensity of the temperature stratification of the North Sea in summer.

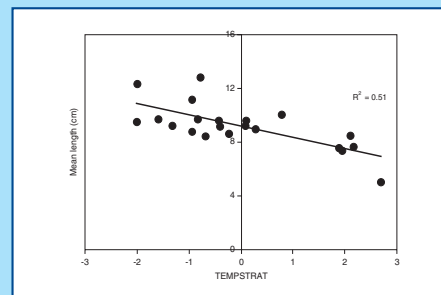


Figure 6: The relationship between the mean length of 9 month old demersal 0-group cod (EGFS data) in relation to TEMPSTRAT, the principal component representing the intensity of the temperature stratification of the North Sea in summer.



Discussion

- Warm conditions appeared initially to favour the survival of cod during the pelagic 0-group phase. With increasing temperature the mortality rate declined in a density dependent fashion, sufficient to compensate for the drop in egg production associated with the decrease in SSB. At around the time of settlement (aged 5 months) the situation was reversed and the decline in the recruitment of the 1-group cod to the fishery appeared to have been largely driven by adverse conditions associated with environmental warming during the demersal 0-group phase.
- Possibly the rate of production of the plankton that cod feed on during the pelagic 0-group phase was enhanced by warm conditions.
- Warm conditions have been associated with a decline in the abundance of large Calanoid copepods on which the cod feed during settlement and this might have contributed to a reduction in the mortality rate of the demersal 0-group cod.
- Being smaller during warm years would make the demersal 0-group cod more prone to predation and an increase in the mortality rate is to be expected. Gurnards consume young cod and there has been a substantial temperature related increase in gurnard recruitment and the abundance of adult gurnards in the North Sea.

Though there is evidence that much of the downturn in cod recruitment was related to the impact of global warming, the situation appears too complex to be able to put any precise figures on what was due to climate and what was due to fishing. This is especially the case if the removal of so many large predators has facilitated the expansion of smaller predators that eat young cod.