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Marine ecosystem management: Fish abundance and size under exploitation

Joe Horwood *

The Centre for Environment, Fisheries & Aquaculture Science (CEFAS), Pakefield Road, Lowestoft, Suffolk, NR330HT UK

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ABSTRACT

This study is targeted on policy makers and environmental scientists to illustrate the typical historical scale of depletion of our fish stocks, and what current and emerging legislation might mean for fisheries management and the metrics of fish stocks. The population demography of the Bristol Channel sole is described since 1820. Their decline in abundance, and change in length compositions, are modelled. By 2000, the mature stock had been depleted to less than 5% of its original size, and larger sole were rarely caught. The implications of maximum sustainable yield targets, and of good environmental status, are examined.

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1. Introduction

Myres and Worm [1] described the fishing induced decline in large predatory marine fish. A range of species were included in their analyses from the cod-like fish to large pelagic tuna and billfish. They argued that these large fish had been depleted to about 10% of their unexploited levels, and that fisheries scientists and managers should use a longer time-horizon in setting baseline measures for these stocks. The study is not without its critics; and Hampton et al. [2] argued that the analyses were not robust for Pacific tunas.

Nevertheless, with 28% of the world's fish stocks overexploited and 52% fully exploited [3], it is not a surprise that stocks of, particularly the larger growing, fish are depleted. For the North Sea, using research survey catches and macro-ecological theory of size spectra, Jennings and Blanchard [4] concluded that fish over 4 kg were 97% depleted. Fish over 16 kg, such as the common skate and angel shark, were 99% depleted. The international stock assessments for cod [5] confirm that older and larger cod are now rare. Jennings and Blanchard also caution about the use of short time-series as baselines for describing population status.

In the North-East North Atlantic, and particularly within the European Union seas, there is increased activity to protect the marine environment and marine ecosystems. The Oslo and Paris Commission (OSPAR) implements the OSPAR Convention for the protection of the marine environment in the North-East Atlantic, and in 1998 extended its remit to the protection and conservation of marine ecosystems and biodiversity. In 2007 the EU adopted an Integrated Maritime Policy for the European Union. Its Thematic Strategy for the protection of the marine environment underpins the EU's conservation objectives and the Marine Strategy Framework Directive (MSFD) [6] is the key policy tool to deliver "good environmental status" for all marine seas.

Two of the eleven "Qualitative Descriptors" of GES are: (3) populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock, and (4) all elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.

Detailed descriptors are not yet agreed. However, for (3) one of the metrics under discussion is for the healthy age and size distribution to be indicated by trends in the 95% percentile of length in fish stocks. For (4) one of the metrics under discussion is the proportion of larger fish in the fish community; this is similar to the metrics for Ecological Quality Objectives (EcoQOs) considered by OSPAR.

Greenstreet and Rogers [7] examined various indicators to support the above descriptors and EcoQOs, including the proportion of fish above a size limit. The UK's Department for Environment, Farming and Rural Affairs (Defra) also uses the proportion of fish 40 cm or over in its reports to the UK Treasury on the effectiveness of fisheries and marine management. The time series are given in Defra's UK Biodiversity Indicators [8].

It can thus be appreciated that there is current interest in the size composition of individual fish stocks and fish communities. There is also a concern that the views of society on the status of fish stocks is too strongly influenced by the available, rather recent data, rather than a full historical perspective of the stocks. Whilst the long-term dynamics of fish length and abundance, from original first exploitation, may be familiar to some fisheries

* Tel.: +44 1502 524248; fax: +44 1502 524515.
E-mail address: joe.horwood@cefas.co.uk

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scientists, it is possible that the more general science and policy community, interested in ecosystem and environmental management, have little feel for the dynamics of fish stocks or communities of fish stocks.

Here, we present the evolution of a single fish stock; the Bristol Channel sole (*Solea solea*) or Dover sole. Based upon historical catch records and a model of its population dynamics we describe how stock size and catch-rates have declined since 1820, and how the size composition of the population has altered over that time. It is in many ways a "typical" fish stock and fishery, but for this exercise it has the advantage that major exploitation started after the collection of fisheries statistics which allows us to reconstruct its full history.

2. Methodology

The dynamics of the Bristol Channel sole were modelled from 1820 to the present. Historical catches, fishing mortality rates, recruitment (i.e. the numbers of young fish), natural mortality and somatic growth were taken from Horwood [9]. Fishing mortality rates from 1971 were taken from the ICES stock assessments [10]. A model that calculates the numbers of sole at each age with time takes the form

$$N(1,t+1) = \alpha.\mathrm{SSB}(t)/(1+\mathrm{SSB}(t)/\beta),$$
$$N(a,t+1) = N(a-1,t).S(a-1,t),\ a=2 \text{ to } 14,$$
$$N(15,t+1) = N(14,t).S(14,t)+N(15,t).S(15,t),$$

Where $N(a,t)$ is the numbers of sole age a at the beginning of year t, SSB is the "spawning stock biomass" or the weight of the mature component of the stock, calculated from the summation over all ages as, $\Sigma_a N(a).W(a).p(a)$, where $W(a)$ is the weight at age a and p(a) is the proportion mature of that age. S is the survival rate given by, $S(a,t)=\mathrm{Exp}(-F(t).q(a)-M(a))$, where F is the annual instantaneous fishing mortality rate, q is the catchability and M is the natural mortality rate.

The parameters $\alpha=7.3$ and $\beta=5300/\alpha$ were determined to give a zero stock size (i.e. extinction) at an equilibrium fishing rate of $F=1.0$, and average recruitment of 5.3 million, age-one sole at a parent biomass of 10,000 t.

Sole length is based on growth rates observed over the period 1985–1990, and length at age ($L(a)$) in cm and weight at age ($W(a)$) in kg are given by

$$L(a) = 44.9 \times (1.0 - Exp(-0.31(a-0.09))),\ \text{and}$$
$$W(a) = 0.00001 \times L(a)^3$$

The model starts the population at its unexploited equilibrium in 1820.

3. Results

Fig. 1a shows that the evolution of the population from 1820 to 2008. Fig. 1 shows the fishing mortality rate over time (F). A value of $F=0.1$ means that just less than 10% of the stock is fished each year, whereas a value of $F=0.65$ means that 45% of the stock is fished. The values are an input to the model, derived from the catch history and an earlier population model. The figure shows light exploitation until the end of the Second World War when fishing expanded. Sole were not easily available to the steam-trawlers nor the otter-trawlers as they buried in the sand during daylight, but with the advent of the beam-trawl fleet, in the 1970s, sole could be caught at any time, and fishing rates expanded, peaking in 1998. Since then a more robust management has brought down fishing rates.

Fig. 1b illustrates how fishing has impacted the stock and the fishing industry. It presents an index of stock size as "catch per unit effort" in this case as catch/F. Catch rates show the stock declining as fishing increases. The War Years give a small reprieve but the increase is quickly countered as fishing recommences. By the year 2000 catch-rates have decreased to 4% of their original level, and so has the mature component of the stock.

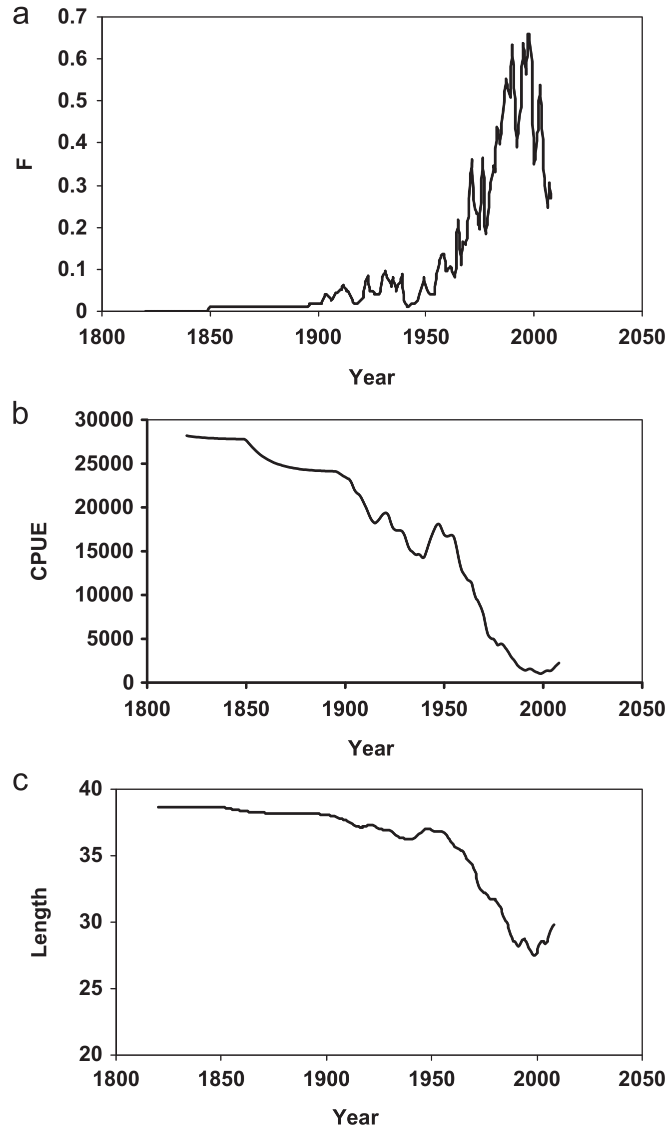

Fig. 1. (a) Instantaneous annual fishing mortality rates (F) of Bristol Channel sole from 1820 to 2008 used as input to a dynamic population model; (b) the catch per unit effort (CPUE) as an index of stock abundance, and availability to the fishery, calculated as catch in tonnes/F; (c) the change in the modelled mean length (cm) of sole, in the catch, from 1820 to 2008.

Fig. 1c shows the average length in the catch declining as the stock declines, or rather as the increased fishing rates reduce the average life and age, of the sole, and hence the average length. The decline in average length is less sensitive than the decline in the stock (Fig. 1b), but the decline accelerates after 1950, and by 2000 the average length has been reduced by almost 30%. However, the recent short period of reduced fishing has allowed the average size to increase by 2 cm by 2008.

4. Discussion

The first question to ask is how robust is the modelling? Can we really have depleted this fish stock by 96%? There will be

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