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**Ecosystem Simulations of the English
Channel: Climate and Trade-Offs**

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**ECOSYSTEM SIMULATIONS
OF THE ENGLISH CHANNEL:
CLIMATE AND TRADE-OFFS**

by

Richard Stanford and Tony J. Pitcher

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Robert Stanford and Tony Pitcher

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DIRECTOR'S FOREWORD

Somehow, I always associate the English Channel, or 'La Manche' as it is rightly called, with courage, or at least gumption. The Normans had it when they crossed La Manche, to grab a country from the Saxons, who had grabbed it from the Celts only a few centuries before. Jumping centuries: Louis Blériot had it when, on July 25, 1909, he first crossed La Manche on his rickety flying machine, and flew into immortality, there to be joined by the Royal Air Force pilots who fought the Battle of Britain, and turned La Manche into a cold, watery grave for another set of would-be invaders.

La Manche is a very dynamic ecosystem, and a transition area between what, until recently, were reasonably stable ecosystems, the Gulf of Biscay and the North Sea. Now, with both of these ecosystems profoundly modified by overfishing, and with water temperatures steadily increasing along the Western European coast, another invasion is taking place, again across La Manche: this time, it is a whole guild of warm-water fish species from the Gulf of Biscay, and even from the further South, moving into the North Sea.

Modeling La Manche using Ecopath, which was designed to capture snapshots of an ecosystem, at a certain time, thus takes courage, or at least gumption. This is compounded by the fact that the data sets available from around La Manche do not cover the fisheries in similar fashion, and in fact, often appear incompatible. Indeed, as illustrated by this Foreword, we cannot even agree on a unique name for that body of water. Yet the authors' effort was successful. The main ecological groups within the ecosystem of La Manche were identified, and the ecological stresses shaping them - notably temperature increases - were quantified, at least in part. That such efforts tend to open up more questions than they answer is part of the challenge.

The authors must be congratulated for their courage in tackling the issue of modeling La Manche, and I certainly hope this will inspire their colleagues on the southern shore of La Manche to join in the next round of model improvement. Let me add to their invitation:

Allez-y, ne laissez pas les Anglais être les seuls à utiliser Ecopath pour construire un modèle de la Manche.

The Fisheries Centre Research Reports series, which is covered by the major abstracting service in marine biology and fisheries (Aquatic Science and Fisheries Abstract), publishes original contributions by faculty and staff of the Fisheries Centre, UBC, and their research partners, and the proceedings of workshops they organize. Hard copies are distributed to libraries of partner institutions, and are also available online at <http://www.fisheries.ubc.ca/publications/reports/fcrr.php>

Daniel Pauly
Professor of Fisheries
Director, UBC Fisheries Centre

ABSTRACT

Ecopath with *Ecosim* (EwE) whole-ecosystem models were built for the English Channel (ICES areas VIIId and VIIe) for the time periods 1973 and 1995. Using *Ecosim*, the 1973 model was run forwards with a time-series of fishing mortality data to assess how realistically it predicted the changes in biomass that had occurred. The parameters for both models were modified so that the biomass trends reflected stock assessment data. This ‘tuning’ required slight changes to some of the basic input parameters, the addition of five juvenile groups, and five functions that forced eight groups to react to annual mean water temperature. The final 1995 *Ecosim* model consisted of 50 functional groups, with nine different fisheries exploiting 31 of these groups.

Market prices, fleet profitability and jobs/catch value ratios were used to run policy optimisation with *Ecosim*. To set extreme boundaries on the possible gains from the Channel fisheries, we initially searched for optima that maximised economic, social, ecological, or ‘rebuilding for recreational species’ criteria. Netting and lining were the most profitable fleets and also created the most jobs, so they were significantly increased for the economic and social optima. Using ecological and rebuilding optima, on the other hand, greatly reduced the fishing fleet.

Trade-off frontiers were created by weighting each of the objective functions differently and these, along with the results of *Rapfish*, a rapid appraisal technique that determined the sustainability of the fisheries, were used to generate three robust management alternatives that were assumed to be most beneficial to Channel stakeholders.

The effect of climate change was incorporated by running the model for two scenarios where the average sea temperature increased by 0.15 °C and 0.3 °C per decade. Some of the inherent uncertainty of the data was accounted for by varying vulnerabilities, sea temperatures, the discount rate, and by using a ‘closed loop’ optimisation analysis.

In the light of these whole-ecosystem simulations, we suggest that management of the English Channel for sustainability will require changes to both the fishing fleet and to the European management structure.

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We would like to thank Dr Villy Christensen for providing invaluable support during this work. Cameron Ainsworth and Dr Sheila Heymans also helped with the modelling. Matthew Dunn, Mike Pawson, Sean Pascoe and Clara Ulrich provided a great deal of helpful advice on the ecology and fisheries of the English Channel. We are also grateful to the following for supplying information about specific groups and aspects: P. Arzel, Keith Bower, Grant Course, Callan Duck, Jim Ellis, M.Genner, Roger Harris, Ewan Hunter, J.Keable, Steve Miligan, Leonard Nevell, Roland Pitcher, Vincent Rideaux, D.Sims, A.Southward, R. Sumaila, D.Viner, Reg Watson, and M.Zarecki. An earlier version of this material formed the basis of a RS’s Masters Thesis in Resource Management and Environmental Science from the University of British Columbia. Financial support for RS was provided in part by the National Scientific Research Council of Canada through an operating grant to TJP.

INTRODUCTION

Objectives

The objective of this report is to describe the ecosystem of the English Channel ('La Manche') using the modelling system of Ecopath with Ecosim and, using the same model, to generate forecasts of ecological, economic and employment responses to possible management alternatives.

A 1997 paper by historian Harry Scheiber outlines the changes that have occurred in fisheries management since the 1890s (Scheiber, 1997). There has been a shift from single species stock assessment to an ecosystem management perspective, the seeds of which have grown from scientific vision into policy, while the management tools to implement this have proved somewhat elusive. Repeated failures of fish stocks around the world, such as the Peruvian anchovy (Walsh, 1981) and Newfoundland cod (Hutchings and Myers, 1994), forced scientists to evaluate the methods that they use and pushed them to look at the relationships between organisms. Because of ecosystem complexity, this holistic approach was extremely problematic in reality. However, a rapid development in

computing power has meant that some of these difficulties can be coped with more adequately than in the past.

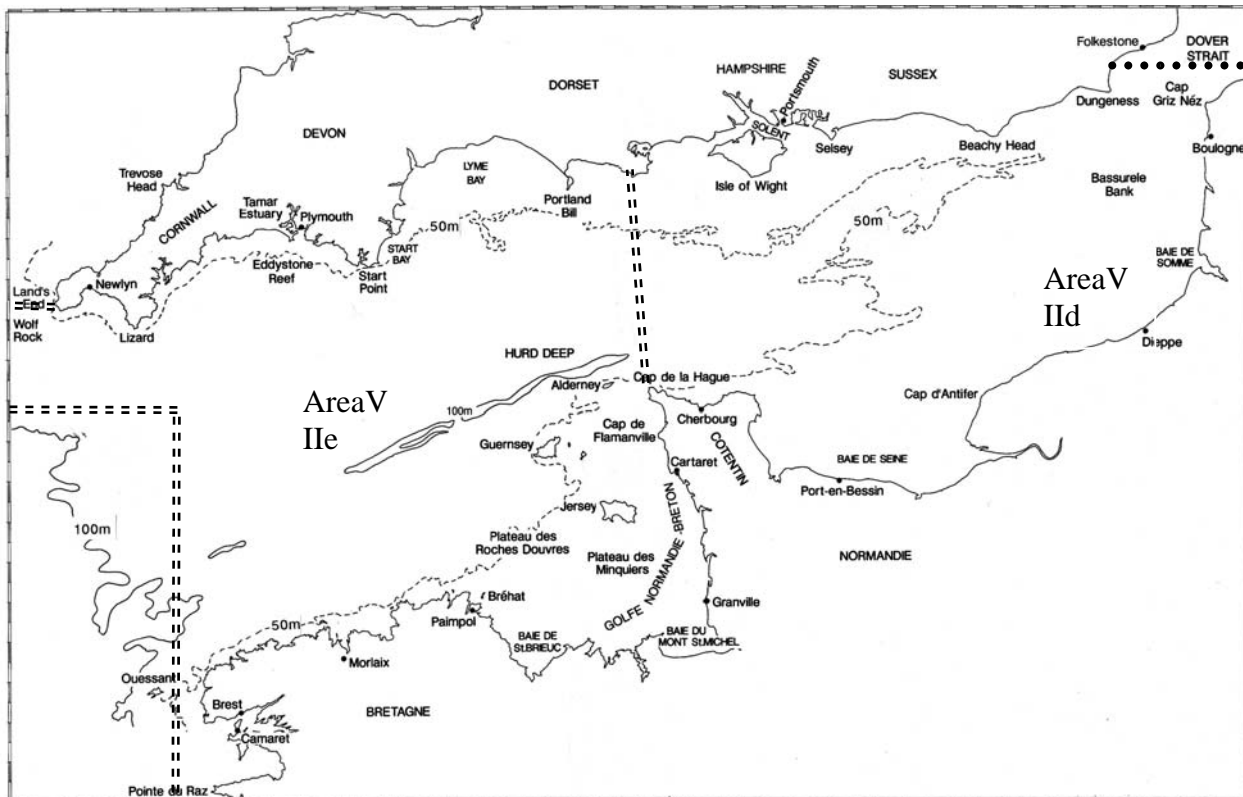
The English Channel

Physical and biological characteristics

The English Channel (hereafter called 'the Channel') is a shallow area of continental shelf between France and England, ranging from 40 m depth in the Dover Straits to 100 m in the Western Approaches (Figure 1.1). It is characterized by strong tides, up to 6-8 knots off Cape de la Hague, with a general range of 6-10 m, although in the Channel Islands it can be as high as 15 m and on the coast of Dorset as low as 1-3 m (Pingree and Maddock, 1977). The strong tides are caused by a propagation of flow from west to east so that when the west is at high tide the east is at low tide (Larsonneur *et al.*, 1982). There is a general current flow from west to east creating a 'river' that connects the northeast Atlantic and the North Sea. The Channel has a range of freshwater inputs, although the Seine estuary accounts for two thirds of the drainage area (Pawson, 1995).

For the purposes of the model, the Channel was

Figure 1.1. The English Channel, showing depth contours, ICES areas boundaries indicated by parallel dashed lines and the names of the significant places referred to in the text. Modified from Pawson (1995).



assumed to be the entirety of ICES areas VIIId and VIIe. The western Channel accounts for 63%, and the eastern Channel the remainder, of the combined surface area of 89,607 km² (R. Watson, Fisheries Centre, UBC, *pers. comm.*).

Although in our model the Channel has been taken as a whole, there would certainly be a rationale for making two models, separating the western from the eastern Channel, because of their distinctiveness. The western Channel is deeper, stratifying in the summer to form a thermocline west of the 100 m isobath. In the eastern Channel the shallower water and constriction ensure homogenous conditions throughout the year. The western Channel sediment is finer, consisting primarily of bioclastic material while the eastern Channel is mostly composed of lithoclastic larger gravels. A large pebbly zone running from Cotentin to the Isle of Wight separates these two regions (Larsonneur *et al.*, 1982). There are exceptions to these general sedimentary patterns and both the French and English coasts have many estuaries and bays (e.g. Fowey Estuary, Lyme Bay and Baie de Seine) where low energy conditions cause the deposition of fine sands and muds (Larsonneur *et al.*, 1982). There are at least 5 different species assemblages in the Channel based on sediment type (Ellis, 2001), and a general decrease in diversity of the benthos from west to east because a number of species are limited in their distribution to the west (Pawson, 1995).

The distribution of species in the Channel has provoked much interest, and a lot of effort has been invested in describing and understanding the situation. Although current systems and substrate type certainly influence both demersal and pelagic organisms, climate also seems to have an effect. It appears that the south-west Channel is close to a marine biogeographic boundary that separates cold-water species to the north and warm water species to the south (Southward *et al.*, 1988a). Climatic fluctuations appear to modify the distribution of indicator species in the 'Russell cycle' (Russell, 1935). Between 1930 and 1936 a plankton community characterized by the chaetognath *Sagitta elegans* was replaced by one characterised by *S. setosa*. Simultaneously, the south-west herring (*Clupea harengus*) fishery crashed and pilchard (*Sardina pilchardus*) eggs recovered in surveys increased by 2 or 3 orders of magnitude (Cushing, 1961). There were similar changes in intertidal barnacles with the cooler water *Semibalanus balanoides* being replaced by warmer water *Chthalamus* spp. (Southward *et al.*, 1995). The ecosystem appeared to remain in this 'warmer' state until the mid 1960s when *S.*

elegans and herring returned. More recently there has been an increase in temperature and there has been a reversal to the 'cooler' phase of the Russell cycle. The Russell cycle entails a 200-400 mile latitudinal shift in the distribution of fish, plankton and benthos (Southward *et al.*, 1995). If global warming has a similar effect on sea temperatures, we can expect to see an equivalent latitudinal shift, as least as long as anthropogenic increases remain in this range.

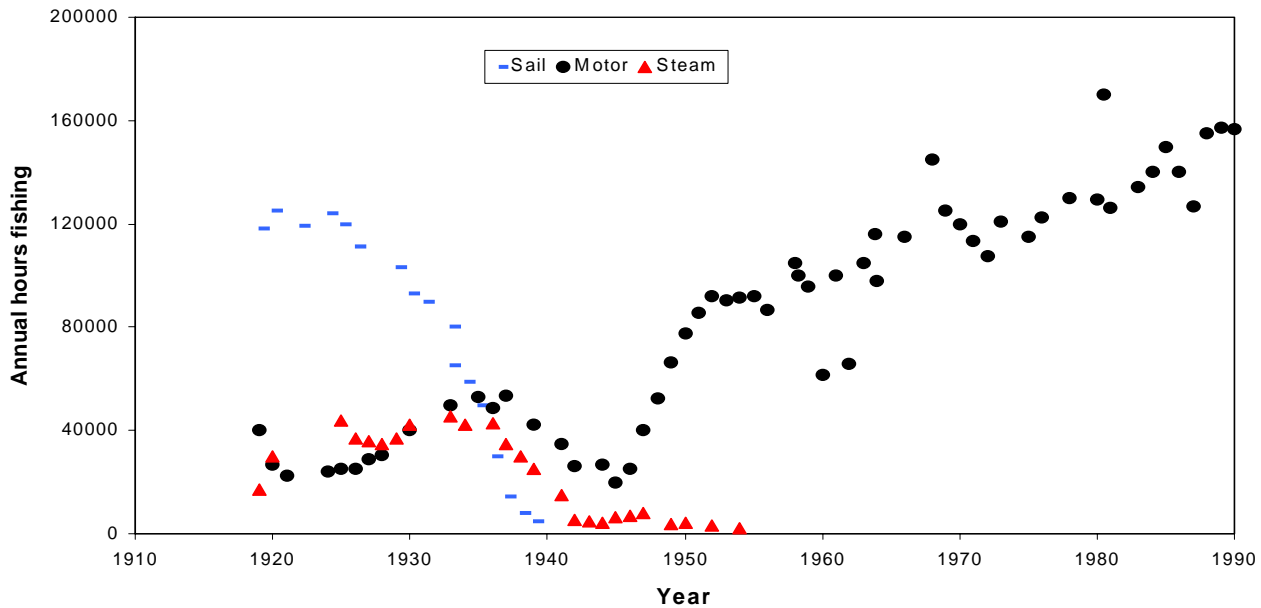
The effects of the North Atlantic drift generated by the Gulf Stream mean that the western Channel is usually warmer during the winter, with a lowest mean monthly temperature of 8.9 °C at Newlyn (west) and 5.9 °C at Dover (east) (averaged from 1980 to 1996, Dunn, 1999b). The shallower eastern Channel is more susceptible to seasonal temperature change and is generally warmer in the summer; the mean at Dover was 16.7 °C and at Newlyn 15.8 °C.

Fisheries

Reports on changes in the herring and pilchard fisheries since the 16th Century (Southward *et al.*, 1988a), and on the history of Brixham (Morton, 2002), underline how important fishing has been to the economy of coastal communities along the Channel. Archaeological studies of middens in coastal monasteries show that fisheries for whiting, cod, herring, pilchard, mackerel and shellfish have been important since the middle ages. Since 1900, fishing effort has been high with the two major English ports of Brixham and Newlyn playing a particularly strong part in the history of the fishing industry. Even before the advent of motorized trawlers there had been considerable fishing effort from sail and steam-powered trawlers (Figure 1.2), with gadoids, rays (*Raja* spp.), flatfish, and pilchards as target species.

The work of the Channel Fisheries Study Group (CFSG), a group of scientists from the UK, France and Belgium, has identified fishing practices according to various *métiers*. A *métier* is defined as "a fishing activity that is characterized by one catching gear and a group of target species, operating in a given area and during a given season, within which the catches taken by any unit of fishing effort account for the same pattern of exploitation by species and size group" (Tetard *et al.*, 1995). There are approximately seventy *métiers* in the Channel that can be broadly separated into one of eight gear types: otter trawls, beam trawls, midwater trawls, dredges, nets, pots, lines and seaweed harvesting (see Table 1.1). For a detailed description of the

Figure 1.2. Fishing effort of three types of trawlers in the English Channel from 1919-1990. Modified from Marine Biological Association data (Anon., 2001b).



fisheries, please refer to Gray (1995).

The Channel fisheries are extremely mixed, with a single boat having the capability to change gear depending on market prices and whether the quota has been reached, making the fishery very fluid and opportunistic. There are approximately 4000 boats operating in the fishery, ranging in length from 3 m to > 30 m, and the total direct employment in the fishery industry is about 4,300 people in the UK and 4,800 in France (Pascoe and Mardle, 2001).

About 50 species are fished commercially in the Channel, but only herring, mackerel, sole (*Solea solea*), plaice (*Pleuronectes platessa*), cod (*Gadus morhua*), whiting (*Merlangius merlangus*), anglerfish (*Lophius piscatorius*), megrim

(*Lepidorhombus whiffiagoni*), hake (*Merluccius merluccius*), and pollack are subject to quota restrictions (Dunn, 1999b).

The UK fleet was estimated to have made losses over the two year period 1995-1997 (Coglan and Pascoe, 2000). The French fleet was estimated to have been profitable during 1997 and accounted for 60% of the Channel landings value, which was € 500 million in total (Boncoeur and Le Gallic, 1998).

As a common pool resource, fisheries are under pressure and face the potential of overexploitation (Hardin, 1968). The Common Fisheries Policy (CFP) is the European Union's policy for managing the fisheries resource, not just between individual fishers but also between

Table 1.1. The significance of eight gear types in the English Channel. Data provided by Tetard *et al.* (1995). BM = boat months, % = % of landings (by weight) for that area. Boat months are an indication of the intensity of effort and are the aggregated months of vessels at sea. It is worth noting that a boat only has to be active for one day in that month for it to constitute 1 boat month. (*) = includes métiers common to the whole channel that could be included in both the eastern and western Channel, hence the total number of Channel boat months is less than the sum of both.

Gear type	Eastern Channel		Western Channel		Total Channel	
	BM	%	BM	%	BM	%
Otter trawl (*)	6,400	14.5	4,860	12.4	11,270	26.8
Beam trawl (*)	320	2.8	1,060	2.9	1,220	5.4
Midwater trawl	275	3.9	280	4.7	530	8.4
Dredge	1,300	4.2	3,000	6.2	4,300	10.4
Nets (*)	9,750	3.2	6,060	3.5	14,000	6.1
Pots	0	0	10,200	10.1	10,200	10.1
Lines	900	0.1	4,600	1.6	5,500	1.7
Seaweed	0	0	360	72.6	360	31.1

all countries with a fishing fleet. The first measures date from 1970, when it was agreed in principle that all member states should have access to other countries fisheries resources. In 1977 member states extended their rights to marine resources out to the 200 nautical miles Exclusive Economic Zone (EEZ). By 1983, many years of difficult negotiations finally produced the CFP, which to a degree has been argued about ever since. Nation states still control the territorial sea (12 nautical miles), with the UK having the further subdivision of the Sea Fisheries Committees (SFCs) controlling 0-6 nautical miles. The legal framework in the territorial sea cannot undercut the CFP; countries still cannot exceed their quota. SFCs have the power to make local byelaws such as temporary closures or increasing minimum landing sizes above those legislated from Europe. Because many countries at this time gained control of the 200 nautical mile zone much of the European distant water fleet, which was concentrated around Canada, Iceland and Norway, was forced to return to European waters and further depleted the local stocks.

In 1994 there were 126 different license types and quotas in the Channel (Dunn, 1999b), but from the 1980s to the present, licenses have become successively more restrictive. Fisheries management in the Channel is complex and for a summary of the Common Fisheries Policy see Dunn (1999b) or the web site:

http://europa.eu.int/comm/fisheries/policy_en.htm.

Previous Research

There are many research institutions on the coast of the Channel and the area has been studied scientifically for over a hundred years. A good source of material has been the Marine Biological Association (UK), which has compiled semi-quantitative data on the changes to demersal fish species and benthic invertebrates since 1913 (Anon., 2001b), as well as publishing the Journal of the Marine Biological Association, which contains many studies on the Channel. The Channel Fisheries Study Group (CFSG) is coordinated by CEFAS (The Centre for Environment, Fisheries and Aquacultural Science) Lowestoft and includes members from IFREMER (Institut Français de Recherche pour L'Exploitation de la Mer) laboratories at Boulogne-sur-Mer, Brest and Port-en-Bessin, the Fisheries Research Station at Ostende, and the Sea Fisheries Committees of Jersey and Guernsey. Publications by the CFSG have included the distribution, reproduction and migrations of 25 of the most commercially

significant finfish and shellfish species in the Channel (Pawson, 1995). Progress has also been made in understanding the exploitation of selected non-quota species (Dunn, 1999b). Regarding the fisheries, comprehensive outlines of the respective métiers and their interactions in the Channel are particularly informative (Tetard *et al.*, 1995).

A simulation model of the Channel has been published (Bio-Economic Channel Model: Ulrich *et al.*, 1999) and there is an optimisation model for the fisheries of the Channel (Pascoe and Mardle, 2001). These models have incorporated both biological and economic data with the intention of designing an optimal fishing fleet for the Channel. However, the biological component of these bioeconomic models is based on simple production-effort relationships. Therefore, they account only for those species that are currently important in Channel fisheries and do not include non-commercial or charismatic species. Furthermore, the models do not account for the predator-prey relationships between species or for the possible effects of climate change. While the aim of our ecosystem-modelling work focussed on the English Channel is very similar, the method by which it is attained is different. The strengths of the *Ecopath with Ecosim* model are the way that the entire ecosystem is quantified and analysed, so that the effects of fishing can be seen throughout the food web from primary production to marine mammals. Moreover, the whole ecosystem model is tuned to all of the historical stock assessment biomass estimates that are available, to biomass surveys of other organisms and can be driven by climate forcing.

If justification for this research is sought then it is no more clearly spelled out than as follows: "the [European] Commission will encourage research not only on technical aspects, but also on the development of an ecosystem approach" (Anonymous, 1999). Furthermore, the mandate for the ecosystem approach in the UK comes from its signature to the 1992 OSPAR Convention. This was further extended by the UK's ratification of the additional Annex V 'On the Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area' to the Convention that was signed in 1998 coming into force on 30 August 2000.

An Ecosystem model of the North Sea has already been built (Christensen, 1995), but the species assemblage and the environment itself is different in the Channel, so extrapolating this would not be reliable (Rogers *et al.*, 1998).

AN ECOPATH MODEL FOR THE ENGLISH CHANNEL IN 1995

The Basic Parameters

Ecopath with Ecosim (EwE) is a mass-balance and dynamic trophic ecosystem-modelling tool¹. The first step to building a model is to define a purpose and an area. In this thesis the purpose was to create an ecosystem model that could be used to predict into the future with a range of management alternatives. The area of this 'ecosystem' was the Channel, specifically ICES areas VIIId and VIIe. It was important to clarify the purpose at an early stage because the aim of the model will shape all other decisions and provides a framework so that the modeller does not get caught in 'interesting' distractions. The next step was to define the functional groups that will enable the aim to be attained. A functional group is a user-defined cluster of similar organisms, an individual species or a particular life stage of one species that warrants being distinguished as a group for the purpose of the model. The core of the Ecopath model is two 'master' equations:

- 1) Production = catch + predation mortality + biomass accumulation + net migration + other mortality.

This is an accounting system of production that breaks down the actual matter of a functional group. If primary production increases as a result of temperature then zooplankton is likely to increase. This equation documents what happens to the potential increase in zooplankton (or any other functional group) biomass.

- 2) Consumption = production + unassimilated food + respiration.

This second equation ensures that in the model the energy coming into a group is balanced by the energy leaving it. As with equation 1, it is an accounting system but this time for energy rather than production.

There are five basic sets of parameters per functional group for an Ecopath model. In addition to a diet matrix summarising how much of each group is eaten by other groups, the modeller enters three of other four parameters:

biomass, production/biomass and consumption/biomass and ecotrophic efficiency (EE). The fourth parameter is estimated by mass-balance. Normally EE is estimated, but, in the absence of biomass data, the modeller can estimate it by making an assumption about EE.

While the static *Ecopath* model provides a snapshot of the ecosystem at a particular time, *Ecosim* allows the modeller to look at how the biomass pools in an ecosystem change through time in response to changes in fishing, or other factors such as climate (Walters *et al.*, 1997, 2000). Different life stages of a single group can be incorporated and this can be very useful when temperature influences recruitment or when fishing gear selects for particular sizes. Predator-prey behavioural relationships can also be included in the model through the setting of vulnerabilities. A very useful aspect of *Ecosim* for the purposes of this Channel work is the optimisation routine (Cochrane 2002, Walters *et al.*, 2002). This allows the modeller to search for a fleet configuration that will provide the greatest profit, employment, ecological health or biomass of certain species. Alternatively a combination of these objectives can be searched for. *Ecosim* differs from other more economically focused models by using the diet composition matrix to incorporate predator-prey relationships to the level of detail that the modeller wishes to incorporate into the model. Trophic mediation functions allow a third organism to impact the feeding rate of one group on another and forcing functions enable environmental effects on the ecosystem to be included. Whereas *Ecopath* describes the structure of the ecosystem, *Ecosim* enables the function of groups within the ecosystem to be simulated. Because *Ecosim* can track dynamic changes in an ecosystem and be modified to reflect past data, it provides an ecosystem model that can be used to predict and forecast, having shown that it is trustworthy with regard to describing the past.

Biomass

This is the total mass of a functional group in units of tonnes per km². A variety of techniques have been used to estimate biomass, as described under the individual group descriptions below. For the main fish species in the Channel, biomass was calculated in one of two main ways:

Fish Biomass Using ICES data

For a single species, Virtual Population Analysis (VPA) uses a historical time-series of catch-at-age data to estimate fishing mortality and biomass

¹ More comprehensive descriptions of the basis, scope and pitfalls of EwE can be found in Christensen *et al.*, (2000), Christensen and Walters (2004), and at www.ecopath.org.

Table 2.1 Methodology for calculating the biomass of each of the finfish groups in the model. ICES reports refer to the annual working group reports for stocks that are subject to quotas.

ICES Reports	Pseudo-equilibrium analysis	Other methods
Sole	Other flatfish	Small demersals
Plaice	Gurnards (<i>Chelidonichthys</i> spp.)	Small gadoids
Whiting	Pollack	Mullet (<i>Mullus</i> spp.)
Cod	Large bottom fish	Dab (<i>Limanda limanda</i>)
Hake	Black bream	Rays and dogfish
Herring	Bass	John Dory (<i>Zeus faber</i>)
Mackerel		Sandeel (<i>Ammodytes</i> spp.)
Scad		Sprat (<i>Sprattus sprattus</i>)
		Pilchard
		Sharks
		Basking shark (<i>Cetorhinus maxim-us</i>)

during each year. The principle behind this is that the total landings for a cohort, combined with some estimate of natural mortality each year, over the course of its lifetime, will equal initial recruitment of that cohort. The fishing mortality co-efficient F may be calculated because the numbers of a cohort caught and the numbers that were alive are both known. The main difficulty with this method is estimating the 'terminal' fishing mortality, the mortality in the most recent year. When moving back in time towards the youngest ages, errors in the numbers alive or F decrease irrespective of the terminal F estimate (Pope, 1972), hence a time-series of catch data that captures a large fraction of the cohort is required. ICES working groups improve the estimate of the terminal F using tuning methods such as Extended Survivor Analysis (XSA) (Shepherd, 1999). XSA requires a large amount of additional data such as survey vessel catchability and commercial fleet CPUE, and was only available for species in the Channel that are subject to quotas (Table 2.1). For large stocks, such as whiting that primarily existed outside of the Channel, it was necessary to estimate the biomass in the Channel by the proportion of catch in the Channel compared to that caught in the whole stock. This has a considerable error attached to it but was the best way to deal with the problem (M. Pawson, *pers. comm.*).

Fish Biomass Using CFSG data

The CFSG has amassed a considerable amount of data in order to calculate the biomass of non-quota species. Clara Ulrich (DIFRES, *pers. comm.*) and Matthew Dunn (CEFAS, *pers. comm.*) provided us with pseudo-equilibrium analysis data for the stocks shown in Table 2.1. This method was used when age-structured data were available only for a short period of time (Pascoe, 2000). Cohort analysis deals with a single year-class throughout its lifetime, but a pseudo-cohort is where each age group in the catch is assumed to belong to the same cohort. This method relies largely on the assumption that

recruitment and F do not show a significant trend from year to year. For the 1990s, the stocks in Table 2.1 where this method was used could reasonably be assumed to be at this equilibrium (Pascoe, 2000).

Production per unit of biomass (P/B)

P/B is equal to total instantaneous mortality, Z (Allen, 1971). Consequently it was calculated as fishing mortality (F) plus natural mortality (M) for commercial exploited stocks, and was set equal to natural mortality for non-commercial stocks. There were two main methods of calculating P/B for the groups (Table 2.2).

First, using the same recruitment, weight at age and fishing mortality at age data provided by C. Ulrich and M. Dunn (*pers. comm.*) to calculate the biomass, production was calculated by:

$$\text{Production} = \text{total mortality} * \text{biomass at age}$$

This was then divided by the total biomass to estimate P/B. Secondly, for non-commercially fished groups or for those where data were not available from the CFSG, natural mortality (M) was calculated using the following empirical equation (Pauly, 1980):

$$M = K^{0.65} * L_{inf}^{-0.279} * T^{0.463}$$

Where K is the von Bertalanffy growth constant, L_{inf} is the asymptotic length in cm and T is the average water temperature in °C. In the Channel the average temperature was taken to be 12.71 °C from climate data provided by the Hadley Centre (Anon., 2001d). Fishing mortality was then estimated individually as shown in Table 2.2.

Consumption per unit of biomass (Q/B)

The intake of food by a group over a specified time period (consumption) divided by the biomass equals the Q/B value for the model. All finfish Q/Bs were calculated using the following empirical equation (Christensen and Pauly, 1992):

$$Q/B = 10^{6.73} * 0.0313^{T_k} * W_{inf}^{0.168} * 1.38^{P_f} * 1.89^{H_d}$$

Where T_k is 1000/average temperature in Kelvin, W_{inf} is the asymptotic weight in grams and was converted from the asymptotic length using the a and b parameters from the length weight

Table 2.2 P/B (year⁻¹) estimation for the fin-fish groups.

Group	P/B (year ⁻¹)	Source
Small demersals	1.32	Based on an M calculated from Pauly (1980) for sand goby and hooknose.
Small gadoids	1.02	Based on an M of 0.82 from Pauly (1980) for pouting and in the absence of data an assumed F of 0.2.
Mullet	0.50	Based on an M of 0.4 from Pauly (1980), in the absence of data an assumed F of 0.1.
Sole	0.43	Calculated on the basis of CFSG data.
Plaice	0.65	Calculated on the basis of CFSG data.
Dab	0.75	Calculated on the basis of CFSG data.
Other flatfish	0.35	Calculated on the basis of CFSG data.
Gurnards	0.43	Calculated on the basis of CFSG data.
Whiting	1.07	Calculated on the basis of CFSG data.
Cod	1.13	Calculated on the basis of CFSG data.
Hake	0.47	Calculated on the basis of CFSG data.
Rays and Dogfish	0.44	Assumed to be the same as in the North Sea (Christensen, 1995) as rays are very heavily exploited in the Channel (Southward and Boalch, 1992).
Pollack	0.62	Calculated on the basis of CFSG data.
Large bottom fish	0.40	Weighted for ling and anglerfish and calculated on the basis of CFSG data.
Seabream	0.58	Calculated on the basis of CFSG data for black bream only.
John Dory	0.46	Based entirely on an M of 0.46 calculated from Pauly (1980).
Sandeel	1.14	Based on M from Pauly (1980).
Herring	0.62	Calculated on the basis of CFSG data.
Sprats	1.21	Sprat in the North Sea have a P/B of 1.21 according to (Christensen, 1995) and this was used for the Channel.
Pilchard	0.66	Based on a value of M of 0.33 from Dias <i>et al.</i> , (1983) and of 0.3 for F from Anon. (2000d). Both these values were for area 8 c, the Bay of Biscay.
Mackerel	0.74	Based on an M of 0.49 calculated from Pauly (1980) and an F of 0.25 (Anon., 1999c).
Scad	0.50	Based on an M of 0.34 calculated from Pauly (1980) and an F of 0.16 (Anon., 1999c).
Bass	0.60	Based on an M of 0.20 calculated from Pauly (1980) and Mike Pawson (<i>pers. comm.</i>) estimating an F of 0.40.
Sharks	0.19	Based on an M calculated from Pauly (1980) and averaged for blue shark, porbeagle and tope.
Basking shark	0.07	Based on an M calculated from Pauly (1980).

relationship for the species from Fishbase (Froese and Pauly, 2000), Pf is equal to one for carnivores and zero for herbivores and detritivores, Hd is equal to zero for carnivores and one for herbivores and detritivores. The results for the finfish groups and the species they were calculated from are shown in Table 2.3.

Diet composition

This provides the trophic links between organisms. They can be entered as percentage weight or volume but not as frequency of occurrence. When data were not specifically available for the Channel, they were taken for the same species from the closest proximity to the Channel.

Ecotrophic efficiency

This is the fraction of production that has been accounted for by the model. 1-EE is the fraction of biological production of the functional group that has not been explained by the model. In situations where the biomass was not available

this had to be estimated to allow the model to calculate the biomass. Once these data had been entered into the model, it was necessary to enter catch and discard data before the Ecopath model could be balanced.

Functional group descriptions

A description of the functional groups for the 1995 Ecopath model follows. The parameters estimated by the Ecopath mass-balance function are identified in Table 2.22.

1) Primary production

The biomass of primary production was comprised three parts:

Phytoplankton

Using data derived by chlorophyll determinations (Harvey, 1950) and a conversion factor of 2 from kilocalories (kcal) to wet weight (Crisp, 1975), the biomass of phytoplankton was calculated as 40 t/km² off the coast of Plymouth. The P/B using these sources was calculated as 67.5 year⁻¹.

Table 2.3. Q/B (year⁻¹) of the finfish groups.

Group	Q/B (year ⁻¹)	Comments
Small demersals	8.98	Averaged from hooknose and dragonet.
Small gadoids	5.93	Averaged from pouting and poor cod.
Mullet	7.10	Based on all four mullets.
Sole	5.06	
Plaice	4.11	
Dab	6.41	
Other flatfish	5.46	Weighted by the biomass of megrim, turbot and brill.
Gurnards	5.74	Weighted by the biomass of grey and red gurnards.
Whiting	5.47	
Cod	3.03	
Hake	3.76	
Rays and Dogfish	4.19	Weighted by the biomass of cuckoo ray, spotted ray, thornback ray, spurdog, lesser spotted dogfish and blue skate,
Pollack	3.23	
Large bottom fish	2.90	Weighted by the biomass of anglerfish, ling, and conger eel.
Seabream	4.72	Blackspot, gilthead and black bream.
John Dory	4.21	
Sandeel	10.82	
Herring	6.39	
Sprat	11.07	
Pilchard	8.58	
Mackerel	6.78	
Scad	5.31	
Bass	3.45	
Sharks	2.37	Based on blue shark, porbeagle and tope.
Basking sharks	3.70	

Alternatively, SeaWiFS data (Reg Watson, *pers. comm.*) indicated that the average productivity for the Channel was 633 g C m². Using a Channel biomass estimate of 4.15 g C m² between 1993-1995 from Plymouth (Roger Harris, Plymouth Marine Laboratory, *pers. comm.*) and SeaWiFS (Sea-viewing Wide Field-of-view Sensor) data a P/B of 152.5 year⁻¹ was calculated. The difference between these estimates may reflect the former point biomass estimate being from Plymouth and the latter being satellite data that included the more productive eastern Channel. Because the SeaWiFS data covered the whole Channel and were more recent, a P/B of 152.5 year⁻¹ was used.

Benthic micro-flora

Using an estimate of 140 mg Chl *a* m⁻² (Sagan and Thouzeau, 1998) and a conversion ratio C/Chl *a* = 40 (De Jonge, 1980) the micro-phytobenthos biomass in the western Channel was estimated to be 5.6 g m⁻² C. This was converted to wet weight using a multiplier of 20 (Crisp, 1975). Because primary production occurred off the coast of Devon to a depth of 25 m (Southward and Boalch, 1992), the calculated value of 112 t/km² was used for areas shallower than 25 m. This was based on average depth values provided by R. Watson (*pers. comm.*). Hence when averaged over the Channel this part of the primary production contributed 3.92 t/km² to the biomass.

Benthic macro-algae

The biomass of macroalgae off the northern coast of Brittany in summer was estimated as 3 million t (Table 2.4) (Kerambrun, 1984; P. Arzel, IFREMER, *pers. comm.*). This study was for the summer biomass only for an area from St. Guenole, south of Brest, to Le Mont Saint Michel, near Granville, both on the north Coast of Brittany. In the winter there was only 13.6 % of the biomass in summer (P. Arzel, *pers. comm.*). This corresponded to a winter biomass of 402,000 t, and so an average of 1,700,000 t was used to represent the annual average biomass. In the absence of data for the entire Channel the annual average biomass was multiplied by four because the study area covered approximately a quarter of the Channel. Hence, macroalgae contributed 6.7 million t (75 t/km²) to primary production. Of the 58,228 t of benthic macroalgae that were harvested off the French coast approximately 74% were *Laminaria digitata*, 3% were *L. hyperborean*, 10% were *Ascophyllum* spp., 10% were *Fucus* spp. and 3% were *Chondrus* spp. The market price of macroalgae was 0.04 €/kg. On the English coast there was no commercial harvesting of macroalgae, but some washed up algae was collected for use as fertilizer (Southward and Boalch, 1992). This was deemed to have a negligible impact on the Channel ecosystem.

Table 2.4 Biomass of macroalgae off the northern coast of Brittany. Data from Kerambrun (1984) and P.Arzel, (IFREMER, *pers. comm.*).

Species	Biomass (tonnes)
<i>Pelvetia canaliculata</i>	4,005
<i>Fucus spiralis</i>	12,015
<i>Ascophyllum nodosum</i>	123,354
<i>Fucus vesiculosus</i>	24,030
<i>Fucus serratus</i>	64,080
<i>Bifurcaria rotunda</i>	10,680
<i>Himantalia elongata</i>	10,680
<i>Laminaria digitata</i>	320,400
<i>Saccorhiza polyschides</i>	962,120
<i>Laminaria ochroleuca</i>	142,400
<i>Laminaria saccharina</i>	71,200
<i>Laminaria hyperboreana</i>	1,214,850
Total	2,959,814

The total biomass of primary producers in the Channel was estimated to be 127 t/km² and the P/B 60 year⁻¹ (Table 2.5).

2) Zooplankton

Splitting zooplankton into only two groups, 'zooplankton' and 'carnivorous zooplankton', can be said to be a broad approach to modelling this sector of the ecosystem, but there seemed little value in further segregating them because the aim of the model was to look at fishing policy in the Channel.

According to Dauvin *et al.* (1998) "The [Channel] mesozooplankton community, defined as a euryhaline marine assemblage, was dominated by the calanoid copepods *Acartia* spp., *Temora longicornis* and *Centropages hamatus*, the cladoceran *Evadne nordmanni* and the appendicularian *Oikopleura dioica*". Consequently, when estimating the biomass of zooplankton a conversion ratio from dry weight to wet weight of 13.95% for copepods was used (Beers, 1966). Dry weight data was used from the eastern and mid English Channel to represent the entire channel (Le Fevre-Lehoeerff *et al.*, 1993). It was averaged from 4 stations over 12 months as 21.6 mg/m⁻³. Then it was averaged by depth to equal 7.4 t/km². Of this 12.9% were allocated to the carnivorous zooplankton group, so a preliminary value of 6.45 t/km² was calculated for zooplankton. A degree of caution must be used with this data because different zooplankters have varying degrees of water content so the conversion from dry to wet weight may not be correct (Harvey, 1950).

Trawl surveys in 1934 and 1949 (Harvey, 1950) indicated that there was, on average, 2 g dry weight of plankton below a square meter. Analysis of mixed plankton communities showed that they contained approximately 83% water. Hence, using a mean value of dry weight biomass of 1.742 g (it was 2 g but 12.9% had been allocated

to carnivorous zooplankton), there would be 8.5 t/km² of zooplankton. This was close to the contemporary data value of Dauvin *et al.* (1998), and because the conversion ratio was specific to the Channel, this was the value that was used in the model.

A P/B of 18 year⁻¹ and a Q/B of 60 year⁻¹ were used, taken from an Ecopath model of the North Sea (Christensen, 1995).

Assuming that the majority of the zooplankton are herbivorous, there is also a small element of predation. Hence, the diet of zooplankton was assumed to be 90% phytoplankton, 3% zooplankton and 7% detritus based on zooplankton in the North Sea (Christensen, 1995)

3) Carnivorous zooplankton

This group was comprised of the Hydromedusae, the Scyphomedusae and the chaetognaths. They were separated from the rest of the zooplankton because they prey primarily on copepods (Nicholas and Frid, 1999). The 'jelly' nature of the two medusae groups has made sampling difficult and there were few studies specifically on the Channel.

Biomass data were taken from Harvey (1950), which indicated that 7.1% of the total biomass of zooplankton was medusae and 5.8% was chaetognaths, hence the 12.9% that were moved from 'zooplankton'. This would correspond to the group having a biomass of 1.1.

A P/B value of 7 year⁻¹ was used for medusae based on medusae data off the coast of British Columbia (Larson, 1987). A Q/B value of 23.33 year⁻¹ was based on the carnivorous jellies group in the southern B.C. shelf (Pauly and Christensen, 1996). The diet composition was assumed to be entirely zooplankton.

Benthos Groups: Discussion

The five benthic groups proved problematic because of species differences depending on habitat within the Channel (Gray, 1974). Consequently, different authors provide different estimates of the abundance of these groups (Mare, 1942; Holme, 1953; Gros and Hamon,

Table 2.5 Biomass and P/B of primary producers in the Channel. P/B for macroalgae came from the Channel (Kerambrun, 1984) and for microphytobenthos from the Elbe Estuary (Kies, 1997).

Group	Production t/km ² /yr ⁻¹	Biomass t/km ²	P/B yr ⁻¹
Phytoplankton	7304	47.8	152.8
Macroalgae	74.3	75	0.99
Micro-phytobenthos	169.7	3.9	43.3
Total	7548	126.7	59.6

Table 2.6 Relative constituents of the benthos from a scoop sampler (Holme, 1953), and biomass apportioned according to the total of 49.1 t/km²

Group	%	Biomass t/km ²
Suspension feeders	10.34	5.07
Polychaeta and Nemertinea	25.79	12.66
Crab	10.51	5.16
Gastropoda	0.02	0
Bivalves	35.46	17.41
Echinodermata	17.88	8.78

1990; Ellis *et al.*, 2000). Personal communication with Jim Ellis (CEFAS), who has been responsible for a great deal of trawl surveys in the Channel, was invaluable in making choices about which data to base the model on. Part of the problem is that different authors have used different techniques to measure the benthos and that, while trawling may have caught large mobile animals, it missed out on worms and smaller bivalves. Using a scoop sampler, Holme (1953) calculated an average total biomass for different substrates around Plymouth as 49.1 t/km², taking into account the weight of sand in guts and those organisms that had been missed by the instrument or been lost through the mesh of the 1.0 mm sieve. These data are shown in Table 2.6. This data was used as a benchmark value for the total benthic biomass in the channel, but there were further considerations that needed to be highlighted:

- These data were from the 1950s and may not represent the current situation;
- The data were from the area around Plymouth and, although they encompassed a range of substrates, they did not go as far as the eastern Channel. Positively, because the data were from the Plymouth area the likelihood is that it would have been heavily trawled and so would reflect the present situation;
- The contemporary trawl data indicate much lower biomasses from CPUE data.

For the purposes of the model, the biomass of crabs from Table 2.6 was not used because sampling was not as effective as later trawl surveys (Table 2.7) (Ellis *et al.*, 2000; Ellis,

2001).

The main difference between Tables 2.6 and 2.7 is the absence of small animals in the trawl surveys, which seems to inflate misleadingly the importance of crabs, echinoderms and suspension feeders. It is noteworthy that data from Holme (1953) does not include representatives from shrimps or prawns, and so in the absence of data we used biomass calculated by the mass-balance in Ecopath.

Coull (1972) records an expected benthic biomass on continental shelves as 50-100 t/km². The highest biomass calculated from the CPUE data was 9.54 t/km² from the eastern English Channel and most of the assemblages were considerably lower than this. Furthermore a macrobenthic biomass of 75 t/km², which did not include 31.5 t/km² of polychaetes, was measured in a muddy deposit off Plymouth, although this was earlier in the twentieth Century (Mare, 1942). Another example of a higher biomass is found in Le Guellec and Bodin (1992) where macrobenthos biomass in the Bay of St. Brieuc is 9.3 g/m² Ash Free Dry Weight. Converting this to wet weight using a ratio of 15:1 (as used by Christensen (1995)) the expected biomass would be 139.5 t/km². The last two examples were close to the coast and one would expect the biomass to be higher in this vicinity, but these data did give legitimacy to base the model mainly from the higher estimates of Holme (1953), while being aware that these may have to be further increased. Consequently, the Holme (1953) estimates of biomass were used for suspension feeders, deposit feeders, bivalves and echinoderms, and the eastern Channel trawl surveys of Ellis (2001) were used for crab.

4) Deposit feeders

This group was mainly composed of worms but also includes small invertebrates such as amphipods that feed on detritus.

The P/B was variable, between 1.9 year⁻¹ and 3 year⁻¹ depending on the substrate, for a generalized group called 'deposit feeders' in the

Table 2.7 Percentage of benthos in the Channel based on beam trawl surveys. In the absence of specific western Channel data, this area was based on the Bristol Channel on the advice of J. Ellis (*pers. comm.*). The weights (Wt) were calculated on the basis that there was 49.1 t/km² total biomass.

Group	East channel (Ellis, 2001)		West Channel (Ellis <i>et al.</i> , 2000)		Total Channel	
	%	Wt	%	Wt	%	Wt
Suspension feeders	64.04	33.94	30.31	14.88	42.78	21.00
Bivalves	2.58	1.37	0	0	0.95	0.47
Deposit feeders	0	0	0	0	0	0
Crab	17.29	9.16	34.53	16.95	28.16	13.83
Echinoderms	16.09	8.53	35.16	17.26	28.11	13.80

Bay of Morlaix, western Channel (Ameziane *et al.*, 1995). A value of 2.5 year⁻¹ was used because this was the P/B of deposit feeders inhabiting coarse gravel, which dominates the Channel (Larsonneur *et al.*, 1982).

Because there were no Q/B estimates available, a value of 0.15 for gross food conversion efficiency was used based on the North Sea model (Christensen, 1995).

Although some worms, such as the Nereidae, are carnivorous, because they were in such small quantities in the Channel (Warwick and Price 1975), cannibalism was deemed to be negligible and it was assumed that this group fed entirely on detritus in accordance with models of the North Sea and of Newfoundland (Christensen, 1995; Bundy *et al.*, 2000).

5) Sessile suspension feeders

Benthic cnidarians, sponges, bryozoans and ascidians seemed to be significant in the Channel both from the work of Holme (1953) and from trawl surveys (Ellis *et al.*, 2000; Ellis, 2001). They merit a group of their own, even though data are scarce, because they are distinct from filter feeding bivalves. The P/B of sessile suspension feeders was taken to be 0.1 year⁻¹ on the advice of Dr Roland Pitcher (CSIRO, Commonwealth Scientific and Industrial Research Organisation, (*pers. comm.*). This was a global approximation in the absence of local data, and hence needs to be treated with caution. Biomass was taken from Tables 2.6 and 2.7 as described above.

A gross food conversion efficiency of 0.15 was used in the absence of other estimates for Q/B.

Diet for sea anemones was composed of zooplankton, isopods, amphipods and polychaetes (Van-Praet, 1985). Hunt (1925) found that the sponges, *Desmacidon fructicosa*, *Ficulina ficus* and *Cliona celata* ate fine detritus and minute diatoms in the area around Plymouth. The diet of the hydroid *Campanularia everta* was recorded as 54% zooplankton and 46% detritus by weight in the western Mediterranean (Coma *et al.*, 1995). Consequently, the diet of this group was entered as 45% zooplankton, 35% detritus, 10% deposit feeders, and 10% primary production.

6) Shrimp and prawns

Very little information could be located for the basic parameters of this group and there was some consideration given to whether it could be combined with crabs to form a broad decapod group. It was decided to leave it separate and base

this group on data from other areas and other Ecopath models. 152 t of pink shrimp (*Palemon serratus*) and 340 t of brown shrimp were reported caught in the Channel with an average value of 10.42 €/kg.

Hopkins (1988) calculated 1.7 year⁻¹ for the P/B of the deep-water prawn *Pandalus borealis* in Northern Norway and in lieu of Channel or species data this had to be used.

In accordance with Mackinson (2001) shrimps and prawns were assigned a gross food efficiency of 15% and an ecotrophic efficiency of 0.95.

The diet of shrimps and prawns was based entirely on Northern shrimp off the coast of Newfoundland (Bundy *et al.*, 2000).

7) Whelk

The biomass of whelk (*Buccinum undatum*) (0.247 t/km²) was calculated in the same way as many finfish species by using age structured data provided by the CFSG. A P/B of 0.586 year⁻¹ was calculated from the same data.

Q/B was not available and so a gross food conversion efficiency of 0.15 was used.

Himmelman and Hamel (1993) examined the stomachs of 200 whelks off the eastern coast of Canada but found only 30 of them contained identifiable prey items. Similarly, Taylor (1978) found that many stomachs were empty. Both sources indicate the high significance of polychaetes in the diet of whelks (50-85%) with molluscs, crustaceans and echinoderms forming the rest of the diet in different quantities depending on the location. The diet composition that was entered into Ecopath is as follows: 70% deposit feeders, 10% bivalves, 10% crustaceans, 5% shrimps and prawns, and 5% echinoderms.

8) Echinoderms

This group represented all echinoderms in the Channel whether they were mostly carnivorous (e.g., *Asterias rubens*), or mainly detritivorous (e.g., *Ophiothrix fragilis*). The main species that occur in the Channel are *Asterias rubens*, *Astropecten irregularis*, *Spatangus purpureus*, *Psammechinus miliaris*, *Echinus esculentus*, *Solaster endeca*, *Ophiura ophiura*, *Crossaster papposus*, *Echinocarsium cordatum* and *Ophiothrix fragilis* (Ellis, 2001). Biomass was taken from Tables 2.6 and 2.7 as described above.

A range of estimates were available for echinoderm P/B: 1) A general value of 2 year⁻¹ for benthos in the North Sea from Christensen (1995)

and 2) a calculated value of 0.26 year⁻¹ using an average depth of 55m, a bottom water temperature of 11°C and a mean individual body mass equivalent to 23.7 KJ (Brey, 1999). The body mass equivalent in KJ was calculated from an average ash free dry weight of 0.25 g of *Asterias rubens* in the Baltic (Anger *et al.*, 1977). This was converted to 5.925 KJ using the conversion factor of 1g ash free dry weight = 23.7 KJ (Brey, 1999). 3) A value of 0.6 year⁻¹ from a Southern BC shelf model had also been calculated for echinoderms using data from Brey (1999). Compared to other models, the value of 0.26 year⁻¹ seemed rather low for echinoderm mortality, and so we used the higher value of 0.6 year⁻¹ was used.

Anger *et al.* (1977) calculated the daily consumption of *Asterias rubens* to range from 1.9 to 11.4 % of body weight. This translated to a Q/B of between 6.935 year⁻¹ and 41.61 year⁻¹. Trawl data (Ellis *et al.*, 2000) indicated that *Asterias rubens* is an abundant echinoderm in the Channel, but because *Asterias rubens* is an active mobile carnivore, its Q/B will be larger than other more sedentary echinoderms. The lowest value in the range was consequently used. The gross efficiency of 0.087 obtained from a P/B of 0.6 year⁻¹ and a Q/B of 6.935 year⁻¹ was comparable with a value of 0.09 year⁻¹ assumed by Jarre-Teichmann and Guénette (1996). This is a value that needs further research in the Channel. Having entered these values, the model calculated a respiration/assimilation ratio of 0.892. This was comparable with values of 0.78 – 0.82 for the sea urchin *Parechinus angulosus* off the coast of South Africa (Greenwood, 1980).

Relative frequency diet data were available for 3 species, *Echinus esculentus*, *Crossaster papposus* and *Solaster endeca* from the north-west Atlantic (Himmelman and Dutil, 1991), and initially, in absence of weight or volume data, these were converted to % weight. By using this approximate method cannibalism was excessive. The species investigated by Himmelman and Dutil (1991) were not completely representative of all echinoderms because many feed on detritus (J. Ellis, *pers comm.*; Hunt, 1925). A study on the diet of *Asterias rubens* in the western Baltic Sea (Anger *et al.*, 1977) indicated that gastropods, bivalves, deposit feeders and detritus were important components of the diet, but also that the diet of *Asterias rubens* corresponds to the species diversity found in the environment. Using this information on echinoderm diets, previous models Christensen (1995); Bundy *et al.* (2000) and also the recommendations of Jim Ellis (*pers. comm.*), the following diet was entered into Ecopath:

5% Primary producers, 11% deposit feeders, 1% suspension feeders, 5% bivalves, 6% Echinoderms, 72% detritus.

9) Bivalves

This group includes bivalves other than scallops such as cockles (*Cerastoderma edule*), soft-shelled clam (*Mya arenaria*), blue mussels (*Mytilus edulis*), and oysters (*Ostrea edulis* and *Crassostrea gigas*). From this functional group, blue mussels, clams, oysters and cockles are caught from the Channel. Biomass was taken from Tables 2.6 and 2.7 as described above.

Natural mortality rates for bivalves range from 0.2 year⁻¹ (*Cerastoderma edule*) to 0.5 year⁻¹ (*Mya arenaria*) in an estuarine mud-flat off Plymouth (Warwick and Price, 1975), where these bivalves were unexploited. A P/B value of 0.6 year⁻¹ was used for this group because, although fishing mortality was very high in certain areas, when averaged over the Channel and all of the bivalve species its impact will be reduced. Catch data from ICES indicated that 13,557 t of non-scallop bivalves were caught on average between 1993 and 1995. No market price was available for this group, so the same value as scallops of 2.63 €/kg was entered.

In the absence of other data a gross food conversion efficiency of 0.09 was used for bivalves, taken from an Ecopath model of the BC shelf (Guénette, 1996).

We found little quantitative information on the dietary composition of bivalves, but it does seem that a combination of phytoplankton (Thouzeau *et al.*, 1996) and detritus (Guénette, 1996) comprises the diet. Hence 50% of the diet was allocated to each.

10) Scallops

As a sub-group of bivalves, scallops (common scallops, *Pecten maximus*, and queen scallops, *Chlamys opercularis*) were separated because they seemed to be a particularly significant fishery in the Channel. Biomass was taken from Tables 2.6 and 2.7 as described above.

The P/B of scallops as estimated from data provided by Ulrich (2000) ranged between 0.35 year⁻¹ and 1.25 year⁻¹ depending on the area, and the midpoint of 0.8 year⁻¹ was used in the model. According to Ulrich (2000), 26,259 t of scallops were landed annually from the Channel, and so the biomass was approximated using catch divided by an average F of 0.6 year⁻¹ (Ulrich, 2000) to be 43,765 t or 0.488 t/km².

In absence of other data a gross food conversion

efficiency of 0.09 was used from bivalves in the BC shelf model (Gu nette, 1996).

As with 'bivalves' above, the diet was allocated 50 % to phytoplankton and 50 % to detritus.

11) Crab

According to both Ellis (2001) and Holme (1953) there are a high proportion of crabs in the Channel, some of which support a large potting fishery. Commercial crabs were separated from the remainder, leaving this 'crab' group including the shore crab (*Carcinus maenas*), the common hermit crab (*Pagurus bernhardus*), the hairy crab (*Pilumnus hirtellus*) and the velvet swimming crab (*Necora puber*). Ellis (2001) indicated that the relative importance of crabs was much higher than Holme (1974) suggested in the Channel, so initially the biomass was entered as 8.67 t/km², the midpoint between the crab biomass in Tables 2.6 and 2.7.

There were no P/B values specifically for this group in the Channel, so an average value of 1.05 year⁻¹ was used based on the mid-point between 1.8 year⁻¹ for 'crabs' from the BC shelf (Jarre-Teichmann, 1996) and 0.3 year⁻¹ for edible crabs in Norway (Gundersen, 1976). The rationale was that many of the crabs in this group are smaller and faster growing than the edible crab.

There were no Q/B estimates so a gross food conversion efficiency of 0.15 was used from Christensen (1995).

The diet of this group was based entirely on a generic benthic crab (Brey, 1995), as composed of 62% detritus, 20% bivalves, 15% shrimps and prawns and 3% cannibalism. There is a lot of uncertainty with the diet composition for this group, mainly because it is difficult to know the proportion of the diet that is already dead, i.e., detritus.

12) Commercial crab

This group was composed of the edible crab, *Cancer pagurus* and the spider crab, *Maja squinado*.

Trawl surveys by Ellis *et al.* (2000) were used to calculate the biomass of commercial crabs in the Channel. J. Ellis (*pers. comm.*) had stated that the Bristol Channel had the most similar assemblage to the western Channel, and spider crab there had a CPUE of 10.8 kg/hr. In the eastern Channel CPUE for spider crab was 2.6 kg/hr, while for edible crab it was 2.3 kg/hr. The greater biomass in crabs from the western Channel seemed to be reflected by the

concentration of effort from both the English and French fishers (Brown and Bennett, 1980; Tetard *et al.*, 1995). Because there were no edible crab recorded in the Bristol Channel and catches were approximately equal to spider crab in the English Channel, 10.8kg/hr was used to represent the western Channel edible crab CPUE and 2.3 kg/hr for the eastern Channel from Ellis *et al.* (2000). This translated into a total commercial crab biomass in the Channel of 0.514 t/km².

A P/B of 0.46 year⁻¹ was used based on a natural mortality of 0.3 year⁻¹ for edible crabs in Norway (Gundersen, 1976) and a fishing mortality of 0.16 from a production model of edible crabs in the Channel (Anon., 1999a).

Q/B data was unavailable, so a value of 0.15 for gross food conversion efficiency was used (Christensen, 1995).

The diet of this commercial crab group was based entirely on a generic benthic crab (Brey, 1995), composed of 62% detritus, 20% bivalves, 15% shrimps and prawns and 3% cannibalism. As with the other crab group, it is difficult to know the proportion of the diet that is dead, i.e., detritus.

13) Lobsters

This group was comprised entirely of European lobsters *Homarus gammarus*. Although a small crawfish (*Palinurus elephas*) catch of 24 t was included, crawfish data were not used to estimate any of the other parameters in the model because the lobster catch was so much larger at 473 t.

Although there were no extensive data on lobsters, because they are such a lucrative fishery (19.17  /kg; Table 2.23), they should be separated from crab. No lobsters were recorded in any of the trawl data suggesting that they were not common enough to be represented, they evaded the trawl, or the rocky areas they inhabit could not be accessed by the gear.

Lobster biomass was estimated on the basis of catch/F = biomass. 473 t of lobster were caught with a fishing mortality of 0.4 year⁻¹ (Bannister and Addison, 1984) = total biomass of 1183 which is 0.013 t/km².

A P/B of 0.5 year⁻¹ was used based on the conventional 0.1 year⁻¹ for M (Anon., 1979) and 0.4 year⁻¹ for F from the south-west stock (Bannister and Addison, 1984). Southward and Boalch (1992) report that lobsters on the south coast of Devon are very seriously overfished.

Q/B data was used from a Newfoundland Ecopath

model (Bundy *et al.*, 2000) including the American lobster, providing a value of 5.85 year⁻¹.

Lobster diet was based entirely on *Homarus americanus* from Bonavista Bay, Newfoundland (Ennis, 1973), with unidentified food being allocated to the detritus because, although lobsters are primarily predators, scavenging behaviour is well developed (Herrick, 1991). Echinoderms form a major part of the diet.

14) Small demersals

This was a group designed to incorporate small demersal fish into the model, since they are eaten by many larger fish. The species included are sand goby (*Pomatoschistus minutus*), hooknose (*Agonus cataphractus*) and dragonet (*Callionymus maculates*). There were many other species that could have been applicable in this category, but these seemed representative of other species. There were no biomass estimates for this group, so an ecotrophic efficiency of 0.95 was entered and Ecopath calculated the biomass as 2.63 t/km².

Diet composition was based on the average of the diets from the sources summarised in Table 2.8.

15) Small gadoids

The parameters for this group were based entirely on pouting (*Trisopterus luscus*), Norway pout (*Trisopterus esmarkii*), and poor cod (*Trisopterus minutus*). The biomass was estimated by the model based on an assumed ecotrophic efficiency of 0.95.

Diet composition for the model was based on an average of pouting and poor cod from the Irish Sea (Armstrong, 1982).

16) Mullet

This group comprised four species of mullet, thinlip mullet (*Liza ramada*), golden grey mullet (*Liza aurata*), thicklip grey mullet (*Chelon labrosus*) and striped red mullet (*Mullus surmuletus*).

No biomass data was available for the group so ecotrophic efficiency was set to 0.95 and the model estimated the biomass as 0.85 t/km².

Only red mullet are landed commercially, and 90% of the 1,005 t was caught by otter trawling.

Table 2.8 Origin and type of diet composition data used for small demersals from W.Scotland.

Species	Data type	Source
Sand goby	% weight	(Gibson and Ezzi, 1987)
Hooknose	% weight	(Gibson and Robb, 1996)
Dragonet	% weight	(Gibson and Ezzi, 1987)

Diet composition for this group was based on striped red mullet from a study in the Bay of Biscay (Olaso and Rodriguez-Marin, 1995).

17) Sole

Sole (*Solea solea*) is a very lucrative species in the Channel, commanding a price of 9.9 €/kg, and landed in large quantities by beam and otter trawls, as well as by dredging and trammel netting. Sole do not migrate extensively out of the Channel (Pawson, 1995). Using ICES data averaged between 1990 and 1999 (Anon., 2000c), a value of the biomass for area VIIId was 17,038 t. For VIIe it was 3,200 t. This gave a total biomass of 20,238 t (0.226 t/km²).

Diet composition for the group was taken from Beyst *et al.* (1999) for juvenile sole off the coast of Belgium. This was very similar to the diet composition data for sole in the whole of the North Sea (Christensen, 1995) and off the North coast of Spain (Molinero and Flos, 1992), with deposit feeders forming approximately 80% of the diet.

A juvenile sole group was added during tuning to incorporate the effect of temperature on recruitment.

18) Plaice

Like sole, plaice (*Pleuronectes platessa*) are considered a very important species in the Channel and are mainly caught by otter and beam trawls, dredging and trammel netting.

ICES area VIIe has a local plaice stock, whose biomass was calculated as 4,102 t, averaged between 1990 and 1999. However, biomass calculations were complicated by the migration of plaice in and out of the North Sea. Many plaice were tagged and recaptured during 1971 and 1972 with the results indicating that 20-30% of the plaice caught in the eastern Channel contained migratory North Sea fish (Pawson, 1995). The estimated plaice biomass in area VIIId was averaged over the years 1990-1999 (Anon., 2000c) as 15,572 t. Since 25% of this would be in the Channel only for 4 months during winter (Pawson, 1995), the total permanent biomass in the Channel, including area VIIe, was estimated as 13,892 t, with an additional 3,893 t being present for 4 months only. In an attempt to incorporate the migration into the model, the whole biomass was included in the basic input, and 21.9% of the diet composition was allocated to import, on the assumption that the migratory plaice consumption while in the Channel would be minimal. So the total biomass entered was 17,785 t, or 0.199 t/km².

Diet composition was based on plaice from the west coast of Scotland (Gibson and Robb, 1996). It included a 13.1% component of unidentified fish that were allocated entirely to small demersals.

A juvenile plaice group was added during tuning to incorporate the effect of temperature on recruitment, and this necessitated an alteration in the input biomass.

19) Dab

Initially, dab (*Limanda limanda*) was included in the 'other flatfish' group (see below) because their biological parameters are similar, but they were separated because dab sells for a much lower price than the other species of flatfish (Table 2.23). A biomass of 3,168 t for the entire Channel was calculated from data originating from CFSG, but this seemed very low. There is extensive discarding of dab because of the low price, so when likely discards were added to the catch, the estimated biomass from total catch divided by fishing mortality (0.35, estimated from CFSG data), was much higher at 0.103t/km², and this value was used in the model.

Diet composition data was based on juvenile dab from the west coast of Scotland (Gibson and Ezzi, 1987).

20) Other flatfish

This group includes lemon sole (*Microstomus kitt*), megrim (*Lepidorhombus whiffiagonis*), turbot (*Psetta maxima*) and brill (*Scophthalmus rhombus*). Initially it was planned to include witch (*Glyptocephalus cynoglossus*), sand sole (*Pegusa lascaris*), and flounder (*Platichthys flesus*) in this group, but their absence in the catch data, and in reported catches of each métier (Tetard *et al.*, 1995) provided no reason to include them at this stage. Lemon sole are targeted by otter trawls, megrim by beam trawls and turbot with nets, with the remainder of the landings being by-catch from trawling, dredging and netting. The total catch of other flatfish according to Ulrich (2000) was 2,717 t. Of this total, 380 t were brill, 425 t were turbot, 1,466 were lemon sole, and 446 t were megrim. The market price for the group was averaged on the basis of the current catches. This was not ideal because brill and turbot have a higher price (6.9 and 9.6 €/kg respectively) than lemon sole (3.8 €/kg) and megrim (3.7 €/kg), but the catch-weighted average value of 5.1 €/kg that was entered into Ecopath does reflect that this is a lucrative fishery (Table 2.23).

Megrim were assessed over a large area, ICES

areas VII b, c, e-k and VIII a, b and d. In this situation and for all stocks that had a proportion of the population migrating into the channel, personal communication with Mike Pawson and Matthew Dunn suggested that the best way to calculate biomass was to estimate the entire stock and then base the proportion of the stock in the Channel on landings into Channel ports. Catch data were used from Ulrich (2000) because in these data there had been an attempt to weed out vessels landing fish caught outside of ICES areas VII d and VII e. Hence, the average biomass of megrim in ICES area VII b, c, e-k and VIII a, b and d, from 1990-99 was calculated as 81,414 t (Anon., 2000e). The 446 t caught in the Channel contributed 2.5% of the total catch and 2.5% of the entire stock biomass is 2,003 t, which is our estimate of the biomass of megrim in the Channel. The biomasses of lemon sole (5,172 t), turbot (1,377 t) and brill (1,239 t) were calculated using data provided by the CFSG. The total biomass for this group amounted to 9,791 t (0.109 t/km²).

Diet composition data were available for adult lemon sole off the west coast of Scotland (Rae, 1965) and for juvenile brill and turbot off the Belgian coast (Beyst *et al.*, 1999). Although all data were in the useable form of % weight, brill and turbot contained a high proportion (> 80 %) of unidentified fish. For this reason, and because lemon sole contributed the majority of the biomass, the data from lemon sole were used to represent the whole group.

21) Gurnards

There are three species of gurnard found in the Channel, red gurnard (*Chelidonichthys cuculus*), tub gurnard (*Chelidonichthys lucerna*) and grey gurnard (*Chelidonichthys gurnardus*). All species were landed primarily by otter trawling and the landings of red gurnard (3,417 t) were considerably greater than the sum of the others (1,826 t).

The biomass of red gurnard was available from data provided by the CFSG but the others were not, so were calculated proportionally on the basis that if a catch of 3,127 t of red gurnard equated to a biomass of 11,414 t (Ulrich, 2000), then a catch of 1,826 t of other gurnards would imply a biomass of 6,617 t. Hence, the total biomass was estimated to be 18,031 t (0.201 t/km²).

Diet composition data were available for grey gurnard from the Northern Mediterranean (Moreno-Amich, 1994) and red gurnard from the Bay of Biscay (Velasco *et al.*, 1996). Information

on presence/absence in the diet of tub gurnard was available and, as this indicated a similarity with grey gurnard, shrimps, prawns and small demersals comprising the diet, the grey gurnard diet was used to represent other gurnards. Red gurnard and grey gurnard diet data were weighted on the basis of biomass.

22) Whiting

There is a large catch of whiting (*Merlangius merlangus*) in the Channel (7,591 t) and it has traditionally been a 'bread and butter' fish for the otter trawlers. In terms of migration, whiting are fairly stationary in the Channel but because abundances are high in the west of the Channel and in the North Sea they are assessed by ICES in two sections. VIId is part of the North Sea assessment in area IV (Anon., 2000c) and VIIe was part of the southern stock assessment in areas VIIe-k (Anon., 2000e). The approach used for the megrim stock (see above) was used for whiting with the assumption that the catch to biomass ratio was the same in the Channel as in the entire stock. The averaged total biomass between 1990-99 in area IV and VII d was 350,784 t with a total catch (averaged between 1990-99) in this area of 93,672 t. The catch in the eastern channel according to (Ulrich, 2000) was 5,484 t, which was 5.85% of the total biomass of 350,784 t, leading to a Channel estimate of 20,537 t (0.229 t/km²)

The total biomass in area VIIe-k was 62,940 t and the catch was 17,641 t. The channel catch was 2,107 t, which was 11.9% of total. The biomass in the western channel was therefore calculated as 7,517 t. A combined biomass of 28,054 t (0.313 t/km²) was averaged over the area of the Channel and entered into Ecopath.

Diet composition data came from Daan (1989) for the North Sea. Some adjustment was necessary for the Channel: 3.1% haddock was allocated to small gadoids; 18.7% other prey fish was allocated 9% to small demersals, 9% to small gadoids and 0.7% to dab; 3.1% other invertebrates went entirely to deposit feeders; 3.1% other macrobenthos was split between deposit feeders and bivalves; and the 9.9% of other crustaceans was allocated 4.9% to shrimps and prawns, 4.9% to crabs and 0.2% to commercial crab.

A juvenile whiting group was added during tuning to incorporate the effect of predation from other gadoid groups on whiting.

23) Cod

North Atlantic cod (*Gadus morhua*) are mainly caught by otter trawlers and gillnets. It is a

species that migrates and this complicates the biomass estimates for the Channel. As with whiting, the assessment for cod in areas VIId and VIIe were part of a much larger assessment. VIId was assessed as part of area IV, VIId and IIIa while area VIIe was part of VIIe-k.

The North Sea had a total stock biomass of 370,405 t and total catches from that of 222,921 t, both averaged from 1990-99 (Anon., 2000c). The VIId catch according to Ulrich (2000) was 2,375 t, which was 1.07% of the total catch and hence the entire Channel biomass was 3,946 t. The southern stock had a total biomass of 20,246 t and catches of 10,897 t, both averaged over the years 1990-99 (Anon., 2000e). The catch of cod in the western Channel was 814 t, which was 7.47 % of the total catch in ICES areas VIIe-k, and hence the total Channel biomass was estimated as 1,512 t. The combined biomass without considering migrations was 5,449 t (0.061 t/km²).

Immature cod in the eastern Channel are generally thought to have been spawned there and approximately 40% of tagged cod, 30-49 cm in length, moved from the eastern Channel to the North Sea during April to November. The impact that this had on the biomass calculations is uncertain because many fish may have been caught before migrating meaning that the biomass had been overestimated for the entire year. On the assumption that fishing pressure and predation were constant throughout the year and that half of this 40% had migrated, midway though the year it was possible to assume that the current biomass calculation estimated from the landings data correctly estimated the actual biomass, including migrating immature fish.

The diet was based on North Sea cod (Daan, 1989).

A juvenile cod group was added during tuning to incorporate the effect of temperature on recruitment.

24) Hake

Hake (*Merluccius merluccius*) are a deeper-water fish confined to the western approaches of the Channel (M. Dunn, *pers. comm.*; Pawson, 1995). The total stock biomass for ICES areas VIIb-k and VIIIA, b and d was 194,411 t averaged from 1990-99 (Anon., 2000e). The catch of this was 51,248 t, averaged from 1990-99. The catch in the channel from Ulrich (2000) was 435 t, which was 0.85 % of the total stock catch. Consequently the Channel biomass was calculated as 1,650 t (0.018 t/km²).

Diet data were used from the Bay of Biscay

(Guichet, 1995). The 5.19% of blue whiting (*Micromestius poutassou*), which did not feature in the model, was allocated to 'whiting' (4.19%) and to John Dory (1%), on the advice of M. Dunn (*pers. comm.*).

25) Rays and dogfish

This group included the cuckoo ray (*Raja naevus*), spurdog (*Squalus acanthias*), lesser-spotted dogfish (*Scyliorhinus canicula*), small-eyed ray (*Raja microocellata*) greater-spotted dogfish (*Scyliorhinus stellaris*), blonde ray (*Raja brachyura*), longnosed skate (*Dipturis oxyrinchus*), blue skate (*Dipturis batis*) spotted ray (*Raja montagui*) and thornback ray (*Raja clavata*). 3,196 t of 'dogfishes' were caught in the Channel, mainly by otter trawling and long/handlining. Rays and skates are also mainly caught by otter trawling, and an average of 3,112 t per year were landed between 1993–95.

The biomass was calculated on the basis of 30,000 m² being covered per hour by the beam trawl (Ellis *et al.*, 2000). Personal communication with Jim Ellis had ascertained that, in the absence of western channel trawl data, the Bristol Channel would be the most accurate substitute for Table 2.9. For the eastern Channel, data from the North Sea were used (Sparholt, 1990).

The total biomass entered into Ecopath was 0.42 t/km². This seemed reasonable compared with a value of 0.53 t/km² in the North Sea (Christensen, 1995).

Diet composition data came from the Bristol Channel for thornback ray (Ajayi, 1982), spurdog (Ellis *et al.*, 1996), lesser-spotted dogfish (Ellis *et al.*, 1996), cuckoo ray (Ellis *et al.*, 1996) and spotted ray (Ajayi, 1982) and were weighted according to biomass.

Where there were no data in one area, then the other area was extrapolated to include the unknown. Where there was no data at all the species was deemed too rare to warrant inclusion.

26) Pollack

According to Fishbase (Froese and Pauly, 2000) the range of haddock (*Melanogrammus aeglefinus*) and saithe (*Pollachius virens*) extends into the Channel, and so, initially, this group included both these species. But the absence of any reported catches (Ulrich, 2000), and the biogeographical work of Pawson (1995), suggests that they are absent from the Channel. This group, therefore, was entirely composed of pollack (*Pollachius pollachius*). The biomass of pollack was estimated as 3,308 t (0.037 t/km²)

Table 2.9 Estimated biomass of rays and dogfish in the Channel from beam trawls.

Species	East Channel t/km ²	West Channel t/km ²	Average biomass
Cuckoo ray	No data	0.042	0.042
Spurdog	No data	0.0807	0.081
Les'r-spotted dogfish	0.21	0.007	0.135
Small-eyed ray	0.07	No data	0.07
Great'-spotted dogfish	No data	No data	0
Blonde ray	No data	No data	0
Longnosed skate	No data	No data	0
Blue skate	No data	0.005	0.0053
Spotted ray	No data	0.0088	0.0088
Blonde ray	No data	No data	0
Thornback ray	0.12	0.014	0.0808

using data provided by the CFSG.

The diet composition of pollack was taken from work in the Norway (Bergstad, 1991): 7.3 % of the diet were unidentified teleosts and these were assigned to small demersals.

27) Large bottom fish

This group was an aggregation of three large bottom dwelling fish and included anglerfish (*Lophius piscatorius*), ling (*Molva molva*), and conger eel (*Conger conger*). 978 t of conger eel were caught in the channel worth 2.2 €/kg, 1,338 t of ling were caught worth 2.1 €/kg and 2,011 t of anglerfish were caught, worth 5.5 €/kg.

Anglerfish biomass was calculated using an ICES stock assessment for areas VIIb-k and VIIIa, b and d (Anon., 2000e) and it was assumed that all of the 2,011 t caught were from this stock. The total stock biomass averaged between 1990-98 was 87,622 t and the total catch was 17,945 t, of which 11.2% was caught in the Channel. This equated to a Channel biomass of 9,814 t. Ling biomass was calculated as 6,172 t using data from the CFSG. Conger eel biomass was unavailable, but was based on the catch to biomass proportion of ling because the same types of gear caught them, mainly fixed net and longlining. The catch of ling was 21.7% of the biomass and, assuming the ratio was the same for conger eel, a catch of 978 t implies a biomass of 4,511 t. So the total biomass for this group was calculated as 20,498 t (0.229 t/km²).

Diet composition for the large bottom fish group was based on data for anglerfish from the Irish Sea (Crozier, 1985) and conger eel from the Bay of Biscay (Olaso and Rodriguez-Marin, 1995), weighted according to their biomass. Presence/absence information for ling (Froese and Pauly, 2000) indicated that the diet includes benthic invertebrates, whiting and other finfish, and hence appeared similar to the weighted diets of anglerfish and conger eel.

28) Seabreams

This group includes blackspot seabream (*Pagellus bogaraveo*), gilthead seabream (*Sparus auratus*) and black bream (*Spondyliosoma cantharus*). Of the three breams, only black bream are caught commercially. Black bream are primarily caught by otter trawling, but are also caught by midwater trawls. The biomass of black bream was calculated as 10,582 t (0.118 t/km²) using data from the CSFG.

Diet composition came from black bream off the coast of Portugal (Gonçalves and Erzini, 1998).

29) John Dory

This group is comprised entirely of John Dory (*Zeus faber*). A trawl survey of the western Channel gave a CPUE of 1.2 individuals/hr and in 1 hour the trawl covered 0.059 km² (Symonds and Vince, 1992). The mean average size of John Dory caught in the Channel was 29 cm (Dunn, 2000), which equated to a weight of 0.479 kg ($a=0.02$ and $b = 2.91$ (Froese and Pauly, 2000)). The number of individuals multiplied by the average weight equalled 0.575 kg in 0.059 km². Multiplying this by the area of the Channel gave a biomass in the Channel of 869 t (0.01t/km²).

The diet composition for John Dory came from Greece (Stergiou and Fourtouni, 1991). 39% of the diet was unallocated bony fish. On the advice of M. Dunn (*pers. comm.*), this was equally split between sprats and small demersals.

30) Sandeel

Sandeels (*Ammodytes tobianus* and *Ammodytes marinus*) proved something of an unknown quantity. In the North Sea there is a large sandeel fishery probably because of extensive sandy habitat in areas like the Dogger Bank (M. Pawson, *pers comm.*). A North Sea Ecopath model reports a sandeel biomass of 2.58 t/km² (Christensen, 1995), and diet information for seabirds and whiting from the North Sea indicate that sandeels are a very important prey species (Furness, 1994; Daan, 1989). Even in the absence of seabird and whiting diet specific to the Channel, the model indicates that sandeels are important prey. Discussion with scientists from CEFAS did not ascertain whether this was correct. It seems on the basis of sediments (Larsonneur *et al.*, 1982) that sandeels may be locally important in bays along the English Channel coast, but this has not been confirmed. Sandeels are not landed commercially in the Channel, but they are caught for bait, although the quantity of this catch is unknown. Consequently, the model calculated the biomass of sandeels from an ecotrophic efficiency of 0.95 as 0.68 t/km². These figures seem low

for a small planktivorous pelagic fish compared to other ecosystems, but may be reasonable if local abundance in suitable sandy areas is averaged over the whole Channel.

According to Meyer *et al.* (1979) zooplankton composes 100% of the diet of the American sandlance (*Ammodytes americanus*) and this was split 60% to zooplankton and 40% to gelatinous zooplankton. This American sandlance diet was used to represent sandeel in the model.

31) Herring

Both the herring (*Clupea harengus*) and pilchard (*Sardina pilchardus*) fisheries have fluctuated in the English Channel according to sea surface temperature (Southward *et al.*, 1988a). The fishery for herring in the western Channel is no longer prosecuted regularly (Pawson, 1995) but small resident stocks still remain. The biomass of these in the western Channel was calculated as 2,134 t using data from Ulrich (2000). In the eastern Channel, migration of the large Downs herring stock makes biomass calculations complicated. Personal communication with M. Pawson and Beatriz Roel, both of CEFAS, ascertained that approximately half of the herring in the Downs stock would be in the Channel during spawning time. They will remain in the eastern Channel from November through to February before returning to the North Sea. Whilst in the Channel these adult herring do not feed. ICES working group data (Anon., 2001c) estimated that on average between 1990-1999 the Downs stock made up 22.8% of the total North Sea Stock. The biomass of the total North Sea herring stock averaged over 1990-99 is 2,443,985 t and the total catch was 523,011 t (Anon., 2000a). So 22.8% of this is 557,473 t. Half of 557,473 t = 278,737 t present in the Channel for only 4 months and not feeding. The resident population was only 1% of the total so in the diet composition import was set as 99% and the resident diet squeezed into the remaining 1%. The total biomass was 3.134 t/km².

The diet composition of herring came from a study in the Irish Sea (Rice, 1963).

32) Sprat

The 2000 ICES herring assessment (Anon., 2000a) includes a short section on sprat (*Sprattus sprattus*) in areas VIIId and VIIe. It comments that "the state of the stock is unknown" and so locating information on their biomass has proved difficult. The method of estimating the sprat stock from egg abundances as with pilchards (see below) proved problematic because a) the mesh used did not sample all of the

eggs as sprat are smaller than mackerel or pilchard, b) the early larvae are not sampled well either and c) the commercial fishery for sprats is well east of Plymouth meaning that they were not consistently sampled by the Marine Biological Association (A. Southward, MBA, *pers. comm.*). Christensen (1995) gave a value of 0.55 t/km² for the North Sea but this was when the catch rates were 0.34 t/km². In the Channel 2,159 t of sprat were caught and this meant a catch rate of 0.024 t/km² (Ulrich, 2000). Using the same catch/biomass proportion of Christensen (1995) would result in a biomass of 0.039 t/km², or 3,479 t in the whole Channel. This seems low and there is too much predation on sprats for this to be a valid figure.

An acoustic survey in the Bay of Biscay estimated 193,000 t pilchards, 18,000 sprats, 105,000 mackerel and 37,000 scad (Anon., 1999c). So the ratios were sprat = 1, scad = 2.06, mackerel = 5.83 and pilchards = 10.72. In the 1995 Channel model there was 1.515 t/km² of mackerel so dividing this by 5.83 equalled 0.260 t/km² of sprat. Dividing the scad value of 0.852 t/km² by 2.06 equalled 0.416 t/km². There are many problems with this method, notably that when the same technique is applied to pilchards a biomass of between 2.7 and 3 t/km² is calculated, which is much more than is estimated below. According to Keith Bower (Brixham Sea Fisheries Inspectorate, *pers. comm.*) the fishery is opportunistic so that when the shoals of sprat are present, local boats will change over from their normal mode of fishing to catch them whilst the market can support their supply. This may help to explain why consistent biomass estimates were impossible to locate. Further biomass data were available from (Milligan, 1986). An estimate of 497,932 t (5.56 t/km²) for the Channel was calculated based on 3 plankton cruises carried out in 1981 and a fecundity/length relationship from the west coast of Scotland (De Silva, 1973). This biomass estimate seems high, and because sprat egg counts were not separated by A. Southward (*pers. comm.*), it was very difficult to determine if this was an extraordinary egg production year or if there were errors in the estimation. Steve Milligan (CEFAS, *pers. comm.*) highlighted that there were potential errors in the conversion of eggs to biomass, particularly because sprat are serial spawners, which makes an individual's seasonal fecundity difficult to estimate, but the reason that this method was used was that the landings catch data could a) not be trusted, and b) was not reflective of the sprat population. Clearly there is a great deal of uncertainty with widely ranging estimates for the biomass of sprat from 0.024 – 5.56 t/km². Very little is known of sprat

and this was a situation where it was necessary to allow the model to calculate biomass using an estimated EE of 0.95 as 0.217 t/km², close to the value from the apportionment method outlined above.

Diet composition data came from immature sprat in the North Sea (Last, 1987).

33) Pilchards

The biomass of Pilchards in ICES area VIIIc and IXa, averaged between 1990-99 was 557,850 t. The catch in this area was 125,219 t and using the same catch to biomass ratio for the Channel as the bay of Biscay, and a catch of 5588 t, the biomass in ICES area VIId and VIIe would be 24,895 t or 0.278 t/km².

There was some scope to check this calculation for pilchard. Working from the number of eggs and the fecundity of females, Cushing (1957) and Southward (1963) calculated that there were approximately 10,000 mature pilchards in each km² of the western Channel with a mean size of 20.5 cm. Using the length-weight relationship of a = 0.0059 and b = 3.077 from the Bay of Biscay (Froese and Pauly, 2000) this corresponds to an average weight of 68.8 g. The total biomass of pilchards was calculated as 0.688t/km². It is noteworthy that pilchards were much more abundant in the western Channel than in the east, so this value could be an over estimate. If pilchards were just in the west, then the average biomass for the entire Channel would be 0.434 t/km². The data of Cushing (1957) from the 1950s is useful because it corresponds to a 'warm phase' of the Russell cycle (Figure 3.6), so it is more likely to represent the present than data from the 1970s and 1980s. Hence a biomass of 0.434 t/km² was used in the model.

Pilchard feed on plankton and their gill rakers are small enough to eat phytoplankton. At some stages this can form up to 50% of the gut contents, but zooplankton are the preferred food (Southward *et al.*, 1988a). Using this information and a dietary frequency occurrence study from northern Spain (Varela, 1988), the diet of pilchards was estimated as 70% zooplankton and 30% phytoplankton.

34) Mackerel

The North-east Atlantic mackerel (*Scomber scombrus*) stock is huge and has been the target of such intense fishing effort that the "mackerel box" was created. This is an area off the south-west coast of England where fishing activity is limited to traditional handlining. In the 1960s and 1970s the majority of the stock over-wintered

in the Channel but now after spawning they migrate to northern Scotland (Pawson, 1995). There was a dramatic fall in mackerel landings after 1979 that was officially attributed to a northwest shift of the mackerel stock (Saville, 1985) although local opinion suggests that purse seiners were responsible (Southward and Boalch, 1988b).

The biomass of mackerel in the Channel was calculated on the basis that the catches only came from the Western stock and not the North Sea stock (M. Pawson, *pers. comm.*). The biomass of this stock, which covers areas II, III, IV, V, VI, VII, and VIIIa and b, was 3,397,576 t and the total landings were 657,076 t (Anon., 2000d). Both of these values were averaged from 1990-99. The catch in the Channel was 26,260 t, which was 4% of total catch, which equates to a biomass of 135,784 t (1.515 t/km²) of mackerel in the channel. Because of a large biomass of overwintering mackerel, a second group of mackerel was added to the model.

The diet of mackerel came from the mid north-east Atlantic (Warzocha, 1988) in which 3.105 % of the diet was attributed to 'Clupeidae', split equally between herring, pilchards and sprats in the model.

35) Scad (=horse mackerel)

As recommended by the mackerel and scad working group (Anon., 2000d) and M. Pawson (*pers. comm.*), scad (*Trachurus trachurus*) in the Channel were attributed to the Western stock and were assumed to behave in a similar way to the Western mackerel. There have been only 7 strong year classes in the last 50 years with the most recent of these being 1982. Scad are a long-lived fish, and it is not uncommon to find specimens of 30 years and more (Pawson, 1995). The biomass of the entire stock was estimated to be 2,534,770 t and the total catch 378,595 t (Anon., 2000d). The Channel catch of scad was 11,407 t, which was 3.01% of the total catch of this stock, and hence the total scad biomass equalled 76,373 t (0.852 t/km²) in the Channel. The diet of scad came from a study in the Bay of Biscay (Olaso *et al.*, 1999).

36) Bass

Between 1993-95 the average annual catch of bass (*Dicentrarchus labrax*) in the Channel was 1,097 t (Ulrich, 2000). These were caught by lining (both longlining and handlining), netting, midwater trawling and otter trawling. It is noteworthy that there was also a recreational fishery for bass that caught 415 t in 1987 and 412 t in 1993 (M. Pawson, *pers. comm.*). It was therefore assumed that 412 t were caught by the

recreational fishery each year from 1993 to 1995.

Although there are multiple stocks of bass in the Channel and these do migrate into the southern North Sea and Western Approaches (Pawson, 1995), M. Pawson (*pers. comm.*) suggested that for the purposes of the model it was fair to assume that emigration was equal to immigration. The biomass was calculated as 8,135 t (0.091 t/km²) in the entire Channel using data from the CFSG.

Diet composition for bass came from the Channel (Kelley, 1953). The data were initially in units of frequency of occurrence in 250 fish and this was converted directly into % weight. A juvenile bass group was added during tuning to incorporate the effect of temperature on recruitment.

37) Sharks

Sharks have proved a difficult group to gain information about because there have been no continuously operating commercial fisheries for them in the Channel. In 1991 a limited longline fishery for blue sharks developed off Newlyn, Cornwall, but the majority of shark catches seem to have been made by recreational fisheries (Vas, 1995). The three species, tope (*Galeorhinus galeus*), porbeagle (*Lamna nasus*) and blue shark (*Prionace glauca*) seem to be the most significant, although starry smooth-hound (*Mustelus asterias*), smooth-hound (*Mustelus mustelus*) and thintail thresher (*Alopias vulpinus*) were also occasionally present. The biomass of sharks in the Channel is difficult to estimate because not all catches of sharks are reported and many shark fisheries are opportunistic, only existing when there is a high biomass in a certain area (Vas, 1995). Exploitation of the Channel blue shark population by a sport fishery began in 1952 and there have been significant declines in catches since the 1960s (Vas, 1990).

The current catch of sharks per year is approximately 500 (Vas, 1995). Assuming a catch rate of 10 % there would be 5000 sharks in the Channel. The average weight of blue sharks caught and tagged off the coast of Ireland was 22kg (www.shark.ie). Assuming that the average weight caught is representative of that in the Channel, 5000 * 22 = 170,000 kg or 170 t in the whole channel (0.0012 t km²).

The biomass of tope was assumed to be the same as in the North Sea, which was 0.0035 t km² (Sparholt, 1990). Approximately 5,000 tope were caught around the UK per year but the 'majority' were released (Vas, 1995). It was assumed that 10

% were kept and half of these came from the Channel, this meant that 250 tope were caught from the Channel. Based on data from Leonard Nevell (UK Shark Trust, *pers. comm.*) the estimated weight of fish landed from the Channel was 20 kg. So the biomass caught would be 5 t.

The biomass of porbeagle was also difficult to determine. Off the coast of Cornwall and west Wales there were an estimated 25 sharks landed per year (Vas, 1995) with a mean weight of 35-40 kg. Assuming a catch rate of 10%, a mean weight of 37.5 kg and that half of these were in the Channel the biomass could be approximately estimated as 4.68 t in the entire Channel. The total biomass of sharks was estimated as 0.005 t/km².

The recreational shark fishery only started in the 1960s and seems to have had a significant effect on biomass (Vas, 1990). Using data from Vas (1990) it was assumed that 30% of the catch of blue shark was landed. At 34 kg per fish (the minimum specimen weight) this meant that the catch in the whole channel was 5.1 t. Combined with tope (5 t) and porbeagle (0.47t) the total catch was estimated as 10.57 t or 0.00012 t/km².

Cephalopods constitute 100% of the diet of blue shark off the coast of France (Clarke and Stevens, 1974) and porbeagle in the NW Atlantic (Bowman *et al.*, 1900). But (Stevens, 1973) showed qualitatively that clupeids and mackerel were important in the Channel, and so in the model 70% of the diet was allocated to cephalopods, 20% to mackerel, 3.3% to sprat, 3.3% to herring and 3.3% to pilchard.

38) Basking sharks

High concentrations of zooplankton off the south west coast of England attract basking sharks (*Cetorhinus maximus*), which remain in the area from May to July. The range of basking sharks extends throughout the western Channel to the Isle of Wight in the North and the Channel Islands in the South (D. Sims, MBA, *pers. comm.*), depending on the location of fronts and the abundance of zooplankton (Sims and Quayle, 1998). A boat survey identified 58 individual sharks from May to July in an area of 350 km² (Sims *et al.*, 1997). The mean length of these sharks was 4.06 m, which corresponds to a weight of 328 kg ($a = 0.0049$ and $b = 3$ (Froese and Pauly, 2000)). Assuming that there were 58 sharks per 350 km² throughout the western Channel for the entire 3 months, there would be 9,360 basking sharks. This is most likely an overestimate because of the patchy distribution of zooplankton. Assuming that the mean weight of

the sharks was 328 kg, this implies a biomass of 3,070 t (0.034 t km²) for 3 months of the year.

February 2001 saw the start of a 3-year project to investigate the abundance and migration of basking sharks in European waters. It seems that the biomass present in the Channel changes from year to year (Speedie, 1999), and that the ecosystem impact of basking sharks is not fully understood.

The consumption of basking sharks is only recently being determined. Basking sharks feed entirely on zooplankton (Sims *et al.*, 1997) and copepods seem to dominate although they also consume teleost eggs, chaetognaths, larval crustacea and at least one species of deepwater shrimp (*Sergestes similes*) (Martin, 2002). The traditional opinion was that they migrate to deeper water during November to March (Matthews and Parker, 1950), but current research suggests that they continue to search for food all year (D. Sims, *pers. comm.*). For the model it was estimated that 30% of their consumption came from the Channel and 70% of their diet was indicated as an import. This represents the fact that a high proportion of their feeding may be outside the boundaries of this study.

39) Cephalopods

This group included squid (*Loligo forbesi* and *Loligo vulgaris*) and cuttlefish (*Sepia officinalis*). The squid species have the same economic value (3.4 €/kg) and are not distinguished by the fishing industry. Between 1993-1995 an annual average of 4,065 t of squid were landed with the more common species being *Loligo forbesi* (Holme, 1974). Squid are almost entirely caught by otter trawling. Squid migrate westwards from the eastern Channel during the autumn and winter as the temperature decreases but they remain in the deeper waters of the western Channel and so no immigration/emigration was included in the biomass calculations. Robin *et al.*, (1998) used landings per unit effort to estimate abundance of squid in area VIIId. This was averaged from 1993-1995 and extrapolated for the entire Channel, so that 0.181 t/km² was calculated for the entire squid catch, composed of *Loligo vulgaris* and *L. forbesi*.

Between 1993-1995 the annual average catch of cuttlefish in the Channel was 10,568 t. The catch of cuttlefish has shown a dramatic increase since the 1980s when market prices were less than 30 % of what they were in 1993-1995 (Dunn, 1999a). Trawl surveys in the eastern Channel indicated that the biomass of cuttlefish, when it was present

Table 2.10 Estimated numbers of seabirds in the English Channel.

Species	Breeding pairs	Non-breeders proportion	Body mass (g)	Days in area
Northern fulmar	3,100	0	810	365 #
Manx shearwater	550*	0.6-all months	450	240 #
British storm petrel	550*	0.5-all months	26	180 #
Arctic skua	10	0.2-all months	465	150 #
Great black-backed gull	1,700	0.2 (2 months), 0.1 (1 month)	1600	365 #
Common tern	4,077	0.1 – 2 months	125	200 #
Arctic tern	5	0.1 – 2 months	100	100 #
Sandwich tern	900	0.1 – 2 months	235	150 #
Guillemot	4,200	0	980	365 #
Puffin	700	0.3 – 3 months	390	365 #
Gannet	9,400	0.2 – 3 months	3000	180 ~
Cormorant	2,600	0.2 – all months	2200	365 ~
Shag	2,400	0.2 – all months	1810	365 ~
Black-headed gull	27,600	0.2 (2 months), 0.1 (1 month)	250	180 ~
Common gull	8	0.2 (2 months), 0.1 (1 month)	380	180 ~
Lesser blackbacked gull	3,000	0.2 (2 months), 0.1 (1 month)	800	180 ~
Herring gull	18,500	0.2 (2 months), 0.1 (1 month)	900	180 ~
Kittiwake	1,480	0.2 – 2 months	390	180 ~

*Refers to an estimate taken, which recorded there were between 101 and 1000 pairs. Number of breeding pairs information from Webb *et al.* (1995). Proportion of non-breeders from Tasker and Furness (1996) for all species except British storm petrel, Manx shearwater and Arctic skua where the data is from Furness (1994). Body mass information from Furness (1994) and Tasker and Furness (1996). Number of days information was for 'North East Atlantic' from Furness (1994) for all species marked # and from the 'North Sea' for all species marked ~ from Tasker and Furness (1996).

at all, was between 0.08 and 0.37 t/km² (Ellis, 2001). A mid point of 0.23 t/km² was taken for the biomass of cuttlefish and this corresponded to a total Channel biomass of 20,162 t. Combining this with the squid biomass resulted in a total biomass of 0.406 t/km².

Using an empirical relationship where natural mortality increased with increasing growth rate, water temperature and decreasing body size, natural mortality was calculated as 2.0 year⁻¹ (Pierce *et al.*, 1996) for *Loligo forbesi*. For *Sepia aculeata* natural mortality was calculated as between 1.33 year⁻¹ and 2.75 year⁻¹ (Rao *et al.*, 1993) and for *S. elliptica* M was 1.59 year⁻¹ (Kasim, 1993). Both of these are Indian species and given that the water in the Channel is cooler, a lower natural mortality would be expected. Hence it was assumed that cuttlefish have a natural mortality of 1.5 year⁻¹. Weighting cephalopod mortalities on the basis of biomass generated a natural mortality of 1.72 year⁻¹. Fishing mortality was estimated to be 0.75 year⁻¹ from a personal communication with M. Dunn. These mortalities were combined to represent the P/B of the entire group as 2.47 year⁻¹.

Consumption/biomass was taken to be 15 year⁻¹ based on a value used for squid from a model of the Alaska gyre (Pauly and Christensen, 1996). There were no % weight diet composition studies available for either squid or cuttlefish. Pinczon du Sel *et al.* (2000) gave an account of the % frequency in the diet of cuttlefish in the northern Bay of Biscay. This indicated that benthic

crustaceans, scad and small demersal fish were most abundant in the diet. For squid, frequency of occurrence data were used for *Loligo forbesi* from Scotland (Pierce *et al.*, 1994) and for *Loligo vulgaris* from Portugal (Pierce *et al.*, 1994). Frequency of occurrence data were converted to percentages and then weighted according to biomass with 80% of the squid biomass being attributed to *Loligo forbesi*.

40) Seabirds

This group includes fulmar (*Fulmarus glacialis*), Manx shearwater (*Puffinus puffinus*), storm petrel (*Hydrobates pelagicus*), gannet (*Sula bassana*), cormorant (*Phalacrocorax carbo*), shag (*Phalacrocorax aristotelis*), arctic skua (*Stercorarius parasiticus*), Mediterranean gull (*Larus melanocephalus*), black-headed gull (*Larus ridibundus*), common gull (*Larus canus*), lesser black-backed gull (*Larus fuscus*), herring gull (*Larus argentatus*), great black-backed gull (*Larus marinus*), kittiwake (*Rissa tridactyla*), sandwich tern (*Sterna sandvicensis*), roseate tern (*Sterna dougalli*), common tern (*Sterna hirundo*), arctic tern (*Sterna paradisaea*), little tern (*Sterna albifrons*), guillemot (*Uria aalge*), razor bill (*Alca torda*) and puffin (*Fratercula arctica*).

The biomass of this group was calculated by multiplying the number of seabirds (times two for pairs) in the Channel (Webb *et al.*, 1995) by their body mass and by the length of time they spend there (Table 2.10). In addition, there will be colonies in the Channel attended by non-breeding and pre-breeding seabirds. As information on this proportion in the Channel was not available, studies on the North Sea populations were used (Table 2.10). Total biomass for this group was 105.8 t (0.0012 t/km²).

The daily ration of seabirds was calculated from the equation:

$$\text{LogR} = -0.293 + 0.85 \log W$$

where R is the daily ration in g and W is the body weight in g (Nilsson and Nilsson, 1976). This value was divided by the mass of the bird and

Table 2.13 Estimates of grey and harbour seals in the Channel. * refers to guesstimates made by V. Ridoux and C. Duck (*pers. comm.*).

Location	Seal species and abundance
Sand banks off Dunkirk	5 Grey, 5 Harbour
Bay of Somme	60 Harbour
Bay des Veys	20 Harbour
Channel Islands	50 Grey *
Baie du Mont Saint Michel	5 Grey, 15 Harbour
St Malo to Brest	20 Grey
Western tip of Brittany	50 Grey
Isolated individuals, Brittany	10 Grey
Isles of Scilly	750 Grey *
Cornwall	200 Grey *
Poole	20 Grey *

'R' in body weight per day (Innes et al., 1987):

$$R = 0.1 \cdot W^{0.8}$$

where W equals the individual weight in kg. This value was multiplied by 365 and then divided by the individual mass to get Q/B and weighted according to biomass leading to a value of 13.727 year⁻¹.

Diet composition was calculated from standardized diets in Pauly *et al.*, (1998a) (Table 2.12) and split to suit the respective groups in the Channel. These values were weighted by biomass and entered into the model.

42) Seals

Population estimates for seals in the Channel were very difficult to locate as much of the British research is based at the Sea Mammal Research Unit in Scotland and has been conducted off the Scottish coast. Personal communications from Callan Duck (Sea Mammal Research Unit, University of St. Andrews) and Vincent Ridoux (Centre de Recherche sur les Mammifères Marins) provided the estimates displayed in Table 2.13.

Based on Table 2.13, there are 1,110 Grey seals (*Halichoerus grypus*) and 100 harbour seals (*Phoca vitulina*) in the Channel and it was assumed that they remained there for the entire year. Based on a mean mass of 63.6 kg for harbour seals and 160 kg for grey seals (Trites and Pauly, 1998) the biomass was then estimated as 184 t (0.0021 t/km²).

The P/B ratio for this group was assumed to be 0.04 year⁻¹ based on a pinniped group in a BC shelf model (Pauly and Christensen, 1996). The Q/B ratio was calculated in the same way as toothed cetaceans using the equation:

$$R = 0.1 \cdot W^{0.8}$$

and a value of 14.567 year⁻¹ was entered into Ecopath.

Diet composition for harbour seals came from the south-west North Sea (Hall *et al.*, 1998), and from the Inner and Outer Hebrides for grey seals (Hammond, 1994). Both of these were based on faeces. The grey seal data was averaged throughout the year and for both the Inner and Outer Hebrides. These estimates were weighted according to biomass and entered into the model.

43) & 44) Detritus groups

The detritus group was further split into a discarded catch group. All discards went to the latter group, which then fed seabirds. The biomass of discarded catch was 0.046.

Prebalancing Diet Matrix

The complete pre-balancing diet composition for the 1995 model is shown below in table 2.14.

Table 2.14 Pre-balancing diet composition for an Ecopath model of the English Channel in 1998. For predators read vertically and for prey, read horizontally. Lobsters, rays and dogfish, bass, sharks, basking sharks, seabirds, toothed cetaceans and seals were not included as prey in this table because they were not consumed by anything.

Group	Zooplankton	Carn. zp.	Dep. feeders	Sus. Feeders	Shrimps	Whelk	Echinoderm	Bivalves	Scallops	Crab	Comm. crab	Lobster	Sm. dem.	Sm. gads.	Mullet	Sole	Plaice	Dab	O. flatfish	Gurnards	Whiting	
Prim. prod	.900			.100	.085		.050	.500	.500			.016	.001									
Zooplankton	.030	1.00		.450	.360								.003	.014	.140	.001					.314	.099
Carn. Zp.																						
Dep. feeders				.100	.030	.700	.110					.025	.871	.176	.820	.832	.675	.844	.640	.329	.071	
Sus. feeders							.005					.048		.456				.005	.200			
Shrimps						.050				.150	.150		.041			.130		.045		.190	.049	
Whelk												.032										
Echinoderms						.050	.060					.168	.014							.032	.003	
Bivalves						.100	.050			.200	.200	.107	.060	.002				.040	.128		.015	
Scallops																.037						
Crab						.100				.030	.030	.500	.005	.278	.028		.001			.066	.049	
Comm. crab																					.002	
Sm. dem.													.005	.075			.102	.066		.101	.090	
Sm. gads																					.239	
Mullet																						
Sole																						
Plaice																						
Dab																						.007
O. flatfish																						
Gurnards																						
Whiting																						.018
Cod																						.001
Hake																						
Pollack																						
Lg. bottom																						
Seabream																						
John Dory																						
Sandeels																						.252
Herring																						.028
Sprat																						.077
Pilchard																						
Mackerel																						
Scad																						
Cephalopods																						
Discards																						
Detritus	.070		1.00	.350	.525		.725	.500	.500	.620	.620	.104			.012							
Import																		.222				

Table 2.14 *continued.*

Group	Cod	Hake	Rays/dogfis	Pollack	Lg. bottom	Seabream	John Dory	Sandeels	Herring	Sprat	Pilchard	Mackerel	Scad	Bass	Sharks	Basking shk.	Cephalopods	Seabirds	Tooth. cet.	Seals	
Prim. prod											300						.048				
Zooplankton	.050		.017	.002			.610	.600	.006	.960	.700	.969	.198			.300		.022			
Carn. Zp.								.399													
Dep. feeders	.112		.130	.049	.069	.817		.001		.040		.001	.543	.006			.003	.032			
Sus. feeders			.015	.303		.038							.069								
Shrimps	.161		.050		.066								.005	.117							
Whelk			.007																		
Echinoderms	.009		.007			.053															
Bivalves			.004		.016	.001							.007							.001	
Scallops																					
Crab	.161	.020	.367		.007				.001				.017	.542			.552	.032			
Comm. crab			.003											.002							
Sm. dem.			.073	.236	.175	.001	.195		.001				.091	.034			.149			.025	
Sm. gads	.131	.042	.083	.410	.287												.084	.001		.007	
Mullet		.004	.060		.081								.037				.010				
Sole			.006														.004			.002	
Plaice	.161		.003																	.037	
Dab			.003		.017															.001	
O. flatfish			.008		.042															.104	
Gurnards					.006																
Whiting	.030	.053	.029		.123															.057	.075
Cod	.017				.010															.057	.126
Hake		.042			.006																
Pollack	.040		.002		.007															.057	.115
Lg. bottom																					.283
Seabream																	.003		.057		
John Dory		.010																			
Sandeels	.080		.020						.001					.297			.073	.360		.131	
Herring	.023		.042		.078							.010			.033		.040	.017	.030	.009	
Sprat	.022	.105	.007				.195					.010			.033			.141	.070		
Pilchard		.183	.011									.010	.019		.033			.017	.070		
Mackerel		.085	.017		.009										.200		.004	.108	.110	.030	
Scad		.455	.007														.005		.070	.013	
Cephalopods		.001	.030		.001	.090							.014	.002	.700		.025		.424	.042	
Discards																					
Detritus																					
Import									.991							.700					

Table 2.15 Annual Channel catch by gear type (t/km²), averaged between 1993-1995 using data provided by Ulrich (2000). Midw refers to midwater trawling, S'weed refers to seaweed harvesting and Sport refers to recreational angling.

Group	Otter	Beam	Midw	Dredge	Net	Pot	Line	S'weed	Sport	Total
Prim. prod.	0.003							0.647		0.650
Shrimps	0.004					0.002				0.006
Whelk						0.114				0.114
Bivalves				0.151						0.151
Scallops	0.011	0.002		0.297						0.310
Comm. Crab	0.002				0.032	0.132				0.166
Lobster						0.005				0.005
Sm. Gadoids	0.044	0.004	0.001							0.050
Mullet	0.010	0.001	0.001							0.012
Sole	0.018	0.011		0.007	0.022	0.002				0.060
Plaice	0.036	0.018	0.001	0.009	0.010					0.074
Dab	0.008	0.001		0.001	0.001					0.011
O. flatfish	0.017	0.008		0.002	0.003					0.030
Gurnards	0.055	0.002	0.002							0.059
Whiting	0.066	0.001	0.004		0.002					0.073
Cod	0.019	0.001	0.001		0.013					0.034
Hake	0.002				0.002					0.004
Rays/dogfish	0.055	0.002	0.001		0.008		0.009			0.075
Pollack	0.011				0.009		0.001			0.021
Lg. Bottom	0.020	0.005		0.001	0.011		0.011			0.048
Seabream	0.017		0.007							0.024
John Dory	0.004									0.004
Herring	0.004		0.076							0.080
Sprat			0.024							0.024
Pilchard	0.001		0.061							0.062
Mackerel	0.040		0.239				0.014			0.293
Scad	0.011		0.116							0.127
Bass	0.004		0.001		0.002		0.004		0.005	0.016
Sharks									0.0001	0.0001
Cephalopods	0.129	0.018	0.002	0.002	0.002	0.010				0.163

Catch Data

Fishery catch data were based on an average of 1993-1995 from the BAHAMAS (Base Halieutique pour Manche Stratifiée) database (Dintheer, 1995). This is primarily an aggregation of national landings statistics from France, the UK and Belgium, but also includes fish caught in the Channel and landed elsewhere. The catch data were broken down into 8 gear types and are shown in Table 2.15. We also includes a recreational fishery that incorporated the catch of sharks (Vas, 1995) and bass (M. Pawson, *pers. comm.*).

There are a number of possible sources of error in this catch data (M. Dunn, *pers. comm.*):

- Non-quota species do not have to be recorded in log-books. It is a false assumption that statistics will be better because there is no reason to mis-report as some fishers simply do not record catches if they do not have to;

- Mis-reporting of landings to avoid management restrictions;
- Illegally landed 'black' fish that would have exceeded quotas;
- Fabrication of landings in order to maintain track records;
- Data from merchants may not be complete because the catch may be sold directly to hotels and restaurants, or used as bait;
- Recreational landings are not recorded;
- Discard data is scarce due to the expense of observers needing to be onboard vessels.

In an attempt to allow for these sources of error, the catch data were modified by Ulrich (2000), so that the values used in the model are the best estimates available.

Table 2.16 Métiers where discarding was measured by the UK Sea Fish authority.

Year	Métier code	Name	Gear and Area of Activity
1995	U1.1	UK TR West	Otter trawl west
1995	U1.2	UK TR East	Otter trawl east
1995	U2.1	UK Beam Off. East	Beam offshore east
1995	U2.2	UK Beam Off. West	Beam offshore west
1995	U2.3	UK Beam In. West	Beam inshore west
1995	U4.1	UK Dredge West	Scallop dredge west
1997/8	U4.1	UK Dredge West	Scallop dredge west
1997/8	U4.2	UK Dredge West	Scallop dredge west

Discards

Otter trawling, beam trawling and dredging discards

The UK fishing industry authority, Sea Fish, commissioned a number of surveys of discarding in the Channel during 1995 (Course *et al.*, 1996) and 1997/8 (Searle *et al.*, 1999). Onboard discard officers measured the size and quantity of discards in 8 UK métiers (Table 2.16). These surveys were used to estimate an average discard rate for each gear as a proportion of the catch. When catch data were split into the eastern and western Channel, as for cod and whiting, the quantity of discards could be calculated for both sides of the Channel independently. For some groups, there were discards when there were no actual catches, which made it impossible for discards to be estimated as a proportion of the catch of that group. Hence the following decisions were made: for spider crabs, discards were set on the basis that for every 130 kg of plaice landed in the western Channel there were 8 kg of spider crab discarded. In the eastern channel the ratio was 41 kg of plaice to 88 kg of spider crab. For beam trawls in the western channel the ratio was 536 kg of plaice to 78 kg of spider crab and in the eastern Channel, 252 kg of plaice to 37 kg of spider crab. For scallop dredging in the western channel it was 6,556 kg of scallop landings and 23 kg of spider crab, in the eastern Channel it was 168 kg of discarded spider crab and 6027 kg of scallop. The percentage of scallop discards was fairly high but Grant Course (CEFAS, *pers. comm.*) maintained that while there would be displacement, scallops were returned alive. As a result discards for scallops and bivalves were set as 0. For rays, the % weight of discards was averaged for spotted ray, blond ray, thornback ray and cuckoo ray. Occasionally in the discard data there would be dragonets and other small demersals but these were in tiny

quantities and were not included in the model. Although there were only a few whelks officially landed from trawlers, the mortality caused by beam trawlers in the North Sea was high (Mensink *et al.*, 2000). Consequently the discards were set as 0.01t/km²

Midwater trawling discards

IFREMER commissioned a study of discarding from the midwater/pelagic trawling sector (Morizur *et al.*, 1996) and the results of this are shown in Table 2.17. Because these métiers were only active in the western Channel, it was assumed that they were representative of the whole Channel. Using Table 2.17, discards were estimated for the entire Channel (Table 2.18).

Herring seemed to have discards that were too low, and so a value of 6.4 % was used based on the total herring discards in ICES areas IVc and VIIId (Anon., 2000a). Scad data were compared with Western stock discard data from Anon. (2000d). The range of this from 1990-1997 was 0.5-4.4 % with the mean being 1.7. The value of 3 % from (Morizur *et al.*, 1996) is hence plausible. For cephalopods it was estimated that there were 1% discards based on Anon. (2000b), who wrote that “the proportion of all commercial cephalopod species discarded can be considered to be negligible compared with landings”.

In the absence of data, it was necessary to estimate the discards for some species. For French pilchard fisheries in the Bay of Biscay, there were sprat discards of 0.05 t for every ton of pilchard landed (Morizur *et al.*, 1996), and so 5 % of the Channel pilchard catch equals 269 t, which was therefore used as the quantity of sprats discarded. The other species caught by midwater

Table 2.17 Midwater/pelagic trawling métier discarding for vessels that were relevant to the catch data. Modified from Morizur *et al.*, (1996).

Fisheries	Métier code	Total discards (t) per landed ton of target species	Main discards	Discards (t) per landed ton of target species
French black bream trawling (VII e)	F3.1	0.34	Black bream	0.10
			Pilchard	0.11
			Mackerel	0.10
			Scad	0.03
French sea bass trawling (VII e, VII b)	F3.1	0.021	Mackerel	0.006
			Pilchard	0.006
			Lumpsucker	0.005
			Garfish	0.003
			Herring	0.001
UK mackerel trawling (VII e)	U3.1	0.13	Mackerel	0.1
			Pilchard	0.03
UK pilchard trawling (VII e)	U3.1	0.14	Pilchard	0.07
			Mackerel	0.07

Table 2.18 Discarding of the main species caught by midwater trawlers in the Channel.

Species	French % discard	UK % discard
Mackerel	5.3	8.5
Bass	0	0
Black bream	10	Not caught
Pilchard	5.8	5
Scad	3	3 (Assumed)
Herring	0.1 (6.4)	Unknown (6.4)

trawling were all non-commercial and were caught in small quantities. In the absence of data, the discard level was assumed to be 0.

In the IFREMER study (Morizur *et al.*, 1996), the French bass fishery caught a single common dolphin, while trawling in the Bay of Biscay caught both bottlenose and common dolphins. The direct impact that fishing has on the cetacean population is still unknown (Cresswell and Walker, 2001), but has been estimated here.

A dolphin report from Cornwall highlighted that midwater trawl fisheries kill dolphins (Anon., 2001a) although it is not known exactly how many. This report described 100 dolphins washed up on the coast of Cornwall between January and March 1992, and 30 and 20 respectively during the same periods in 1993 and 1994. Because these figures covered just the coast of Cornwall, and only extended over a quarter of the year, a value of 200 dolphins per year was estimated to be killed by the pelagic trawl fishery, equating to a 0.00018 t/km². There was also a bycatch of porpoises from the Celtic Sea hake gillnet fishery, estimated to be 6.2% of the population per year (Cresswell and Walker, 2001). As described above, the majority of the hake stock exists outside of the

Channel, and so the porpoise kill in the Channel is likely to be a lot less. In lieu of actual data, it was estimated that 2% of the porpoise biomass was killed, i.e., 6×10^{-6} t/km².

Net discards

It was possible to estimate the netting discards from Smith *et al.* (1995). This report outlined the discard rates of the English static net fisheries. For all species, except for whiting and plaice, there was only a single value available for the level of discarding, hence this was used to represent the discard rate for all métiers. Whiting and plaice were caught by a number of métiers and there were different discard percentages depending on the métier. For plaice it was either 30% discards (in the sole net métier) or 0% in the plaice net métier. When 290 t of sole were caught, there were 5 t of plaice and this ratio was used to calculate the plaice discards. Whiting discards were low in all métiers, and so were set at 0%.

Discard summary

In the absence of data to the contrary, it was assumed that all of the fish that were discarded died, except for the flatfish. For all flatfish groups in the model (sole, plaice, dab and other flatfish) the percentage of discards surviving was assumed to be 50% from otter trawls (Millner *et al.*, 1993) and 10% from beam trawls (Van Beek *et al.*, 1989). There was no data available for discards from potting or lining, and so this was left as 0%.

The final discards that were entered into Ecopath are shown in Table 2.19.

Balancing the Model

Table 2.19. Channel discards, in t/km², as entered into the Ecopath model. The potting, lining, seaweed and recreational fisheries were assumed to have zero discarding.

Group	Otter trawl	Beam trawl	Midw trawl	Dredge	Net	Total
Whelk		0.010				0.010
Commercial crab	0.065	0.002		0.003		0.070
Small gadoids	0.046	0.006				0.052
Mullet	0.001					0.001
Dab	0.017	0.003			0.005	0.025
Sole				0.001	0.001	0.001
Plaice	0.010	0.001		0.002		0.013
Other flatfish	0.002	0.009				0.011
Gurnards	0.049	0.001				0.050
Cod	0.001					0.001
Whiting	0.014	0.002				0.016
Rays and dogfish	0.012	0.001				0.014
Pollack	0.018					0.018
Large bottom fish				0.003	0.001	0.004
Seabream	0.018		0.001			0.019
Herring			0.005			0.005
Sprat			0.003			0.003
Pilchard			0.003			0.003
Mackerel	0.011		0.019			0.030
Scad	0.007		0.003			0.010
Bass	0.0001					0.0001
Cephalopods	0.001					0.001
Toothed cetaceans			0.0002			0.0002

Table 2.20 Groups that prevented the model balancing by having an ecotrophic efficiency greater than 1.

Group	Ecotrophic efficiency (EE)
Deposit feeders	1.52
Suspension feeders	2.821
Bivalves	1.868
Crab	1.3
Commercial crab	1.217
Other Flatfish	1.812
Gurnards	1.256
Hake	1.281
Pollack	1.73
John Dory	1.4
Pilchard	1.068

As Table 2.20 indicates, there were a number of groups that had greater mortality than production. The input data indicated that more of them were being eaten or caught than actually existed or were produced. Model balancing is a manual iterative process in which parameters or diet values that are least certain are varied until a satisfactory mass-balance is achieved. [Note that since this work was completed, an auto balancing routine has been developed by Kavanagh *et al.*, (2004).]

The following adjustments were performed on the preliminary values in Table 2-13 and 2 2-14..

- Hake cannibalism was reduced from 0.042 to 0.02, and the P/B was increased to 0.6 year⁻¹ (P/B was changed and not biomass because biomass from both CFSG and ICES data agreed).
- The biomass of pollack was increased from 0.037 t/km² to 0.11 t/km², because fishing mortality was too high.
- The biomass of commercial crab was increased from 0.514 t/km² to 0.65 t/km² because fishing mortality was too high.
- Predation on bivalves by crabs was reduced from 0.2 to 0.08 with the rest going to detritus; still with the increased biomass of crabs there was a high pressure on bivalves that necessitated an increase in their biomass from 17.401 t/km² to 20 t/km².
- The biomass of deposit feeders was increased from 12.660 t/km² to 19 t/km² because of high predation pressure from many groups.
- The biomass of crab was increased from 9.16

t/km² to 10.5 t/km².

- The P/B of suspension feeders was too low to accommodate echinoderm predation pressure, so it was increased from 0.1 year⁻¹ to 0.3 year⁻¹.
- The calculated fishing mortality of sole, other flatfish, mackerel and gurnards was very high compared to predation mortality and this was a function of either too low of a P/B or too low of a biomass. The P/B of 0.347 year⁻¹ for other flatfish was low compared to the other flatfish groups and ICES WG reports indicated an average fishing mortality of 0.32 year⁻¹ for this group. The average natural mortality from these species was calculated as 0.28 year⁻¹ (Pauly, 1980). Total mortality calculated from a combination of these equalled 0.6 year⁻¹, which seemed to be likely when compared to the other flatfish groups in the model, and so the P/B was raised to this value. The biomass was also increased from 0.109 t/km² to 0.155 t/km² because of high fishing pressure. The biomasses of gurnards was increased from 0.201 t/km² to 0.275 t/km² and of John Dory from 0.01 t/km² to 0.0125 t/km² because of high fishing mortality. These changes brought both the EEs close to 0.95.
- The 3% of the mackerel diet that had been attributed to 'Clupeidae' was allocated 1.8% to herring, 1.1% to sprat and 0.1% to pilchard as predation on pilchards from the large mackerel group was too high for the biomass to sustain.
- Bass EE seemed too low at 0.37, and as the fishing mortality was probably only 0.19 rather than 0.4 (M. Pawson, *pers. comm.*), the biomass was reduced to 0.043.

Further adjustments

After conversation with Villy Christensen there were adjustments that needed to be made in the gross efficiency ratio (production/consumption – P/Q). A value of less than 10% is unacceptable for marine fish species (Table 2.21 shows the problem groups). It is noteworthy that although the herring group was only marginally below 10 %, it comes from the same stock as the North Sea and was changed to concur with Christensen (1995).

After these changes had been made, the model was found to be in mass-balance (Table 2.22).

Table 2.21 Problem groups with an unacceptably low P/Q ratio and the necessary changes that were made.

Group	P/B	Q/B	P/Q	Changes made to rectify P/Q
Mullet	0.496	7.097	0.070	Q/B reduced to 4.96 year ⁻¹ to make P/Q 0.1
Sole	0.437	5.063	0.086	P/B increased to 0.65 year ⁻¹
Gurnards	0.432	5.740	0.075	P/B increased to 0.574 year ⁻¹
Herring	0.620	6.388	0.097	P/B increased to 1.04 year ⁻¹ and Q/B lowered to 4.6 year ⁻¹ .
Pilchard	0.66	8.58	0.077	Q/B reduced to 6.6 year ⁻¹

Table 2.22 Preliminary parameters for a balanced English Channel Ecopath model. See Table 2.26 for values modified after tuning. NOTE that diet composition remained the same as Table 2.14 except for the changes that were made during balancing to crab predation on bivalves, hake cannibalism, and mackerel feeding on pilchard, herring and sprat. For final diet matrix see Table 2.22.

Group	Biomass	P/B	Q/B	P/Q	EE
Primary production	127	60	-	-	0.072 [^]
Zooplankton	8.500	18.000	60.000	0.300 [^]	0.736 [^]
Carnivorous zooplankton	1.100	7.000	23.330	0.300 [^]	0.381 [^]
Deposit feeders	19.000	2.500	16.667 [^]	0.150	0.938 [^]
Suspension feeders	5.070	0.300	2.000 [^]	0.150	0.553 [^]
Shrimps and prawns	11.031 [^]	1.700	11.333 [^]	0.150	0.950
Whelk	0.247	0.586	3.907 [^]	0.150	0.964 [^]
Echinoderms	8.780	0.600	6.935	0.087 [^]	0.783 [^]
Bivalves	20.000	0.600	6.667 [^]	0.090	0.936 [^]
Scallops	0.488	0.800	10.000 [^]	0.090	0.902 [^]
Crab	10.500	1.050	7.000 [^]	0.150	0.831 [^]
Commercial crab	0.650	0.460	3.067 [^]	0.150	0.815 [^]
Lobster	0.013	0.500	5.850	0.085 [^]	0.728 [^]
Small demersals	2.632 [^]	1.319	8.980	0.147 [^]	0.950
Small gadoids	1.304 [^]	1.022	5.928	0.172 [^]	0.950
Mullet	0.852 [^]	0.496	4.960	0.100 [^]	0.950
Sole	0.226	0.650	5.063	0.128 [^]	0.583 [^]
Plaice	0.199	0.650	4.109	0.158 [^]	0.778 [^]
Dab	0.103	0.753	6.408	0.118 [^]	0.733 [^]
Other flatfish	0.155	0.600	5.464	0.110 [^]	0.929 [^]
Gurnards	0.275	0.574	5.740	0.100 [^]	0.712 [^]
Whiting	0.313	1.068	5.466	0.195 [^]	0.922 [^]
Cod	0.061	1.134	3.031	0.374 [^]	0.666 [^]
Hake	0.018	0.600	3.764	0.159 [^]	0.968 [^]
Rays and dogfish	0.423	0.440	4.191	0.105 [^]	0.490 [^]
Pollack	0.110	0.618	3.230	0.191 [^]	0.890 [^]
Large bottom fish	0.229	0.396	2.900	0.136 [^]	0.540 [^]
Seabream	0.118	0.575	4.727	0.122 [^]	0.968 [^]
John Dory	0.013	0.457	4.206	0.109 [^]	0.879 [^]
Sandeels	0.681 [^]	1.137	10.816	0.105 [^]	0.950
Herring	3.134	1.040	4.600	0.226 [^]	0.298 [^]
Sprat	0.217 [^]	1.210	11.072	0.109 [^]	0.950
Pilchard	0.434	0.660	6.600	0.100 [^]	0.716 [^]
Mackerel	1.515	0.736	6.778	0.109 [^]	0.338 [^]
Scad	0.852	0.497	5.307	0.094 [^]	0.510 [^]
Bass	0.043	0.600	3.448	0.145 [^]	0.653 [^]
Sharks	0.005	0.190	2.370	0.080 [^]	0.124 [^]
Basking sharks	0.034	0.070	3.700	0.019 [^]	0 [^]
Cephalopods	0.406	2.470	15.000	0.165 [^]	0.521 [^]
Seabirds	0.001	0.400	72.120	0.006 [^]	0 [^]
Toothed cetaceans	0.006	0.400	13.727	0.029 [^]	0.078 [^]
Seals	0.002	0.400	14.567	0.027 [^]	0 [^]
Discarded catch	0.36	-	-	-	0.049 [^]
Detritus	1.000	-	-	-	0.079 [^]

[^] and **bold type** = refers to values estimated by the model.

Table 2.23 Market price of the commercially exploited species in the English Channel.

Group	Price (€/kg)	Group	Price (€/kg)
Seaweed	0.04	Cod	2.50
Herring	0.30	Bivalves	2.63
Small gadoids	0.41	Scallops	2.63
Pilchard	0.50	Seabream	2.75
Mackerel	0.60	Pollack	3.10
Whelk	0.90	Lg bottom fish	3.72
Whiting	1.10	Hake	4.70
Dab	1.12	Other flatfish	5.12
Gurnards	1.17	Mullet	6.10
Plaice	1.30	John Dory	6.70
Scad	1.40	Bass	9.74
Rays/dogfish	1.81	Sole	9.90
Sprat	1.96	Shrimps/prawns	10.42
Comm. crab	2.07	Lobster	19.17
Cephalopods	2.24		

Economic Data

Aside from the ecological balancing of the *Ecopath* model, price, profit and employment data are required to estimate economic outputs that may be used by the optimal policy search routines in *Ecosim*.

Market price

The average market price for the commercially exploited species was entered into the model (Ulrich, 2000). For lobsters and crabs the French price was considerably higher than the UK price and to reflect the high degree of exporting to the French market, the French market price was used in the analysis. For functional groups that represented more than one species, the average for the group was based on the biomass (Table 2.23). In the model, prices were assumed to be fixed regardless of the quantity landed. This is a considered to a fair assumption for UK landings (Pascoe, 2000). But it is noteworthy that in France, the prices of sole, scallops, spider crab and brill, seem to be more responsive to the quantity landed (Pascoe, 2000).

Fleet profitability

In order to run relevant policy simulations, data on the relative profitability of each fishery was

needed. A survey by Cattermoul and Pascoe (2000) separated the percentage of the revenue that was composed by fixed costs and running costs into gear type for the UK English Channel fleet during 1994-1995 and this work was ideally suited to an *Ecopath* model (Table 2.24). Fixed costs are those that do not vary within a year regardless of the effort, and they include repairs and maintenance, harbour dues, interest payments, insurance costs, equipment hire and administration costs. Running costs vary according to the level of activity and include fuel, food, ice and crew costs, which are related to the number of days fished and levies, which are determined as a percentage of the catch. In the absence of available French data, the UK data was used to represent the entire Channel fleet although this was not an entirely accurate assumption because the French fleet appeared to be more profitable (Pascoe, 2000).

Table 2.24 An economic breakdown of the English fishing industry by gear type during 1994-1995 (Cattermoul and Pascoe, 2000).

Fleet	Fixed cost	Running cost	Profit
Otter trawl	43.1	44.0	12.9
Beam trawl	35.3	58.7	6.0
Midwater trawl	39.9	40.0	20.1
Dredge	31.7	52.4	15.9
Net	48.0	37.7	14.3
Pot	31.9	46.2	21.9
Line	21.0	11.8	52.8

Relative employment

The policy optimisation routine in *Ecosim* uses employment created by each fishery gear type. Therefore, data must to be entered for the number of jobs per value of catch. S. Pascoe (CEMARE, *pers. comm.*) provided data on the number of jobs in both France and England for the 8 different gear types.

The mean size of each gear was calculated (Tetard *et al.*, 1995) and this was used to estimate the average number of jobs per vessel (Table 2.25). Then the number of boat units was multiplied by the number of jobs to calculate a job unit index for the entire Channel catch.

Table 2.25 Ratio of jobs to catch value throughout the Channel métiers. Boat units refer to the number of months that a métier was practiced in the Channel.

Gear	Mean length (m)	Crew number	Number of boat units * no of jobs	Catch value €/kg	Jobs/catch value
Otter trawl	13	3.17	35734	1.324	0.301
Beam trawl	32.9	5.61	6844	0.255	0.299
Midwater trawl	19.8	5	2650	0.463	0.064
Dredge	11	2.65	11403	1.000	0.127
Nets	8.7	2.14	29979	0.473	0.707
Pots	8.3	1.8	18360	0.529	0.387
Lines	7.1	2.1	11550	0.117	1.102
Seaweed	9	2.1	756	0.026	0.326

Final 1995 input parameters

The final versions of the basic parameters for the 1995 model are shown in Tables 2.26 and 2.27. These data were used to run the optimisations described below, and differ from Tables 2.14 and 2.22 because they include modifications made during the tuning, also described below.

Table 2.26 Final parameters for the 1995 English Channel Ecopath model following tuning.

Group	Biomass	P/B	Q/B	P/Q	EE
Primary production	127	60	-	-	0.072 [^]
Zooplankton	8.500	18.000	60.000	0.300 [^]	0.739 [^]
Carnivorous	1.100	7.000	23.330	0.300 [^]	0.381 [^]
Deposit feeders	19.000	2.500	16.667 [^]	0.150	0.944 [^]
Suspension feeders	5.070	0.300	2.000 [^]	0.150	0.553 [^]
Shrimps and prawns	11.120 [^]	1.700	11.333 [^]	0.150	0.950
Whelk	0.247	0.650	4.333 [^]	0.150	0.869 [^]
Echinoderms	8.780	0.600	6.935	0.087 [^]	0.783 [^]
Bivalves	20.000	0.600	6.667 [^]	0.090	0.936 [^]
Scallops	0.488	0.900	10.000	0.090	0.819 [^]
Crab	10.500	1.050	7.000 [^]	0.150	0.831 [^]
Commercial crab	0.650	0.460	3.067 [^]	0.150	0.815 [^]
Lobster	0.013	0.550	5.850	0.094 [^]	0.728 [^]
Small demersals	2.636 [^]	1.319	8.980	0.147 [^]	0.950
Small gadoids	1.304 [^]	1.022	5.928	0.172 [^]	0.950
Mullet	0.852 [^]	0.496	4.960	0.100 [^]	0.950
Sole	0.184	0.650	5.063	0.128 [^]	0.583 [^]
Plaice	0.150	0.650	4.109	0.158 [^]	0.829 [^]
Dab	0.103	0.753	6.408	0.118 [^]	0.733 [^]
Other flatfish	0.155	0.600	5.464	0.110 [^]	0.929 [^]
Gurnards	0.275	0.574	5.740	0.100 [^]	0.712 [^]
Whiting	0.115	1.068	5.466	0.195 [^]	0.922 [^]
Cod	0.044	1.134	3.031	0.374 [^]	0.924 [^]
Hake	0.018	0.600	3.764	0.159 [^]	0.968 [^]
Rays and dogfish	0.423	0.440	4.191	0.105 [^]	0.490 [^]
Pollack	0.110	0.618	3.230	0.191 [^]	0.890 [^]
Large bottom fish	0.229	0.496	3.647	0.136 [^]	0.540 [^]
Seabream	0.118	0.575	4.727	0.122 [^]	0.968 [^]
John Dory	0.013	0.457	4.206	0.109 [^]	0.879 [^]
Sandeels	0.681 [^]	1.137	10.816	0.105 [^]	0.950
Herring	3.134	1.040	4.600	0.226 [^]	0.298 [^]
Sprat	0.217 [^]	1.210	11.072	0.109 [^]	0.950
Pilchard	0.434	0.660	6.600	0.100 [^]	0.717 [^]
Mackerel	1.515	0.736	6.778	0.109 [^]	0.338 [^]
Over-wintering	0	0.736	6.778	0.109 [^]	0.000 [^]
Scad	0.852	0.497	5.307	0.094 [^]	0.510 [^]
Bass	0.043	0.600	3.448	0.174 [^]	0.653 [^]
Sharks	0.005	0.190	2.370	0.080 [^]	0.124 [^]
Basking sharks	0.034	0.070	3.700	0.019 [^]	0 [^]
Cephalopods	0.406	2.470	15.000	0.165 [^]	0.528 [^]
Seabirds	0.001	0.400	72.120	0.006 [^]	0 [^]
Toothed cetaceans	0.006	0.400	13.727	0.029 [^]	0.078 [^]
Seals	0.002	0.400	14.567	0.027 [^]	0 [^]
Juvenile bass	0.032	1	6.896	0.145	0.003
Juvenile sole	0.042	1.300	10.126	0.128	0.471
Juvenile plaice	0.150	1.300	8.218	0.158	0.169
Juvenile cod	0.103	2.268	6.064	0.374	0.039
Juvenile whiting	0.115	2.136	10.954	0.195	0.598
Discarded catch	0.360	-	-	-	0.049 [^]
Detritus	1.000	-	-	-	0.080 [^]

[^] and **bold type** = values estimated by Ecopath.

Table 2.27 continued. Diet composition for juvenile sole was not included as this was identical to adult sole.

Group	Sprat	Pilchard	Mackerel	Scad	Bass	Sharks	Basking sk.	Cephalopod	Seabirds	Tooth. cet.	Seals	Juv. bass	Juv. plaice	Juv. cod	Juv. whiting
Prim. prod		.300						.048							
Zooplankton	.960	.700	.969	.198			.300		.022			.050	.001		.090
Carn. Zp.															
Dep. feeders	.040		.001	.543	.006			.003	.032			.450	.113	.480	.020
Sus. Feeders				.069											
Shrimps				.005	.117							.450	.472	.300	.300
Whelk															
Echinoderms															
Bivalves				.007						.001			.013		
Scallops															
Crab				.017	.542			.552	.032			.050			.010
Comm. Crab					.002										
Sm. dem.				.091	.034			.149			.025		.020	.220	.350
Sm. gads								.084	.001		.007				
Mullet				.037				.010							
Sole											.002				
Plaice											.037				
Dab											.001				
O. flatfish											.104				
Gurnards															
Whiting										.057	.075				
Cod										.057	.126				
Hake															
Pollack										.057	.115				
Lg. bottom											.283				
Seabream								.003		.057					
John Dory															
Sandeels					.297			.073	.360		.131				
Herring			.018			.033		.040	.017	.030	.009				.230
Sprat			.011			.033			.141	.070					
Pilchard			.001	.019		.033			.017	.070					
Mackerel						.200		.004	.108	.110	.030				
Scad								.0054		.070	.013				
Cephalopods				.014	.002	.700		.025		.424	.042				
Juv bass															
Juv sole								.004							
Juv plaice															
Juv cod															
Juv whiting															
Discards															
Detritus															
Import	.991						.700						.380		

AN ECOSYSTEM MODEL OF THE ENGLISH CHANNEL IN 1973

Reconstructing the Past

Building a past model, and running this to a current model of the same system, allows the modeller to monitor how biomasses have changed through time. This enables model predicted biomasses to be compared with stock assessment estimated biomasses and where discrepancies between these occur, it may be necessary to modify the input parameters so that the model more accurately reflects the reality of the ecosystem. Originally it had been intended to build a past model of the 1950s but the earliest ICES data that were accessible went back only to 1960. Furthermore, fishing mortality data for a number of groups only began in the early 1970s so it was decided to build the past model from 1973. This would mean that time series data only stretched over a 22-year period but that these data were more accurate and would provide a better anchor to the model than going back further.

Modifying P/B and Q/B

Fishing mortality on several stocks was much lower in 1973 than in 1995 so the total mortality estimates from 1995 were too high and needed to be reduced (Table 3.1). Because the P/Q ratio for a species remains more similar throughout its life than the P/B or Q/B (V. Christensen, Fisheries Centre, UBC, pers. comm.), changes to Q/B were also necessary (Table 3.1).

Catch data

The 1990s model was based on catch data for the Channel that had been collated and analysed by IFREMER and CEFAS experts. Matthew Dunn and Clara Ulrich we consulted about the possibility of obtaining data back until 1973, but there were a number of barriers to this:

- The type of catch data used for the 1995 model were only available in the 1990s.
- Dunn (1999b) published UK data for 8 non-quota species

Table 3.1 Changes in P/B for groups that were fished less heavily in 1973. The changes in Q/B that were necessary to maintain a constant P/Q are also shown.

Group	1995	1973	Q/B changes
	P/B	P/B	
Whelk	0.586	0.25	Changed by Ecopath.
Scallops	0.900	0.800	Changed by Ecopath.
Commercial crab	0.46	0.36	Changed by Ecopath.
Lobster	0.500	0.4	To 4.68
Whiting	1.068	0.868	To 4.451
Cod	1.134	0.834	To 2.2299
Pollack	0.618	0.318	To 1.665
Large bot' fish	0.396	0.296	To 2.161
Scad	0.497	0.397	To 4.223
Bass	0.60	0.25	To 1.724

and said in a personal communication that there may be other scattered data, however it would be difficult to assemble a comprehensive dataset from these.

- RS attempted to access raw data from the UK and France in order to get alternative view of catches, but the cost of retrievals proved prohibitive.

The BAHAMAS (Dintheer, 1995) database was originally developed by CFSG to store international bioeconomic fisheries data in a common format, and because there were concerns about the ICES database allocating catches to the Channel that were not actually caught there. But after exhausting all the other possibilities, it seemed that to use ICES data for the 1973 model was the only option. It is worth mentioning that, although the ICES data were deemed less trustworthy, they still provided some useful trends. Moreover, the ICES data was not be used in the crucial policy optimisation routine, as this was run from the 1995 model where the BAHAMAS data had been used. One further problem was that the ICES data were

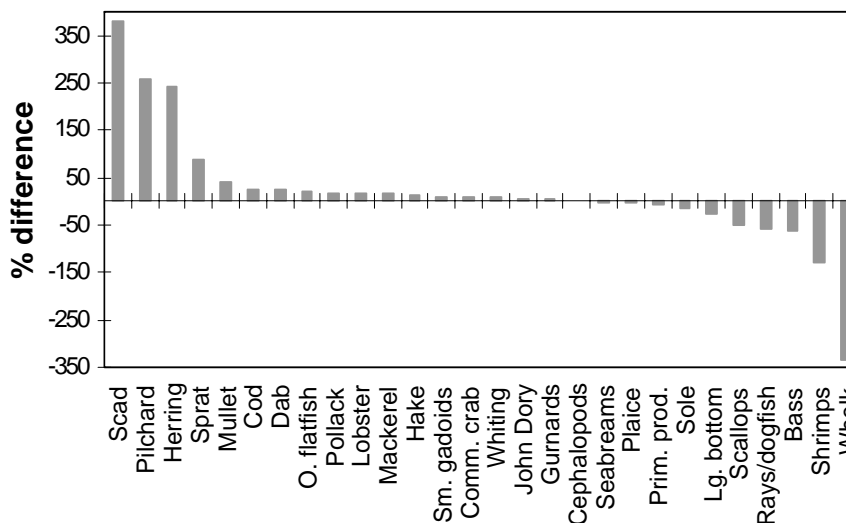


Figure 3.1 Percentage difference between the two landings data sets in the years 1993-95. Positive values are groups where ICES data were higher and negative values where CFSG data (BAHAMAS, Ulrich, 2000) were greater. Both data sets were similar for the middle groups, close to zero.

sometimes grouped together so that, for example, there would be a catch of 'fin-fishes' that could have been composed of a number of different species. Because the proportion of species in these groups was unknown from year to year it was decided to only include data that could easily be allocated to one of the Ecopath functional groups.

The catch data for 60% of the groups were less than 25% different (Figure 3.1), and the contemporary ICES catch data can be used for these groups with some confidence. For the other groups, ICES data still had to be used but, for the purposes of tuning, these data were less trustworthy. Moving further back in time, the catch data are likely to be less reliable because there may be changes that reflect the UK joining the European Union's common fishing policy, which increased policing of the industry and, according to M. Dunn (*pers. comm.*), resulted in more catches being declared. These increases were likely to have taken place in the late 1970s and early 1980s.

1973 Model Functional Group Descriptions

1) Primary production

Although variations in species assemblages have been occurring, inter-annual variation of primary productivity has been low (Tappin and Reid, 2000), and it has been suggested that any changes in primary productivity have had little effect on the long-term state of the Channel (Southward, 1980, 1983). It is possible that in warmer periods, spring blooms occur earlier but with the same intensity (Southward and Boalch, 1988b). The outcome is that we assume that primary production in the Channel has remained constant from 1973 to 1995.

2) Zooplankton and

3) Carnivorous zooplankton

There have been changes in the species assemblage (Southward and Boalch, 1988b), but the absolute biomass of both zooplankton and carnivorous zooplankton groups shows no long-term variations and hence were assumed to have remained constant.

4) Deposit feeders, 5) suspension feeders and 6) shrimps and prawns

In lieu of other data, deposit feeders, suspension feeders and shrimp and prawns were assumed to be the same in 1973 as in 1995.

7) Whelk

Whelk biomass in the North Sea was reported to have declined over the last 20-25 years, and this

may well have been a result of increased beam trawl fishing and the associated mortality (Ten Hallers-Tjabbes *et al.*, 1996; Mensink *et al.*, 2000). There was no extensive whelk fishery prior to 1978, and so it was assumed that the biomass had decreased in the English Channel. Biomass was therefore set to be 1.5 times as large in 1973 as in 1995. The mortality resulting from discards was estimated as 0.008 t/km², based on the assumption that, although there was less beam trawling in 1973, that there would still be significant mortality.

8) Echinoderms

In lieu of other data, echinoderm biomass was assumed to be the same as in 1995.

9) Bivalves

The biomass of bivalves was increased from 20 t/km² in 1995 to 22 t/km² in 1973, because catches were greater and the increase was necessary to prevent the EE exceeding 1.

10) Scallops

The biomass is very likely to be larger in the past because there has been a great deal of exploitation since 1973. Based on catch data, it was initially estimated as 1.5 times bigger. There has been a scallop fishery off the coast of Devon since the 1960s, but it collapsed in the 1970s according to Southward and Boalch (1992). This decline was not in evidence in the catch data of the whole channel stock, but it does seem likely that the biomass of scallops was higher in 1973.

11) Crab

In lieu of other data, crab biomass was assumed to remain constant.

12) Commercial crab

Off the coast of Devon, there was a large increase in crab fishing effort during the 1970s and it seemed that this higher level of exploitation could be sustained. In reality, however, during the 1980s boats needed to travel further offshore to maintain catches (Southward and Boalch, 1992), and it therefore seemed prudent to increase crab biomass in the 1973 system. In the absence of data, it was assumed to be 1.5 times higher; a reasonable estimate according to M. Dunn (*pers. comm.*).

13) Lobster

The south-west lobster fishery appears to have been seriously overfished with catches showing a marked decline (Southward and Boalch, 1992). Consequently very few lobsters now reach their maximum size. The biomass was set to be 1.5 times larger in 1973; a reasonable estimate in the

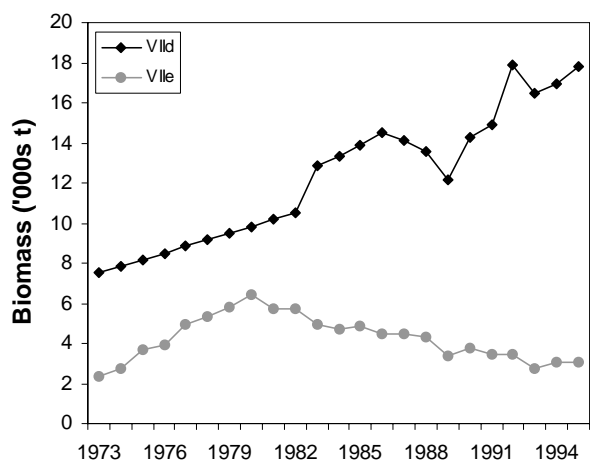


Figure 3.2 ICES biomass estimates for the two sole stocks in the Channel.

opinion of M. Dunn (*pers. comm.*).

14) Small demersals, 15) small gadoids and 16) mullet

No changes were made to these groups, but as their biomass was calculated from an EE of 0.95 and predation on them was different to the 1995 model, their biomasses were calculated to be slightly different (Table 3.3).

17) Sole

ICES data for the biomass of sole was available for area VIIe from before 1969 (Anon., 2000e), and for VIIId from 1982 (Anon., 2000c). The two areas showed different trends in biomass, with area VIIe peaking in the early 1980s but remaining fairly flat thereafter, while area VIIId showed an increase with time (Figure 3.2). Biomass in 1973 was estimated as 7,500 t, which combined with VIIe, gave a total of 9,873 t (0.110 t/km²). This indicated that the biomass of sole had approximately doubled, even though fishing mortality had increased between 1973 and 1995. This trend in part seems to be substantiated by MBA survey data (M. Genner, MBA, *pers. comm.*), which showed that the 2001 sole abundance was more than twice that in 1985. A strong pulse of recruits in the early 1990s appear to have caused this increase.

18) Plaice

Plaice fishing mortality and biomass data were available back until 1980 for area VIIId (Anon., 2000c) and 1976 for area VIIe (Anon., 2000e). The biomass trends were plotted in order to fill in the gaps back until 1973 (Figure 3.3). The biomass for both areas increased in the mid 1980s with VIIId showing a sharp peak resulting from a particularly strong year class in 1986. VIIe was estimated to decline to 1,900 t in 1973. VIIId followed a similar pattern to data for the North Sea and these data reached back until 1957

(Anon., 2000c). Consequently, the fairly constant profile of biomass back from 1980-1973 meant that a constant value of 16,512 t was used from 1973 to 1980 for area VIIId. The total biomass was therefore 18,412 t or 0.205 t/km².

19) Dab

Dab are a species that live close inshore and are rarely caught below 40 m. It can therefore be assumed that even before 1973 they would have endured a considerable mortality from small boats that fished close inshore. There had been a decrease in dab landings since the late 1980s, possibly suggesting a reduction in biomass, although discards of this species are so high that it is very difficult to ascertain trends from landings data. Furthermore, the biomass of dab in the North Sea had been increasing even when fishing mortality was increasing (Heessen and Daan, 1996). M. Dunn (*pers. comm.*) said that there are still large quantities of dab, and he suggested keeping the biomass of this group constant. As a result, the parameters of this group remained unchanged in the 1973 model.

20) Other Flatfish

One of the reasons that this group was created was to account for the significant flatfish species in the Channel that are not covered by ICES stock assessments. Because of this, finding time series data for this group was difficult, as ICES stock assessment data for megrim only went back to 1984 and this showed little significant change. Moreover, megrim are more of a deep water fish that are caught mainly outside of the Channel, so even if we had a longer data series, it may not reflect changes in turbot, brill and lemon sole. MBA survey data (M. Genner, *pers. comm.*) showed large fluctuations although there did

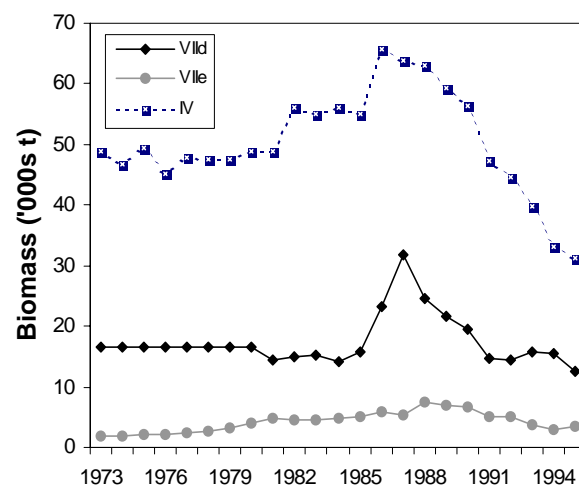


Figure 3.3 ICES biomass estimates for three plaice stocks. IV is the ICES area code for the North Sea.

seem to be a slight reduction in biomass from the 1970s to the present day. But with no firm information upon which to base changes, the biomass was kept the same in 1973 as in 1995.

21) Gurnards

There were no data for fishing mortality or biomass trends of gurnards in the Channel, but some data exist for the North Sea (Heessen and Daan, 1996). This showed a fluctuating abundance until the late 1980s, when the biomass steadily increased until 1993. These data must be taken with caution, because there are large errors associated with trawl surveys for gurnards, which occasionally form dense shoals (Heessen and Daan, 1996). M. Dunn (*pers. comm.*) suggested that a doubling of gurnard biomass since 1973 was not unreasonable because 1), they seem to have increased because of the disturbance on the seabed caused by trawling, and 2), a lot of warmer water species such as the streaked gurnard had become more abundant in the Channel.

22) Whiting

The western and eastern sides of the Channel exhibited reverse population trends (Figure 3.4). Area VIIId is part of the North Sea assessment, and this showed a decline such that the stock is currently only a fifth of the biomass of 1973. In the western Channel, data only went back to 1982, but showed a whiting biomass increased 3.6 times. Extrapolating back to 1973 from 1982 suggested that the stock in VIIe-k had increased 5-fold since 1973. Consequently it seemed reasonable to base the biomass of whiting on the proportion of catches currently made in the Channel, i.e., 73.2 % of the catch was from Area VIIId, so increased 5-fold this is, $0.313 * 0.722 * 5 = 1.130 \text{ t/km}^2$. Area VIIe had the opposite trend, so $0.313 * 0.278 / 5 = 0.017 \text{ t/km}^2$. The estimated total biomass in 1973 was therefore 1.147 t/km^2 .

23) Cod

The ICES catch data for the Channel indicated that 2,077 t of cod were caught. In the North Sea

section 239,051 t were caught from a total stock biomass of 655,931 t (36.4%). In VIIe-k 4,015 t were caught from a total biomass of 9,816 t (41%). It was assumed that the same proportion of catches were made from the east and west Channel as in the 1995 model, i.e., 25.5% west and 74.5% east Channel. Hence there would be 1,547 t caught from the east, and 530 t caught from the west. So if 1,547 t were 36.4% of the biomass, then the biomass was 4,246 t in the east Channel, and if 530 were 41% of the biomass, the biomass in the west Channel was 1,295 t. So the total biomass was estimated at 5,541 t, or 0.062 t/km^2 .

24) Hake

According to ICES data the catch of hake in 1973 was 787 t (M. Zarecki, ICES, *pers. comm.*). The ICES report provides biomass for hake in area VIIe-k back to 1978 (Anon., 2000e). These data show a steady decline through time (Figure 3.5). Extrapolating back to 1973, we estimate that the biomass was 327,500 t for area VIIe-k. The ratio of biomass to catch was plotted in order to estimate the entire catch for the area in 1973. There was a trend from 1978 until 1984 of higher biomasses to catch ratio, and so a trend line was drawn using this data, and a value of 46,786 t was estimated for 1973. Hence a catch in the Channel of 787 t implied a biomass of 5,509 t, or 0.0614 t/km^2 . Because the 1995 biomass was only 30% of 0.0614 t/km^2 , this seemed too high based on the gradient of Figure 3.5. Consequently, it was assumed that the Channel hake remained a constant proportion of the larger stock, and the biomass in 1973 was estimated as 3,179 t (0.036 t/km^2).

It is worth noting that one problem with using a biomass estimate of 0.036 t/km^2 arises in 1979, when hake landings are higher than the biomass. It seems that ICES catches in this particular year are 3 times larger than in the years either side. This resulted from France reporting 2,326 t from ICES area VIIId, which seems unusual as normally

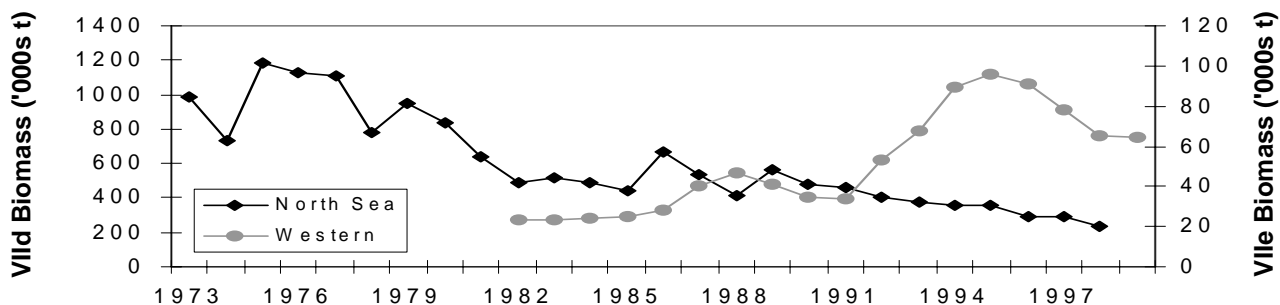


Figure 3.4 Change in biomass of both stock of whiting in the Channel. Only a small proportion of these biomasses reside in the Channel. The North Sea stock corresponds with VIIId axis and the Western stock with the VIIe axis.

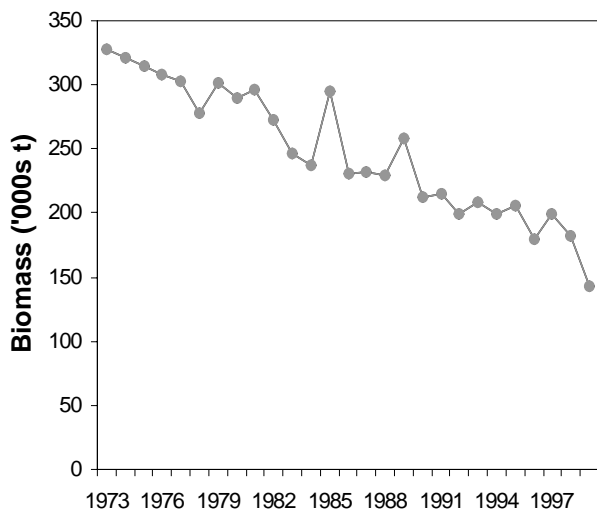


Figure 3.5 ICES biomass estimates for the entire hake stock in VIIe-k.

very little hake are reported from this area. It was not possible to confirm that this datum was incorrect, but we assumed that it refers to hake caught outside of the Channel and hence was not included in the model.

25) Rays and Dogfish

From MBA survey data (M. Genner, *pers. comm.*), it seems that rays and dogfish have remained fairly constant since 1973. M. Pawson (*pers. comm.*) considers that little is known about changes in dogfishes and rays. Theoretically, their longevity and low fecundity should make them vulnerable to overfishing, but nothing catastrophic has happened since 1973. M. Dunn (*pers. comm.*) maintained that, in certain areas, dogfish are the dominant species by biomass in the trawl, and that, although there may be less rays today, they are still often caught in trawls. He also mentioned the presence of two stingray species in the channel, which are typically warm water fish, and so there may be shifts in the abundance of different species of rays caused by climate (Southward and Boalch, 1992). To maintain the biomass of this group as constant seems a reasonable assumption.

26) Pollack

There are no specific stock assessments or time series data for Pollack, and so it was necessary to base the 1973 model biomass on similar species. There were two similar gadoid groups, whiting and cod, and both of these were caught in approximately the same way as pollack, primarily by otter trawls and nets. The problem with this method is that whiting and cod have very different profiles since 1973. Whiting show a decline in catches, F and biomass (Figure 3.4), while cod exhibit an increase in F and a peaked in

catches. Furthermore, there are differences between the different stocks of both cod and whiting, with a decrease in biomass of the North Sea stock and an increase in biomass of the Celtic Sea stock. Because the catch profile was more similar to cod than to whiting, the values of F for cod were scaled for Pollack, and this was used to calculate a biomass of 322 t (0.004 t/km^2). But this was extremely low and the EE of pollack in the model exceeded 1. Consequently, in lieu of other data it was assumed that the biomass of pollack was twice as large in 1973 as in 1995, and so a value of 0.22 t/km^2 was entered into the model. It is noteworthy that pollack are more abundant in the western Channel and “relatively scarce” in the southern North Sea (Pawson, 1995). Hence pollack biomass may actually have increased with time, as organisms in the western Channel have spread eastwards with the increase in temperature.

27) Large bottom fish

ICES data for anglerfish from 1986 indicated that there was little change in biomass. In the absence of other indications, the biomass of large bottom fish was assumed to be the same in the two periods.

28) Seabream

Seabream are warm water fish and M. Dunn (*pers. comm.*) suggested that the biomass would have been less in 1973 than currently, so it was reduced to half of the 1995 biomass, and 0.059 t/km^2 was entered into the model. Although the biomass should be lower in cooler water, the catch data hints that the stock may have been heavily exploited.

29) John Dory

M. Dunn (2000) wrote that “the current status of the John Dory population in UK waters is unknown and investigations of the biology of John Dory in the northeast Atlantic have been limited”. But John Dory have increased in the Channel since 1973 and, in the absence of data, Dunn (*pers. comm.*) estimates that they have doubled. The increase is brought about by a large stock of John Dory in the Western Approaches that migrates according to sea surface temperature. Recent warm years have resulted in an increased biomass entering the Channel. The estimated 1973 biomass was 435 t, or 0.005 t/km^2 .

30) Sandeel

None of the input parameters were changed, but as the biomass was estimated by the Ecopath model from an EE of 0.95, this value changed with predator/prey relationships.

31) Herring

In the late 1990s, 22.8% of the North Sea herring stock was composed of the Downs stock. We assumed that this percentage remained the same, and that half of this stock entered the Channel to spawn. Consequently half of 22.8% of North Sea herring (1,155,651) was 131,744 t. The fishery for herring in area VIIe was more significant in the past than it is at present, indicating that the biomass was probably higher (Pawson, 1995). The 1970s and 1980s corresponded with a cooling trend that favours herring, and so a biomass of 4,000 t was used for VIIe. As in the 1995 model, this was dwarfed by the Downs stock. Hence the total 1973 biomass entered was 135,744 t, or 1.515 t/km².

32) Sprat

We experienced the same difficulties in obtaining sprat data for 1973 as we did for 1995. In a preliminary survey in 1970 off the coast of Plymouth (Demir and Southward, 1974), the total annual egg counts were 10,842 sprat and 74,430 pilchard, i.e., the abundance of sprats was 14.6% that of pilchard. But in the 1995 model the biomass of sprats was 55% of the biomass of pilchards, suggesting that basing biomass data on egg counts may be inaccurate. Because separating sprat eggs from other clupeids is time consuming, there is no time-series data for them. Temperature seems to be a significant factor in the spawning of sprat and it has been considered in Russell Cycle investigations (A. Southward, *pers. comm.*). Sprats have a long spawning season and, following a cold winter, spawning is retarded, meaning that a proportion of the larvae will not metamorphose before the following winter. It was therefore proposed that colder winters may cause a reduction in biomass (De Silva, 1973). Fage (1920) gives the temperature range for spawning as 8-11°C, but, since 1973, the Channel monthly mean temperature has only once dropped below 8 °C (to 7.93 °C in 1986). Hence temperature was assumed to have had no

effect in the model and, in absence of other data, the biomass was estimated by Ecopath using an EE of 0.95 as in the 1995 model.

33) Pilchard

Time series data on the biomass of pilchards are not available, but it is possible to examine climatic effects on biomass from the trends documented in association with the Russell Cycle. A warm phase favourable to pilchard during the 1950s gave way to a cold-period decline from 1960 to 1985, and then to a rapidly increasing temperature (Figure 3.6). The early 1980s saw the return of the pilchard fishery, indicating that the biomass had increased. Using egg count data (Southward *et al.*, 1988a), biomass in 1973 was estimated as 0.066 t, around which there may be a small amount of error caused by overlap between pilchard and sprat eggs in May and June (Demir and Southward, 1974). But this estimate was far too small to support the fishing mortality, as catches were approximately the same in 1973 as in 1995. Hence we allowed Ecopath to estimate pilchard biomass, based on an EE of 0.95.

34) Mackerel and

35) Over-wintering mackerel

The biomass and fishing mortality for 1973 was taken from an ICES working group report (Anon., 2000d). The total biomass of the Western stock was estimated as 4,039,602 t and the landings were 219,445 t. Channel landings were reportedly 46,296 t, and so the stock was estimated as 852,229 t, or 9.511 t/km². This made it 6 times larger than the stock in 1995 and could not be sustained by the model estimates of Clupeidae prey. Pawson (1995) refers to the Western mackerel stock over-wintering in the Channel during the 1960s and throughout the 1970s, but this changed in the 1980s when they over-wintered off northern Scotland. This seems to be reflected in the catch data, which shows a big decline during the 1980s (Figure 3.7). Southward *et al.*, (1988a) also refer to a decline in mackerel

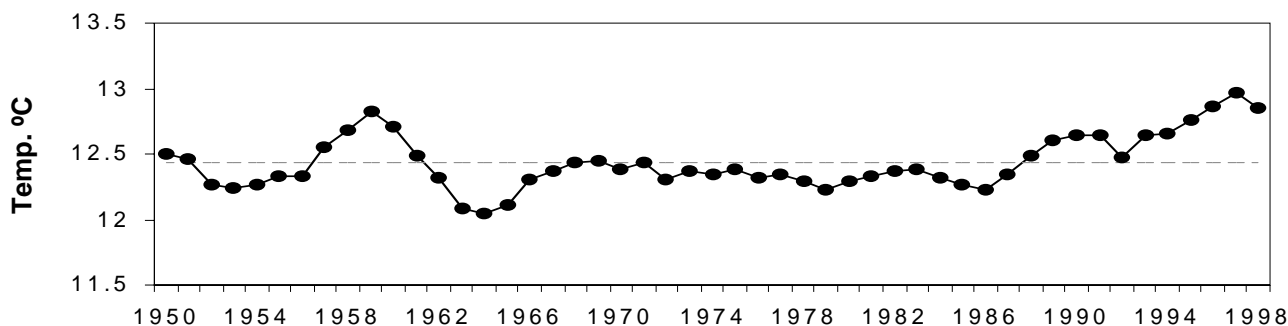


Figure 3.6 Five-year running annual average of sea surface temperature in the Channel. The grey dashed line is the mean temperature between 1950 and 2000. Data courtesy of Anon. (2001d).

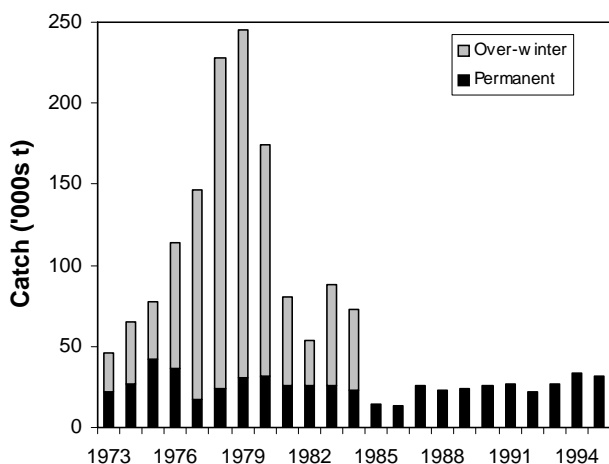


Figure 3.7 Mackerel landings from the Channel. Data courtesy of ICES (M. Zarecki, *pers. comm.*).

stocks after 1979, commenting that this may not have been merely a migratory change, but the result of intensive purse seining. The large biomass of mackerel was probably there only in winter, and so would not be feeding but would be available for capture. Consequently, it was necessary to create a new group, over-wintering mackerel, which has identical parameters to mackerel except that the diet is 100% imports. It was necessary to split both biomass and catch into 'mackerel' or 'over-wintering mackerel'. There was a gradual decreasing trend in the total stock biomass, so that in 1995 it was 84.1% of the 1973 biomass. The same trend was assumed for the Channel mackerel biomass, so that, in the 1973 model, biomass was 1.802 t/km². The over-wintering biomass was hence estimated as 9.511 – 1.802 = 7.709 t/km².

The Channel catch was split into permanent stock and over-wintering stock on the basis of F from ICES stock assessments (Anon., 2000d). The remainder of ICES recorded catches were allocated to the over-wintering component. Using this method, time-series data indicated that by 1986, the biomass of the over-wintering stock had disappeared completely.

This new group, over-wintering mackerel, were also inserted into the 1995 model as a dummy group because, during the tuning process, it was necessary to run its biomass down to zero. And in this way, future modellers are warned that there is a 'second' mackerel group that may need to be included.

36) Scad

ICES catch data (M. Zarecki, *pers. comm.*) for the Channel indicated that 62,157 t of scad were landed in 1973 and 62,376 t in 1995. But catch data from CFSG (Ulrich, 2000) showed an annual

average catch in the Channel between 1993 and 1995 of only 11,407 t. Hence there was a great deal of inconsistency between these two data sets (Figure 3.1). Scad stock assessments only go back as far as 1982, so it is necessary to extrapolate to 1973. But this is complicated by the stock's large infrequent recruitment pulses (Pawson, 1995; Anon., 2000d). Fishing mortality was assumed to remain constant at 0.15 back to 1973. The biomass was then estimated by the equation Channel catch/F = biomass. If the catch was 62,157 t according to the ICES catch data, then biomass was 4.6 t/km², which seems very high, and with such a high degree of difference between the 1995 catch data it was assumed that the catch data are suspect. The USSR reportedly caught a vast quantity of scad, and when this was removed, the catch was just 3,364 t. This meant a biomass of 0.902 t/km², which seemed much more reasonable.

37) Bass

Bass is a long-lived, slow-growing species and because, in the early 1980s, anglers complained about the small size of bass (M. Dunn, *pers. comm.*), there was probably a much larger biomass of older fish in 1973. M. Pawson (*pers. comm.*) said that it would not be unreasonable for a 1973 biomass to have been reduced to 20-25% by 1995. The more conservative of these estimates was chosen, leading to a biomass of 0.172 t/km².

38) Sharks

Vas (1990) outlined the change in CPUE of blue shark since 1973, and this was used to estimate the biomass of the entire shark group by assuming a constant catchability. The value that was used for 1973 was a CPUE of 2.0, which was 2.29 times the CPUE of the mid 1990s. Hence the biomass of the shark group in 1973 was entered as (0.005 * 2.29) = 0.012 t/km². Using data from Vas (1990), the recreational fishery was estimated to have landed twice as many sharks in 1973 than in 1995 (0.00024 t/km²).

39) Basking shark

In lieu of other data, all basking shark parameters were assumed to be the same.

40) Cephalopods

Although the catch of cephalopods rapidly increased in response to higher market prices in the 1980s, it is uncertain if the fishery has had a significant effect on the biomass. There is a suggestion that this group responds positively to warmer temperatures (Robin and Denis, 1999); (Pierce, 1995), but in the absence of data to the contrary, the parameters for this group were kept the same in 1973.

41) Seabirds

The UK's Joint Nature Conservation Committee (JNCC) has conducted surveys to determine how seabird populations have changed. The first survey of this kind, 'Operation Seafarer', was conducted in 1969–1970 and the second was conducted between 1985–1988. A summary of the changes that have occurred between these dates throughout Britain and Ireland is provided by Furness (1989). (At the time of writing, data from a third survey, 'Seabird 2000', is being analysed.) Herring gulls decreased from 600,000 to 364,000, great black backed gulls have declined slightly but the majority of seabird species have increased. Guillemot abundance doubled from 1969-70 to 1985-88, and possible reasons for this were an increase in sandeels, as their predators had been depleted by fishing, and increases in fishery discards. The population of Arctic terns showed a positive relationship ($r = 0.68$) with the sandeel recruitment estimates. It was interesting to note that most seabirds peaked between the surveys and then declined prior to the 1985-88 study. While one would expect an increase in the Channel birds as smaller fish increased in biomass, the abundance of sandeels is unknown. Furthermore, until the results of the 2000 survey become available, it is not known if the decline prior the 1985-88 study continued. We decided to reduce the biomass in 1973 by 10% to 0.0011 tkm², mainly because of the lower discards.

42) Toothed cetaceans

Groups of thousands of dolphins have become rare since the 1950s, and Cornish fishermen report a notable decline in recent years (Anon., 2001a). The exact magnitude of this decline, or the reasons for it are unknown. It is possible that the reduction in over-wintering mackerel may have caused dolphins, which are very migratory, to go elsewhere. The killing of toothed cetaceans by pelagic fisheries in the Channel may have had an effect, but because the majority of them live outside of the Channel, the effects on the stock may primarily be because of the tuna drift net fishery (Anon., 2001a), rather than any Channel métiers. Whatever the cause, there does seem to have been a decline, and, in the absence of other data, the biomass was set to be 50% larger than

the 1995 biomass, namely 0.009 t/km².

43) Seals

In lieu of other data, the input parameters for seals were kept the same in 1973 as for 1995.

44) Discarded catch

The biomass of this group was reduced to 0.325 t/km² because the fishery was much smaller in 1973 than in 1995.

Balancing the 1973 Ecopath Model

One of the main problems with the unbalanced 1973 model was whiting (Table 3.2), whose increased predation on sandeels forced an increase in sandeel biomass, which consequently made the EE of zooplankton and carnivorous zooplankton greater than 1. Because there was a great deal of uncertainty about the whiting biomass estimate, the biomass in 1973 was adjusted to be twice that in 1995, resulting in a value of 0.626 t/km². This immediately lowered the zooplankton and carnivorous zooplankton EEs below 1. The biomass of deposit feeders was increased from 19 to 22 t/km², and bivalves were increased from 20 to 22 tkm², in order to meet increased predation mortality from small demersals and small gadoids. Ecopath identified fishing mortality as too high for gurnards, dab and seabream. M. Dunn (*pers. comm.*) indicated that the catch data for gurnards may be incorrect because they were often used as a blanket group to which demersal catches may be allocated. In the absence of alternative catch data, these EEs were set to be the same as in 1995, 0.712. For dab, the biomass increased from 0.103 t/km² to 0.2 t/km². For seabream, the biomass increased to 0.155 t/km².

Electivity

The diet composition of each group was kept the same in both models, but it was important to compare the electivities of both. Electivity describes a predator's preference for a prey on a scale of -1 to +1, with -1 being total avoidance of the prey, +1 being total preference for a prey and 0 meaning that the prey is eaten proportionally to its abundance (Ivlev, 1961). The electivity equation used in Ecopath is the standardized forage ratio (S_i) by Chesson (1983), transformed so that it can be interpreted as the Ivlev index (Christensen *et al.*, 2000).

$$S_i = (r_i/P_i) / (\sum_{n=1}^n r_n/P_n)$$

Table 3.2: Functional groups in the 1973 model with an EE greater than 1 and the main cause of this excessive EE.

Group	EE	Cause
Zooplankton	1.031	Whiting
Carnivorous zooplankton	1.746	Whiting
Deposit feeders	1.146	Whiting
Bivalves	1.031	Whiting
Crab	1.248	Whiting
Gurnards	2.144	Fishing Mortality
Dab	1.414	Fishing Mortality
Seabream	2.539	Fishing Mortality

where r_i is the relative abundance of a prey in a predator's diet, P_i is the prey's relative abundance in the ecosystem and n is the number of groups in the system.

If electivities are very different between the two models, it may indicate that the diet composition entered into the contemporary model was incorrect. Because the biomasses of herring and sole were twice as large in 1995, the groups rays and dogfish, large bottom fish, and seals, all of which prey on sole and herring, showed more in the diet that when these prey were scarcer in 1973. Conversely, in 1995 the biomass of dab was half of 1973, and so there was much less eaten by whiting, rays and dogfish, and large bottom fish in 1973. These changes in electivity were in the region of 0.2 to 0.3, and although they generated questions concerning how much preference predators would show for prey, they were not large enough to warrant a change in the diet matrix.

Final Balanced 1973 Model

The final balanced parameter values for the 1973 model are shown in Table 3.3.

Table 3.3 Basic input parameters for the 1973 balanced model.

Group	Biomass	P/B	Q/B	P/Q	EE
Primary production	126.720	59.560	-	-	0.073 [^]
Zooplankton	8.500	18.000	60.000	0.300 [^]	0.777 [^]
Carnivorous	1.100	7.000	23.330	0.300 [^]	0.681 [^]
Deposit feeders	22.000	2.500	16.667 [^]	0.150	0.768 [^]
Suspension feeders	5.070	0.300	2.000 [^]	0.150	0.525 [^]
Shrimps and prawns	11.161 [^]	1.700	11.333 [^]	0.150	0.950
Whelk	0.371	0.250	1.667 [^]	0.150	0.230 [^]
Echinoderms	8.780	0.600	6.935	0.087	0.777 [^]
Bivalves	22.000	0.600	6.667 [^]	0.090	0.863 [^]
Scallops	0.733	0.800	8.889 [^]	0.090	0.600 [^]
Crab	10.500	1.050	7.000 [^]	0.150	0.895 [^]
Commercial crab	0.975	0.360	2.400 [^]	0.150	0.527 [^]
Lobster	0.020	0.400	4.680	0.085 [^]	0.547 [^]
Small demersals	2.438 [^]	1.319	8.980	0.147 [^]	0.950
Small gadoids	1.750 [^]	1.022	5.928	0.172 [^]	0.950
Mullet	0.730 [^]	0.496	4.960	0.100 [^]	0.950
Sole	0.110	0.650	5.063	0.151 [^]	0.429 [^]
Plaice	0.205	0.650	4.109	0.187 [^]	0.315 [^]
Dab	0.200	0.753	6.408	0.118 [^]	0.728 [^]
Other flatfish	0.155	0.600	5.464	0.110 [^]	0.604 [^]
Gurnards	0.313 [^]	0.574	5.740	0.100 [^]	0.718 [^]
Whiting	0.626	0.868	4.451	0.195 [^]	0.148 [^]
Cod	0.062	0.834	2.230	0.374 [^]	0.696 [^]
Hake	0.036	0.600	3.764	0.125 [^]	0.925 [^]
Rays and dogfish	0.423	0.440	4.191	0.126 [^]	0.269 [^]
Pollack	0.220	0.318	1.665	0.191 [^]	0.352 [^]
Large bottom fish	0.229	0.296	2.160	0.137 [^]	0.334 [^]
Seabream	0.155	0.575	4.727	0.122 [^]	0.967 [^]
John Dory	0.015	0.457	4.206	0.150 [^]	0.693 [^]
Sandeels	1.216 [^]	1.137	10.816	0.105 [^]	0.950
Herring	1.515	1.040	4.600	0.226 [^]	0.575 [^]
Sprat	0.384 [^]	1.210	11.072	0.109 [^]	0.950
Pilchard	0.330	0.660	6.600	0.100 [^]	0.716 [^]
Mackerel	1.802	0.736	6.778	0.109 [^]	0.266 [^]
Over-wintering	7.709	0.736	6.778	0.109 [^]	0.053 [^]
Scad	0.902	0.397	4.223	0.094 [^]	0.439 [^]
Bass	0.172	0.250	1.724	0.145 [^]	0.115 [^]
Sharks	0.023	0.190	2.370	0.080 [^]	0.540 [^]
Basking sharks	0.034	0.070	3.700	0.019 [^]	0 [^]
Cephalopods	0.406	2.470	15.000	0.165 [^]	0.423 [^]
Seabirds	0.001	0.400	72.120	0.006 [^]	0 [^]
Toothed cetaceans	0.009	0.400	13.727	0.029 [^]	0.052 [^]
Seals	0.002	0.400	14.567	0.027 [^]	0 [^]
Discarded catch	0.314	-	-	0.050 [^]	0.050 [^]
Detritus	1.000	-	-	0.087 [^]	0.087 [^]

[^] and **bold type** refers to values estimated by the model.

TUNING AND SIMULATING THE ENGLISH CHANNEL ECOSYSTEM USING ECOSIM

Because Ecopath represents a description of an ecosystem at one particular reference point, it gives no indication of the changes that may occur with differences in fishing mortality. Ecosim provides the opportunity to dynamically simulate the responses of model biomass pools to changes in fishing mortality or other factors, and so can illuminate management and policy. Moreover, an Ecosim model may be run alongside biomasses from time-series stock assessment data, and the model adjusted to reflect changes that are known to have occurred, a process known as ‘tuning’.

Tuning the English Channel Ecosystem Model

Time-series Data

Continuous time-series estimates for fishing mortality and biomasses were available from VPA for some groups from stock assessments. For all exploited groups there were time-series data for

catches from ICES (M. Zarecki, *pers. comm.*). For each exploited group it was necessary to enter values of fishing mortality from 1973 to 1995 (read as a CSV file) to see how the biomasses of each group changed in the Ecosim model (Appendix, Table A1). These fishing mortalities (Table 4.1) drove changes in simulated catch and biomass in the model, while the original biomass and catch estimates from VPA were used for comparison. Groups without fishing mortality data retained the same fishing mortality throughout the time-series as in 1973.

Vulnerabilities (flow control)

In Ecosim, vulnerabilities (V) are assigned to individual predator/prey relationships and indicate whether the biomass of different groups is controlled primarily by the predator or by the prey. Vulnerabilities range from 0 to 1; when V is high, a high proportion of the biomass is vulnerable to predation, resulting in fluctuating predator–prey curves. Conversely, if prey are able to hide from predators, V will be lower. In this model, Vs were based both on tuning to biomass data and on the trophic level of the prey. The principle behind this is that higher trophic level organisms have been most heavily depleted in

Table 4.1 Origin of time-series estimates of F and biomass for tuning the model.

Group	Time-series data availability and sources
Whelk	Fs from both models were used as starting and end-points. F was kept constant until 1978 and then steadily increased until 1995, based on the catch data.
Scallops	Fs from both models were used as starting and end-points. Based on the catch data, F was steadily increased until a maximum in 1980 and then slightly reduced until 1995.
Commercial crab	Fs from both models were used as starting and end-points and F was constantly increased between both.
Lobster	Fs from both models were used as starting and end-points and F was constantly increased between both.
Sole	ICES Fs were weighted between the two stocks by biomass. Biomass data were also available for this group.
Plaice	ICES Fs were weighted between the two stocks by biomass. Biomass data were also available for this group.
Other flatfish	Fs from both models were used as starting and end-points. F was kept constant at 0.15 between 1973-1981, constant at 0.20 between 1982-1984, constant at 0.25 between 1985- 1989 and constant at 0.35 between 1990-1995, based on catches.
Whiting	F was estimated from ICES data using the equation catch/biomass and weighted between the two stocks.
Cod	F was estimated from ICES data using the equation catch/biomass and weighted between the two stocks. Biomass data were also available for this group.
Hake	ICES Fs were used from 1979 to 1995 and between 1973-1979 it was assumed that F was 0.22. Biomass data were also available for this group.
Pollack	Fs from both models were used as starting and end-points. F was kept constant between 1973-1976 and then increased constantly until 1995.
Large bottom fish	ICES F and biomass data were available for anglerfish back until 1986. F was assumed to have constantly increased from the 1973 model to 1985.
Seabream	Based on the catch data and the suspected crash of the stock in the early 1980's (M. Dunn, <i>pers. comm.</i>) F was kept constant in 1973-1976 then increased to 0.9 between 1977-1980 before being 0 in 1981 and then returning to the constant 1973 level again.
John Dory	Using the F calculated by both models and the catch data I estimated F to be 0.05 in the 1970's, 0.15 in the 1980's and 0.3 in the 1990's.
Herring	Biomass was forced based on ICES data.
Mackerel	F and biomass was used from ICES.
Over-wintering mackerel	Biomass was forced based on ICES data.
Scad	ICES F and biomass was only available from 1984 and because of the large catch data inconsistencies the model remained constant between 1973-1983.
Bass	Based on M. Pawson (<i>pers. comm.</i>) the F of bass was estimated as 0.05 in the 1970s, 0.2 in the 1980s and 0.4 in the 1990s.
Cephalopods	Fs from both models were used as starting and end-points and F was constantly increased between both.

ecosystems (Cheung *et al.*, 2002). If fishing was significantly reduced, these stocks may be expected to recover towards their un-fished state and hence should be allocated a higher V . Initially, using time-series biomass data it was possible to understand how each group had changed since 1973. The V s were allocated for each group from 0.2 to 0.7, based on trophic level. Each group was then checked against the time-series biomass data during tuning, and it was found that using this method of estimating V s produced realistic responses to changes in fishing.

Tuning Individual Model Groups

As well as running the model with the time-series F data, we ran scenarios in which F was reduced to zero and increased to 4 times the 1995 value. These 'extreme' runs of the model showed up any problems and suggest parameter changes that were necessary in each of the functional groups.

Whelk. Whelk biomass nearly vanished between 1973 and 1995, and as there is still an important whelk fishery in the Channel, this change was thought too severe. When fishing was zeroed in the 1995 model, whelk biomass increased dramatically, so it was decided to increase the P/B value from 0.586 year^{-1} to 0.650 year^{-1} . This also seemed logical because the EE in the 1995 model was very high, 0.964. The rapid decline of whelk biomass also indicated that past biomass was significantly more than 1.5 times larger. With a P/B of 0.65 year^{-1} the biomass of whelks increased by 2.5 times from 1973 when F was 0.

Scallops. When F was set at 0 in the 1995 model, biomass more than trebled. This seemed too large, and was caused by fishing mortality comprising almost all of the mortality. P/B was increased to 0.9 year^{-1} as there was a range of possible initial estimates, and then scallop biomass then increased two-fold when F was 0.

Lobster. When F was 0 the biomass of lobster increased rapidly 4-fold, so P/B was increased from 0.5 year^{-1} to 0.55 year^{-1} , reducing this to a more reasonable 3-fold increase.

Sole. F was a high proportion of total mortality, and ICES data indicated that it had increased in the period 1973 to 1995 and that both catch and biomass of sole in the Channel had been increasing (Anon., 2000e; Anon., 2000c). This suggested some factor other than fishing was affecting sole. The index of recruitment showed a general increase, and so it was assumed that temperature was an important driving force

behind the biomass increase, based on studies by Rijnsdorp *et al.*, (1992), Henderson and Seaby (1994) and Philippart *et al.* (1996). There is some debate about the time of year that temperature most affects recruitment. Philippart *et al.*, (1996) showed that severe winters had a positive effect on the recruitment of sole in the Wadden Sea. While Rijnsdorp *et al.*, (1992) agreed with this for the North Sea, the same was not true in the Bristol Channel, English Channel or Irish Sea. Henderson and Seaby (1994) found significant correlations between average annual temperature and spring temperatures with year class strength. With the ICES and Hadley Centre data (Anon., 2001d) there was a stronger correlation between recruits and the annual average temperature (Pearson correlation = 0.62, $p < 0.01$), and this was used to create a forcing function in the model. A trendline was fitted to the temperature (in °C) and recruit data and the following equation was calculated:

$$\text{No. of recruits} = 14507 * \text{av annual temp} - 155414$$

The values from this equation were divided by the 100-year temperature mean and then 'stretched-out' by multiplying the positive values by thirty. The multiplier of thirty was iteratively chosen as the value which caused the model to have the lowest sum of squares difference between the predicted biomass and the ICES time-series data. Then, because temperature affected recruitment, a juvenile sole group was added to the model. Based on ICES working group data it was assumed that sole recruit to the fishery at age 2, that K from the VBGF was 0.3, that their average adult weight/transition weight was 1.75, that their P/B and Q/B were twice as large as the adult group, and that 18.7 % of the total biomass was juveniles. Hence, of the initial 0.226 t/km^2 that was entered into Ecopath, 0.042 t/km^2 was allocated to juvenile sole. The climate forcing function was applied only to the juvenile group. Sole predation by cephalopods was also moved from adult sole to juvenile sole. The diet composition of juvenile sole was assumed to be of the same organisms as adults. For sole, and all groups that were split into adults and juveniles, all of the discards were allocated to the juvenile group.

Even with the addition of the forcing function, the biomass trend predicted by the model significantly differs from the ICES data (Figure 4.1). Part of the reason for this was that juveniles recruit to the fishery at age two and, because in the temperature time-series there were rarely two consecutively warm years, the variation in total juvenile numbers proved to be a lot less than from

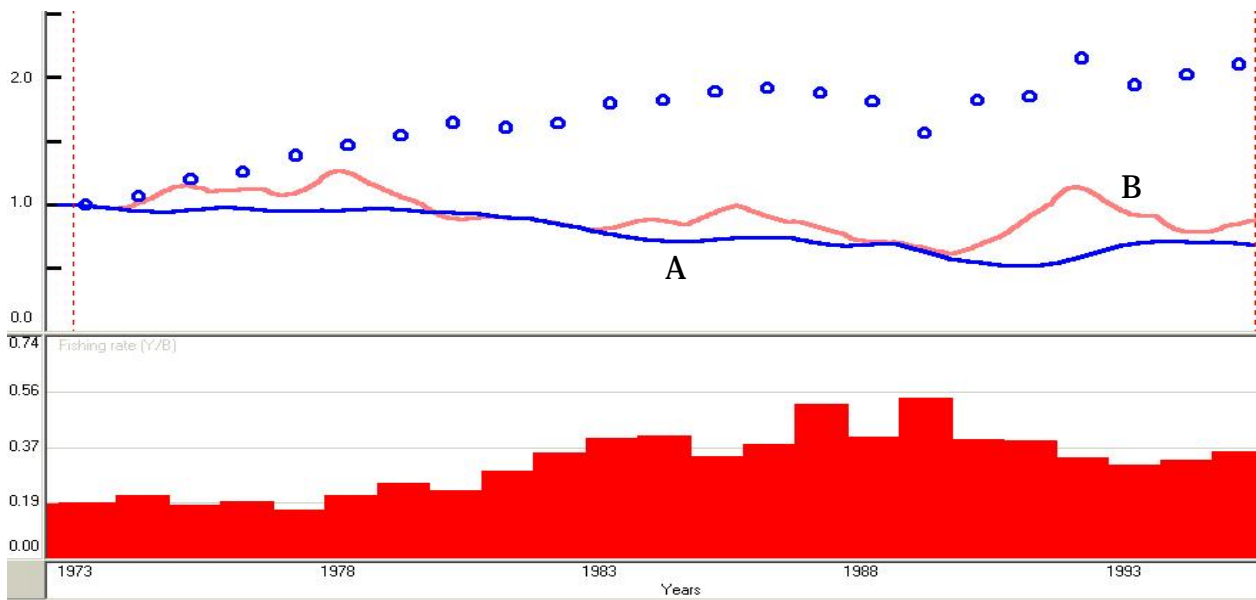


Figure 4.1 Impact of a temperature forcing function on adult sole biomass. The blue line (A) shows the predicted sole biomass without the forcing function, the pink line (B) shows the predicted sole biomass with the forcing function and the blue circles show the absolute adult biomass from ICES data. The time-series of fishing mortality from stock assessment is shown by the red bars beneath the line graph.

year-to-year. The changes in adult sole biomass predicted by the model were in the right direction, but were not as large as the ICES data suggested. The model accurately predicted catches however, and M. Dunn (*pers. comm.*) suggested that the biomass results could be biased to a certain extent, as catch rates were higher in the 1990s due to technology creep.

Plaice. There was a large increase in plaice biomass in the mid 1980s that seemed to be caused by recruitment responses to temperature. Research on the recruitment of plaice suggests that, in the North Sea, the temperature between February and June is strongly correlated with recruitment, but there are no indications of such a strong for the Channel (Fox *et al.*, 2000). In the ICES data there was a significant correlation of 0.50 ($p=0.015$) between temperature and recruitment, but when the large 1986 recruitment was removed, the correlation was merely 0.18, which was non-significant. Therefore to build a relationship into the model based only on temperature is problematic as the regression line has huge residuals. Because there is a high degree of plaice migration from the North Sea, possibly one option for the sharp increase in biomass in 1986 would be more fish migrating from the North Sea, and temperature seems to have some effect on migration (Ewan Hunter, CEFAS, *pers. comm.*), although the exact mechanism is unknown. Nevertheless it does seem that very cold years are advantageous for plaice (Philippart *et al.*, 1996, Van der Veer and Witte, 1999, Fox *et*

al., 2000) and it is important that this is incorporated into the model in some form. For the purposes of this model, a forcing function was entered so that when the temperature drops below 9.6°C the biomass of the juvenile group becomes twice as large. Clearly this would not be adequate when predicting futures with cooler scenarios, but was considered adequate for tuning.

Half of the total plaice biomass was composed of juveniles, and they become adults at 2 years old. The average adult weight/average juvenile weight was 2.94, and K was 0.08. Hence half of the plaice biomass was moved to the juvenile group, but this meant the EE of adult plaice rose above 1. Consequently, 95% of cod predation was allocated to juvenile plaice. Still the EE remained too high because of fishing mortality, and it was necessary to increase adult biomass from 0.1 to 0.145, which brought the EE below 1 and made F approximately 0.5 year⁻¹, which the value suggested by the ICES data. The same biomass value was used for juvenile plaice. Diet composition for juvenile plaice came from the Belgian coast (Beyst *et al.*, 1999), and as 38% of the eastern Channel juveniles came from the North Sea (Pawson, 1995), 38% of the diet was allocated to import.

Dab. From the catch data and from Southward and Boalch (1992), there was some suggestion of lower biomass when temperatures increase. But in the North Sea, even when the temperatures

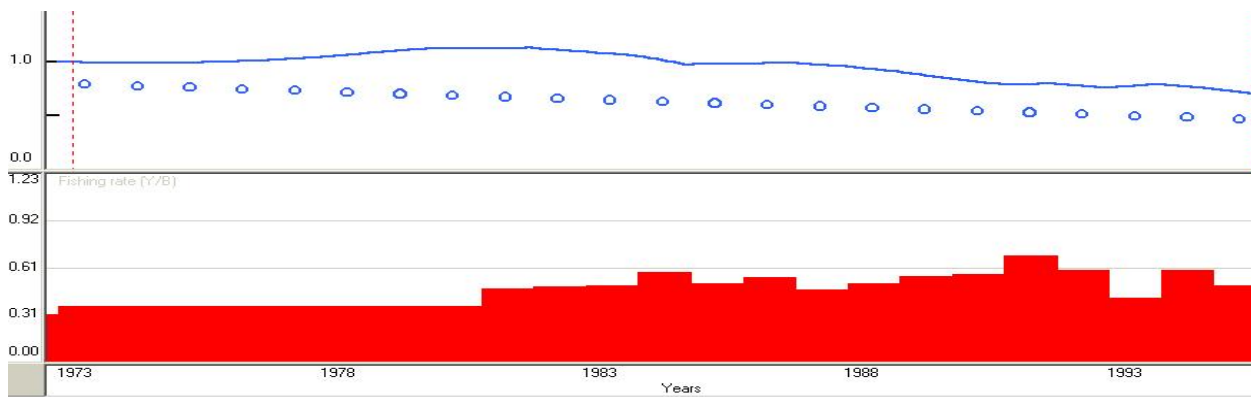


Figure 4.2 Biomass of hake predicted by the model. The model biomass estimates are shown as a blue (solid) line and the ICES absolute biomass data are open circles. Fishing mortality estimates are solid bars beneath the graph. At the left of the graph, the 'absolute' circles start off lower than the model value because this had to be increased in to ensure that F was correct.

have been warm, the biomass of dab has increased (Heessen and Daan, 1996), and consequently there is not sufficient evidence to justify using a forcing function for this group.

Hake. F changed from 0.22 to 0.37 year⁻¹ but F in the 1973 model was too high, meaning that biomass was increasing even though fishing mortality was gradually increasing. This was one example of many of the inconsistencies between F estimates from catch/biomass, and those from ICES data. To overcome this problem the 1973 hake biomass was increased to 0.045 t/km² so that, with lower F , hake in the model more accurately reflected trends in the ICES data (Figure 4.2).

Whiting. This group has proved very problematic because of inconsistent data and a high degree of uncertainty (Pope and Macer, 1996; Anon., 2000c). In 1997 the ICES working group (WG) reported that hake spawning stock biomass (SSB) had remained stable since 1984 in the North Sea, and that recent fishing mortality, if maintained, should lead to increases in biomass (Anon., 1997). By 1999 this view had been revised, and the WG said that both SSB and recruitment had steadily reduced since 1980 (Anon., 1999b). The relationship between SSB and recruitment is complex (J. Keable, CEFAS, *pers. comm.*) and it is still uncertain as to what are the causes of the 'gadoid outburst' of the 1970s and the recent decline (Hislop, 1996; Serchuk *et al.*, 1996). At times, whiting has replaced itself "comfortably higher" than the impact of the highest F , while at other times it has had very low replacement rates (Pope and Macer, 1996).

One of the main problems when looking at

changes in whiting through time using Ecosim was that there was a large difference between F estimated by ICES stock assessments and F estimated from catch/biomass by the model. In 1973, ICES estimated F to be 0.98 year⁻¹, but when using catch/biomass for the entire stock, F was only 0.27 year⁻¹. Because the model calculated F from catch/biomass, the same method was used to enter F for the time-series data. Running the model through time showed that an initial biomass of 0.626 t/km² was too high, because the starting F was so low. Consequently, two aspects of the model were changed. First, the 1973 biomass for whiting in the Channel was lowered to 0.4 t/km². Secondly, because F was still too low and because there was predation from other gadoids, a juvenile whiting group was created. For the juvenile group, P/B and Q/B were set to twice those of the adult, diet composition came from Hamerlynck and Hostens (1993) for 0-group whiting in the southern North Sea, and the biomass of juveniles was estimated from CFSG data as 50% of the total biomass, based on an age of transition to the adult group of 1. K was estimated as 0.25 and the average adult weight/average juvenile weight was 6.27. All predation from whiting, cod and hake on the 'whiting' group was allocated to juveniles, and 75% of predation from rays and dogfish and large bottom fish were allocated to juvenile whiting. Juveniles comprised 16.4% of the catch composition according to ICES (Anon., 2000c), and so this was taken from the adult group and allocated to juvenile whiting. Although there was some evidence that whiting recruitment is positively affected by cooler temperatures (Philippart *et al.*, 1996), with such uncertainty in the whiting data there was not a clear enough relationship to warrant employing a forcing function in the model. Finally, when running the

model with these changes, it seemed that F in the 1995 model was still too low. As a result, the biomass of both adult and juvenile whiting groups was lowered from 0.156 t/km^2 to 0.115 t/km^2 .

Cod. Like whiting, the estimates of F from ICES were very different from that calculated by catch/biomass for the model. As a result, time-series catch/biomass estimates of F were used. Cod is influenced by temperature (Figure 4.3), Planque and Fox, ((1998) and O'Brien *et al.*, (2000) indicating that cooler water is advantageous for recruitment. Consequently, a juvenile cod group was added to the model; 70% of the 1995 stock biomass and 7% of the catch were juveniles and the age of transition to the adult group was 1 (Anon., 2000c). P/B and Q/B were set at twice that of adult cod, K was 0.2, and the average adult weight/average juvenile weight was 5.8. Diet composition for this group was based on 12–16 cm cod from the Baltic Sea (Hussy *et al.*, 1997).

Predation from whiting and cod on the 'cod' group was allocated wholly to juvenile cod, and 50% of large bottom fish predation went to juvenile cod. Because adults only composed 30% of the total biomass, but the majority of the catch was adults, fishing mortality was 1.92 and the EE became 2.28 in the 1995 model. To combat this, F was reduced to 0.8 year^{-1} by using a biomass of 0.044 t/km^2 , which meant that the juvenile biomass was 0.103 t/km^2 .

In the Irish Sea, Planque and Fox (1998) and O'Brien *et al.*, (2000) showed that there was a negative correlation between the February–May temperature and recruitment. This appeared to be the case in the North Sea too (Pearson value – 0.46, $p < 0.01$), and to a lesser degree in the Celtic Sea (Pearson value – 0.37, $p < 0.05$). Because the Channel seems to have a greater affinity with the North Sea stock of cod (Pawson, 1995), the relationship between February–May temperature (in °C) and North Sea recruitment was used to create the equation:

$$\text{Recruits} = -225195 * \text{temperature} + 3,000,000$$

The forcing function entered into Ecosim was the difference between the number of recruits from the equation, and the estimated value from the February–May mean temperature 1900–2000. The forcing function was used to drive both adult and juvenile groups as there was a suggestion from the data that cooler years may permit more North Sea cod to reside in the Channel.

Large bottom fish. The estimated biomass was assumed to be constant, but when the model was run with the time-series F s, the predicted biomass halved. It was assumed that P/B needed to be higher, so it was increased in both models by 0.1 year^{-1} , which in the 1995 model produced a P/B of 0.496 year^{-1} . This seemed reasonable as M was estimated to be between 0.15 and 0.2 year^{-1} using the empirical equation of Pauly (1980), and combined with an F of 0.3 year^{-1} , this was close to $Z = P/B = 0.5 \text{ year}^{-1}$. Even with this change, large bottom fish still declined gradually. In fact, M. Dunn (*pers. comm.*) indicated that there was concern about the anglerfish stock, so the model predictions were not unreasonable.

Seabream/John Dory. There were few data available for seabream, but both the catch data and M. Dunn (*pers. comm.*) strongly suggested that the stock was larger, or that there was a second stock in the western Channel. The stock seemed to be under very high pressure in the late 1970s when the modal length changed from 37–38 cm in 1977 to 28–30 cm in 1979 (Pawson, 1995). Because black bream all mature as males and then between 30–40 cm turn into females, a change in size of 7–8 cm can have great importance. Hence there is sufficient evidence to believe that the stock did indeed crash after 1980. Furthermore, M. Dunn (*pers. comm.*) referred to increases in both seabream and John Dory as the Channel warmed. Fishing mortality was increased in the 1970s to cause the model to make the stock crash, and a forcing function was used in an attempt to replicate its recovery. It is important to note that this group was tuned only for trends as,

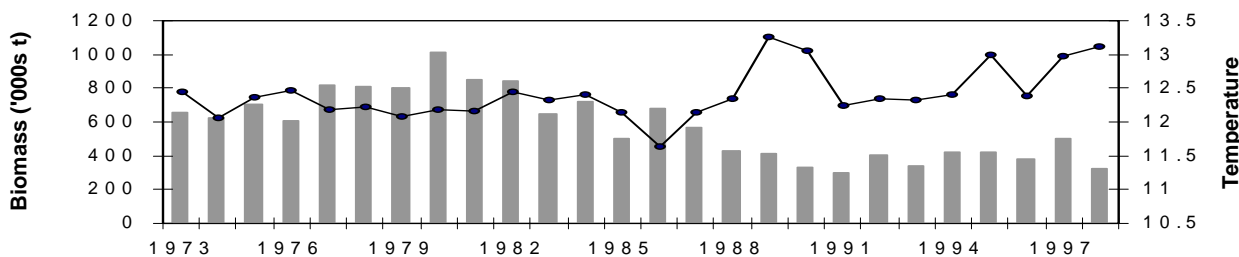


Figure 4.3 Response of North Sea cod to temperature. The filled bars show total stock biomass as estimated from XSA, and the solid line the average annual temperature.

in the absence of point estimates of biomass or fishing mortality, all that could be hoped for was that the group would behave in a manner that was reasonable. For both seabream and John Dory the same forcing function was used. This was calculated by the equation:

$$1 + (\text{difference in temp. from the 100-year mean} * 20)$$

where temp. = temperature is expressed in °C.

Pilchard. There were three data sets available to understand changes in pilchard biomass over time; catch, temperature and egg counts, but there were no correlations among them. Unfortunately, egg counts stopped before the warmer years of the 1980s, which, if pilchards were affected by temperature, would have been a very important period. A further problem was that there were large differences between the pilchard catch data from the CFSG and that from ICES. For example, between 1993 and 1995 the CFSG estimated that there were 5,588 t of pilchards landed per year, but during the same period ICES showed a figure of 20,000 t. Time series biomass data were not available, and as the egg count data had proved unreliable in 1973, this could not be used as a surrogate. Consequently, although both Southward *et al.* (1988a) and Haynes and Nichols (1994) argue that there is a relationship with temperature, the magnitude of the impact remains unknown. As a default, we used the same forcing function as for seabream and John Dory.

Scad. Inconsistencies in the catch data, and the fact that the ICES stock assessment only extended back to 1982, meant that there was a great deal of uncertainty about scad. Consequently, the model conservatively predicted a biomass that changed

little over the simulated period, even though it is known that large infrequent recruitment pulses have a strong effect on biomass (Pawson, 1995).

Bass. The biomass of bass significantly decreased along with step-like increases in F (Figure 4.4). According to M. Pawson (*pers. comm.*), the 1990s saw the beginning of a recovery of bass stocks, following a warm year in 1989. It was therefore important to include the effect of temperature on bass in the model. A juvenile bass group was added, because there was a relationship between temperature and recruitment. Using data from Henderson and Corps (1997) and Pawson (1992), a simple linear relationship was calculated connecting temperature, in °C, between July and October with relative year class abundance;

$$\text{recruits} = 23.059 * \text{temperature} - 336.04$$

The number of recruits from the equation was divided by the estimated number of recruits from the 100-year mean temperature to obtain the forcing function used in the model.

Using data from the CFSG, juvenile bass were estimated as 20% of the adult biomass. They recruited to the fishery at age 4, had a K of 0.2, and a value of 2.48 for the average adult weight/weight at transition. P/B and Q/B were double the adult values. The diet composition of juvenile bass was based on frequency occurrence studies by Kennedy and Fitzmaurice (1972) in Ireland and Kelley (1953) in the Channel. Shrimps and deposit feeders dominated, with some copepods and crab, and so 45% was allocated to shrimps and prawns, 45% to deposit feeders, 5% to copepods and 5% to crab.

When fishing mortality was zero, the biomass of bass doubled whereas a greater change was

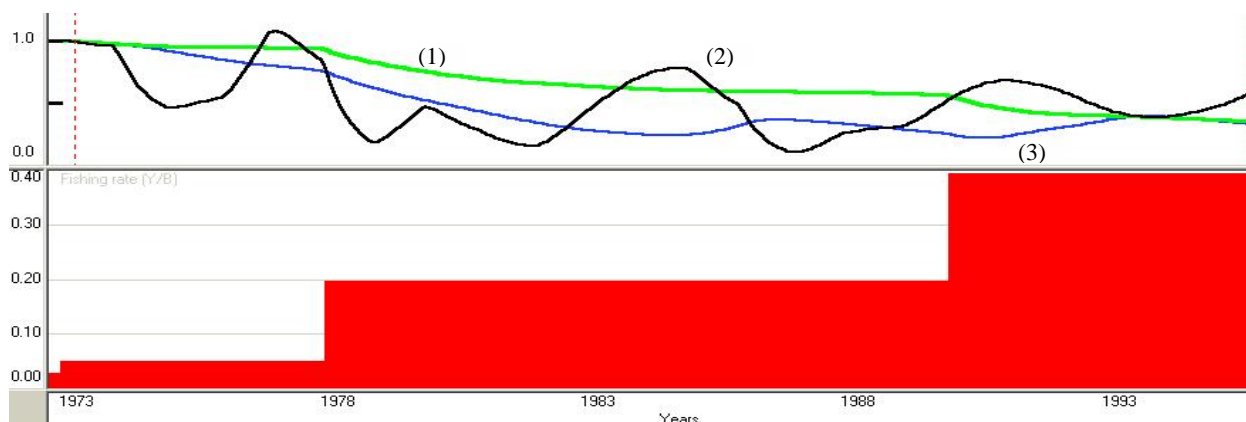


Figure 4.4 Biomass of bass predicted by the model. The green line (1) shows adult biomass with no forcing function, the blue line (3) shows the adult biomass with the forcing function included, and the black line (2) shows juvenile bass biomass with the forcing function. The red blocks beneath the graph show the estimated increase in fishing mortality.

expected. P/B was therefore lowered from 0.6 to 0.5 year⁻¹ in the 1995 model.

Sharks. When F for sharks entered into the 1995 model was multiplied 10-fold from 0.01 to 0.1 year⁻¹, biomass was barely affected. So, in the absence of data, shark biomass in the 1995 model was reduced to one fifth of the estimated value. This meant that sharks in the model became much more sensitive to changes in fishing mortality, which historically seems to have been the case (Vas, 1990, 1995).

Cephalopods. Temperature and landings of Scottish squid (Pierce, 1995) and in the English Channel (Robin and Denis, 1999) are positively related, although more research is required to ascertain the mechanism and the precise changes in biomass. As with pilchard, a forcing function of unknown magnitude was required. Part of the problem was that fishing effort on cuttlefish had simultaneously increased with temperature, so it would be hard to separate the effects of temperature from increased effort. Hence the same forcing function as seabream, John Dory and pilchard was employed, and this produced a maximum change in biomass of only 20% even in the warm year of 1989.

Toothed cetaceans. Changes in the herring population in the early 1980s allowed the simulated biomass of toothed cetaceans to increase. This increase was unrealistic because the majority of toothed cetaceans are in the western Channel and the herring stock primarily lives in the eastern Channel. Ideally there would be one model for each side of the Channel, or a spatial model for the whole Channel that could incorporate this effect, but in the absence of these, the herring component of the cetacean diet was reduced from 0.07 to 0.03, and the remainder was added to mackerel.

Simulations: Single Objective Results

The aim of the Channel Ecosim model was to explore optimal fishing fleet structure. 'Open loop' optimisation allows the modeller to specify weightings on 1 or more of 4 objective functions, according to management priorities. By altering relative fishing mortalities, the algorithm then searches for an optimal fleet structure that maximises the total specified benefit.

The four different objectives are:

1. *Economic.* This adjusts the fishing fleet to maximise pure profit. It tends to focus fishing effort on the most lucrative species. Operating and fixed costs, and discounting

over the simulated period, are included in the calculations.

2. *Social.* Maximises direct employment in the fishery. For each gear type or fishery sector, the number of jobs per catch value is specified in the model and this focusses effort on the most labour intensive gears.
3. *Ecosystem structure.* Maximises specified ecological values derived from the ecosystem. The default setting favours long-lived species as a proxy for charismatic and more 'healthy' fauna (Odum, 1971); this is achieved by weighting each group in the model as the inverse of the P/B ratio. A user can enter other values, perhaps based on risk of local extinction, if desired.
4. *Mandated rebuilding.* Adjusts fishing mortalities across the gear types to maximise the biomass of groups that receive a weighting value from the user.

Note that searches for putative optima have to be repeated and rigorously challenged before acceptance (Walters *et al.* 2002; Ainsworth and Pitcher, in press).

Five alternative aims investigated using the 'open loop' search routine are as follows:

- *Purely economic;*
- *Purely social;*
- *Purely ecosystem values (longevity);* (For the above three aims, the specified objective function was weighted with 10 and the alternatives set to 0.)
- *Mandated rebuilding for recreational fishery.* Cod, rays, large bottom fish, bass and sharks were judged to be the most significant recreational fisheries. Each of these groups was weighted with 10 and the mandated rebuilding objective function was weighted with 10, while the other objective functions were set at 0;
- *Authors' choice.* Using all of the available information, we attempted to produce 'best' combinations of objectives to optimise; three such scenarios, A, B and C, are discussed in the final chapter below.

Climate change modelling has a high degree of uncertainty and employs many variables (Figure 4.5). Using data from D.Viner (University of East Anglia, *pers. comm.*), two 40-year climate change scenarios were created using a minimum sea temperature change of 0.15°C per decade and a maximum change of 0.3°C per decade. The temperatures were entered into forcing function equations to produce a time-series for the affected groups. For the forcing functions, an average temperature of 12.57°C between 1993-1995 was used as the starting point. Hence, in

Table 4.2 Optimal fleets for single objective optimisations. The values are multipliers of the current level of fishing. Two results for social are shown because social (1) was too costly economically, while social (2) was a useful local optimum. Levels of profit, jobs and ecosystem health are shown relative to the current level.

Fishery sector	Economic	Social (1)	Social (2)	Ecosystem	Rebuilding
Otter trawl	1.02	7.91	0.59	0.02	0.02
Beam trawl	0.06	0.24	0.86	0.11	0.01
Midwater trawl	1.86	6.40	0.31	0.10	0.09
Dredge	0.81	0.45	0.79	0.10	0.33
Net	1.68	3.17	3.91	0.07	0.02
Pot	0.71	0.65	0.46	0.03	2.83
Line	2.07	20.09	8.9	0.21	0.07
Profit objective	1.34	-3.54	0.43	-1.68	-2.09
Jobs objective	1.19	5.51	2.27	0.07	0.51
Ecosystem objective	0.99	0.89	1.03	1.49	1.30

extreme circumstances, the forcing function represented an increase in sea temperature to 13.77 °C after 40 years. The forcing functions are shown in Appendix Table A2.

As well as seeking for the optimal fleet under scenarios where the Channel increases in temperature, the effect of temperature on the initial optimal fleet was also investigated. To ensure that the search routine did not stop at a local optimum, each optimisation was run 3 times from starting values of base Fs and 20 times from random Fs. All searches used Adams-Basforth optimisation (Walters *et al.* 2002).

Optimising for economic objectives

With an economic objective alone, the simulated optimal fishing industry generated 34% more profits than in 1995 (Table 4.2); much of this due to an increase in highly-profitable lining and midwater trawling (Table 2.22). By reducing fishing mortality from potting on crabs and lobsters, and on scallops by dredging, their stocks recovered. This resulted in catches of commercial crab and lobster that were higher than, and of scallops that were nearly equal to, current levels (Figure 4.6), but associated with much reduced costs.

Some of the higher trophic level predators, such as large bottom fish, rays and dogfish, toothed cetaceans and seals, were reduced. Increased midwater trawling meant that the mortality of toothed cetaceans became large enough to deplete their biomass. The biomass of seals also decreased, because large bottom fish, which constitute an important part of their diet, were depleted by the lining fishery. Increases in all the finfish fisheries caused the higher trophic level piscivorous species, such as large bottom fish and rays and dogfish, to be reduced in biomass. This allowed increases in whiting, small gadoids, small demersals, and other flatfish.

There was less change in the biomass of cod, pollack, whiting and cephalopods than expected from the increased fishing effort, because the reduction of toothed cetaceans, seals, large bottom fish and rays and dogfish made predation lower. The biomass of sprat did not dramatically increase, yet catches and value of this species nearly doubled. This was the result of predators such as hake, rays and dogfish being depleted, and the potential biomass increase being removed by midwater trawling. Although both hake (4.7 €/kg) and seabream (2.75 €/kg) are valuable species, and when abundant form a significant part of fishers' income because their biomass is small compared to mackerel and the flatfish, they

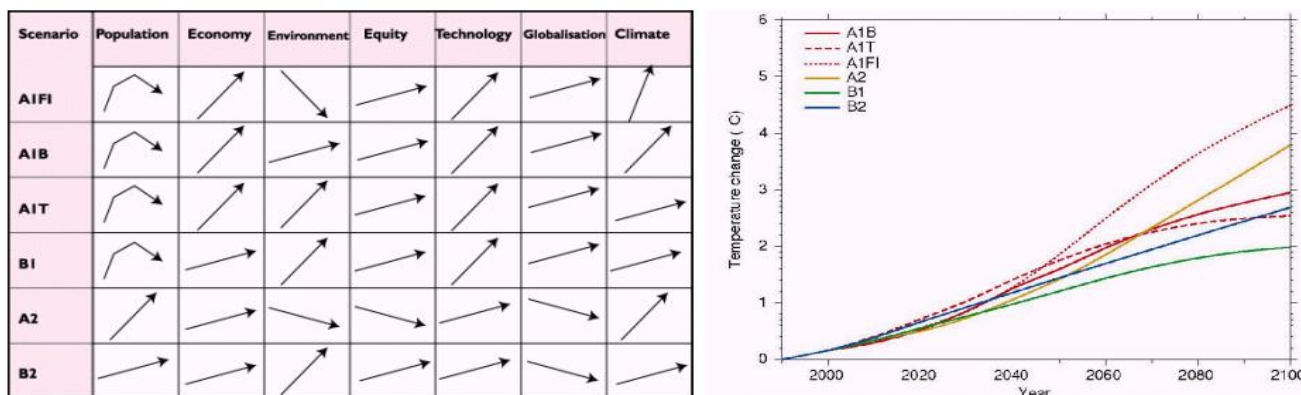


Figure 4.5 Potential sea temperature changes in the Channel. Left panel shows qualitatively how 7 factors are influenced by 6 climate prediction scenarios. Right panel quantifies these differences. Figures after Watson *et al.* (2001).

did not contribute much to the value of the fishery. Groups such as seabreams will were caught as a by-product when pursuing other species, because in their own right they do not carry enough economic weight.

Both conservationists and recreational anglers would find this option unacceptable because toothed cetaceans, seals, bass, cod, rays and large bottom fish are all depleted. Furthermore, the partial replacement of natural predator mortality with fishing mortality constitutes a major manipulation of the ecosystem. Such large changes may generate unexpected repercussions, that may not be identified by the Ecosim model, which is best at describing small perturbations.

Optimising for social objectives

The jobs created by lining were much greater than

any other gear (Table 2.25), and as a result the optimisation to maximize the social objective calls for a 20-fold increase in the effort employed by this sector (Table 4.2). Netting also had a high jobs/catch value ratio, and consequently this too was significantly increased. Although jobs related to midwater trawling were low, pelagic species such as sprat and herring increased in abundance as their predators were removed, enabling a large increase of effort to be sustained. Although in one sense effort was sustained, as fish were still being landed, the effect of social optimisation (1) was over-exploitation. From an ecological standpoint the results were a disaster, as the only fisheries that remain are those for lobster, small gadoids and mullet, sole, herring, sprat, and cephalopods. Two positive outcomes for conservationists would be that the biomass of seabirds increases 9-fold because of high discarding, and that a reduction in potting allows lobster biomass to increase.

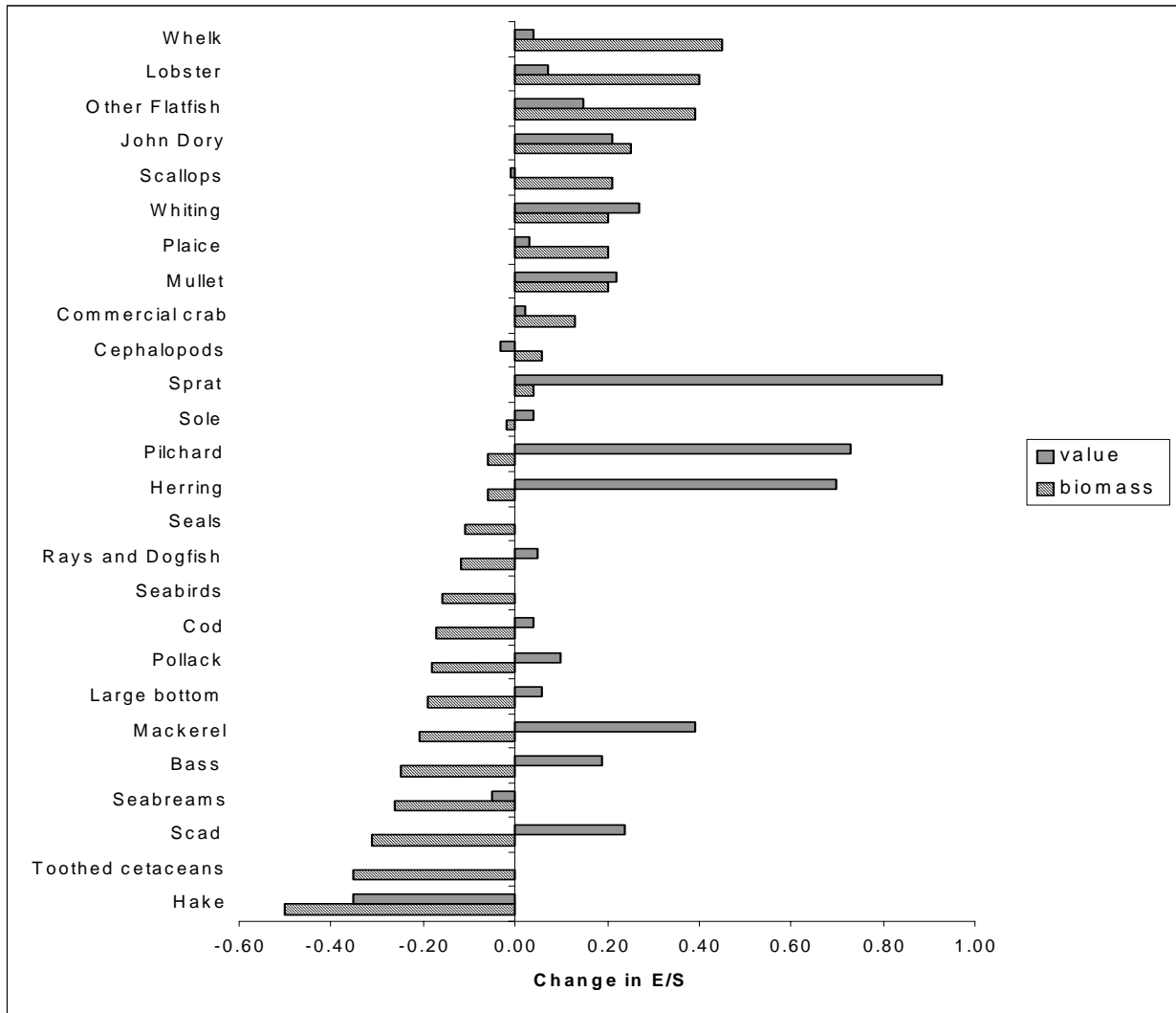


Figure 4.6 Optimal economic fleet configuration. Change in biomass and value of the groups that showed a difference of more than 5% . The change in E/S refers to the difference from the start to the end of the biomass over the simulation period. In this figure, +1 means the biomass has doubled and -1 if the group became locally extinct.

In reality, using this fleet configuration, the ecosystem has been significantly changed, with most finfish species becoming locally extinct. Furthermore, tremendous over-capacity is generated, with costs increasing by two-and-a-half times, meaning that subsidies would be required to make this a feasible option (Table 4.2), far from a plausible management scheme.

Apart from the overall solution described above (social 1), the optimisations often settled on one local optimum (social 2), and we determined that this provides a more viable scenario. Increased lining and netting provided 2.3 times as many jobs, half the value of social (1) (Table 4.2). The main difference between this optimisation and social (1) is that large bottom fish are the only group wiped out completely (Figure 4.7). Their local extinction allows an increase in whiting, which in turn, combined with the decrease in midwater trawling, allows toothed cetaceans to

increase. Because fish caught by netting and lining yields greater employment, competing fisheries were lowered. Consequently otter trawl effort is reduced and prevents the extinction of rays and dogfish, and bass. Potting is also reduced, preventing the extinction of commercial crab; midwater trawling is reduced and so mackerel can be caught by netting; and beam trawling/dredging decrease, enabling netting for sole, cephalopods and plaice.

Optimising for ecological objectives

In the purely ecological optimum, all fishing fleets were reduced, allowing the ecosystem to return towards its un-fished state composed of large, long-lived species. In the Channel, bass provides a classic example of decline in long-lived species; in recent years recreational anglers have argued that they catch many more small bass than in previous times (M. Pawson, *pers. comm.*). The

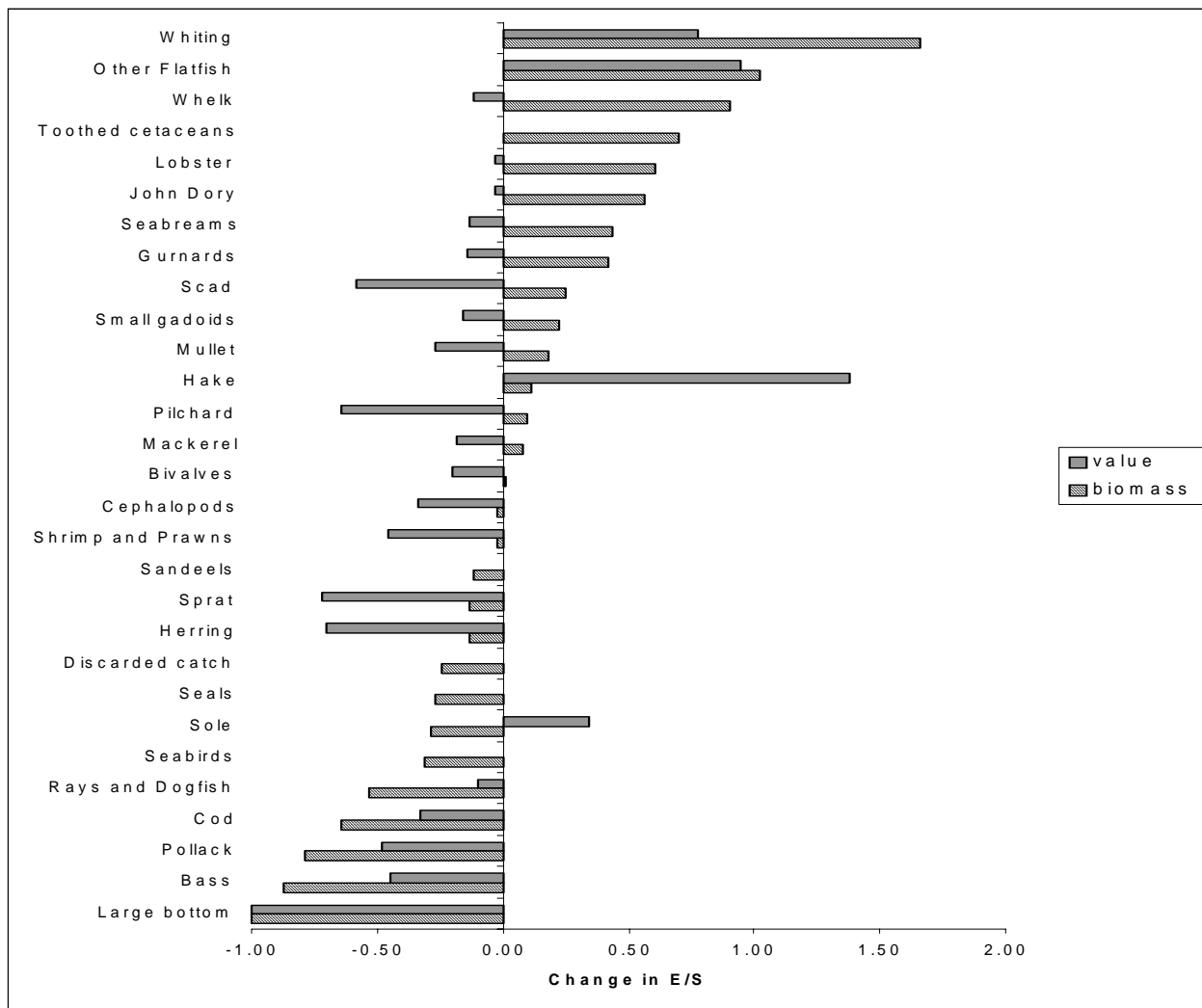


Figure 4.7 Optimal social fleet configuration. The change in biomass and value of the groups that showed a difference of more than 5%.

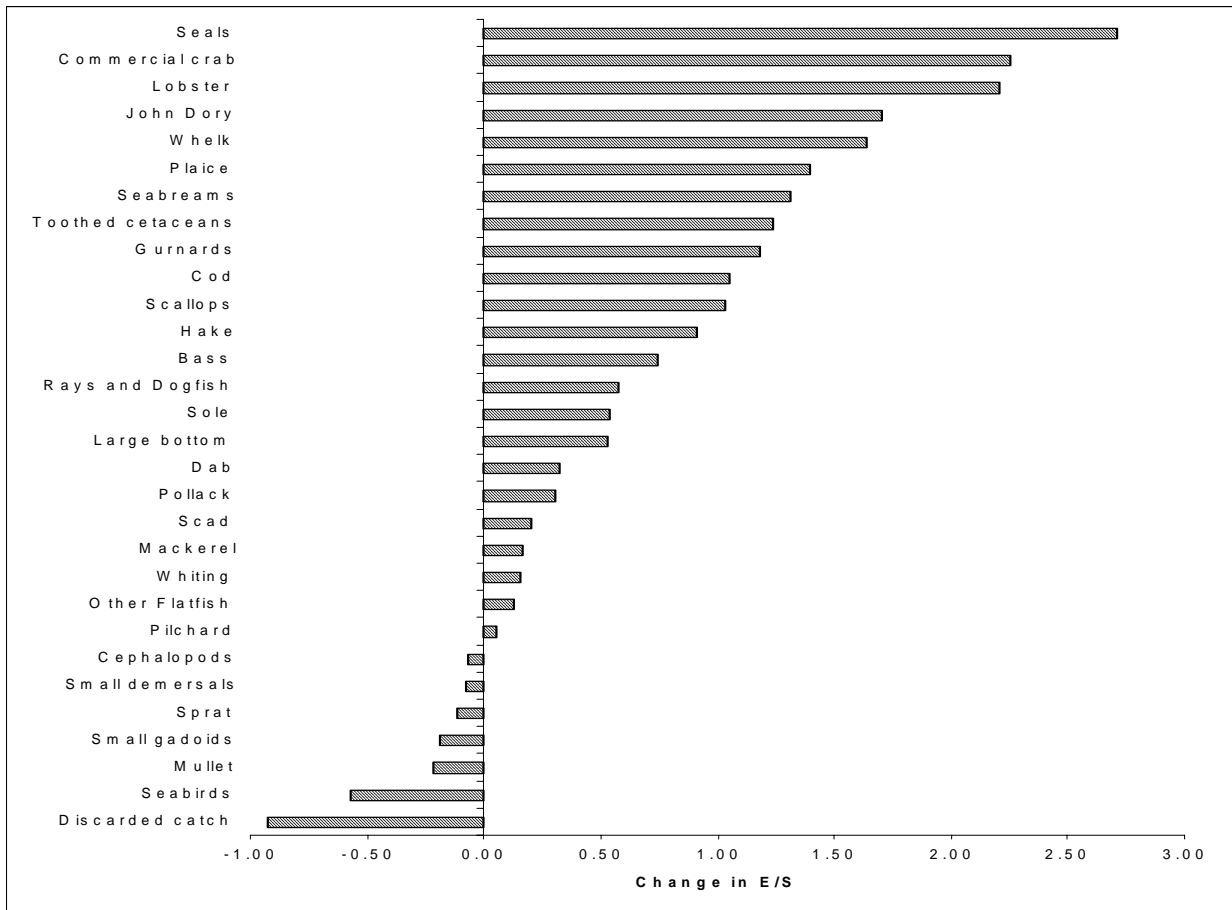


Figure 4.8 Ecologically optimal fleet configuration. Changes in biomass from baseline of more than 5%.

model predicts that, with a large decrease in fishing effort, bass will ‘bounce back’ (Figure 4.8). There are similar resurgences in shellfish species such as crabs, lobsters, scallops, rays and dogfish, large bottom fish and cod, that are currently heavily-exploited; although the increase of some finfish species, such as whiting, is tempered by the rise in predation from seals and toothed cetaceans.

This gives an indication of how fisheries may have displaced marine mammals at the peak of the food chain in the Channel. In this scenario, the lower trophic level schoolers (‘bait fish’, or ‘forage fish’), small gadoids, small demersals, mullet and sprats, all decrease as the ecosystem shifts to favour longer-lived, high trophic level organisms, which prey on them. One notable exception is seabirds. The model suggests that the decrease in discards from a reduced fishing fleet lowers their biomass by more than half.

This optimisation produces a ‘healthy’ ecosystem, with large numbers of long-lived species. The reason for some fishing remaining, rather than a complete cessation, appears to be that some

fishing effort has positive effects on a group. An obvious example is the way that discards feed seabirds. Again, sharks are positively affected by lining, because competition among their prey is reduced as lining depletes rays and dogfish and large bottom fish.

The impact of this fleet configuration on levels of profit and employment was drastic (Table 4.2), with the heavy reduction in fishing reducing employment to less than 10% of current levels. Large losses resulted because of the high percentage of fixed costs (Table 2.24) that were present even when the fleet was reduced close to zero.

Optimising for mandated rebuilding of the recreational fishery

In general, the fleet structure in this optimisation was quite similar to the ecosystem scenario, but except for an increase in potting (Table 4.2). Potting catches commercial crabs and cephalopods, which have a diet composition that overlaps with cod, rays and dogfish, large bottom fish, and bass. Although a mixed trophic impact

analysis (Appendix Table A3) indicates that the individual negative effect of commercial crabs and cephalopods on each group is small, there is a cumulative effect reducing the biomass of these competitors. Cephalopods form a large proportion of the diet of sharks, and this limits the increase in potting.

Using this fleet configuration, the biomass of cod more than doubles because fishing mortality is greatly reduced and because juvenile plaice and pollack, two important prey species, increase in biomass (Figure 4.9). Predators of cod increase as there are no fisheries for seals or toothed cetaceans, and large bottom fish increase when the lining fishery is reduced for bass. Rays and dogfish are caught primarily by otter trawling and netting, and these gears are reduced to almost nothing (Table 4.2). With no natural predators in the model, and with little change in the biomass of their prey, a reduction in fishing mortality is the only reason for the increase in rays and dogfish. Fishing mortality on large bottom fish is significantly reduced, and although the increase of seals limits the growth of their biomass, there is still an increase of 1.6 times. Bass biomass

nearly doubles as a result of the reduction in fishing mortality; the increase would have been greater still if the recreational fishery had been shut down. The same is true with sharks. Because there is no commercial fishery for sharks, a greater increase in biomass could be achieved by shutting the recreational fishery. An increase in shark biomass of 7% was caused by increased mackerel biomass that came from reduced midwater trawling.

The impact of varying vulnerabilities

Figure 4.10 illustrates the effects of changing the vulnerabilities to extreme values of 0.2 and 0.8 for the four optimal fleet configurations in Table 4.2. Although a range of 0.2-0.7 set according to trophic level was used for the basic model, these turned out to be fairly conservative values and resulted in an ecosystem that was not very different from a setting of 0.2. The reason for this is that much of the diet of the higher trophic level organisms was composed of low trophic level organisms that had a low V.

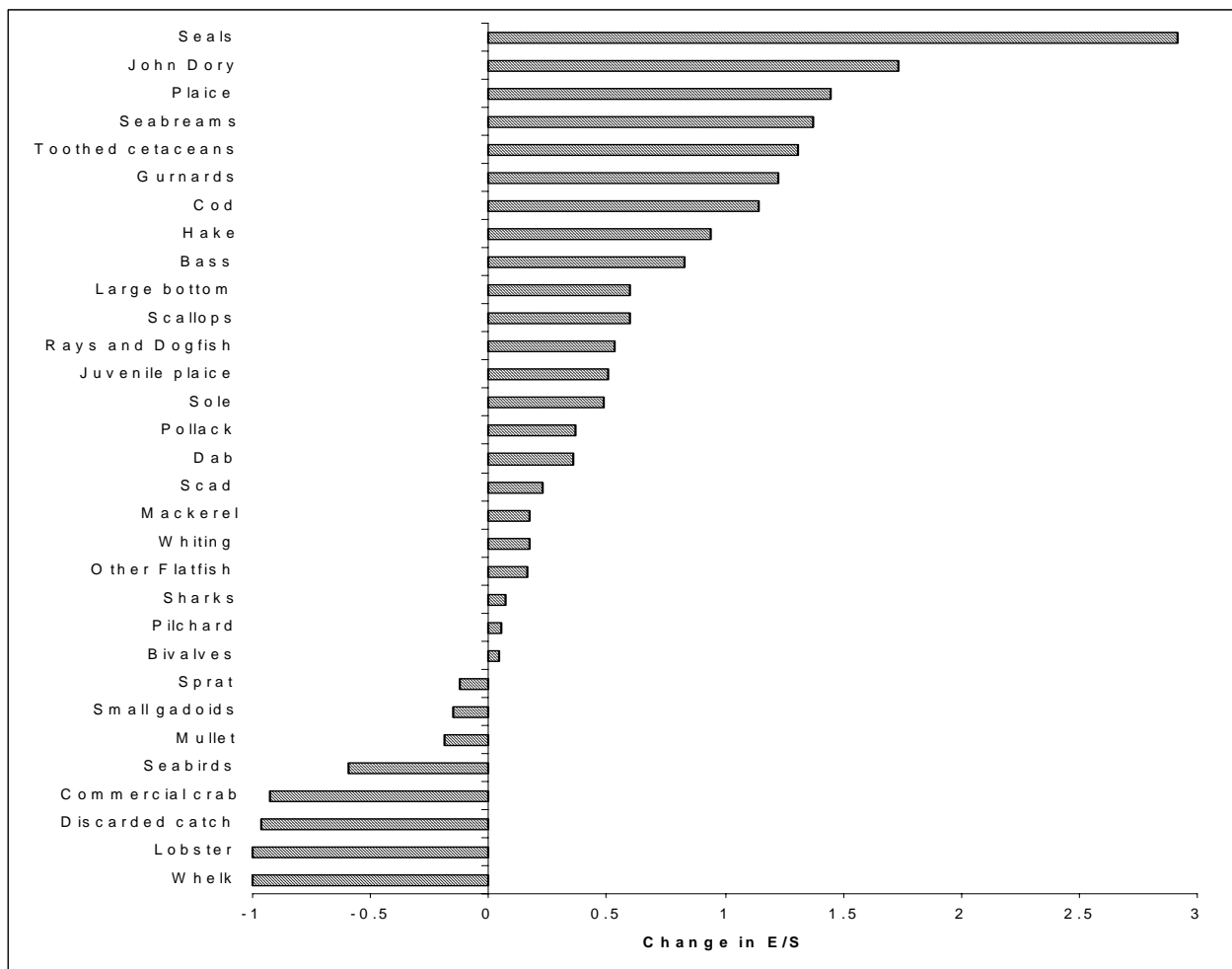


Figure 4.9 Biomass changes for the 'mandated rebuilding of the recreational fishery' optimal fleet configuration.

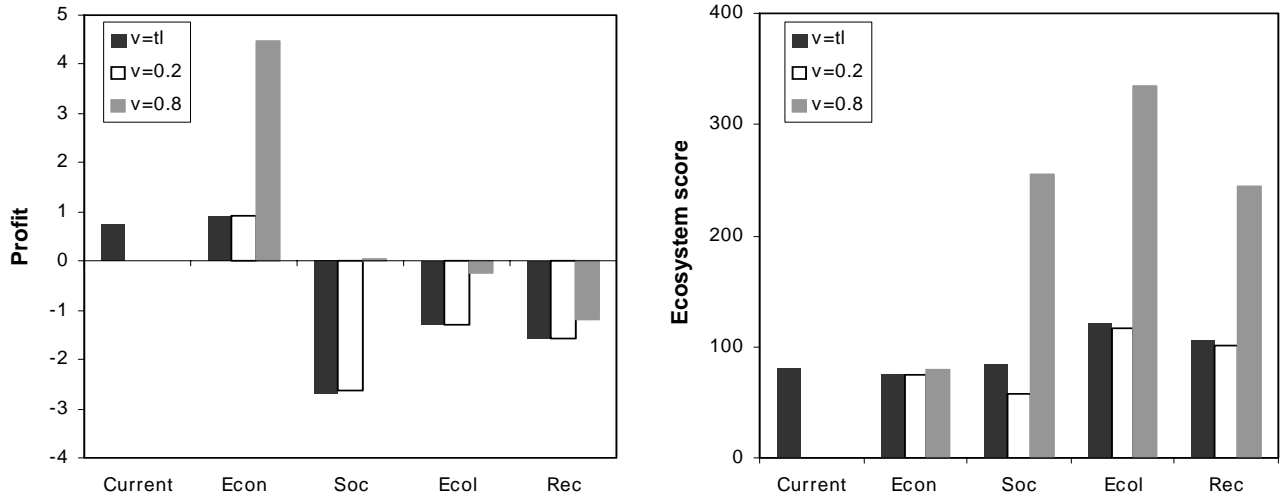


Figure 4.10 Effect of high and low default vulnerabilities on profit (left panel) and ecosystem structure (right panel) for the optimal fleet configurations.

Using a V of 0.8 produced large differences in both profit and ecological values because, when specifically optimising for these characteristics, a higher V meant that rewards were much greater.

Testing Vs was a valuable exercise because it showed that higher Vs accentuated what the modeller would hope to achieve. Hence, it was prudent to use conservative Vs, as the actual outcome of a specific fleet configuration may be better than expected, rather than using high Vs and building false hopes. It is noteworthy that when the social optimum has a high V the system is healthier. The reason for this is that higher discarding and more sandeels benefits seabirds, which have a high B/P ratio, while seals and toothed cetaceans increase with the whiting and

other flatfish are made available by the absence of rays and dogfish and large bottom fish. But, many of the finfish species have rendered extinct by the intensive fishing and so this system cannot be labelled as healthy.

The impact of temperature

The effect of increasing temperature was positive, enabling higher profits and a 'healthier' ecosystem. Adult and juvenile sole and cod, seabreams, John Dory, pilchard, cephalopods and juvenile bass had a temperature forcing function acting directly on them, but because of the complex predator-prey relationships in the ecosystem model, these were not the only groups influenced by temperature. As much as the model

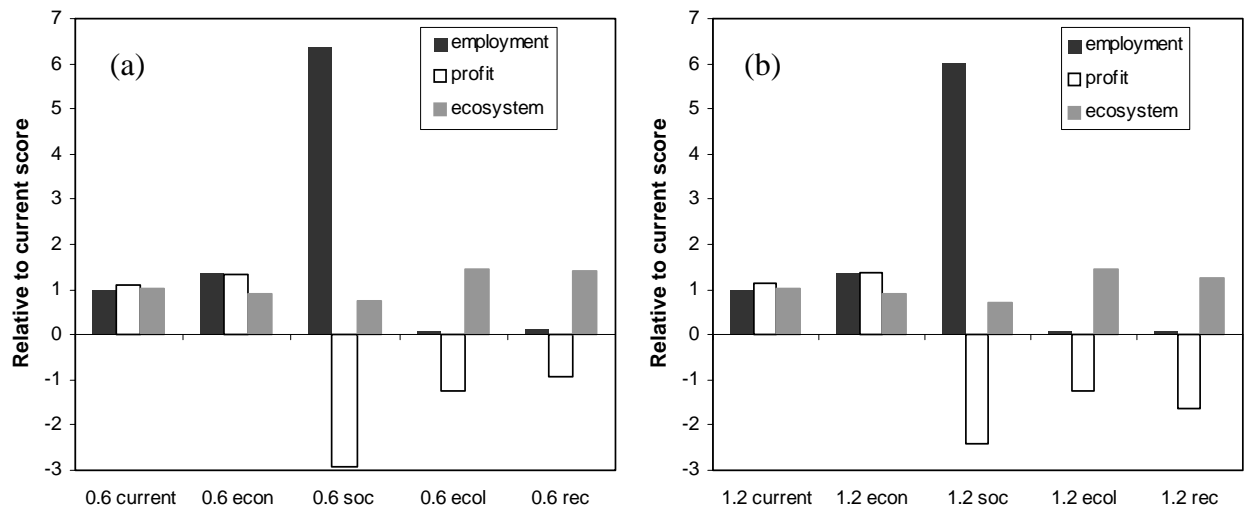


Figure 4.11 Maximum potential discounted profits, employment, ecosystem health and mandated rebuilding for a temperature increase of 0.6 °C (left panel, a) and of 1.2 °C (right panel, b). Optimisations were run with the forcing functions described in the text.

Table 4.3 Optimal economic fleet configuration with the forcing functions.

Gear	Current economic optimum	Economic optimum: 0.6°C increase	Economic optimum: 1.2°C increase
Otter trawl	1.02	1.13	1.24
Beam trawl	0.06	0.24	0.05
Midwater trawl	1.86	1.97	1.91
Dredge	0.81	0.77	0.77
Net	1.68	2.70	2.70
Pot	0.71	0.50	0.48
Line	2.07	1.26	2.01

was capable of predicting changes that would occur if the Channel warmed, it showed that using the current fleet structure led to more profits because of the increase in lucrative sole and bass fisheries. Increases in a number of finfish species and cephalopods also allowed higher trophic level predators to increase in biomass, leading to a 'healthier' ecosystem.

Optimisations were also run with temperature increases of both 0.6°C and 1.2°C for each of the single objective functions (Figure 4.11). When optimising with an assumed increase of 0.6°C, the maximum potential profit was 86%, and with an increase of 1.2°C it was 89%, greater than the 1995 current maximum profit. The actual fleet structure that generates these profits changes little (Table 4.3), with only netting significantly increased because of the larger sole biomass. Unlike trawling, netting catches only a few species, so it is able to more effectively respond to temperature by selectivity.

When optimising for employment with an increase in temperature, the search routine did not halt at a local optimum, and so it led to an

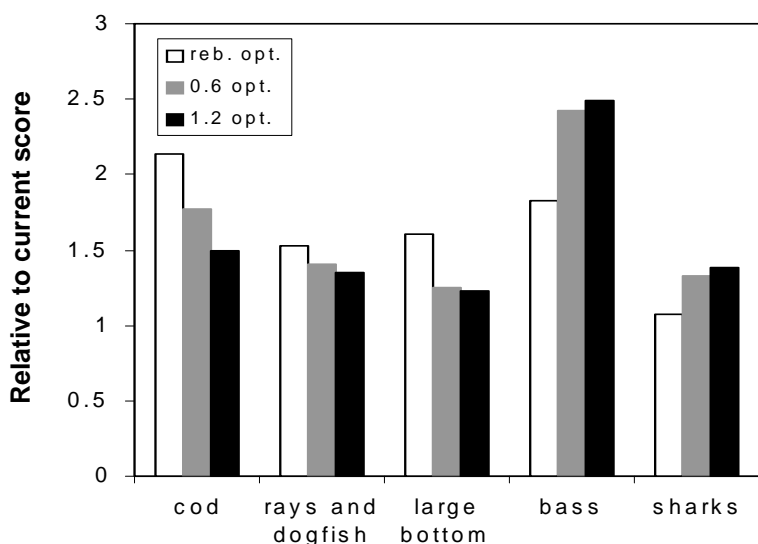


Figure 4.12 Effect of temperature on the potential rebuilding of five recreationally important stocks. All values are relative to the current biomass of 1.

Table 4.4 Optimal social fleet configuration with the forcing functions.

Gear	Current social optimum		Social optimum: 0.6 °C increase	Social optimum :1.2 °C increase
	Social (1)	Social (2)		
Otter trawl	7.91	0.59	10.52	10.75
Beam trawl	0.24	0.86	0.24	0.309
Midw' trawl	6.40	0.31	4.55	4.72
Dredge	0.45	0.79	0.23	0.22
Net	3.17	3.91	10.40	8.78
Pot	0.65	0.46	0.32	0.37
Line	20.09	8.9	3.04	3.13

ecosystem that was excessively depleted. Table 4.4 shows that the effort is even higher than social (1), and that the growth of sole biomass permitted an increase in netting effort.

In contrast, the ecological optimisation showed little change in fleet configuration in response to temperature forcing.

Figure 4.12 indicates that temperature is be very important for recreational fishers. An increase of 1.2°C would mean that cod biomass increase would be limited to just 1.5 times the current level, rays and dogfish to 1.35 times the current level, and large bottom fish to only 1.23 times the current level. Cod is directly affected by temperature, but rays and dogfish and large bottom fish decrease, as there is increased competition for small gadoids from cephalopods. Bass increase purely through the recruitment from the forcing function on juveniles, while sharks increase due to their prey, cephalopods, being directly affected by temperature. Further temperature effects can be seen throughout the ecosystem.

The model is not sensitive enough to pick up the kind of zooplankton changes recorded by Southward (1963, 1983), but it does show that an increase in cephalopods depletes sandeels, which allows carnivorous zooplankton to multiply. There are important changes at the top of the food chain in response to cephalopods (Figure 4.13). With a reduction in large bottom fish and sandeels, the biomass of seals drops to less than half of its current biomass. Similarly, sandeel depletion causes a drop in seabird biomass by half. Conversely the increase in cephalopods provided additional prey for sharks and toothed cetaceans causing their biomass to increase.

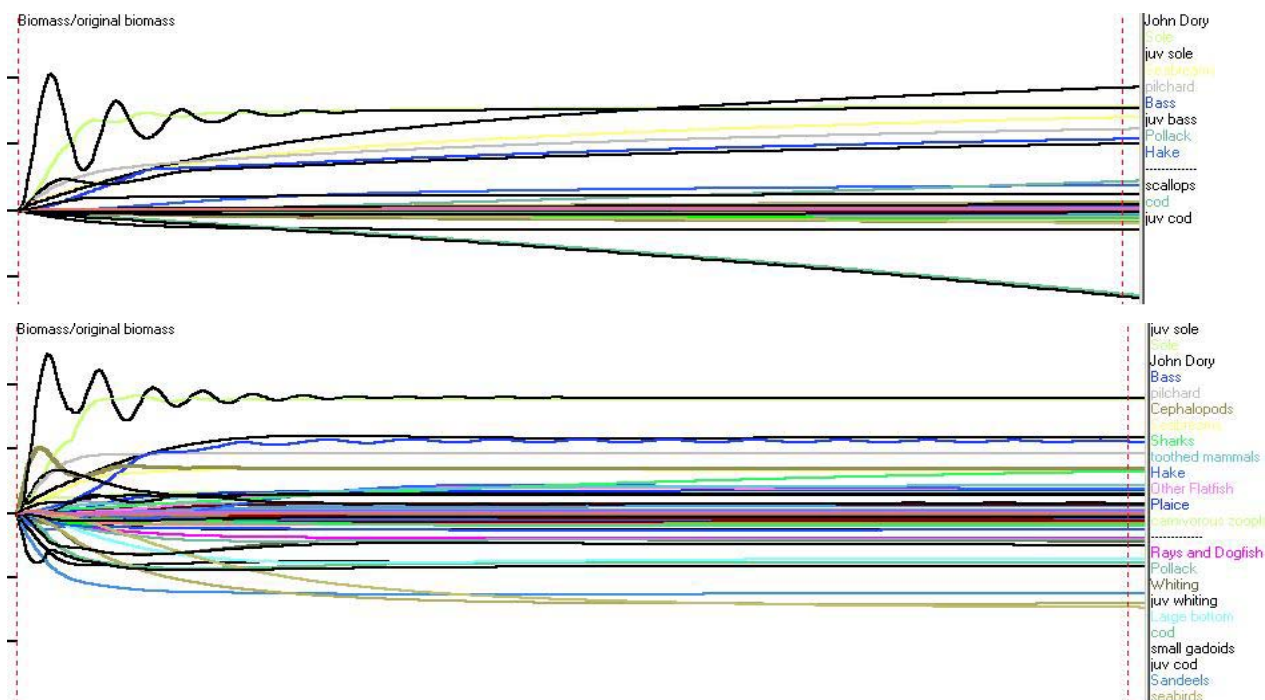


Figure 4.13 Significance of cephalopods in the Channel. These are screen captures from two Ecosim runs both with fishing effort kept at current rates. Lower panel shows how the addition of the cephalopod forcing function to the model had a considerable effect on many groups. See text for a description of the cephalopod forcing function.

The Impact of the Discount Rate

For all the optimisations documented up to this point, the economic discount rate was left at the default setting of 0.04; so a sensitivity analysis was carried out to determine its effect on the optimal solutions (Figure 4.14).

Essentially, the higher the discount rate, the more susceptible the fishery was to ‘fishing down the food web’ (Pauly *et al.*, 1998b; Sumaila, 2001). When the discount rate was high, there was an increase in lower trophic level fish such as sprats and small gadoids. Otter trawling markedly increased because, although it was not the most profitable gear, it rapidly removed the greatest amount of catch, so that the money could be invested elsewhere.

It is worth noting from Figure 4.14 that there were no significant changes in mode output until the discount rate increased above 0.2. In

the U.K. and France, according to R. Sumaila (Fisheries Centre, UBC, *pers. comm.*), the discount rate is likely to vary from slightly greater than 0 to 0.1, and so for the purposes of this model, discounting does not seem to be a significant issue.

We used conventional economic discounting, not intergenerational discounting, an option that has recently been added to the optimal policy search algorithm (Sumaila and Walters, 2003, 2004).

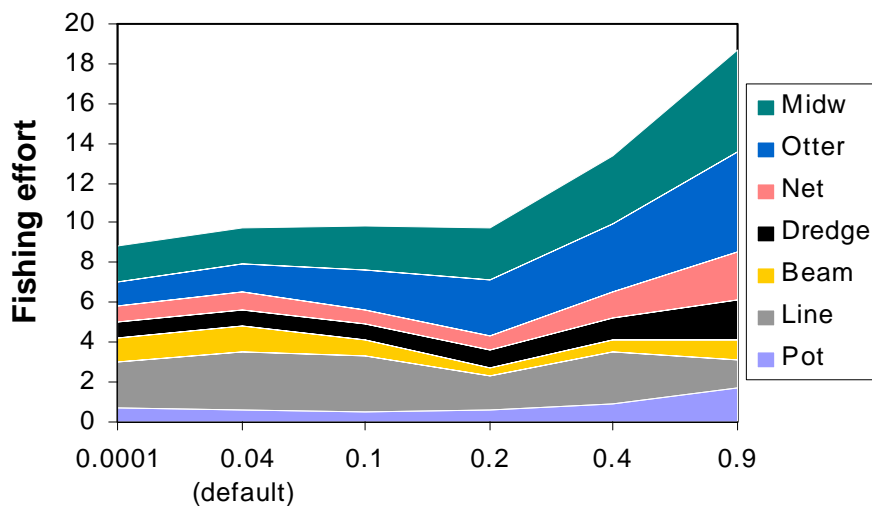


Figure 4.14 Impact of changing the discount rate when optimizing purely for economics.

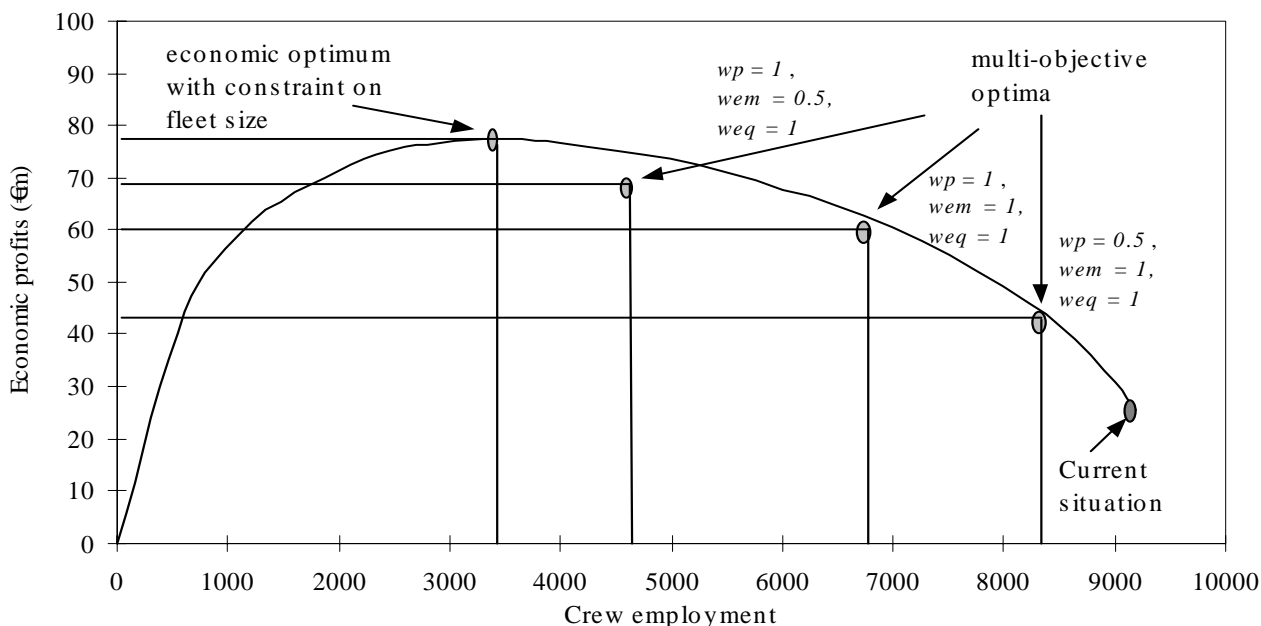


Figure 4.16 Trade-off between profit and employment in the Channel according to the CFSG bio-economic model. Figure kindly provided by Sean Pascoe, from Pascoe (2000).

Trade-offs among Multiple Objectives: Eat it or Leave it?

Up to this point we have considered only individual optima in the policy search results, but in the background there has constantly been the issue of trade-offs. An old saying spells out this truth as “you cannot have your cake and eat it”. The sections above show clearly that the optimum ecological fleet configuration is not the same as the optimal social or economic fleet structure. Because the fisheries and ecosystems that define these different objectives are incompatible, with respect to practical management of the Channel, there are a number of trade-offs and prices that need to be paid. The aim of this section is to elucidate these trade-offs to make the task of selecting the ‘authors’ choice’ scenarios in the final chapter clearer.

Although there are micro-scale trade-offs in many of the predator prey relationships in the ecosystem, such that one cannot expect to have more cephalopods if there are many more sharks, the three trade-

offs that are most significant to the making policy choices from model are those between overall employment and total profit, between profit and ecosystem health, and between jobs and ecosystem health.

Employment and Profit

By weighting employment and profit differently, yet keeping ecosystem health at a constant of 1, it was possible to create Figure 4.15. This shows the economic optimum and also the social optimum, but only includes runs when there was a positive profit. The most significant aspect is that the

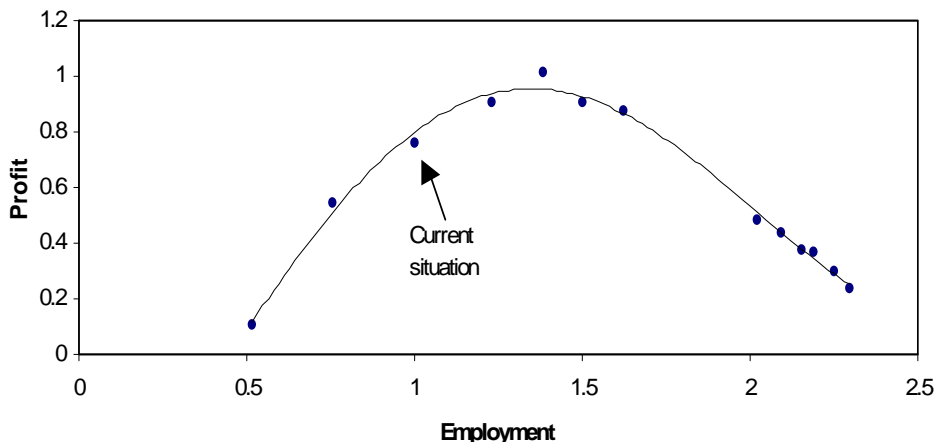


Figure 4.15 Trade-off between profit and employment as estimated by our whole-ecosystem model. The point estimates refer to specific optimisations run with different objective function weightings.

analysis suggests that employment can be increased, and there would still be an increase in profit up until 1.4 times as many jobs. After this point any increase in employment will have negative implications for profits.

Sean Pascoe and Simon Mardle (2001) investigated the same profit/employment frontier using a bio-economic approach and came up with a very different result (Figure 4.16). Their work suggested that there was currently overcapacity in the Channel, and that higher profits could be obtained by reducing jobs. Their optimum economic fleet configuration was entered into the Ecosim model, and this generated profits only 65% of the current situation.

Clearly the two models produce very different results, even though much of the data for them comes from similar sources. The two models draw on the same sources of data for prices and fleet profitability. Some of the biomasses that were entered into the EwE Channel model came from the same CFSG data used by the bio-economic model. One important difference in the data sources was that in the bio-economic model the number of jobs for each fleet was more precise than the semi-quantitative boat months used in the EwE model, but because the EwE model was only optimising for profit this should not have had an effect.

Both models had certain weaknesses that may have contributed to the difference between them. For example, the EwE model aggregated all of the métiers. The EwE model had 8 gear types, while the bio-economic model used 13 gears, split into France and the UK, but it seems unlikely that this alone would have made the results so different.

The bio-economic model used production-effort relationships that did not consider how fishing might affect predator-prey relationships. This is likely to be the cause of much of the difference between the two models, because, when dissecting what the EwE search routine was doing to produce the optimal fleet, it became clear that groups were suppressed by a gear mainly to prevent their predation on other

species. These effects would not be seen in the bio-economic model.

Intuitively one would think that with the Channel having had such a high intensity of fishing for decades, many stocks would be in a similar state of depletion to shellfish and that the most profitable option would be to allow a recovery of stocks, which is what the bio-economic model indicates. But the EwE model indicates that for maximum profit, slightly higher effort for some gears is required and that many groups can be reduced to almost zero. This is an important difference between the models, and the cause of this difference needs further research.

Furthermore, a comparison of the production-effort relationships and the 5 basic input parameters in the EwE model would be extremely useful to highlight why the two models respond differently. The reduction of dredgers and potters when optimising for profit in EwE were similar to the changes required in the bio-economic model. In EwE, the important point about these groups was that they responded positively when fishing was lowered. This may mean that the P/B, biomass or vulnerabilities of other groups was too low and that changing fishing was not having a strong effect. Low vulnerabilities mean that groups become resistant to increases in fishing, potentially allowing fishing effort to be increased without wiping them out.

Finally, regarding the initial input parameters, we did not enter negative biomass accumulations in the EwE model. This implies that, as a starting point, the current level of fishing is assumed to be sustainable. But this may not be correct. For example, some of the gadoid biomasses such as whiting seem to be decreasing at the current level

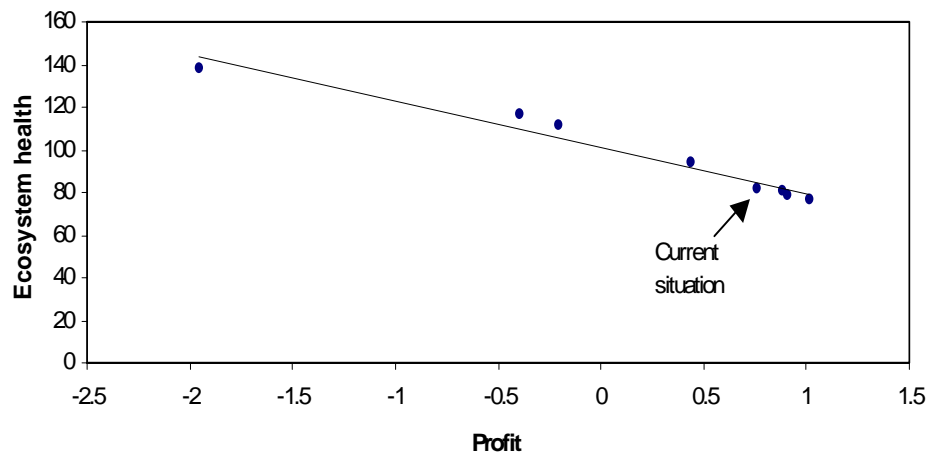


Figure 4.17 Trade-off between profit and ecosystem health as estimated by our whole-ecosystem model.

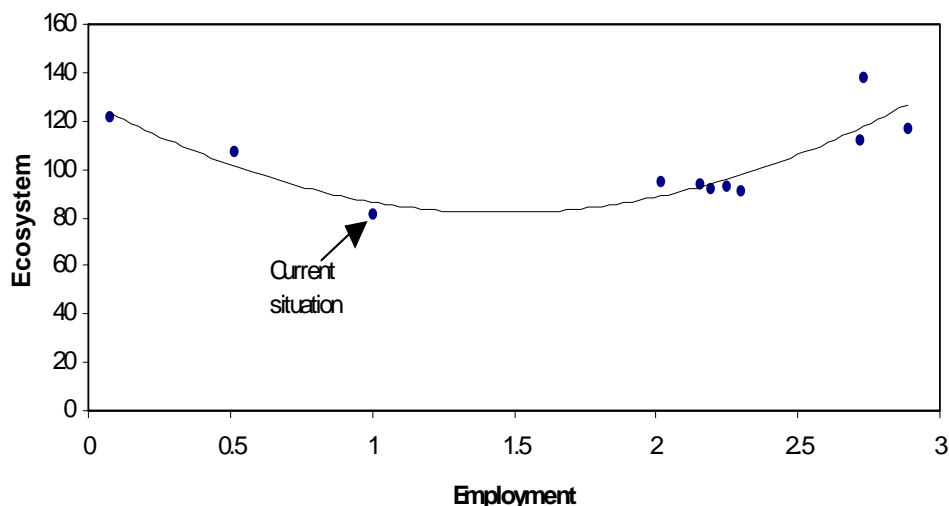


Figure 4.18 Trade-off between employment and ecosystem health as estimated by the EwE model.

of fishing. If this is indeed the case, and suitable adjustments made to the starting values in Ecosim, the policy routine may opt to lower whiting F in order to allow this group to recover.

Further research is required to ascertain what causes the differences between the two models, but this kind of research is helpful. Different models are being used to simulate the Channel and predict optimal fleets, and because they are producing different results, scientists are pressed to confer and look more deeply at the strengths and weaknesses of each of the models, hopefully leading to a better simulation of Channel fisheries in the future.

Profit and Ecosystem Health

Figure 4.17 indicates that, as a general trend, a decrease in profits is required to increase ecosystem health. There is one point on the graph that is important though. When economic was weighted with 2 and ecological and social with 1, there were 16% more profits, 62% more jobs and a reduction of only 0.1% for ecosystem health. In theory this seems an ideal solution, but in reality this scenario has decreases in bass and marine mammals that would be unacceptable to conservationists and recreational anglers. This serves to show that, although these trade-off graphs have value, a detailed examination of the ecosystem response to fishing is required.

Employment and Ecosystem Health

With only an ecosystem health objective, the number of jobs decreased to nearly zero (Figure 4.18). As the weighting on employment was increased, ecosystem health decreased until the current situation was reached where both jobs

and ecosystem health were much lower than they could be. One would expect that as fishing pressure is increased to accommodate more employees, a downward trend in ecosystem health would occur, as indeed we see with increasing profits in Figure 4.17.

The reverse occurs, however, because as the social weighting was increased, trawling and dredging destroy their targets, while lining and netting rapidly increase. This caused large bottom fish and bass to be wiped out entirely, while rays and dogfish were greatly reduced. These losses allowed the biomass of whiting to increase. Whiting are an important component of the diet of toothed cetaceans and seals, so, in turn, their biomass consequently increased. Hence, the ecosystem is perceived to be healthier because the biomass of these heavily-weighted mammals increases.

In fact, in these scenarios, there were a number of local extinctions, and a significant decline in many finfish species, so by many criteria the ecosystem in this scenario was not as ‘healthy’ as the model indicated.

Comments on the Scenarios

A number of other criteria have recently been used to evaluate ecosystems from the Ecosim optimal policy search results (Pitcher 2004a, 2004b). These include risk of local extinction (=extirpation) of each model group (Cheung and Pitcher 2004), reduction in biodiversity using a diversity index modified for use with this type of model (Ainsworth and Pitcher 2004), and a resilience index derived from network theory (Heymans 2004). Furthermore, the weightings entered in the Ecosim policy search are not linearly related to their effect on the overall objective function values and should be adjusted iteratively to approximate any desired ratio.

Hence the scenarios presented in this report probably need more rigorous examination using these recent developments in technique before further conclusions about management can be drawn.

Further Reference Points

Two further simulations were run using the Ewe model to enable comparisons to be made.

The first of these was a scenario that reduced fishing by all gears to zero, including the recreational and seaweed fishery, and the second scenario was to incorporate an annual 2% increase in catching efficiency of the gear ('technology creep').

1 - Zero fishing. Fishing effort for the ecological optimum (section 4.2.1) was reduced close to zero for each gear, but because there was still a small amount of fishing, a complete removal of this allowed the majority of commercially exploited groups to increase even more (Figure 4-19). The only groups that significantly differed from the ecological optimum were discards, which of course were reduced to zero, and consequently seabirds.

When the default vulnerability (V) setting for each group was 0.2 the resulting biomasses

showed little difference compared to the use of Vs corresponding to trophic level. An increase in Vs to 0.6 allowed the seabird biomass to quadruple despite the reduction in discards. Furthermore, toothed cetaceans, commercial crab, lobster, whelk, sole, rays and dogfish, bass and seabreams at least a doubled in biomass when V was increased from the baseline trophic level values to 0.6. This sensitivity analysis highlights how significant the vulnerability function is in EwE. Many key species such as cod, bass and scallops are under great fishing pressure in the Channel and would be expected to increase if fishing was reduced. Under extreme situations, such as this scenario simulating the complete removal of all fishing, the importance of the Vs is heightened. On the basis of higher V settings, the model indicates that the biomass of a species like cod would rapidly rebuild after a fishing ban, and so a management policy might be encouraged to allow fishing to resume early.

With so much uncertainty in assigning the Vs, this area of the model requires caution; better time-series data can more adequately estimate Vs.

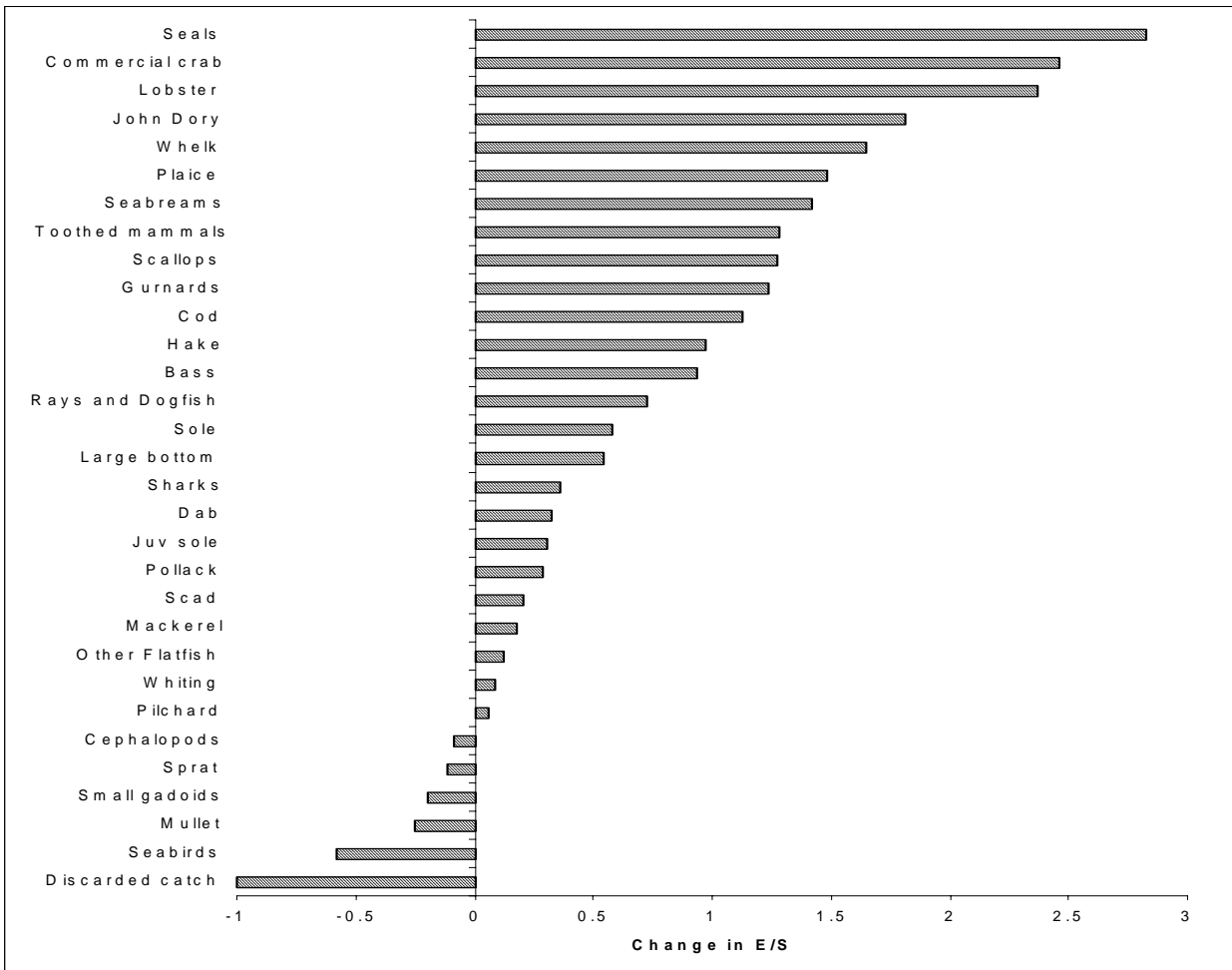


Figure 4.19 Change in biomass of model groups when fishing mortality was zero for all gears.

2 – Annual 2% increase in catching efficiency

Each year through a greater understanding of the fishery, and because of technical advances, fishers tend to become more efficient in catching fish. An average figure over many fisheries is 2-3% per year. Purely mathematically, a 2% per year increase in fishing mortality has a tremendous cumulative impact over 40 years, and the effects of this are clearly seen in a number of model groups (Figure 4-20). Only low trophic level prey species increase such as sprats, small gadoids, small demersals and mullet, and these result in rising seabird and cephalopod biomass. All other model groups all show a decline in biomass, with sensitive shellfish groups, lobster, commercial crab, whelk and scallops nearly becoming extinct. There is no respite for any commercial species, meaning that high trophic level groups such as marine mammals and large bottom fish show large decreases in biomass.

Currently the model does not include the effects of geographical range reduction, and if already depleted stocks did aggregate in smaller areas that the fishers became aware of, the declines

might be further exacerbated.

This steady increase in fishing efficiency throughout all gear types squeezes the fishery tighter and tighter each year. When running the model with predicted temperature increases of 0.6°C and 1.2°C, both seabreams and John Dory decreased in biomass even though a positive forcing function was acting on them. The increase in fishing efficiency on bass cancelled out the forcing function, leaving little change in biomass. Cephalopods still increased in biomass with climate change, but the higher rate of fishing mortality reduced the magnitude.

These simulations cover a plausible 2% increase in fishing efficiency and indicate how steady technology creep can negate the positive effects of climate change and exacerbate the negative effects. For example, only a tiny remnant of cod are left under a temperature increase of 1.2°C. The combined negative impacts of climate change and increasing fishing efficiency may help to explain the gradual erosion of the North Sea gadoid stocks, bringing a threat in 2002 of a complete ban on cod fishing.

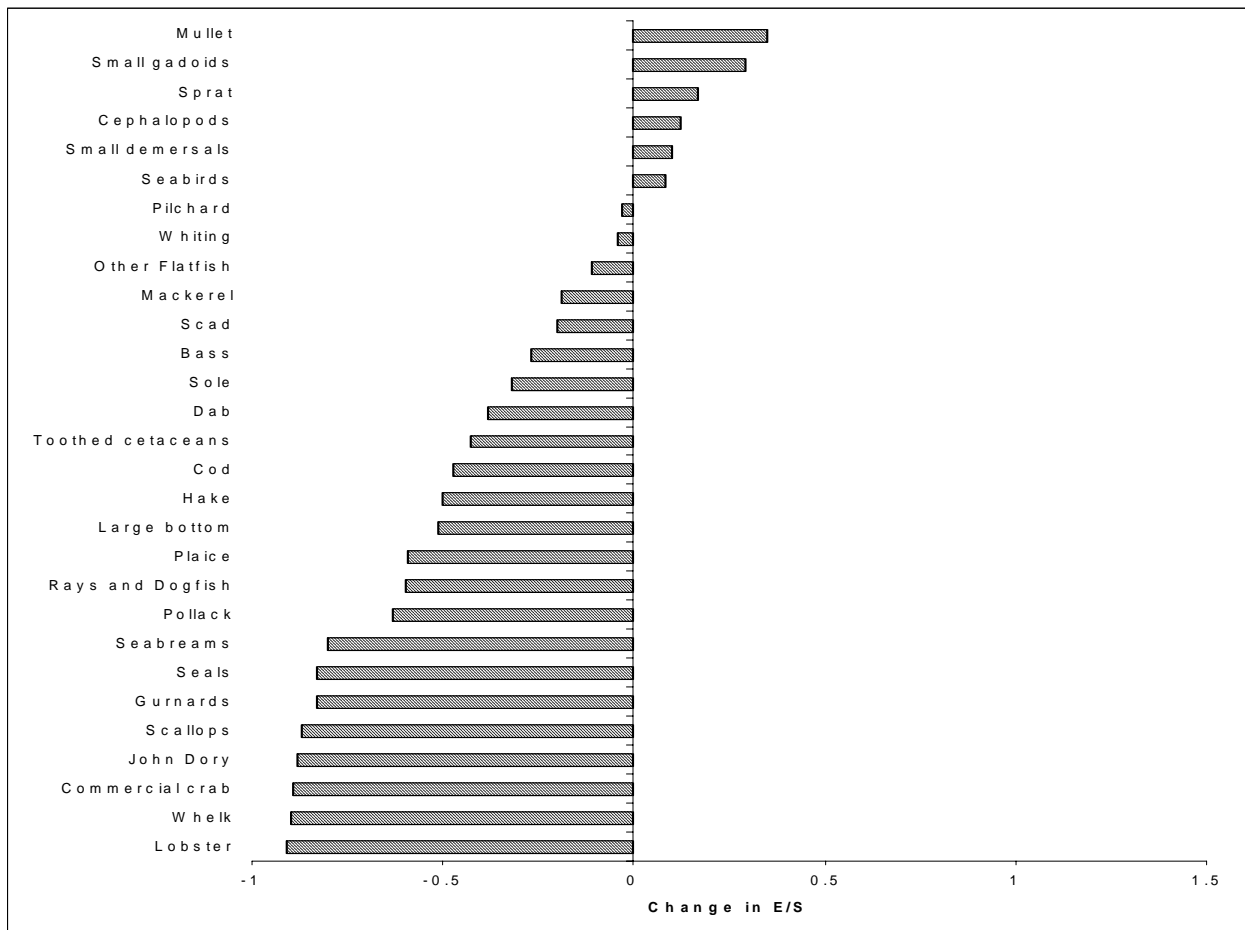


Figure 4.20 Change in biomass of model groups under a 2% annual increase in gear efficiency.

RAPFISH

Rapfish, a new rapid appraisal technique for evaluating the sustainability of fisheries has been developed at the Fisheries Centre, UBC (Pitcher and Preikshot, 2001). In the standard version of *Rapfish*, different categories of fishing can be compared and contrasted for five independent evaluation fields: ecological sustainability, economic sustainability, technological sustainability, social sustainability and ethical sustainability.

For each field there are 8-10 attributes that require a score on a scale from good to bad: 'good' referring to a fishery that is sustainable, and 'bad' for a fishery that is unsustainable. Using a Visual Basic add-in for Microsoft Excel (Kavanagh and Pitcher, 2004), ordinations can be performed using multi-dimensional scaling (MDS). For MDS to be acceptable, goodness of fit stress values must be below 0.25 (Clarke and Warwick, 1997). Leverage analyses can be used to indicate the relative importance of each attribute to the position on the MDS 'map' and values should be less than 10 % (Pitcher and Preikshot 2000). A Monte Carlo routine is also available to estimate errors. For a more detailed description of the *Rapfish* methods see Pitcher and Preikshot (2001).

For the purposes of this analysis, *Rapfish* provides a useful tool that helps us focus on sustainability issues in the Channel, many of which are not incorporated into the EwE model. For example, in EwE the social objective function is based entirely on jobs, whereas *Rapfish* has much more detail, including the importance of the fishery to the local economy and to families containing a fisher. In conjunction with the results from the model, it was hoped that *Rapfish* would enable a more holistically-determined optimal fleet configuration to be discussed.

Rapfish data for the Channel came from three people who were interviewed: the head of the Sea Fisheries Inspectorate in Brixham, Devon (the UK governmental fisheries enforcement agency); the fisheries officer of the Sussex Sea Fisheries Committee; and a CEFAS fishery scientist. For some attributes, such as primary production, direct estimates were available from other sources, but for the majority of attributes the interview technique was used. Where there was disagreement on the scoring for an attribute, the final value was based on the author's judgement.

Data used in the analysis are listed in Appendix Table A4. Results of two-dimensional *Rapfish*

ordinations are presented in Figure 4.21.

Individual Rapfish Fields

Ecological Evaluation

- Acceptable: highest leverage was less than 5% (see Appendix, Figure A1).
- Acceptable: Stress = 0.14

The gear scores ranged from 74 (pot) to 55 (net) (Figure 4.21). There were no large differences among gears because 3 of the attributes were scored equally across them. Potting scored highly because there were few discards, with the majority of the discarded fish being returned alive, and because crabs and lobsters do not migrate extensively.

Netting, the lowest scoring gear, caught many species and had high discards and bycatch. Netting also caught migrating species such as hake, and according to the interview data the netting catch had also decreased in size. It is noteworthy that migration and catch may actually be correlated. Because some species migrate further, they may be susceptible to other types of gears that can deplete their biomass. Hence the average size could be reduced, making netting seem more ecologically perilous than it is. Certainly it is worth considering how attributes may be related.

Economic Evaluation

- Acceptable: highest leverage was 7% (see Appendix, Figure A1).
- Acceptable: Stress = 0.14

For this field, the gears were more bunched in the centre than for the ecological ordination, with a range from 64 (line) to 52 (dredge) (Figure 4.21). Lining was slightly higher than the rest because sector employment was less than 10% and because it was highly profitable, but aside from this there was little separating the economic sustainability of the fisheries. Many *Rapfish* economic ordinations have provided a similar result.

Social Evaluation

- Acceptable: Highest leverage was less than 5% (see Appendix, Figure A1).
- Acceptable: Stress = 0.16

The range of social sustainability of the gears was lowest score of 49 (net) to a highest score of 61 (midwater trawl). Pots, lines and otter trawls had

Table 4.5. Relative performance of each gear type analysed by ranks: 1 is the top score, the most sustainable. Best and worst rankings for each gear are shaded. 'Range' refers to the range of scores for all gears for that field.

Gear	Ecol.	Econ.	Social	Tech.	Ethical	Av. Rank
Pot	1	6	4	3	1	3
Line	6	1	4	2	2	3
Midw trawl	5	2	1	6	4	3.6
Otter trawl	2	5	4	4	5	4
Beam trawl	3	3	2	7	7	4.4
Net	7	4	7	1	3	4.4
Dredge	4	7	6	5	6	5.6
Range	55-74	52-64	49-61	37-63	33-56	

an identical score of 54, very similar to dredging (53.3) and beam trawling (56). Nets scored lowest because a single attribute, conflict status, was higher than for the equally ranked otter trawl, lines and pots. This is certainly legitimate because passive netting prevents other commercial and recreational fisheries from accessing the fishing grounds over a wide area for a long period of time. Midwater trawling scored highest because of low conflict with other resource users, because they work as part of a fishing cooperative, and because the majority of household income comes from fishing.

Technological Evaluation

- Acceptable: Highest leverage was less than 6% (see Appendix, Figure A1).
- Acceptable: Stress = 0.14

Scores for this evaluation field were broadly spread compared to the 3 fields above, ranging from a worst score of 37 (beam trawl) to a highest score of 63 (net). The gears could roughly be separated into a lower group of active gears (the three trawlers and dredging, 37-45) and an upper group of passive gears (lines, pots and nets, 57-63). Whether the gear was passive or active had the most significant leverage, which helped to explain the difference between these groups. Furthermore, the active group tended to be much larger and go for longer fishing trips than the smaller inshore activities of the passive gear, who landing their catch at dispersed sites.

A focus of much recent research (Collie *et al.*, 2000; Kaiser *et al.*, 2000) has been the effects of towed gear on bottom structure, and these are incorporated into this field by awarding higher scores for destructive fishing practices.

Ethical Evaluation

- Acceptable: Highest leverage was less than 5% (see Appendix, Figure A1).
- Acceptable: Stress = 0.17

Scores ranged from the lowest at 33 for beam trawls to a high of 56 for potting. There is less segregation between active and passive gears than in the technological field, but lining, potting and netting are still rate as the most sustainable gears. The active gears score poorly because they cause significant damage to the ecosystem and there is less mitigation. Beam trawling scores particularly badly because of high discarding and a considerable amount of illegal fishing. Of the passive gears, netting scores lowest because a number of net fisheries have no minimum mesh sizes specified.

Conclusions

Pots, lines, midwater trawls all achieve top scores in one evaluation field and are never the lowest scoring gear. Of these gears, pots score marginally better overall. Dredge (once) and beam trawl (twice) are among the worst scores. Netting was awarded the lowest sustainability score twice and the best score once, so this gear shows the most inconsistencies among the evaluation fields. Otter trawls always score in mid-range.

Of the five fields technological and ethical seem to be the most significant and have the greatest range (Table 4.5). Ecological, economic and social fields all have a smaller range of scores, almost all of which are greater than 50%. Generally there is very little to segregate the different fisheries from one other and on many occasions a number of attributes received the same score. This is because the Channel is a multi-species, multi-gear fishery: there is a great deal of overlap of the species that each gear catches and, because boats will change from one gear type to another, it proved difficult to see distinctions between the gear for the three fields. However, the technological and ethical evaluation fields had a much wider range of results, and both had low scores in the 30s. They more clearly distinguished the active from the passive gears, and emphasised the negative effects that beam trawling and dredging can have on the ecosystem.

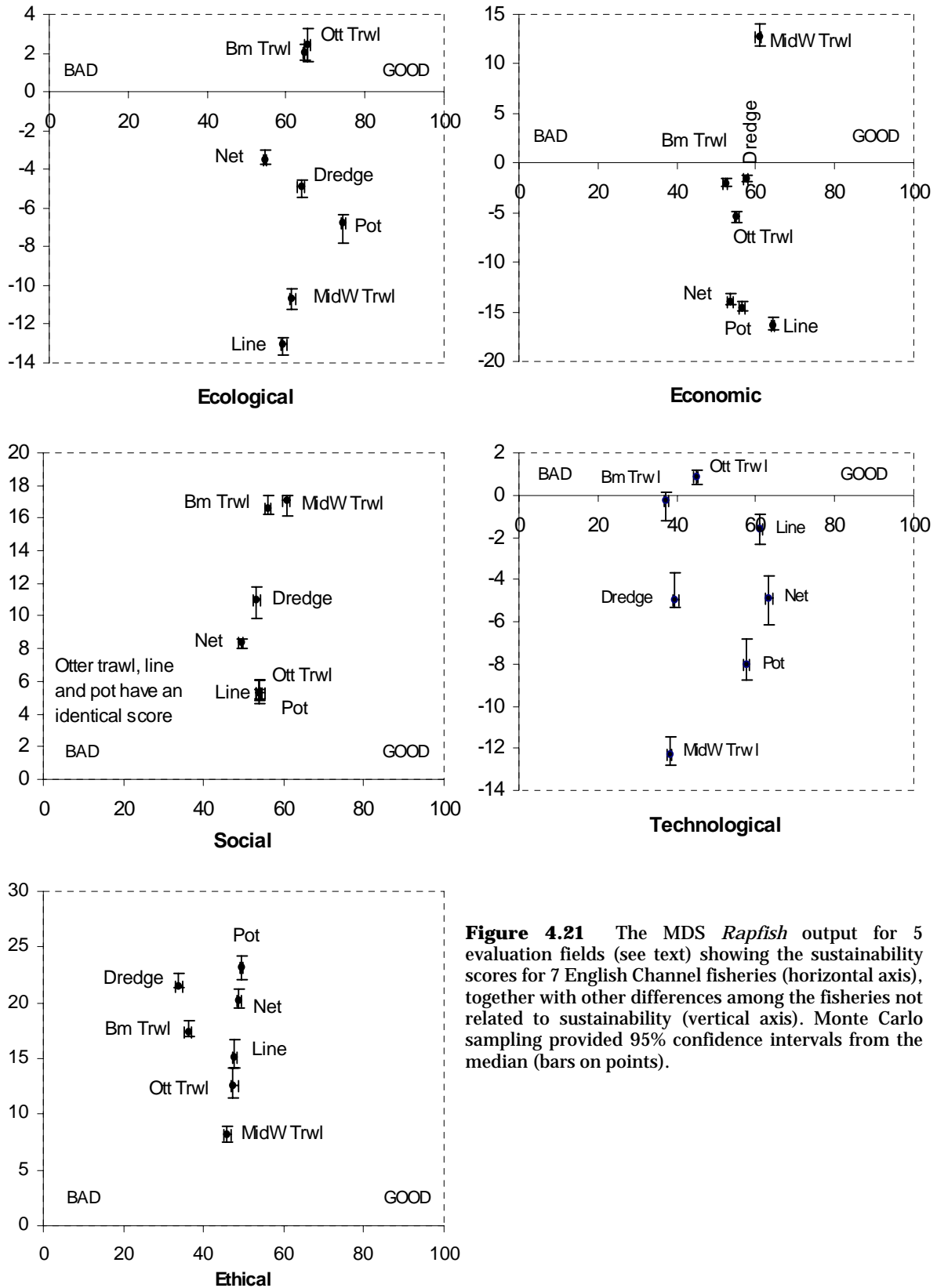


Figure 4.21 The MDS *Rapfish* output for 5 evaluation fields (see text) showing the sustainability scores for 7 English Channel fisheries (horizontal axis), together with other differences among the fisheries not related to sustainability (vertical axis). Monte Carlo sampling provided 95% confidence intervals from the median (bars on points).

MAKING TOUGH DECISIONS

Towards a Solution

Although there will be many opinions that are important in choosing the 'best' fleet configuration, some, such as that from the sport diving industry, will be less important than others. Consequently, the following 4 'voices' articulating priorities were identified as the most important. The order does not reflect their importance:

1. *Profit making objectives of the industry.* Both fishers and government are intent that the industry will be as profitable as possible. This implies a reduction in overcapacity, a streamlining of the fleet to favour the most profitable gear types, and, perhaps, the removal of species that may inhibit profits.
2. *A continuation of recreational angling along with larger specimens for anglers.* While the recreational anglers themselves are well organized with relatively powerful members' organizations, there are also a number of valuable industries that are linked to angling. During summer commercial fishers' vessels may be used exclusively by anglers. Countless bait and tackle shops are dependent upon anglers, and to a lesser extent so is the tourism industry in coastal areas, providing anglers with accommodation, food, etc. These non-market values for fish have not been included in the model, but nevertheless require consideration when selecting a 'best' fleet.
3. *Regional and community dependency on fishing.* At one time fishing was the heartbeat of whole Channel towns, but increases in fishing efficiency and effort combined with decreasing stocks have meant that the fishing sector has lost significance. However in places such as Newlyn and Brixham, fishing is still extremely important, and there is strong pressure from fishers for their jobs to survive. Historically, there was an expectation that boys would join their fathers fishing, so that in the early twentieth century "9 out of 10 young men of Brixham going to sea" (Dickinson, 1987). There were also strong kin relationships in the processing and marketing aspects of the industry. The social *Rapfish* field indicated that these bonds are weaker today, with many fishers having left to pursue alternative careers or to become part-time (Dunn, 1999b). With the formation of fishing

cooperatives the voice of those fishers that remain has become louder. Furthermore, the areas that are most dependent on fishing also have the highest unemployment rates (Slaymaker, 1989), so any increase in employment would be well received. Hence, while the social considerations may not be as large as in previous years, they are still very important.

4. *Conservation priority.* For the general public, marine mammals and seabirds are the most charismatic species in the ecosystem and consequently they receive a high profile. The Royal Society for the Protection of Birds has a huge British membership; it is birds caked in oil that receive the greatest publicity following an oil spillage. NGOs such as the Whale Conservation Society and the World Wildlife Fund ensure that any harm caused to marine mammals is publicly understood. Unlike the social community voice above, conservation has become a hotter potato in recent years and the effect of any fleet configuration on marine mammals and birds, as well as sharks and other elements of the ecosystem, will be sure to be carefully scrutinised for ill-effects on charismatic species, and therefore requires careful thought.

Although these 4 voices are loud and have lobbying power, it is important to remember that they do not manage the English Channel fishery. At its core, that responsibility today lies in the hands of the European Commission.

European Commissioner Franz Fischler has outlined that the principal problem is overcapacity, and the resulting stock depletion causes increased fishing effort to catch what remains. He argues that:

"We cannot put up with this situation any longer. It is our collective responsibility to end this vicious circle for the sake of today's sector as well as for future generations. I am fully committed to proposing and defending difficult measures that will impose tough times on all concerned but which will represent the best guarantee for a sustainable fisheries sector" (Fischler, 2002).

This statement was extremely encouraging to us, and relaxed the boundaries to our subsequent analysis, enabling a range of options to be considered with confidence, because the decision makers appear willing to make sacrifices. It is very important that scientists and policy makers

Table 5.1 Three alternative optimal fleet configurations, (A,B and C), objectives chosen for optimal policy searches, and how the four special interest groups may react to the results. Fleet values are multipliers of mortality from the current fleet. Note that beam trawls were eliminated from all scenarios: shading indicates fixed values for gears. An ideal outcome for a special interest group warrants 3 smiley faces, while a disaster is signified by 3 skull and crossbones.

Gear Types	Fleet Options		
	A	B	C
Otter trawl	0.48	0.5	0.69
Beam trawl	0	0	0
Midwater trawl	0.68	1.91	1.03
Dredge	0.85	0.83	0.84
Net	1.90	2.37	1.7
Pot	0.79	0.70	0.77
Line	0.23	2.04	0.44
Objectives			
Economic (profit)	1	1	1.2
Social (jobs)	0	0	0
Ecology (rebuilding) (groups mandated)	0.5	0	0.5
	Cetaceans bass		cetaceans bass
Interest Group			
Fishing industry	☠☠☠	😊😊	😊
Sport anglers	😊😊	☠☠	😊
Fishing villages	☠☠	😊😊	☠
Conservationists	😊😊😊	☠☠😊	😊😊

are on the same wavelength. Historically, there has been a reductionistic approach, in which economists have provided information about how the fishery can become economically efficient, local communities have argued about the level of employment that is necessary for sustenance, and scientists have provided biologically acceptable limits for stocks. There has been little interaction among these three groups of advisors.

The failure of this type of management is in evidence throughout the world (see in particular Pauly *et al.*, 2002). This was recently highlighted in the 2002 World Summit on Sustainable Development in Johannesburg, where the global restoration of depleted fish resources was of high importance on the agenda. Hence there is a responsibility on both the scientist and the decision maker to overlap

(Scheiber, 1997).

Consequently, using the information that was collected, Franz Fischler's guidelines, and the 4 priorities from the different groups above, it was possible to generate three 'best' fleet configurations (Table 5.1).

After the *Rapfish* analysis it was decided that as much as possible the destructive benthic dragging gear should be reduced. Beam trawling and dredging seemed to be the most destructive. Scallop dredging is an extremely valuable fishery in the Channel but has been over exploiting stocks for a long time, so this was reduced to allow stocks to recover. This, as the economic optimisation (Figure 4.6) showed, did not result in a major reduction of catch. The toughest decisions concerned otter trawling and beam trawling, particularly for beam trawling which has been very destructive to benthic flora and fauna. Because it composed less than 6% of the workforce and was only half as profitable as otter trawling, it was removed completely for all scenarios. Because both trawlers were indiscriminate catchers of fish and had severely depressed many stocks, otter trawling was fixed at half the current level in option B and reduced in the other two 'best' fleet optimisations by weighting mandated rebuilding of bass and toothed cetaceans.

Option A

The fleet configuration for option A was created by eliminating beam trawling by fixing it at 0, and then allowing the search routine to locate an optimum using a weighting of 1 in economic and

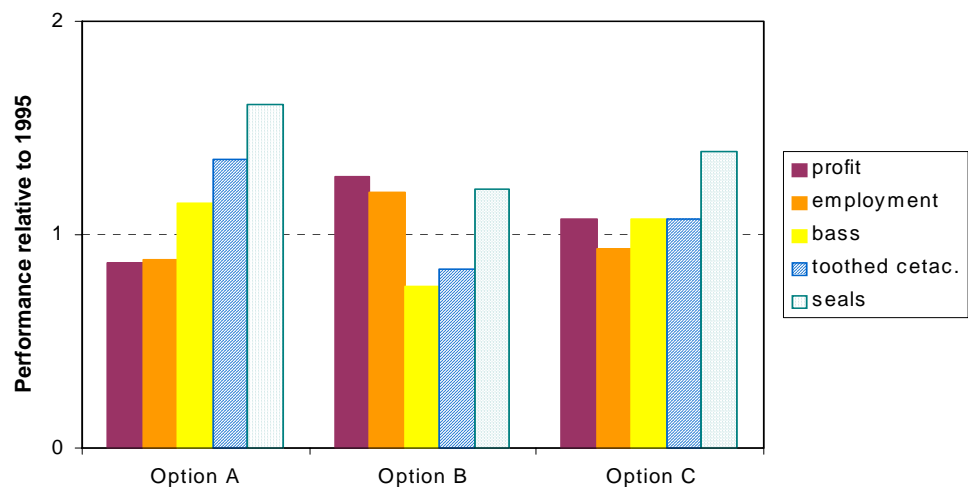


Figure 5.1 A comparison of the outcomes of three 'best' fleet configurations with the 1995 situation. The dashed line at 1 indicates the level of profits, jobs and biomasses during 1995.

0.5 in mandated rebuilding. Toothed cetaceans and bass were allocated a weighting of 2 for rebuilding, because these were the most critical to conservationists and anglers. The result was a fleet with markedly reduced effort, with only the netting sector being increased. Despite this reduction, there still remained 88% of the present employment and 87% of profits (Figure 5.1). From his comments, this may be the kind of fleet reduction that Franz Fischler envisaged (Fischler, 2002).

In this scenario, the major species changes were predominantly positive (Figure 5.2). There were large increases in seals and toothed cetaceans, which the conservationists would find appealing; there were also increases in bass, large bottom fish, rays and dogfish, which the recreational anglers would benefit from. Sharks showed no change in biomass while cod showed a slight decrease because of the increase in netting. Seabirds also significantly decreased, but this was inevitable because of their dependence in the model on discarded fish. As the biomass of seabirds is said to be 'unnaturally high' as result of discarding of fish (Anon., 1999d), a moderate decrease in their biomass may not, one might

think, be a cause for serious concern among conservationists.

Although to obtain the ecosystem of scenario A there would have to be some fairly large initial changes in beam and otter trawling, the model suggests that benefits for the industry would certainly accrue at a later stage. Figure 5.2 shows that, aside from hake and cod, it is generally the inexpensive and lower trophic level groups, such as mullet, small demersals, small gadoids and sprat, that would decrease. Lucrative flatfish species, as well as shellfish, all have predicted increase in biomass, which would be available for capture when safe sustainable limits had been ascertained.

Option B

To achieve this fleet structure in the optimisation routine, otter trawling was fixed at 0.5, beam trawling was again fixed at 0, and the maximum profit was sought from the ecosystem. Because the extreme economic fleet configuration (see above) was thought too ecologically damaging, the aim of this option was to head towards a highly profitable Channel, while tempering the

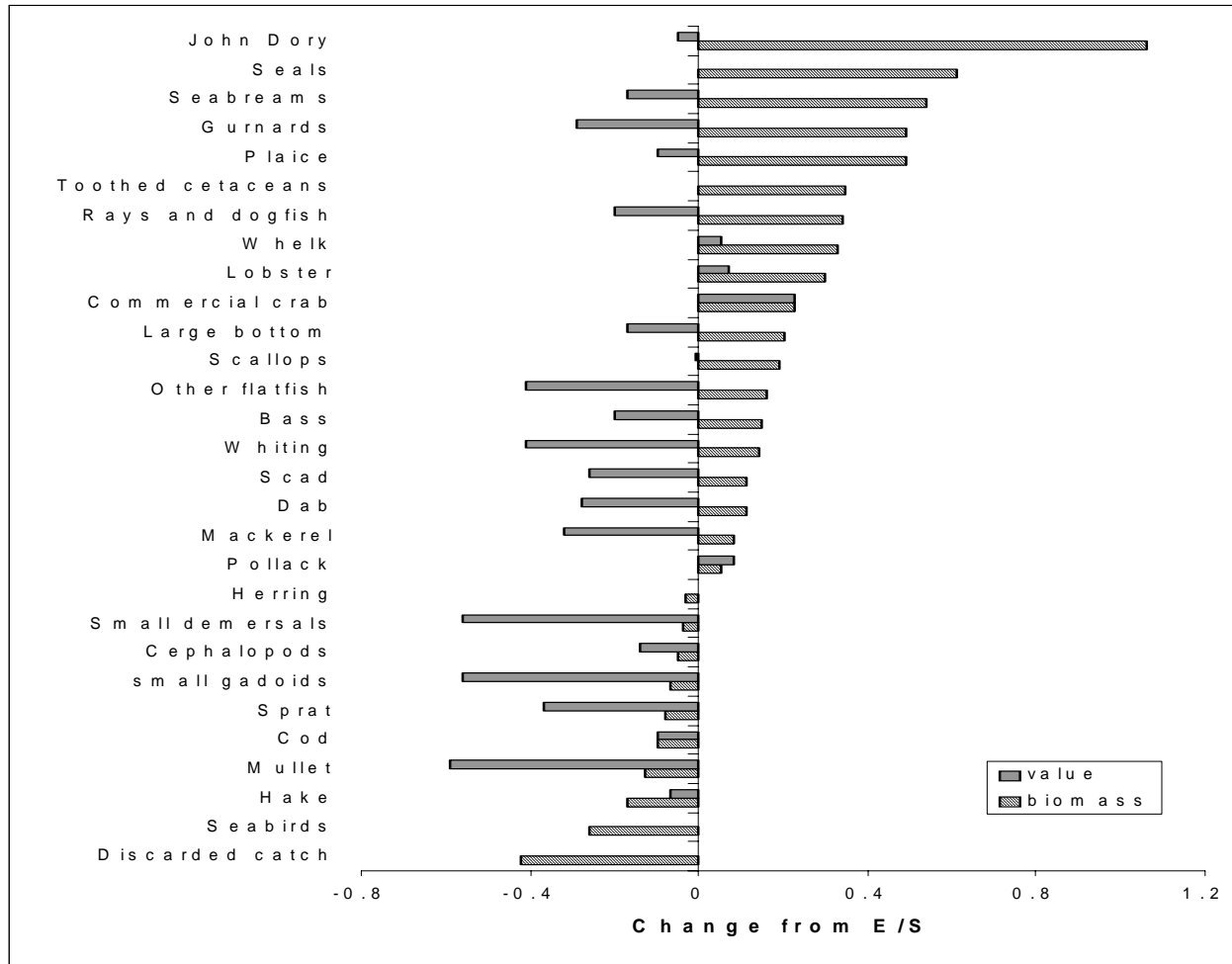


Figure 5.2 Major changes in biomass and value that result from option A.

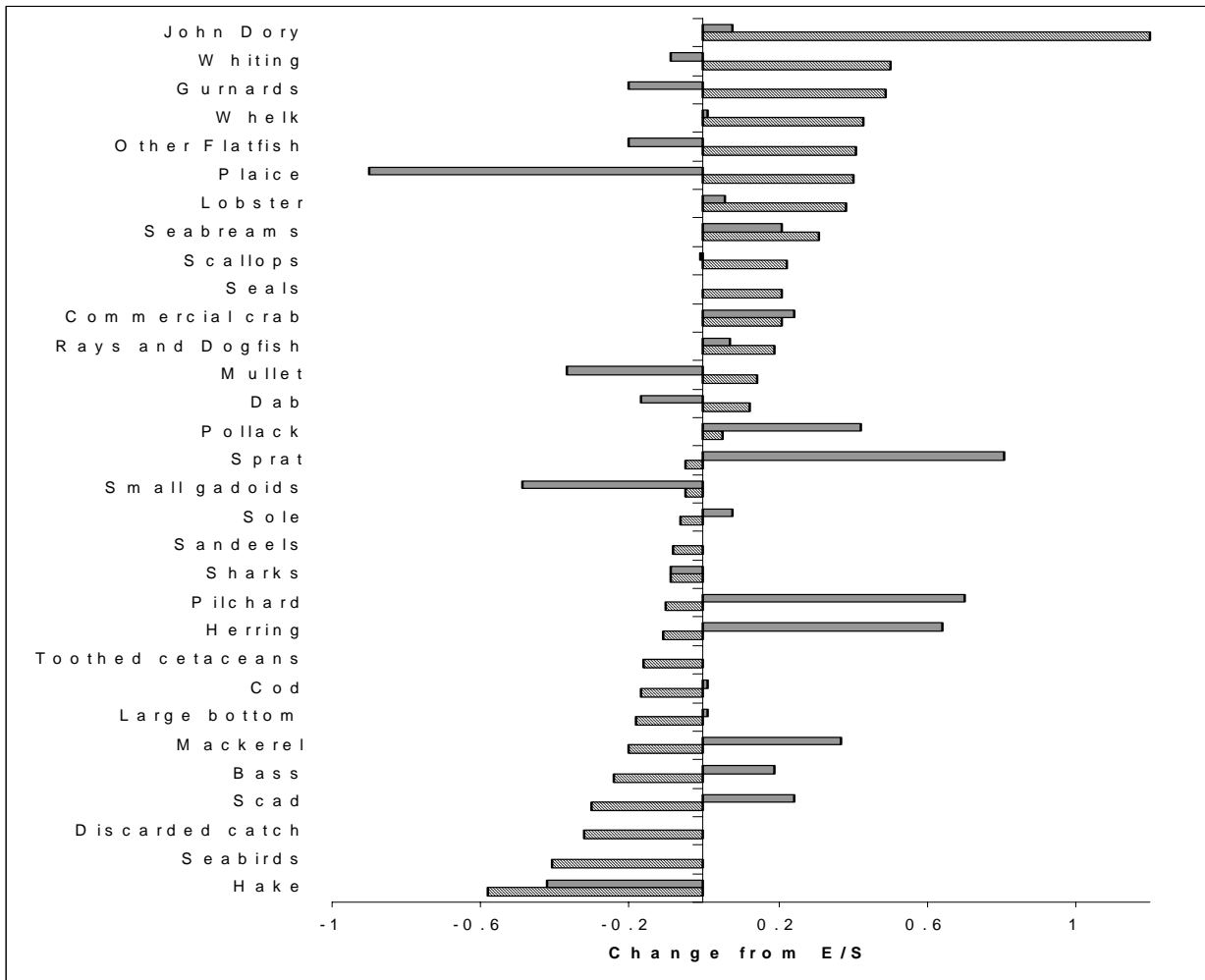


Figure 5.3 Major changes in biomass and value that result from option B.

ecological harm by fixing otter trawlers at half their current rate.

Table 5.1 shows that the optimisation lowered dredging and potting because of reduced costs, although catch was nearly the same as a result of shellfish biomass recovering. Midwater trawling increased to 1.9 times the current level, because higher netting reduced hake predation on scad, and with the reduction in otter trawling and the removal of beam trawling, the were additional whiting and seabream to be caught from the ecosystem of option B. Furthermore, as the mackerel stock was fished down, their prey, sprat, were allowed to recover, and were caught in higher quantities by the midwater trawl. Netting and lining increased to make the most of the available sole, large bottom fish, rays and dogfish and bass that the reduction in trawling allowed; netting also reduced hake, allowing higher John Dory and scad catches.

There were increases in profits (26%) and jobs

(20%) (Figure 5.1) that would please the fishing industry and governments, although the cost of this scenario might be unacceptable to conservationists and recreational anglers. Of the crucial charismatic and recreational species, only seals and rays and dogfish showed a positive response, with bass, toothed cetaceans, sharks, cod, large bottom fish, and seabirds all exhibiting declines (Figure 5.3). Other lucrative species such as sole and hake declined, but with such a large increase in netting and lining this was to be expected.

This option would be much more amenable to conservationists if the toothed cetaceans bycatch from midwater trawling could be minimized, as this causes their biomass decline in the model.

Option C

Fleet C was generated with beam trawling eliminated as before, bass and toothed cetaceans allocated a mandated rebuilding weight of 2, and

the search routine optimised for profit weighted with 1.2, and ecology objective of mandated rebuilding weighted with 0.5.

As Table 5.1 clearly shows, options A and B split the 4 special interest groups. Option A was beneficial for recreational anglers and conservationists, but not so good for the industry or communities, and option B expressed the converse. Consequently, the 'best' option, C, sought a compromise and attempted to satisfy more of the interest groups.

Otter trawling was not fixed at half the present value as in option B, and the search routine increased it above this value (Table 5.1), although it was still reduced compared to the present. This constitutes the greatest change from option A. As with both of the other options, dredging and potting decreased, allowing stocks to recover.

Because there were toothed cetacean discards from midwater trawling, there was a clear effect of the different weighting schemes among options A—C (Table 5.1). With a higher economic emphasis (option B), highly profitable midwater trawling increased to capitalize on the scad and sprat stocks, depleting toothed cetaceans through discarding as well as reducing important diet components such as mackerel and scad. The weighting on toothed cetacean biomass in option A caused midwater trawling to be reduced. Because option C was seeking for a compromise, midwater trawling was only marginally increased from the current level, and the biomass of toothed cetaceans rose following an increase of their diet: seabreams, whiting, mackerel and cod. Because otter trawling was slightly higher in option C than in options A and B, there was less catch available for the more profitable netting, and so this increased to only 1.7 times its current level. Lining decreased because mackerel had been

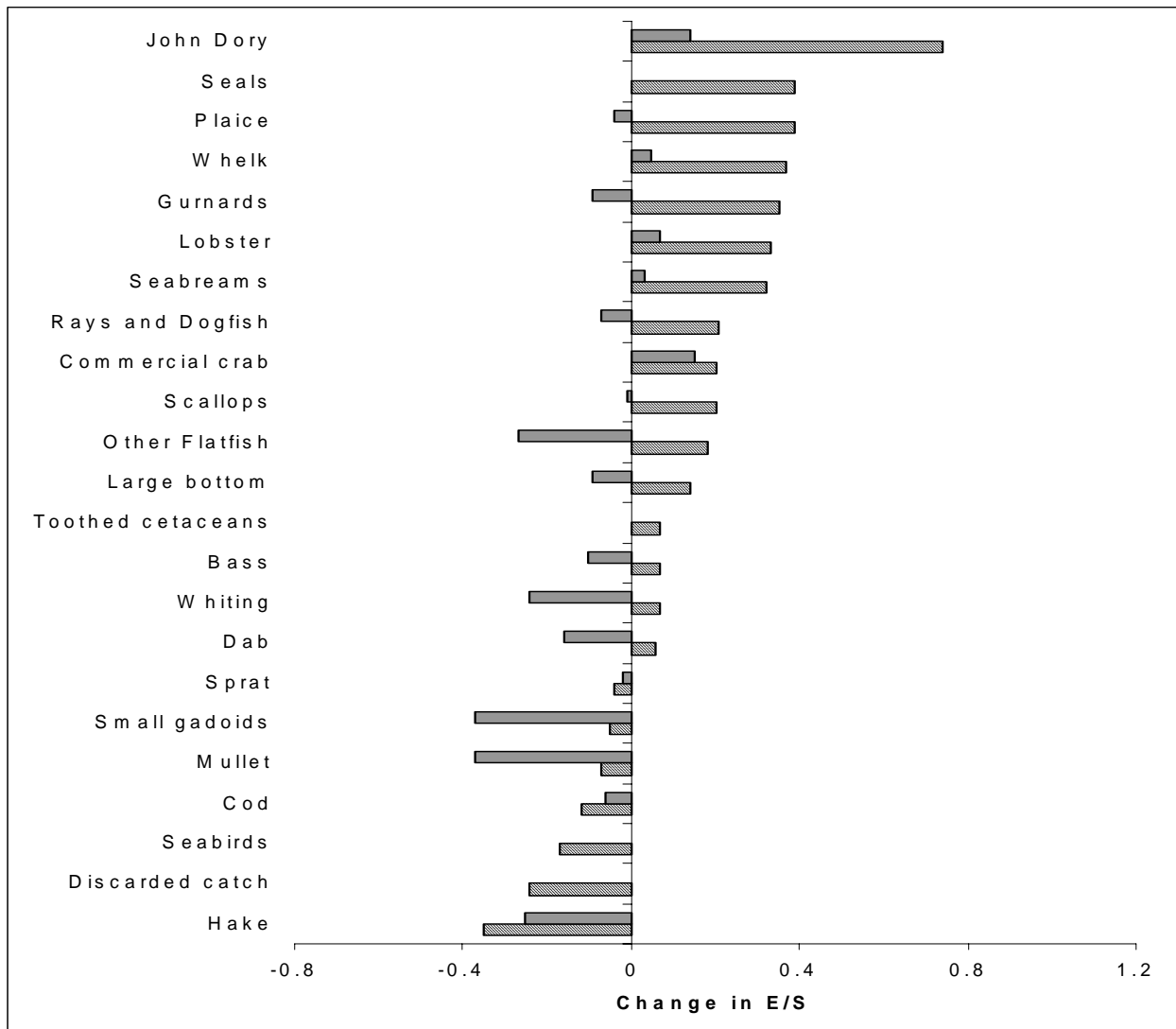


Figure 5.4 Major changes in biomass and value that result from option C.

caught by increased midwater trawling, large bottom fish and rays and dogfish were caught by increased netting. Bass, the other main group caught by lining, was 'protected' by the mandated rebuilding option.

While option C might pacify the fishing industry, it would still require huge structural changes because the fleet configuration is so different to the current situation. If painful changes were to be contemplated, it seems prudent to make them for the bigger long-term gains of option A. Perhaps an attempted compromise in Option C to please all interest groups is an example of the standard unsuccessful way of managing fisheries, and a bolder stance, such as option A, needs to be advocated.

Changes in Temperature and Vulnerability

With increasing temperature scenarios, all options became more profitable and bass biomass increased relative to the baseline (Figure 5.5). When vulnerability (V) was 0.2 for all options, the responses of profits and of the important biomasses were less strong. When temperature was increased, the biomass of toothed cetaceans rose in option A, the most favourable option for conservationists and recreational anglers. Seals

significantly decreased relative to the baseline, although even with an increase of 1.2°C their biomass was still 2% higher than the current level. The reason for this was that there was a decrease in large bottom fish, their prey, with increasing temperature, as cephalopods compete with large bottom fish for small gadoids. When V was 0.6, profit and the biomass of toothed cetaceans and seals increased tremendously. Option C had a very similar profile to option A (Figure 5.5), although it looks like option A with a lower V, i.e., there were not such large changes from the baseline.

In option B, increasing temperature lowered seal biomass until it was 73% of 1995 levels. Toothed cetaceans increased, so that using this option with a 1.2 C increase would mean that the biomass decline was only 8 % from 1995 levels. A V of 0.6 caused a large increase in profits and seal biomass, but a large decline in bass and toothed cetacean biomass

In summary, option B seems to be the most robust to changes in temperature and V, with the outcome changing the least out of the three options. A positive aspect of option A is that increases in temperature and V served to emphasize the bass and toothed cetacean biomass

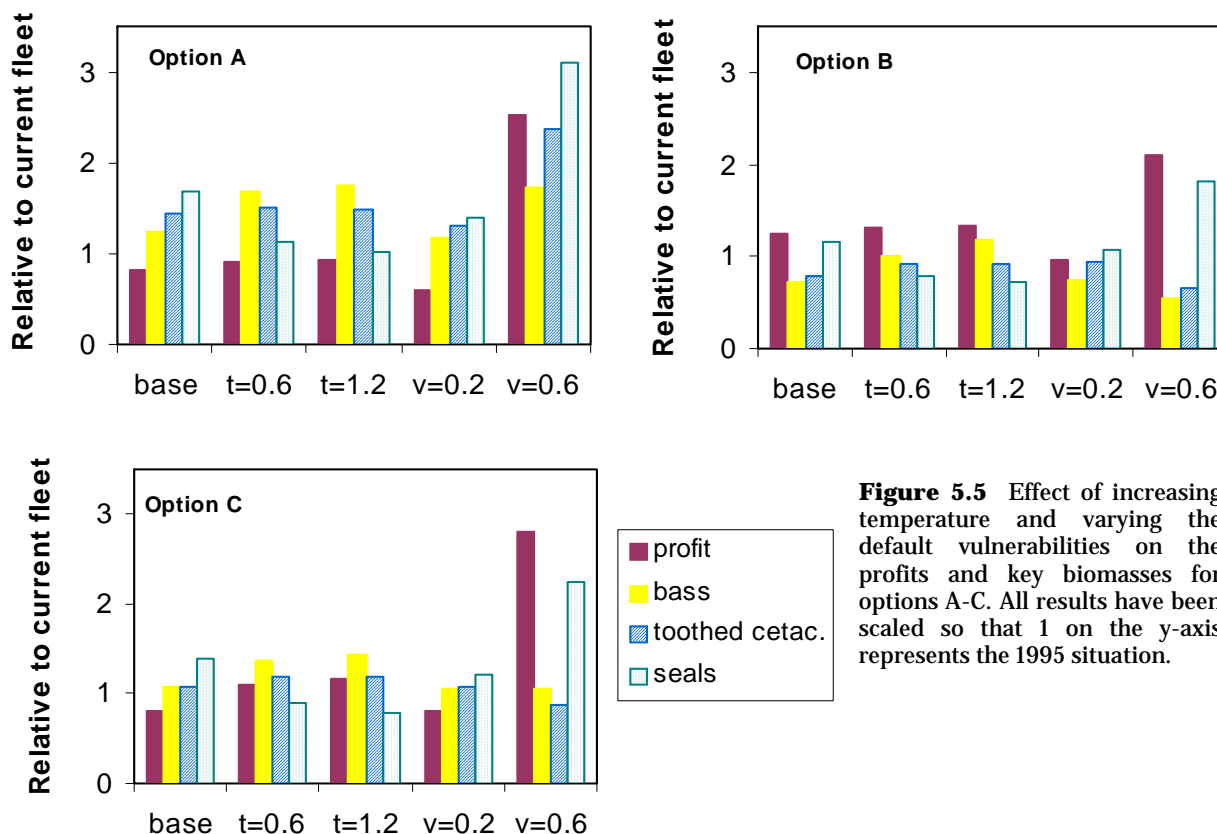


Figure 5.5 Effect of increasing temperature and varying the default vulnerabilities on the profits and key biomasses for options A-C. All results have been scaled so that 1 on the y-axis represents the 1995 situation.

increases, which would maintain anglers' and conservationists' confidence in this policy. A negative aspect is that, although these specific groups increased, there were large changes in other groups, meaning that, although the industry in theory would make higher profits (Figure 5.5), exactly how much and from which group would depend on the V or the temperature. Although the Channel is a mixed gear fishery and smaller boats are able to adapt quickly to changes in the ecosystem, for larger boats the unpredictability of option A may create a problem.

In many respects option C is a poorer version of option A, although it has advantages in not shrinking the trawling fleet so dramatically, being marginally more profitable, responding less to changing temperature, and being less sensitive to V . Changes in temperature lead to industry and recreational anglers being more pleased with option B: conservationists feel about the same because, while seals decrease, toothed cetaceans increase.

Closed Loop Analysis

In order to model not only ecological dynamics over time, but also the dynamics of the stock assessment and regulatory process, a 'closed-loop' simulation routine has been added to *Ecosim* (Christensen and Walters and 2004). This routine includes 'submodels' for the dynamics of assessment (data gathering, random and systematic errors in biomass and fishing rate estimates), and for the implementation of assessment results through limitation of annual fishing efforts. It is also possible to investigate the impact that the coefficient of variation (CV) in estimates of F and in catchability on the potential errors of implementing management policies

Hence, having run the optimal search routine using an 'open loop' optimisation routine, we attempted to assess how imperfect knowledge would affect the results using the 'closed loop' option. The open loop search routine finds the system that is the best in a perfect world, assuming perfect knowledge of the stocks and the ability to catch exact quotas. The reality is that things are not that simple, and it is uncertainty that makes fisheries science so difficult.

Differences between the open loop (perfect information) results and closed loop (imperfect information) results constituted the errors, and Figure 5.6 examines the changes in these errors when altering CV for 2 assessment methods of fishing mortality, catch/biomass and direct assessment. The errors are also shown for annual

increases in catchability for each option. When calculating fishing mortality for options A-C the trends are essentially the same (Figure 5.6).

Whether F is estimated by C/B or by direct assessment as the CV increased (i.e., as greater mistakes are made in fisheries management), the social and economic optima became lower and the errors increased (Figure 5.6). Conversely, the ecosystem health and mandated rebuilding objectives were actually improved by an increase in CV. Looking more closely, economically, option A seems the most robust to the effect of changing CV for both methods of estimating F , with errors less than scenarios Option B and Option C. Options A and C show very similar error profiles for mandated rebuilding.

An increase in annual catchability causes almost identical increases in errors for each option. Economically and socially, the greatest increase in errors comes when catchability changes from 0 to 0.2, and after 0.2, increases in gear efficiency of up to 4 times have little effect compared to the initial rise. For mandated rebuilding and ecosystem structure, there were more continuous increases, with a large jump between an increase of 1 and 2 per year. Option A was economically more robust to increases in catchability, having lower errors than the other options regardless of the rate of increase of catchability.

The 'closed loop' analysis gives an interesting insight into how implementing these three options may affect the four objectives. It is clear from this analysis that no single option is significantly better or worse when it comes to implementation. but that option A is slightly more favourable economically.

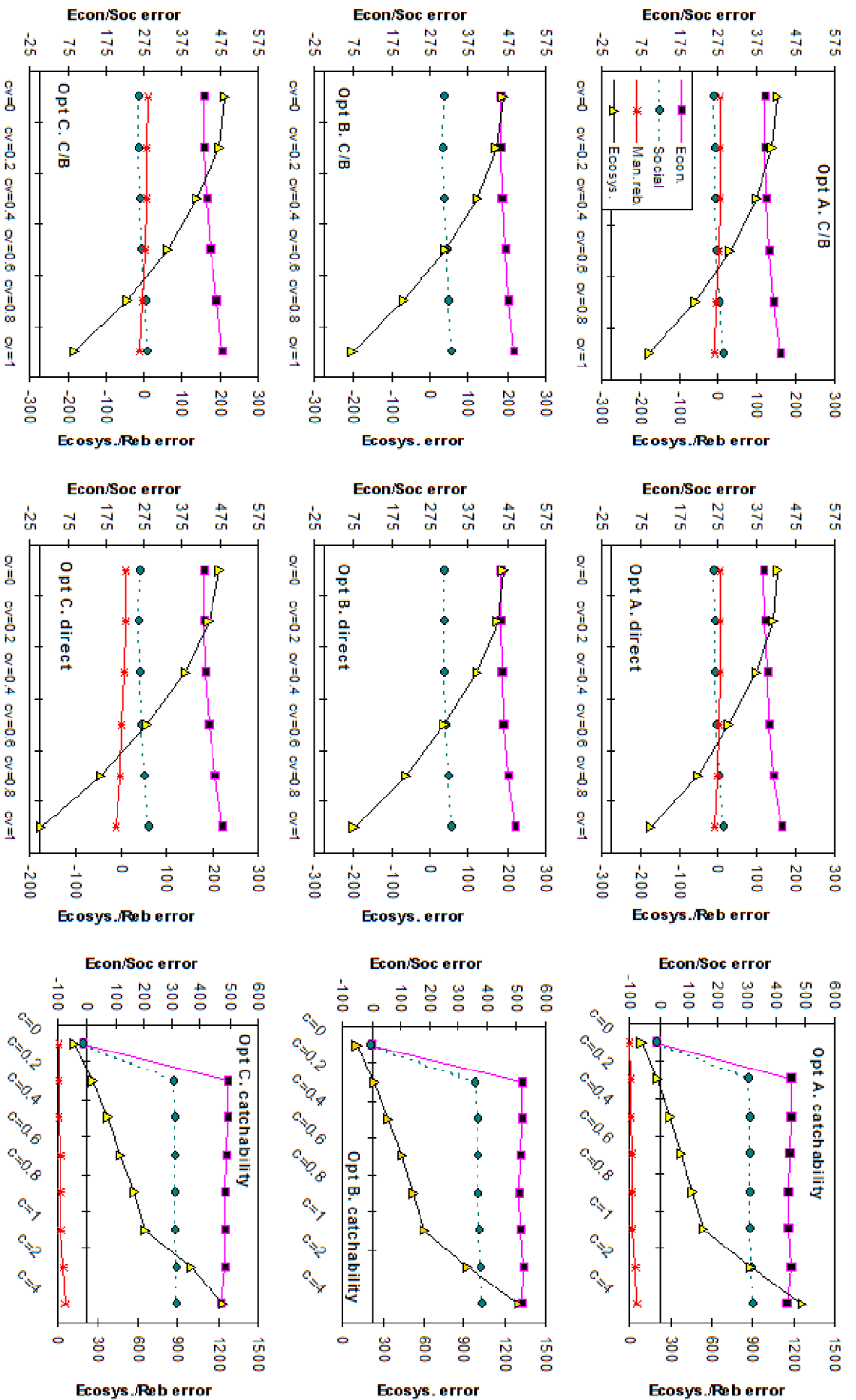


Figure 5.6 Difference between open loop and closed loop simulations for the three options. The errors from estimating fishing mortality by catch/biomass (left) and by direct assessment estimates (middle) while changing the coefficient of variation (CV on the x-axis) are shown. Furthermore, the errors that result from varying annual increases in catchability (C on the x-axis) are shown (right).

Discussion

The Greatest Benefit

“Fisheries management is concerned with the utilization of the natural fish resource for the greatest benefit to society” (Pascoe *et al.*, 1997). This statement begs the question, what is the greatest benefit to society? In Devon and Cornwall there is a strong community reliance on the fishing industry and few alternatives to fishing (Slaymaker, 1989). The fishing industry has strong linkages with other industries, meaning there are positive and negative multiplier effects depending on the success of fishing (Slaymaker, 1989). For these Channel communities to have a thriving fishing industry is much more significant than for, say, Berkshire, a English county with no coastline and only recreational angling in lakes and rivers. The greatest benefit for the residents of Berkshire, on the other hand, is to have a Channel free from pollution where they can spend their holidays, although people in Berkshire would also be concerned if their taxes were being used to supply unemployment benefit for Devon and Cornwall. Hence, there is inequality between areas. The need of certain regions for fishing may be acute, yet on a national and international stage those needs may be dwarfed. The “greatest benefit to society” will depend on how society is defined.

The possible management options that have been described above for the Channel are options in a perfect world. Even though imperfections have been included using the ‘closed loop’ analysis, the costs of changing fleet structure to the optimum have not been included, nor have the costs of training redundant fishers or providing them with early retirement been calculated. Conversely, the costs to future generations by further depleting the natural resources of the Channel have not been included, and the issue of whether fish have an intrinsic value (= existence cost) has not been considered.

A fundamental ethical question is whether we as humans have a right to manipulate the ecosystem to suit our needs? If by removing marine mammals we were able to catch significantly greater values of fish sustainably, would it be right to do so? Could it be argued that the Channel is not a significant place for marine mammals and that the European commission could sacrifice them for the sake of the fisheries? Similarly, prior to trawling, the bottom structure and fauna of the Channel was very different to its state today. The cost of returning to an un-fished

state would be substantial, as trawling and dredging would need to cease. Is society at large prepared to accept the burden of this cost for some corals that few will see? Could marine parks be created instead to allow recreational divers to view the sea floor, while the majority of the Channel aims towards maximum economic efficiency?

The purpose of this research was not to provide answers to these questions. They are raised because they serve to highlight that, even if this was a perfect ecosystem model, even with the ability to perfectly understand stocks and to catch exact quotas, the initial question of what is ‘best’ for society still remains. The government still has to make decisions, weighting social, economic and ecological factors. This difficult process still exists and will only become a greater issue as our abilities to manipulate ecosystems increase.

Nevertheless, some objectives are clearer than others, and the fact that there has been depletion of many of the Channel stocks through short-term decision-making is known to be a problem. In the next section some suggestions are proposed about how these problems may be tackled

Management Suggestions

The primary issue raised by Fischler (2002), Slaymaker (1992) and Anon. (1999d), and reflected throughout the world’s oceans (Pauly *et al.* 2002), is that the excess capacity of the fishing fleet needs to be reduced.

The fleet needs to be streamlined in the manner of option A above. Franz Fischler clearly stated that this will mean job losses, but in order to safeguard the industry in the long-term this is inevitable. The problem that this brings is that many of the areas where job cuts will occur are the places, such as Devon and Cornwall, where employment is most needed. The European Union has some aid available for retraining and early retirement schemes for fishers, but as Dunn (1999b) indicates, some fishers simply do not want to do anything else. Even when there are no profits being made, fishers often still hold on to their boats and licenses.

Although it is sad to see the loss of a way of life, we feel that there is little room for this sentimentality in what by world standards are two very rich countries and a heavily industrialised fishery that has largely brought about its own downfall. The collapse of the coalmining industry in the UK caused tremendous upheaval for many regions and the

same will occur in fishing unless pruning occurs now. Possibly the increase in bass and mammals may allow some skippers to use their boats purely for recreational fishing or eco-tourism, which may soothe this issue a little, although the EU must be tough, and it appears that they are prepared to be so (Fischler, 2002).

For the fishers that remain after the initial job cuts, producers organisations (POs) could be encouraged. POs are good for three main reasons (Goodlad, 1992):

- 1) Decisions are made at the level of the fisher meaning that the PO is more able to respond to market demand;
- 2) They remove the pressure from the government to allocate quotas;
- 3) Each vessel is allowed to plan its annual fishing in order to maximize potential profitability.

But their development in the Channel needs to be monitored. Because the POs apply for an allocation of the national quota based on track records, there is a tendency for PO members to jeopardize future catching opportunities to ensure they have a positive track record. This can lead to competition between vessels in the PO and independent vessels. The only way to overcome this is to reduce overcapacity, so that in essence there are enough fish to go around for the remaining vessels (Slaymaker, 1992). The POs would then help to magnify potential profits through reasons 1) and 2) above.

Enforcement is a crucial issue that is emphasized by both Fischler (2002) and Dunn (1999b). This relates to both the ethical and social evaluations of *Rapfish* in the sense that certain fisheries are more prone to illegal fishing than others. There is one positive example in South Devon, where the social interaction between different fishers mean that cheating is not an option (Hart, 1996), but generally, illegal fishing does occur and better policing of fisheries is imperative. The problem that exists in the EU is the unequal policing between different countries that exploit the same stocks. This causes resentment among fishers and even less incentive to abide by the regulations. If a more homogenous and equitable method of enforcement can be used in managing the EU, perhaps as part of the forthcoming revisions to the Common Fisheries Policy (CFP), compliance might be greatly encouraged.

Similar inequality exists between countries' scientific programs. Traditionally, the intention of fisheries scientists was to aid the industry by

enabling it to make the most out of what was available. Hence the financial support could come from the industry itself. The problems came when the fishers of one country were paying for monitoring, while another country that accessed the same stock did not have such stringent monitoring. Although ICES, an international body, provides much of the stock advice, this is provided by scientists who have been working on the fisheries of their own country. Inequality would be greatly reduced if more financial support that must be used for stock assessment support could be provided for each country.

The issues of the involvement of ICES and the relationships between the industry, scientists and policy makers were neatly brought together by Corten (1996). This paper identified that many of the problems are structural in nature. The European Union has jurisdiction over the entire area, and so in theory, after the establishment of the CFP, inter-country squabbling over the resources should be minimal. ICES has existed since 1902 and prides itself on the best scientific advice. Just reading a working group report emphasises the sophistication of the methods that are used to assess stocks. Countless institutions across Europe produce highly educated scientists who push the boundaries of fisheries science further and further. Yet the paradox is that in the midst of all of these scientific achievements, the stocks have still declined. Understandably, the fishing industry, taxpayers and environmentalists are not happy with what has been going on.

Corten (1996) writes "modern fisheries management requires advisory and decision making bodies that can react quickly to specific local problems". This is exactly what the European Commission and ICES are not doing. While the management of the majority of sectors have been de-centralized, decisions about the fishing industry across Europe are still made by politicians in Brussels. They are too far from the situation and, as a result, decisions are made at too high a level. ICES is a scientific organization where speed is not required, and if the EU wants specific advice on a problem it has to go through a bureaucratic chain of governments and institutions to get an answer. The total procedure takes a minimum of 1 year, and is not a good incentive for communication (Corten, 1996).

When conducting *Rapfish* interviews RS found that the Sussex Sea Fisheries Committee were repositories of a great wealth of knowledge. They were aware of each of the boats in their jurisdiction, had a working relationship with many of the fishers, and were intimately aware of

many issues that were specific to that coastline. Like all SFCs, they are capable of making byelaws that apply to their local region. They can rapidly respond to disasters such as pollution or to problems with recruitment. They are not perfect, but they are an example of the small-scale local institutions that the current EU management system needs to encourage. Of course, the SFCs cannot deal adequately with migratory stocks, but the EU could delegate its management to regional departments that were large enough to include the majority of most stocks. The North Sea would be an example of the appropriate size. Regional management would also enable the fishers, decision makers, and scientists to have a closer relationship. Funding could be contributed by the industry for the regional stock assessments, and this would increase the accountability of the scientists.

In concluding this section, we sense a degree of discouragement in that many of these issues have remained as mere rhetoric. Three years after the paper of Corten (1996), a report from the European Commission (EC) outlined most of the same points (Anon. 1999d). The EC wanted to reduce overcapacity to match the resources available, in agreement with Slaymaker's (1992) opinion; they suggested increased financial support for scientific research, a greater contribution from scientists into fisheries management, and improved selectivity of fishing gears. One can see this as a positive step, with the European Commission responding to the advice of scientists. But the most important part of Corten (1996) was the issue of regional management, and, surprisingly, this was not mentioned in the EC report. Possibly most discouraging of all is that, 3 years after the EC Report, the website of Franz Fischler is saying the same thing, meaning that in the 6 years between Corten (1996) and Franz Fischler, very little has actually happened.

The year 2002 signals a reform to the CFP and what Franz Fischler wants, everybody wants, "environmental, economic and social sustainability". He gives ideas of what is necessary to achieve this, i.e. increasing accountability and scientific advice, which Corten (1996) would agree with, but the question of exactly how these aims will be achieved needs to be asked. Fischler (2002) says that "there is no time to lose" and the authors would heartily agree, encouraging the European commission to get some practical proposals on the table. Hopefully the CFP reform will see this occur.

Limitations and Future Research

Clearly, a model will only be as good as the data that is used to create it. Hence, although building the model acts as an ecological accounting system such that unreasonable values can be weeded out at an early stage, there are different levels of accuracy in the data.

Given a wish-list of which data to improve, our first choice would be the diet composition data. Much of this comes from areas outside of the Channel, where the species compositions may be different. The classic example of this occurred sandeels, which have a high importance in the diet of many seabirds. Although a number of pictures of puffins eating sandeels originate from the south coast of England, the lack of a sandeel fishery suggests they are not as abundant as in the North Sea. Hence, the diet of seabirds may comprise more sprats in the Channel than in the North Sea. This may have had implications for the sprat biomass data. The ecological relationships hinge on the diet composition data, so a stomach-sampling program would be invaluable in tightening up this aspect of the model. Acoustic surveys for small pelagics such as sandeels would also be very helpful.

The second data that would be very useful is better stock assessment of shellfish. Tappin and Reid (2000) refer to the absence of scientific studies for management purposes of shellfish, and, for such an important part of the Channel fisheries, these studies need to be done. As well as for the commercially exploited shellfish, the benthic groups certainly rated the worst in the model pedigree (Appendix, Figure A2), and better information, particularly on P/B as well as on biomass, would be essential for further work.

At best, boat-months were only a semi-quantitative method of evaluating effort. Tetard *et al.*, (1995) referred to boat-months as a month in which a gear type had seen a 'significant activity,' but in reality, even if a gear was used for only 1 day in that month, it would constitute 1 boat month (M. Dunn, *pers. comm.*). Consequently, the jobs/catch value data were not as precise as one would hope, and in future research a more quantitative method of estimating effort and jobs should be used.

Some conclusions were made from EwE model scenarios that forced increases in temperature, but it is important to make 3 points about these.

- 1) The actual increase in temperature that is likely to occur is unknown;

- 2) Because during the 1990s the Channel is experiencing a very warm period, the effect of increasing the temperature even further has unpredictable effects; one suspects that the influx of warm water species such as John Dory and cuttlefish will be greater, but the magnitude of this is unknown;
- 3) Aside from cod there may be other negative effects on cooler water species such as lemon sole; these have not been included in the model at this stage, and, as lucrative warmer water species are increasing, the model is biased towards giving more favourable economic results.

Our *Rapfish* analysis fulfilled its purpose because it identified additional aspects of sustainability, which helped to choose optimum fleets with broader perspectives. The sample size should be increased to include France, and should incorporate the opinions of fishers and other stakeholders, so that comparisons can be made between the different groups of people to see how the fisheries are performing.

One of the most frustrating aspects of the model building work was conflicting data. Catch data were the classic example, where ICES time-series data were different in the 1990s to that provided by the CFSG. It also proved difficult to harmonise catch, biomass and fishing mortality data when tuning the model. There were many groups that had no time-series F or biomass data, and although basing time-series estimates of F on catches, similar species, and personal communications was better than nothing, it was far from ideal. There may be other untapped sources of information for non-quota species available, or in the absence of this, information on the fishing effort of gears could be used to drive the model.

To take formal account of uncertainties, EwE includes the 'Ecoranger' option, which allows the user to enter a range and mean/mode values for all the basic parameters (Christensen and Walters 2004). Hence with the uncertainty in seabird diet discussed above, it would be possible to allocate a range of both sprats and sandeels in the diet. The Ecoranger routine allows the modeller to have a number of models and can help the user to select one that fits a given set of constraints. Because Ecoranger was not yet connected to the optimisation routine at the time of this work, it was not used in this analysis, but the long-term aim would be to have a more fluid starting model so that each point estimate becomes a range of values based on the confidence of that data. Then, when running this in the optimisation routine,

one could more adequately consider uncertainty. To some degree, the 'closed loop' analysis, testing with a range of vulnerabilities and different temperatures, has considered some aspects of uncertainty, but this could be more focused on the initial input parameters themselves. Moreover, the EwE model could be run varying market prices, discount rates and recruitment in order to further test if the optimisation is robust to these unpredictable variables. To pre-program the model to run a number of optimisations varying these parameters overnight would be a useful time-saving addition to EwE. It would also be very useful if the modeller could pre-program various weightings for the objective functions so that the model could locate the optima that are necessary to produce trade-off graph figures such as those in section 4.3. [*similar facilities to these have in fact been implemented recently.* Ed]

Although the next procedural step is to further compare and contrast our model with the work of the Channel Fisheries Study Group's bio-economic model, after this has taken place, it would be very useful to use Ecospace to add a spatial dimension to the model. One of the biggest problems that faces the Ecopath user is defining the area over which the ecosystem model will be built. While the English Channel contains stocks that only exist in ICES areas VIIId and VIIe, many of the important commercial stocks overlap into the North Sea or the Western Approaches. In an ideal world there would be three separate but linked Ecospace models, the North Sea, the English Channel and the Western Approaches. This would mean that stocks such as herring could be traced from the North Sea into the English Channel and back out again. The effect of increasing temperature would be clearly seen by the eastward movement of species towards the North Sea. An Ecospace model of the Channel would also enable the investigation of marine protected areas. Already the mackerel box has been established to the south-west of England and an Ecospace model could look at the effectiveness of this. A large amount of biogeographical work on the Channel already exists (Pawson, 1995), and because this even includes the movements of juveniles and locates where most fish are caught, there is much detail available that could be incorporated into future models.

The model could also be made more detailed by separating the gear types into a lower level such as inshore and offshore, large and smaller boats. This would mean that with more social data the optimisation routine could become less "ruthless" (Shepherd and Garrod, 1981). Having had

communication with the policy makers, the model could be used to run any number of optimisations. For example, if they decided that certain sectors of the industry could not possibly be reduced because of social implications, these could immediately be tested in the model.

Summary

At the conclusion of this project it is clear that the whole ecosystem model needs further testing and improvement before it could be used seriously. Throughout the whole process the best data available have been retrieved and applied. There has been considerable contact with the Channel experts, particularly from the English side, and where possible they have provided constructive criticism. But as they have made extremely clear since the first communications, because many of the boats in the Channel are less than 10 m long, catch data can be dubious. Similarly, because there were data suitable for stock assessment for only 7 species (Tappin and Reid, 2000), one must be cautious about the inferences that were made for the non-quota species.

Nevertheless, as long as the attitude persists that no model is perfect then the model is useful. This EwE model has pieced together much scattered information on the Channel, it has identified linkages in the ecosystem that are not seen in the bio-economic work of the CFSG, it clarifies the need for further research in specific areas, and it has provided possible options for the management of the Channel which can be included in future discussions.

In closing, one stock in the Channel has provoked much interest. There have only been 7 strong year classes of scad in the last 50 years (Pawson, 1995). The cause of exceptionally strong year classes is unknown, and until it is known it cannot be modelled. Hence, all of the uncertainty with scad and other groups must lead decision-makers towards the precautionary principle. Ecosystems are extremely complex and models will continue to improve in their ability to simulate them, but they will never fully capture this complexity. There is consequently a large responsibility to step back from fishing on the brink of the survival of species in the Channel and there is certainly hope from the European Commission that European fisheries management is moving in this direction.

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APPENDIX

Table A1 CSV file used when tuning the model. 'Pool code' is the group number in the Ecopath model and 'type' refers to the type of data i.e. -1 = biomass forcing, 0 = relative biomass, 1= absolute biomass 2 = forcing function, 4 = F and 6 = catch.

	P. prod	Shrimps	Whelk	Whelk	Bivalves	Scallops	Comm. crab	Comm. crab	Lobster	Lobster	Small gadoids	Mullet	Sole	Sole	Sole	Plaice
Pool code	1	6	7	7	9	10	12	12	13	13	15	16	17	17	17	18
Type	6	6	4	6	6	6	4	6	4	6	6	6	1	4	6	0
1973	0.000	0.017	0.022	0.000	0.682	0.337	0.155	0.106	0.219	0.004	0.027	0.000	0.090	0.186	0.016	0.205
1974	0.000	0.014	0.022	0.001	0.725	0.291	0.165	0.107	0.227	0.004	0.035	0.003	0.096	0.210	0.015	0.206
1975	0.041	0.011	0.022	0.001	0.732	0.280	0.174	0.157	0.235	0.004	0.036	0.005	0.108	0.177	0.015	0.207
1976	0.041	0.010	0.022	0.001	0.696	0.302	0.184	0.175	0.244	0.002	0.077	0.007	0.113	0.190	0.020	0.208
1977	0.135	0.005	0.022	0.000	0.750	0.229	0.193	0.190	0.252	0.004	0.064	0.010	0.125	0.161	0.021	0.211
1978	0.343	0.009	0.049	0.042	0.783	0.228	0.203	0.208	0.260	0.004	0.077	0.010	0.132	0.210	0.025	0.213
1979	0.284	0.003	0.075	0.002	0.840	0.146	0.212	0.207	0.268	0.005	0.074	0.008	0.138	0.251	0.034	0.220
1980	0.354	0.012	0.102	0.039	1.015	0.188	0.222	0.218	0.277	0.005	0.075	0.007	0.148	0.227	0.031	0.230
1981	0.019	0.012	0.128	0.044	0.686	0.155	0.231	0.193	0.285	0.006	0.072	0.003	0.144	0.292	0.037	0.215
1982	0.394	0.012	0.155	0.046	1.126	0.142	0.241	0.181	0.293	0.005	0.073	0.005	0.147	0.354	0.046	0.218
1983	0.482	0.007	0.181	0.048	0.470	0.128	0.250	0.177	0.301	0.007	0.086	0.009	0.161	0.404	0.039	0.220
1984	0.657	0.009	0.208	0.005	0.254	0.135	0.260	0.193	0.310	0.007	0.070	0.007	0.164	0.411	0.042	0.212
1985	0.704	0.006	0.235	0.005	0.255	0.133	0.269	0.176	0.318	0.005	0.050	0.006	0.170	0.342	0.053	0.234
1986	0.795	0.010	0.261	0.055	0.248	0.113	0.279	0.146	0.326	0.005	0.065	0.006	0.172	0.382	0.049	0.323
1987	0.673	0.008	0.288	0.067	0.157	0.085	0.288	0.158	0.334	0.008	0.052	0.006	0.168	0.520	0.055	0.416
1988	0.716	0.006	0.314	0.130	0.347	0.110	0.298	0.158	0.342	0.006	0.088	0.006	0.162	0.408	0.047	0.357
1989	0.724	0.006	0.341	0.050	0.173	0.093	0.307	0.140	0.351	0.006	0.049	0.005	0.141	0.539	0.042	0.318
1990	0.694	0.004	0.367	0.067	0.254	0.112	0.317	0.178	0.359	0.006	0.059	0.012	0.164	0.398	0.042	0.293
1991	0.679	0.004	0.394	0.073	0.258	0.135	0.326	0.175	0.367	0.005	0.064	0.010	0.166	0.395	0.052	0.221
1992	0.694	0.002	0.420	0.020	0.283	0.191	0.336	0.168	0.375	0.005	0.070	0.011	0.193	0.339	0.051	0.216
1993	0.513	0.003	0.447	0.013	0.248	0.194	0.345	0.150	0.384	0.005	0.059	0.012	0.174	0.314	0.052	0.219
1994	0.678	0.003	0.473	0.019	0.299	0.218	0.355	0.187	0.392	0.006	0.065	0.010	0.182	0.330	0.054	0.207
1995	0.609	0.001	0.500	0.047	0.359	0.208	0.364	0.202	0.400	0.007	0.045	0.025	0.189	0.360	0.052	0.198
	Plaice	Plaice	Dab	Other flatfish	Other flatfish	Gurnards	Whiting	Whiting	Cod	Cod	Cod	Hake	Hake	Hake	Rays and dogfish	Pollack
Pool code	18	18	19	20	20	21	22	22	23	23	23	24	24	24	25	26
Type	4	6	6	4	6	6	4	6	0	4	6	1	4	6	6	4
1973	0.360	0.035	0.024	0.150	0.010	0.067	0.275	0.040	0.087	0.664	0.022	0.035	0.220	0.009	0.041	0.008
1974	0.360	0.035	0.012	0.150	0.009	0.052	0.403	0.065	0.082	0.577	0.037	0.035	0.220	0.019	0.042	0.008
1975	0.360	0.032	0.023	0.150	0.010	0.045	0.258	0.104	0.093	0.724	0.051	0.034	0.220	0.019	0.054	0.008
1976	0.360	0.029	0.013	0.150	0.015	0.044	0.327	0.096	0.081	0.680	0.037	0.034	0.220	0.015	0.050	0.008
1977	0.360	0.033	0.019	0.150	0.015	0.059	0.313	0.076	0.107	0.605	0.062	0.033	0.220	0.013	0.054	0.072
1978	0.360	0.036	0.017	0.150	0.023	0.064	0.243	0.085	0.107	0.682	0.119	0.032	0.220	0.011	0.078	0.088
1979	0.360	0.040	0.024	0.150	0.030	0.059	0.257	0.075	0.107	0.618	0.084	0.032	0.224		0.076	0.104
1980	0.363	0.053	0.021	0.150	0.030	0.038	0.267	0.088	0.137	0.778	0.051	0.031	0.251	0.012	0.104	0.120
1981	0.474	0.070	0.028	0.150	0.029	0.034	0.302	0.105	0.117	0.786	0.056	0.030	0.262	0.015	0.159	0.136
1982	0.493	0.071	0.023	0.200	0.033	0.048	0.262	0.097	0.115	0.806	0.041	0.030	0.298	0.015	0.078	0.152
1983	0.499	0.070	0.026	0.200	0.042	0.063	0.259	0.071	0.092	0.877	0.046	0.029	0.314	0.015	0.082	0.169
1984	0.586	0.066	0.027	0.200	0.038	0.047	0.250	0.073	0.098	0.710	0.035	0.028	0.345	0.012	0.063	0.185
1985	0.512	0.082	0.027	0.250	0.038	0.041	0.278	0.081	0.077	0.694	0.044	0.028	0.245	0.010	0.057	0.201
1986	0.552	0.083	0.032	0.250	0.030	0.051	0.210	0.044	0.098	0.854	0.105	0.027	0.232	0.013	0.096	0.217
1987	0.472	0.109	0.036	0.250	0.033	0.057	0.215	0.089	0.088	0.863	0.114	0.026	0.271	0.013	0.081	0.233
1988	0.510	0.128	0.036	0.250	0.034	0.060	0.289	0.096	0.082	0.782	0.133	0.026	0.304	0.017	0.080	0.249
1989	0.556	0.099	0.022	0.250	0.033	0.055	0.254	0.011	0.079	0.923	0.015	0.025	0.326	0.004	0.064	0.265
1990	0.572	0.115	0.016	0.350	0.037	0.061	0.317	0.017	0.059	0.844	0.014	0.024	0.326	0.005	0.061	0.281
1991	0.695	0.104	0.016	0.350	0.039	0.061	0.375	0.018	0.051	0.964	0.010	0.024	0.282	0.006	0.060	0.297
1992	0.598	0.087	0.017	0.350	0.036	0.062	0.324	0.071	0.063	0.867	0.033	0.023	0.327	0.010	0.049	0.313
1993	0.413	0.069	0.017	0.350	0.032	0.063	0.258	0.072	0.057	0.887	0.035	0.022	0.243	0.006	0.046	0.329
1994	0.599	0.077	0.015	0.350	0.034	0.060	0.302	0.089	0.069	0.845	0.037	0.022	0.332	0.007	0.049	0.345
1995	0.497	0.064	0.010	0.350	0.043	0.060	0.289	0.076	0.070	0.728	0.052	0.021	0.372	0.004	0.049	0.361

Table A1 continued.

	Pollack	Large bottom	Large bottom	Large bottom	Seabream	Seabream	John Dory	John Dory	Herring	Herring	Sprat	Pilchard	Mackerel	Mackerel	Mackerel	O-winter mackerel
Pool code	26	27	27	27	28	28	29	29	31	31	32	33	34	34	34	35
Type	6	0	4	6	6	4	4	6	-1	6	6	6	1	4	6	-1
1973	0.001	0.978	0.101	0.020	0.061	0.390	0.049	0.000	1.515	0.222	0.037	0.065	1.802	0.134	0.242	7.709
1974	0.002		0.120	0.023	0.052	0.390	0.049	0.000	1.203	0.065	0.042	0.052	1.853	0.162	0.301	8.322
1975	0.002		0.139	0.026	0.057	0.390	0.049	0.000	0.907	0.227	0.018	0.081	1.807	0.262	0.474	5.336
1976	0.004		0.158	0.035	0.063	0.390	0.049	0.001	0.497	0.157	0.042	0.099	1.636	0.250	0.408	7.550
1977	0.027		0.177	0.049	0.073	0.500	0.049	0.001	0.307	0.016	0.036	0.164	1.590	0.123	0.195	16.320
1978	0.038		0.197	0.052	0.088	0.700	0.150	0.003	0.324	0.015	0.056	0.146	1.583	0.166	0.262	16.307
1979	0.033		0.216	0.050	0.087	0.850	0.150	0.003	0.523	0.020	0.166	0.160	1.451	0.233	0.337	13.266
1980	0.032		0.235	0.057	0.063	0.900	0.150	0.002	0.838	0.040	0.198	0.149	1.349	0.261	0.352	8.379
1981	0.032		0.254	0.059	0.000	0.000	0.150	0.002	1.508	0.072	0.155	0.109	1.387	0.211	0.292	2.818
1982	0.024		0.273	0.072	0.011	0.390	0.150	0.003	2.377	0.152	0.074	0.090	1.341	0.212	0.284	1.553
1983	0.043		0.292	0.108	0.010	0.390	0.150	0.003	3.332	0.264	0.077	0.152	1.410	0.205	0.289	3.649
1984	0.029		0.311	0.083	0.007	0.390	0.150	0.003	3.470	0.181	0.050	0.037	1.311	0.193	0.254	3.018
1985	0.023		0.330	0.061	0.012	0.390	0.150	0.002	4.020	0.134	0.042	0.080	1.375	0.200	0.156	0.000
1986	0.035	0.956	0.349	0.055	0.030	0.390	0.150	0.002	4.281	0.089	0.013	0.084	1.383	0.172	0.144	0.000
1987	0.049	0.896	0.318	0.073	0.019	0.390	0.150	0.002	4.910	0.072	0.030	0.048	1.371	0.213	0.284	0.000
1988	0.041	0.786	0.339	0.072	0.031	0.390	0.150	0.003	4.634	0.243	0.061	0.061	1.479	0.233	0.253	0.000
1989	0.051	0.799	0.380	0.074	0.018	0.390	0.300	0.004	4.202	0.275	0.040	0.074	1.491	0.191	0.272	0.000
1990	0.066	0.794	0.381	0.064	0.027	0.390	0.300	0.004	3.952	0.180	0.025	0.098	1.388	0.199	0.290	0.000
1991	0.046	0.809	0.345	0.052	0.035	0.390	0.300	0.003	3.720	0.236	0.029	0.104	1.563	0.219	0.299	0.000
1992	0.028	0.824	0.270	0.039	0.040	0.390	0.300	0.004	3.742	0.188	0.081	0.266	1.623	0.259	0.250	0.000
1993	0.024	0.919	0.200	0.037	0.051	0.390	0.300	0.004	3.578	0.227	0.020	0.216	1.548	0.332	0.295	0.000
1994	0.028	1.087	0.199	0.038	0.042	0.390	0.300	0.005	2.770	0.289	0.076	0.267	1.460	0.326	0.370	0.000
1995	0.024	1.167	0.247	0.040	0.034	0.390	0.300	0.005	3.134	0.309	0.040	0.185	1.508	0.301	0.350	0.000
	Scad	Scad	Bass	Bass	Shark	Cephalopods	Cephalopods	Juv cod	Juv whiting	FF Juv plaice	FF Seabream etc.	FF Juv bass	FF Juv sole	FF Juv cod		
Pool code	36	36	37	37	38	40	40	47	48	1	2	3	4	5		
Type	0	4	4	6	6	4	6	6	6	2	2	2	2	2		
1973			0.050	0.005	0.000	0.121	0.049	0.001	0.023	1	1.284	0.910	1.000	1.078		
1974			0.050	0.005	0.000	0.134	0.014	0.002	0.031	1	1.000	0.303	3.355	1.024		
1975			0.050	0.008	0.000	0.147	0.068	0.006	0.023	1	1.143	0.425	1.000	0.939		
1976			0.050	0.006	0.000	0.160	0.036	0.001	0.016	1	1.311	2.426	1.687	1.022		
1977			0.050	0.009	0.000	0.173	0.070	0.015	0.039	1	1.000	0.607	3.676	1.048		
1978			0.200	0.010	0.000	0.186	0.039	0.007	0.017	1	1.000	0.061	1.000	1.031		
1979			0.200	0.013	0.000	0.199	0.013	0.006	0.025	1	1.000	0.728	1.000	1.119		
1980			0.200	0.013	0.000	0.212	0.022	0.007	0.009	1	1.000	0.243	1.000	1.182		
1981			0.200	0.014	0.000	0.225	0.036	0.003	0.008	1	1.000	0.182	1.000	0.972		
1982			0.200	0.012	0.000	0.238	0.061	0.006	0.009	1	1.288	1.881	1.000	1.048		
1983			0.200	0.013	0.000	0.251	0.088	0.003	0.011	1	1.097	1.681	3.403	0.924		
1984	25.711	0.240	0.200	0.013	0.000	0.264	0.063	0.007	0.018	1	1.211	1.639	1.141	1.131		
1985	33.739	0.100	0.200	0.011	0.000	0.276	0.059	0.001	0.018	1	1.000	0.699	2.489	1.060		
1986	36.115	0.160	0.200	0.015	0.000	0.289	0.061	0.042	0.026	20	1.000	0.139	1.000	1.043		
1987	37.341	0.090	0.200	0.018	0.000	0.302	0.054	0.009	0.016	1	1.000	1.395	1.000	1.318		
1988	37.404	0.090	0.200	0.013	0.000	0.315	0.085	0.010	0.020	1	1.112	0.433	1.000	1.117		
1989	36.861	0.110	0.200	0.012	0.000	0.328	0.148	0.002	0.002	1	2.600	2.692	1.318	0.971		
1990	32.717	0.180	0.400	0.011	0.000	0.341	0.205	0.001	0.003	1	2.284	2.129	18.898	0.754		
1991	31.349	0.180	0.400	0.011	0.000	0.354	0.119	0.001	0.002	1	1.000	1.580	15.161	0.708		
1992	28.028	0.180	0.400	0.011	0.000	0.367	0.102	0.007	0.015	1	1.121	0.971	1.000	1.074		
1993	29.058	0.140	0.400	0.012	0.000	0.380	0.181	0.001	0.011	1	1.095	0.936	1.430	0.971		
1994	27.561	0.110	0.400	0.011	0.000	0.393	0.131	0.004	0.014	1	1.207	1.195	1.125	0.928		
1995	28.736	0.180	0.400	0.012	0.000	0.406	0.192	0.005	0.010	1	2.171	2.500	2.440	1.021		

Table A2 Forcing functions used when optimising with a predicted temperature change of 0.6 °C and 1.2 °C.

	FF 0.6 °C Seabream	FF 0.6 °C Juv bass	FF 0.6 °C Juv sole	FF 0.6 °C Juv cod	FF 1.2 °C Seabream	FF 1.2 °C Juv bass	FF 1.2 °C Juv sole	FF 1.2 °C Juv cod
Pool code	2	3	4	5	2	3	4	5
Type	2	2	2	2	2	2	2	2
1995	1.486	1.534	5.745	0.991	1.486	1.534	5.745	0.991
1996	1.511	1.555	6.034	0.987	1.535	1.576	6.322	0.983
1997	1.535	1.576	6.322	0.983	1.584	1.618	6.900	0.974
1998	1.560	1.597	6.611	0.978	1.633	1.660	7.477	0.965
1999	1.584	1.618	6.900	0.974	1.682	1.702	8.055	0.957
2000	1.609	1.639	7.189	0.970	1.731	1.744	8.632	0.948
2001	1.633	1.660	7.477	0.965	1.780	1.786	9.210	0.940
2002	1.658	1.681	7.766	0.961	1.829	1.828	9.787	0.931
2003	1.682	1.702	8.055	0.957	1.878	1.870	10.365	0.922
2004	1.706	1.723	8.343	0.953	1.926	1.912	10.942	0.914
2005	1.731	1.744	8.632	0.948	1.975	1.954	11.520	0.905
2006	1.755	1.765	8.921	0.944	2.024	1.996	12.097	0.897
2007	1.780	1.786	9.210	0.940	2.073	2.038	12.675	0.888
2008	1.804	1.807	9.498	0.935	2.122	2.080	13.252	0.880
2009	1.829	1.828	9.787	0.931	2.171	2.122	13.829	0.871
2010	1.853	1.849	10.076	0.927	2.220	2.164	14.407	0.862
2011	1.878	1.870	10.365	0.922	2.269	2.206	14.984	0.854
2012	1.902	1.891	10.653	0.918	2.318	2.248	15.562	0.845
2013	1.926	1.912	10.942	0.914	2.366	2.290	16.139	0.837
2014	1.951	1.933	11.231	0.910	2.415	2.332	16.717	0.828
2015	1.975	1.954	11.520	0.905	2.464	2.374	17.294	0.820
2016	2.000	1.975	11.808	0.901	2.513	2.416	17.872	0.811
2017	2.024	1.996	12.097	0.897	2.562	2.458	18.449	0.802
2018	2.049	2.017	12.386	0.892	2.611	2.500	19.027	0.794
2019	2.073	2.038	12.675	0.888	2.660	2.542	19.604	0.785
2020	2.098	2.059	12.963	0.884	2.709	2.583	20.182	0.777
2021	2.122	2.080	13.252	0.880	2.758	2.625	20.759	0.768
2022	2.146	2.101	13.541	0.875	2.807	2.667	21.337	0.760
2023	2.171	2.122	13.829	0.871	2.855	2.709	21.914	0.751
2024	2.195	2.143	14.118	0.867	2.904	2.751	22.492	0.742
2025	2.220	2.164	14.407	0.862	2.953	2.793	23.069	0.734
2026	2.244	2.185	14.696	0.858	3.002	2.835	23.647	0.725
2027	2.269	2.206	14.984	0.854	3.051	2.877	24.224	0.717
2028	2.293	2.227	15.273	0.850	3.100	2.919	24.801	0.708
2029	2.318	2.248	15.562	0.845	3.149	2.961	25.379	0.700
2030	2.342	2.269	15.851	0.841	3.198	3.003	25.956	0.691
2031	2.366	2.290	16.139	0.837	3.247	3.045	26.534	0.682
2032	2.391	2.311	16.428	0.832	3.295	3.087	27.111	0.674
2033	2.415	2.332	16.717	0.828	3.344	3.129	27.689	0.665
2034	2.440	2.353	17.006	0.824	3.393	3.171	28.266	0.657

Table A3 Mixed trophic impact from the final model. Red (bold) values indicate positive impacts.

Impacted ↙ Impacting →	PP	Zp	C. zp	DF	SF	Shr.	Whe.	Ech.	Biv.	Sca.	Crab	C. C.	Lob.	SD	SG	
Prim. prod	-0.362	0.3	0.14	-0.051	0.217	0.16	-0.009	0.006	0.298	0.14	-	0.031	0.028	-	0.038	
Zooplankton	-0.374	-0.533	0.157	-0.015	0.177	0.12	-	-	-	-	-	-	-0.014	-0.034	0.04	
Carn. Zp.	0.067	-0.083	-0.293	0.003	-0.031	-0.019	0.002	0.003	0.032	0.018	0	0.003	0.001	0.005	-0.017	
Dep. feeders	-0.001	0.013	-0.03	-0.473	-0.158	-0.054	0.312	-0.089	-0.062	-0.118	-0.158	-0.218	-0.138	0.374	0.053	
Sus. Feeders	0.013	-0.018	-0.009	-0.014	-0.063	-0.005	-0.01	0.003	0.005	0.005	0.003	0.003	0.05	-0.013	-0.001	
Shrimps	0.126	-0.175	-0.046	-0.07	-0.051	-0.163	-0.025	-0.014	0.045	0.013	0.015	0.068	-0.028	-0.106	0.307	
Whelk	0	-0.001	-0.001	-0.007	0.006	0.003	-0.222	-0.004	0.002	0.002	-0.002	-0.134	-0.216	-0.003	-0.001	
Echinoderms	0.007	0.007	0.003	-0.052	-0.17	0.01	-0.013	-0.457	-0.134	0.03	-0.004	-0.013	0.076	-0.035	-0.006	
Bivalves	-0.078	-0.037	-0.009	-0.056	-0.055	-0.06	0.006	-0.007	-0.086	-0.197	0.017	0.105	0.043	0.015	-0.028	
Scallops	-0.001	-0.001	-0.001	-0.001	0.001	0	0.001	-0.001	-0.006	-0.337	-0.001	-0.006	0.001	0	0.003	
Crab	-0.019	0.082	0.145	0.043	0.042	-0.361	0.036	-0.011	-0.355	0.061	-0.326	-0.104	0.321	-0.03	-0.068	
Comm. Crab	0	0.004	-0.006	0.004	0.002	-0.012	-0.231	0.002	-0.026	0.005	-0.001	-0.199	-0.287	0.004	0.011	
Lobster	0	0	-0.001	0	-0.004	0.001	-0.023	-0.002	0.001	0	-0.003	-0.003	-0.008	0	0	
Sm. Dem.	0.005	0.002	0.047	-0.204	0.07	-0.003	-0.129	0	-0.054	0.068	0.035	0.068	0.035	-0.251	-0.045	
Sm. Gads	-0.016	0.008	0.001	0.025	0.011	-0.062	0.014	0.007	0.083	-0.022	-0.156	-0.019	-0.065	-0.101	-0.129	
Mullet	0.002	-0.004	-0.003	-0.041	0.004	0.011	-0.026	0.007	0.01	0.009	0.003	0.016	0.007	-0.027	-0.013	
Sole	-0.001	0.001	-0.001	-0.008	0.005	-0.006	-0.006	0.002	0.002	-0.065	0.003	0.003	-0.017	0	-0.005	0.004
Plaice	0	0	-0.005	-0.001	0.006	-0.001	-0.002	0.001	0.001	-0.007	0.002	-0.012	0.004	-0.015	0.009	
Dab	0	0.001	-0.002	-0.004	0	-0.001	0	0.001	-0.001	0.001	0.003	-0.007	0.002	-0.012	0.002	
O. flatfish	-0.002	0.004	-0.001	-0.003	-0.178	0.002	-0.007	-0.003	-0.009	0.001	0.002	-0.003	-0.006	0.001	0.002	
Gurnards	-0.001	0.001	-0.013	0.003	0.004	-0.011	0.011	0.002	0.005	-0.003	-0.004	-0.019	0.001	-0.032	0.01	
Whiting	0.01	-0.011	0.129	-0.002	-0.003	0.003	0.006	-0.001	-0.007	0.004	0.02	-0.012	0.011	0.015	-0.088	
Cod	0.003	-0.004	0.007	-0.004	-0.001	0.016	0.002	-0.001	0.001	0.004	0	-0.006	-0.001	0.013	0.009	
Hake	0.001	-0.001	0.003	-0.002	0.04	0.002	-0.001	0	0	0.001	-0.001	-0.001	0.001	0.012	-0.005	
Rays and dog	-0.002	0.002	-0.021	0.003	0.004	0.017	-0.054	-0.003	0.006	0.005	-0.018	-0.009	0.017	0.031	-0.041	
Pollack	0	0.001	-0.004	0.002	-0.001	0.001	0.007	-0.001	-0.009	0.002	0.018	-0.011	0.008	-0.006	-0.091	
Lg. Bottom	0.001	0	-0.022	-0.001	0.039	0.011	0.001	-0.001	-0.011	0	0.017	0.001	0.006	0.033	-0.087	
Seabream	-0.004	0.006	-0.025	-0.008	-0.016	-0.01	0	-0.003	-0.008	0.001	0.016	-0.004	0.009	0.008	0.025	
John Dory	0	0	-0.001	0.001	0	0	0.001	0	0	0	0	-0.001	0	-0.002	0.001	
Sandeels	-0.046	0.057	-0.645	-0.001	0.022	0.024	-0.001	-0.003	-0.019	-0.012	-0.007	-0.006	-0.005	-0.007	-0.02	
Herring	0	-0.001	0.017	0.007	0.02	0.005	0.003	0	0.005	-0.002	-0.007	-0.005	-0.003	-0.019	-0.022	
Sprat	0.008	-0.01	0.01	-0.002	0.008	-0.002	-0.001	0	0.003	0.003	0.002	0	0.002	0.004	-0.008	
Pilchard	0.004	-0.007	-0.001	0	0.014	-0.001	-0.001	0	0.002	0.002	-0.001	0.001	0.001	0.005	-0.004	
Mackerel	0.026	-0.032	-0.014	-0.002	0.039	-0.007	0.003	0.001	0.013	0.008	-0.002	-0.003	0.002	0.018	0.004	
Scad	-0.01	0.015	-0.023	0.013	-0.308	-0.007	0.013	0.001	-0.006	-0.007	0.011	-0.006	-0.01	-0.077	0.028	
Bass	0.002	-0.004	0.032	0	-0.002	0.002	0.001	0	0.005	0	-0.006	-0.002	-0.003	-0.002	0.001	
Sharks	-0.001	0.001	-0.004	0	0	-0.002	0	0	-0.002	0	0.002	0	0.001	0.001	0.003	
Basking sk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Cephalopods	0.029	-0.051	0.24	0.029	-0.007	0.11	0.004	0.001	0.091	0	-0.146	-0.003	-0.088	-0.095	-0.215	
Seabirds	0.001	-0.001	0.022	0	-0.002	-0.001	0	0	0	0	0	0	0	0	0.001	
Toothed Cet.	-0.003	0.004	-0.019	-0.001	0.009	-0.008	-0.001	0	-0.005	-0.001	0.006	0.003	0.004	0.006	0.022	
Seals	0	0	0.003	0	0.002	-0.003	-0.001	0	0.002	0	-0.003	0.002	-0.001	-0.005	0.018	
Juv bass	-0.001	0.001	0	-0.001	0.001	-0.004	-0.001	0	0	0	-0.001	0	0	0	-0.002	
Juv sole	0	0	0.001	-0.004	0.001	-0.002	-0.002	0.001	0.001	-0.029	0.001	0.001	0.001	-0.003	-0.002	
Juv plaice	-0.004	0.005	0.001	0.002	0.002	-0.025	0.002	0.001	-0.002	-0.002	0	-0.005	0.001	-0.001	-0.007	
Juv cod	-0.001	0.002	-0.001	0.006	-0.001	-0.008	0.004	0.001	0.002	-0.002	0	-0.003	0	-0.032	-0.002	
Juv whiting	-0.003	0.003	-0.013	0.026	-0.007	-0.017	0.017	0	0.004	-0.008	-0.001	-0.014	-0.001	-0.086	-0.001	
Discards	0	0	0.005	0	0	0	0	0	0	0	0	0	0	0	0	
Detritus	-0.005	-0.003	0.054	0.452	0.037	0.095	0.169	0.286	0.028	0.188	0.352	0.275	0.105	0.273	0.156	
Otter trawl	-0.008	0.012	-0.082	-0.009	0.039	-0.011	0.083	0.001	-0.016	-0.006	0.029	-0.158	0.033	0.05	0.113	
Beam trawl	0	0	-0.005	0.001	0.029	-0.003	-0.05	0	-0.002	0.009	0.004	0.009	0.019	0.007	0.007	
Midw trawl	-0.01	0.011	0.033	-0.004	0.134	0.016	-0.007	-0.001	-0.001	-0.001	-0.011	0.005	-0.001	0.025	-0.035	
Dredge	0.002	0.001	0.002	0.002	0.002	0.002	0.003	0.001	-0.007	-0.537	0	-0.004	0.002	0	0.003	
Net	-0.001	0	0	0.004	-0.012	-0.005	0.036	0	0.005	0.019	-0.004	-0.092	-0.007	-0.009	0.028	
Pot	-0.001	-0.001	0	0.003	-0.003	0	-0.491	0.004	0.01	-0.003	0.007	-0.321	-0.573	0.002	-0.001	
Line	-0.001	0.002	-0.002	0	-0.008	-0.004	0.005	0	0	-0.001	0	0.001	-0.002	-0.009	0.022	
Recreational	0	0	-0.005	0	0.001	0.001	0	0	0	0	-0.001	0	-0.001	-0.001	-0.004	

Table A3 *continued.*

Impacted Impacting	Mul.	Sole	Pla.	Dab	OF	Gurn	Whit	Cod	Hake	Rays	Poll	LB	Seab	JD	Sand
Prim. prod	0.027	-	-	-0.05	0.042	0.087	0.101	0.052	0.097	-	0	-0.026	-0.076	0.21	0.2
Zooplankton	0.061	0.003	-0.023	-0.037	0.002	0.12	0.12	0.062	0.072	-	0.023	-	-0.043	0.275	0.309
Carn. Zp.	-0.011	-0.001	0.001	0.002	0	-0.025	0.039	0.002	-0.013	0.004	-0.013	-0.006	0.003	-0.056	0.21
Dep. feeders	0.301	0.369	0.328	0.398	0.213	0.131	0.032	-0.01	0.039	0.002	0.07	0.102	0.4	0.024	0.43
Sus. Feeders	-0.035	-0.017	-0.016	-0.009	0.174	-0.013	-0.008	-0.005	0.014	0.01	-0.006	-0.003	0.026	-0.018	-0.008
Shrimps	-0.081	0.017	-0.092	-0.072	-0.095	0.026	0	0.156	-0.075	0.005	0.293	0.089	-0.081	-0.173	-0.129
Whelk	-0.006	-0.01	-0.011	-0.003	-0.014	0.006	0.003	0.01	0.005	0.011	0.007	0.001	0.001	0.003	0.001
Echinoderms	-0.023	-0.028	-0.026	-0.044	-0.057	-0.009	0	0.007	-0.005	-0.004	-0.004	-0.009	-0.016	0.006	0.005
Bivalves	-0.042	-0.076	-0.048	-0.011	0.07	-0.03	-0.004	-0.023	-0.017	0	-0.023	-0.006	-0.042	-0.014	-0.029
Scallops	0.004	-0.011	-0.044	-0.006	-0.006	-0.005	0.002	-0.001	0.008	-0.006	0.003	-0.022	-0.003	-0.006	0
Crab	-0.016	-0.033	0.008	-0.005	-0.026	-0.007	-0.041	0.004	0.036	0.209	-0.16	-0.072	-0.031	0.031	-0.063
Comm. Crab	0.018	-0.062	-0.031	-0.024	0.007	-0.04	-0.009	-0.057	-0.024	-0.046	-0.032	-0.035	-0.02	-0.028	0.01
Lobster	0	0	0.001	0	0	0	0	0	0	-0.001	0.001	0	0	0	0
Sm. dem.	-0.18	-0.164	-0.057	-0.144	-0.148	0.002	0.008	-0.031	-0.033	0.02	0.134	0.083	-0.188	0.146	-0.045
Sm. Gads	0.009	-0.016	-0.043	-0.063	-0.05	-0.099	0.12	0.018	-0.054	-0.058	0.259	0.169	-0.015	-0.074	0.008
Mullet	-0.057	-0.037	-0.032	-0.049	-0.047	-0.021	-0.026	-0.011	-0.016	0.044	-0.017	0.054	-0.035	-0.008	-0.001
Sole	0.003	-0.065	-0.041	-0.023	-0.012	-0.013	0	-0.04	-0.018	-0.017	-0.019	-0.03	-0.011	-0.009	0.003
Plaice	0.011	-0.046	-0.053	-0.019	-0.022	-0.029	-0.007	-0.02	-0.006	-0.026	-0.017	-0.032	-0.014	-0.03	0.005
Dab	0.002	-0.021	-0.021	-0.016	-0.01	-0.021	-0.003	-0.018	-0.012	-0.016	-0.014	0	-0.013	-0.017	0.003
O. flatfish	0.004	-0.027	-0.039	-0.018	-0.073	-0.014	-0.009	-0.018	-0.012	-0.01	-0.01	0.009	-0.016	-0.012	0.005
Gurnards	0.023	-0.007	-0.035	-0.025	-0.001	-0.087	-0.037	-0.031	-0.008	-0.065	-0.037	-0.018	-0.042	-0.074	0.014
Whiting	0.005	-0.004	-0.013	-0.083	-0.002	-0.038	-0.09	-0.045	-0.024	-0.026	-0.048	-0.015	-0.024	-0.067	-0.14
Cod	0.001	-0.023	-0.024	-0.007	-0.001	-0.003	-0.004	-0.12	-0.01	-0.009	-0.086	-0.018	-0.009	-0.006	-0.011
Hake	0.041	-0.006	-0.002	-0.003	0.004	0	-0.004	-0.007	-0.156	0.001	-0.002	0.005	-0.001	-0.119	-0.004
Rays and dog	-0.214	-0.136	-0.057	-0.067	-0.114	-0.015	-0.108	-0.008	-0.017	-0.06	-0.054	-0.076	0.01	-0.005	0.023
Pollack	0.013	-0.014	-0.01	0.002	0.012	-0.01	-0.022	0.001	0.002	-0.016	-0.058	-0.048	-0.01	-0.012	0.005
Lg. Bottom	-0.129	0	0.013	-0.15	-0.266	-0.001	-0.154	-0.092	-0.302	-0.019	-0.086	-0.14	0.011	0.078	0.022
Seabream	0.009	-0.009	-0.011	-0.016	-0.011	-0.025	0	-0.006	-0.005	-0.013	-0.004	0.001	-0.013	-0.014	0.031
John Dory	0.001	0	-0.001	0	0	-0.003	-0.004	-0.002	0.005	-0.003	-0.001	-0.001	-0.001	-0.012	0.001
Sandeels	0.006	-0.002	-0.01	-0.016	0.002	0.007	0.169	0.039	0.008	-0.001	-0.019	-0.025	-0.017	0.017	-0.298
Herring	0.004	-0.003	-0.005	-0.016	-0.021	-0.011	-0.002	0.014	-0.047	0.029	-0.021	0.07	-0.008	-0.002	-0.018
Sprat	0.009	-0.003	-0.002	-0.007	0	-0.006	0.063	0.011	0.078	0.005	-0.008	0	-0.008	0.172	-0.02
Pilchard	0.013	-0.003	-0.001	-0.001	0	-0.001	-0.005	-0.001	0.14	0.012	0	0.004	-0.007	-0.019	-0.007
Mackerel	0.067	-0.002	-0.012	0.004	0.024	-0.041	-0.047	-0.007	-0.039	-0.043	0.007	-0.052	-0.037	-0.12	-0.019
Scad	-0.328	0.014	0.004	0.009	-0.04	-0.001	0.021	0.018	0.298	-0.022	0.001	-0.025	0.005	-0.045	0.038
Bass	0.005	-0.002	-0.002	0.003	0.006	-0.003	-0.006	-0.005	0.002	-0.012	-0.001	-0.014	-0.002	-0.004	-0.036
Sharks	0	0	0	-0.001	-0.001	0.001	0.002	0.001	0	0.002	0.001	0.002	0.002	0.002	0.005
Basking shk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cephalopods	-0.034	0.031	-0.02	0.042	0.044	-0.039	-0.147	-0.079	-0.01	-0.087	-0.093	-0.079	-0.133	-0.08	-0.29
Seabirds	-0.002	0	0.001	0.001	0	0.001	-0.007	-0.002	-0.003	0	0.001	0.002	0.002	-0.005	-0.023
Toothed Cet.	0.007	0.002	0.006	0.002	-0.002	0.008	-0.027	-0.082	-0.01	0.011	-0.055	0.013	-0.058	0.011	0.023
Seals	0.017	0.004	-0.01	0.023	0.003	0.003	0.005	-0.057	0.043	0.006	-0.033	-0.114	0.002	-0.007	-0.003
Juv bass	0	-0.001	0	-0.001	0	-0.001	0	-0.001	0	0	-0.002	-0.001	0	0.001	0.001
Juv sole	-0.002	-0.004	-0.001	-0.003	-0.001	-0.001	-0.001	-0.002	-0.001	-0.001	-0.002	-0.001	-0.003	0	-0.001
Juv plaice	0.005	-0.007	-0.006	-0.002	0.002	-0.009	-0.004	0.127	0	-0.008	-0.026	-0.009	-0.003	-0.003	0.004
Juv cod	0.006	0.003	0	0.002	0.004	-0.003	-0.001	0.013	0	-0.003	-0.012	-0.001	0.005	-0.006	0.003
Juv whiting	0.014	0.013	-0.002	0.001	-0.002	-0.019	-0.009	0.006	0.035	-0.009	-0.037	0.038	0.018	-0.033	0.016
Discards	0	0	0	0	0	0	-0.002	0	-0.001	0	0	0	0	-0.001	-0.005
Detritus	0.226	0.244	0.194	0.296	0.2	0.094	0.001	0.035	0.014	0.127	0.072	0.053	0.294	-0.054	-0.057
Otter trawl	0.139	-0.061	-0.265	-0.227	-0.02	-0.714	-0.302	-0.248	-0.064	-0.52	-0.227	-0.137	-0.415	-0.579	0.094
Beam trawl	0.012	-0.124	-0.191	-0.031	-0.153	-0.003	0.016	0.001	0.021	-0.014	0.02	-0.055	0.013	-0.035	0.006
Midw trawl	0.128	-0.004	-0.002	-0.005	0.013	0.012	0.013	0.065	-0.181	0.012	0.053	0.028	-0.035	0.079	-0.022
Dredge	0.005	-0.069	-0.057	-0.001	-0.003	0.01	0.011	0.007	0.016	0.004	0.011	-0.029	0.006	0.006	-0.001
Net	0.028	-0.256	-0.089	-0.055	0.036	0.02	0.035	-0.196	-0.107	-0.064	-0.072	-0.121	0.012	0.025	0.001
Pot	-0.004	0.016	0.027	0.015	0.008	0.018	0.006	0.025	0.011	0.018	0.013	0.018	0.012	0.015	-0.001
Line	0.041	0.014	0.004	0.034	0.058	0.004	0.042	0.017	0.057	-0.083	-0.001	-0.145	-0.004	-0.008	0.004
Recreational	-0.001	0.001	0	0	-0.001	0	-0.001	0	-0.001	0.002	-0.001	0.002	-0.002	0	0.005

Table A3 continued.

Impacted Impacting	Herr	Spr	Pil	Mac	Scad	Bass	Shk	BS	Ceph	Sbir	TC	Seal	JB	JP	JS
Prim. prod	-0.086	0.1	0.4	0.261	-0.034	0.03	0.062	0.114	0.033	0.1	-	0.05	0.024	-	0.019
Zooplankton	-0.092	0.219	0.146	0.339	-0.005	0.036	0.039	0.1	-	0.1	-	0.063	0.03	0.006	0.011
Carn. Zp.	0.014	-0.053	-0.026	-0.063	0	0.054	-0.056	-0.025	0.013	0.049	0.026	0.026	-0.008	-0.013	-0.009
Dep. feeders	-0.004	0.03	-0.128	-0.02	0.292	-0.077	0.009	0.004	-0.084	0.023	-0.043	0.088	0.145	0.505	0.028
Sus. Feeders	0.007	-0.007	-0.03	-0.017	0.049	0	-0.009	-0.005	-0.008	-0.006	-0.004	0.013	-0.009	-0.005	-0.002
Shrimps	-0.018	-0.09	-0.035	-0.13	-0.038	0.042	-0.066	-0.053	0.006	-0.066	0.07	0.044	0.29	0.044	0.273
Whelk	0.001	-0.002	0	0	-0.003	0.003	-0.006	0	-0.005	0	0	0.001	0.008	0.001	-0.004
Echinoderms	0	0	0.025	0.009	-0.041	0.002	0.001	0.002	0.001	0.001	0.002	-0.009	-0.011	-0.041	-0.004
Bivalves	0.008	-0.022	-0.032	-0.023	-0.023	0	-0.001	-0.011	0.007	-0.015	0.01	-0.006	-0.044	-0.072	-0.014
Scallops	-0.001	-0.001	0	0	-0.001	0.001	-0.002	0	-0.002	0	0	-0.008	-0.005	0.017	-0.021
Crab	-0.041	0.055	0.027	0.033	-0.012	0.226	-0.031	0.025	0.258	0.011	0.091	-0.042	-0.128	-0.25	-0.177
Comm. Crab	0	0.01	0.006	0.002	0.006	-0.022	0.017	0.001	-0.007	0.005	-0.016	-0.021	-0.05	0.003	0.015
Lobster	0	0	0	0	0	-0.001	0	0	-0.001	0	0	0	0.001	0.001	0.001
Sm. dem.	-0.089	-0.012	0.027	0.001	-0.042	0.018	0.052	0.001	0.105	-0.02	0.056	0.033	-0.099	-0.267	0.007
Sm. Gads	0.038	-0.007	0.003	-0.003	0.009	-0.097	0.07	0.003	-0.034	0	0	0.086	-0.101	0.043	-0.064
Mullet	0.007	0.002	-0.009	-0.008	0.01	-0.003	0.003	-0.001	0.003	-0.002	-0.003	0.003	-0.018	-0.034	0.006
Sole	-0.001	0.002	0.004	0.002	-0.001	-0.014	0.013	0	-0.001	0.001	-0.009	-0.017	-0.016	-0.013	0.015
Plaice	0.002	0.005	0.003	0	-0.001	-0.007	0.003	0	-0.006	0.002	-0.008	0.019	-0.028	0.001	-0.002
Dab	0.003	0.003	0.003	0	-0.002	-0.005	0.004	0	-0.002	0.001	-0.005	-0.005	-0.022	-0.002	0.003
O. flatfish	0.001	0.006	0.008	0.003	-0.011	-0.001	0.001	0.001	-0.002	0.003	-0.004	0.094	-0.013	-0.002	0.003
Gurnards	0.01	0.017	0.007	-0.004	-0.002	-0.01	0.001	0	-0.012	0.006	-0.014	-0.017	-0.094	0.013	-0.012
Whiting	0.007	-0.174	0	-0.009	0.003	-0.027	0.012	-0.003	-0.009	-0.063	0.034	0.033	-0.041	0.008	0.018
Cod	0.001	-0.011	-0.001	-0.003	0	-0.008	0.006	-0.001	-0.001	-0.005	0.042	0.093	-0.001	-0.002	-0.539
Hake	0.005	-0.018	-0.001	0	-0.11	-0.001	0.007	0	0.01	-0.003	0.017	-0.001	-0.001	-0.011	0.005
Rays and dog	0.024	0.005	-0.062	-0.047	-0.028	-0.036	-0.032	0	-0.081	0.002	-0.026	-0.053	-0.014	0.081	0.009
Pollack	-0.002	0.005	0.001	-0.001	0	-0.003	0.001	0	-0.002	0.002	0.05	0.094	-0.013	0.003	-0.004
Lg. Bottom	0.049	0.045	0.001	-0.017	0.043	-0.032	0.036	0	0.009	0.011	-0.019	0.187	0.03	-0.009	0.069
Seabream	0.015	0.005	0.001	-0.001	-0.005	0.008	-0.051	0.002	-0.063	0.01	0.015	-0.001	-0.034	0.052	-0.009
John Dory	0	-0.039	0	0.001	0	0	-0.001	0	0	-0.004	-0.002	-0.001	-0.003	0.001	0
Sandeels	-0.018	-0.009	0.019	0.036	-0.003	0.156	-0.119	0.017	0.032	0.212	0.012	0.102	-0.003	-0.028	-0.017
Herring	-0.061	0.014	-0.024	-0.049	-0.047	-0.018	0.054	0	0.024	0.005	-0.067	0.021	-0.002	-0.016	-0.008
Sprat	0.003	-0.03	-0.007	-0.022	-0.031	-0.005	0.032	-0.003	0	0.105	0.037	0.002	-0.004	-0.002	-0.008
Pilchard	0.005	0.009	-0.016	-0.056	-0.046	-0.004	0.028	-0.002	0.004	0.008	-0.014	-0.002	0.001	-0.004	0.001
Mackerel	-0.181	-0.427	-0.068	-0.213	-0.143	-0.077	0.219	-0.01	0.02	0.011	-0.22	0.003	-0.036	-0.021	-0.008
Scad	0.026	0.02	-0.4	-0.053	-0.135	0.008	-0.079	0.004	-0.071	0.005	-0.112	0.003	0.003	0.077	-0.014
Bass	-0.001	0.001	0.001	-0.002	-0.002	-0.234	-0.725	-0.001	0.005	-0.011	0	-0.009	-0.002	-0.004	0.003
Sharks	0.003	0.001	-0.002	-0.003	0.002	-0.003	-0.029	0	-0.01	0.001	-0.003	0.001	0	0.009	-0.001
Basking sk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cephalopods	-0.145	0.023	0.02	-0.061	-0.056	-0.111	0.548	-0.015	-0.331	-0.095	0.303	-0.068	0.013	-0.593	0.088
Seabirds	0.003	-0.031	-0.005	-0.015	0.004	-0.004	-0.001	0	-0.002	-0.183	0.002	-0.004	0.001	0.002	0.001
Toothed Cet.	0.009	-0.008	-0.017	-0.009	-0.014	0.011	-0.038	0.001	-0.038	0.005	-0.023	-0.014	0.005	0.034	0.05
Seals	-0.006	-0.002	0	0.001	-0.007	0.006	-0.007	0	-0.002	-0.001	-0.004	-0.043	-0.001	0.003	0.034
Juv bass	0	0	0	0.001	0	0	0	0	0	0	0	0	-0.002	-0.001	-0.001
Juv sole	-0.001	0	0.001	0	-0.002	0	0.003	0	0.003	0	0.001	-0.001	-0.002	-0.007	0.001
Juv plaice	0.002	0.003	0.002	0.004	0.001	-0.003	0.003	0.002	-0.001	0.002	0.003	0.011	-0.018	-0.001	-0.092
Juv cod	0.004	0.001	0	0.001	0	-0.001	-0.001	0	-0.004	0.001	-0.002	0	-0.002	0.007	-0.012
Juv whiting	-0.261	0.003	0.005	0.013	0.017	-0.004	-0.018	0.001	-0.024	0.003	0.009	0.004	-0.013	0.041	-0.015
Discards	0.001	-0.006	-0.001	-0.003	0.001	-0.001	0	0	0	0.169	0	-0.001	0	0	0
Detritus	-0.044	0.031	-0.121	-0.049	0.242	0.103	-0.039	-0.001	0.107	0.001	0.05	0.063	0.138	0.286	0.03
Otter trawl	0.032	0.138	0.062	-0.029	-0.005	-0.049	0.021	0.004	-0.041	0.044	-0.06	-0.119	-0.801	0.035	-0.076
Beam trawl	0.003	-0.003	-0.002	0.004	0.004	0.009	-0.02	0	-0.018	0.002	-0.005	-0.035	0.015	0.012	-0.026
Midw trawl	0.009	0.158	-0.026	-0.427	-0.355	-0.028	-0.006	0.003	0.067	-0.027	-0.744	0.007	0.024	-0.065	-0.028
Dredge	-0.003	-0.003	0	0.002	0	0.005	-0.005	0	-0.001	0	0.002	-0.008	0.01	-0.031	-0.033
Net	-0.012	-0.003	0.003	0.008	0.019	-0.085	0.086	0	0.005	0.001	-0.042	-0.064	0.017	-0.026	0.115
Pot	0.001	-0.004	-0.003	0	0.001	0.009	-0.011	0	-0.004	-0.001	0.003	0.012	0.02	0.008	-0.008
Line	-0.005	0.005	0.008	-0.018	0	-0.19	0.18	0.001	0.004	0	0.012	-0.03	-0.002	-0.004	-0.013
Recreational	-0.002	-0.001	0.001	0.004	-0.001	-0.206	-0.773	0	0.009	0.002	0.003	0.001	0	-0.008	0

Table A3 *continued.*

Impacted Impacting → ↓	JC	JW	Dis	Det	Ott	Beam	Midw	Dred	Net	Pot	Line	Rec
Prim. prod	-	0.045	-0.125	-0.049	0.044	0.003	0.153	0.184	0.002	0.014	0.081	0.031
Zooplankton	-0.005	0.038	-0.157	-0.013	0.043	0.002	0.166	-0.117	0.001	-0.016	0.11	0.036
Carn. Zp.	-0.003	-0.009	-0.049	0.002	-0.003	0	-0.031	0.021	0.001	0.003	-0.016	0.051
Dep. feeders	0.26	0.065	-0.023	-0.247	0.061	0.161	0.045	-0.08	0.075	0.023	0.018	-0.075
Sus. Feeders	-	-0.008	0.006	0.002	0	0.02	0	0.005	-0.001	-0.003	-0.005	-0.001
Shrimps	0.108	0.144	0.066	-0.051	0.047	0.01	-0.077	0.023	0.053	0.028	-0.002	0.039
Whelk	-0.005	-0.003	0	0.004	-0.01	0.062	0	0.001	-0.033	0.264	0.003	0.003
Echinoderms	-0.026	-0.004	-0.001	0.002	-0.008	-0.02	-0.002	-0.025	-0.014	-0.011	0	0.002
Bivalves	-0.031	-0.01	0.015	-0.064	-0.009	-0.008	-0.019	0.165	0.005	0.055	-0.01	0
Scallops	0.007	0.009	0	-0.001	0.005	-0.001	-0.001	0.407	-0.009	-0.003	-0.007	0.001
Crab	-0.071	-0.141	-0.011	-0.009	0.022	0.029	0.013	-0.075	-0.028	-0.023	0.057	0.22
Comm. Crab	0.016	0.02	-0.005	0	0.046	-0.017	0.003	-0.001	0.17	0.293	-0.022	-0.021
Lobster	0.001	0.001	0	0	0	-0.002	0	0	0.001	0.007	0	-0.001
Sm. dem.	0.039	0.198	0.02	0.112	0.008	-0.042	-0.021	0.022	-0.012	-0.018	0.034	0.019
Sm. Gads	-0.131	-0.123	0	-0.002	0.077	0.061	0.008	0.012	0.02	-0.006	0.034	-0.093
Mullet	-0.04	-0.038	0.002	0.019	0.004	-0.014	-0.001	0.008	-0.003	-0.003	0.02	-0.003
Sole	0.011	0.012	-0.001	0.005	0.01	0.079	0.001	-0.028	0.143	-0.004	-0.014	-0.013
Plaice	0.004	0.01	-0.002	0	0.028	0.143	0.001	0.012	0.057	-0.007	-0.015	-0.007
Dab	-	-0.003	-0.001	0.002	0.02	0.021	0	0.002	0.036	-0.004	-0.005	-0.005
O. flatfish	-0.005	-0.002	-0.003	0.003	0.013	0.134	0	0.002	0.007	-0.005	0	-0.001
Gurnards	-0.016	0.001	-0.006	-0.001	0.091	0.009	0.002	-0.001	-0.022	-0.005	-0.023	-0.009
Whiting	-0.053	-0.055	0.063	0.001	0.042	-0.009	-0.006	0	-0.009	-0.004	-0.016	-0.026
Cod	-0.206	-0.005	0.005	0	0.006	-0.004	-0.002	0	0.07	-0.003	-0.009	-0.007
Hake	0.002	-0.018	0.003	0.001	0	0.001	-0.023	0.001	0.013	-0.001	0.002	-0.001
Rays and dog	0.048	-0.19	-0.002	-0.002	0.022	-0.048	-0.03	0.002	0.014	-0.031	0.159	-0.036
Pollack	0.017	0.022	-0.002	-0.002	0.015	-0.01	0	-0.002	0.052	-0.003	0.016	-0.003
Lg. Bottom	-0.291	-0.299	-0.011	-0.001	-0.025	-0.022	0.009	0.002	0.04	0.002	0.22	-0.03
Seabream	-0.011	0.003	-0.01	0.005	0.027	-0.013	0.014	-0.003	-0.006	-0.004	0.003	0.007
John Dory	0	0	0.004	0	0.004	0.002	-0.001	0	-0.001	0	-0.001	0
Sandeels	-0.011	-0.001	-0.212	-0.003	0.016	0.002	0.016	-0.014	0.002	-0.002	0.022	0.149
Herring	-0.032	0.173	-0.005	-0.004	0.007	0.004	0.098	0.001	0.007	0	0.007	-0.016
Sprat	-	-0.008	-0.105	0.001	0.002	-0.001	0.029	0.003	0.002	0	-0.007	-0.004
Pilchard	0	-0.006	-0.008	0	-0.002	0	0.077	0.002	0.004	0	-0.015	-0.003
Mackerel	0.018	-0.009	-0.011	0.002	0.03	0.002	0.27	0.008	-0.01	0	0.232	-0.07
Scad	-	-0.015	-0.005	-0.006	0.002	-0.015	0.117	-0.007	0.005	0	-0.029	0.006
Bass	0.007	0.008	0.011	0	0.002	0.001	0.001	0.001	0.011	0	0.075	0.728
Sharks	-0.001	0	-0.001	0	-0.001	-0.001	-0.001	-0.001	0	0	-0.001	0.021
Basking sk	0	0	0	0	0	0	0	0	0	0	0	0
Cephalopods	0.075	0.023	0.095	-0.022	0.04	0.088	-0.058	0.031	-0.021	0.025	-0.071	-0.095
Seabirds	0	0	-0.817	0	-0.001	0	-0.007	0	0	0	-0.005	-0.004
Toothed Cet.	0.018	0	-0.005	0.001	-0.009	-0.003	-0.009	-0.002	-0.009	-0.001	0.001	0.009
Seals	0.057	0.041	0.001	0	0	-0.003	-0.002	0	-0.015	0	-0.03	0.005
Juv bass	-0.001	-0.001	0	0.001	0	0	0	0	0	0	0	0
Juv sole	-0.002	-0.001	0	0.002	-0.001	0	0	-0.016	0.004	0	0	0
Juv plaice	-0.036	-0.006	-0.002	0.002	0.008	0.006	0.002	0.001	0.009	-0.002	-0.004	-0.003
Juv cod	-0.01	-0.012	-0.001	-0.002	0.001	0.002	0.001	-0.001	0	0	-0.001	-0.001
Juv whiting	-0.032	-0.111	-0.003	-0.012	0.017	0.016	-0.026	-0.004	0.001	0	0.011	-0.005
Discards	0	0	0	0	0	0	-0.002	0	0	0	-0.001	-0.001
Detritus	0.239	0.045	-0.001	0	0.126	0.164	0.017	0.137	0.175	0.218	0.043	0.099
Otter trawl	-0.072	0.118	-0.044	0.005	-0.207	-0.095	-0.008	-0.019	-0.178	-0.045	-0.179	-0.047
Beam trawl	0.008	0.016	-0.002	-0.001	-0.015	-0.077	0.002	-0.002	-0.043	-0.018	-0.016	0.009
Midw trawl	-0.015	0.003	0.027	0	-0.018	0.01	-0.261	0	0.008	0.002	-0.133	-0.028
Dredge	0.013	0.011	0	0.001	-0.008	-0.025	0	-0.336	-0.018	-0.001	-0.006	0.004
Net	0.098	0.067	-0.001	-0.001	-0.018	-0.037	0.006	0.007	-0.118	-0.032	-0.057	-0.081
Pot	-0.006	-0.009	0.001	-0.003	-0.018	-0.043	0	0	-0.069	-0.381	0.01	0.008
Line	0.047	0.072	0	0	0	0.008	-0.008	-0.001	-0.013	0.003	-0.084	-0.18
Recreational	-0.001	-0.002	-0.002	0	0	0.001	0.001	0	-0.003	0	-0.02	-0.22

Table A4 *Rapfish* data used in the analysis and its origin. The scientist's scores were generally used when there were discrepancies between scores because the scientist had worked on the whole Channel fisheries, including the French, and had a holistic perspective.

Field/attribute	Scores							NOTES: Origin of score
	Ott trawl	Bm trawl	Midw trawl	Dredge	Net	Pot	Line	
Econ: Exploitation status	2	3	2	3	3	2	2	Scores based purely on scientist's values.
Ecol: Recruitment variability	2	2	2	2	2	2	3	Scores based purely on scientist's values.
Ecol: Change in T level	0	0	0	0	0	0	0	Two scorers allocated 0 and the other. I opted for 0.
Ecol: Migratory range	0	0	2	0	1	0	1	Scores based purely on scientist's values.
Ecol: Range collapse	0	0	0	1	0	0	0	Scores ranged from 0 to 1.5 and I agreed with the scientist's values.
Ecol: Size of fish caught	0	0	0	0	1	0	1	Scores ranged from 0 to 1.5 and I selected the entered values.
Ecol: Catch < maturity	1	1	1	1	1	1	1	Two scorers allocated 1 and the other 0. I opted for 1.
Ecol: Discarded bycatch	1.4	2	1	2	1	0.5	1	Scores were based on the discard data entered into Ecopath (section 2.4).
Ecol: Species caught	1	1	0	0	1	0	0	All scorers agreed for all gears.
Ecol: Primary production	2	2	2	2	2	2	2	(Joint and Groom, 2000)
Econ: Profitability	1	1.5	0.8	1	1	0.8	0	Scores ranged from 0 to 2 and I selected the entered values.
Econ: GDP/ person (1000's)	0	0	0	0	0	0	0	Two scorers allocated 0 and the other. I opted for 0.
Econ: Average wage	2	3	3	3	2	2	2	Scores ranged from 1 to 3 and I selected the entered values.
Econ: Limited entry	4	4	4	3	4	3	3	All scorers agreed for all gears except pots where 1 scorer allocated 4.
Econ: Marketable right	2	2	2	1	1	1	1	Scores were the same for the trawlers but different for the other gears so I selected these scores.
Econ: Other income	3	3	3	2	3	3	2	All scorers agreed for all gears.
Econ: Sector employment	2	1	0	1	1	1	0	One SFC scored 1 for all gears while the other scored 0. I opted to use the scientist's values.
Econ: Ownership/transfer	0	1	2	1	0	0	0	All scorers agreed for otter trawling, nets, pots and lines but for the other gears there was disagreement so I choose the scores.
Econ: Market	1	1	2	1	0	0	0	All scorers agreed for otter and beam trawling and for the other gears I opted to use the scientist's values.
Econ: Subsidy	0	0	0	0	0	0	0	All scorers agreed for all gears.
Soc: Socialization of fishing	0	2	2	2	0	0	0	No gear was the same from all scorers so I selected the scores for each gear.
Soc: New entrants into fishery	0	0	0	1	0	0	0	All scorers agreed for beam and midwater trawling, pots and lines and for the other gears I used the scientist's scores.
Soc: Fishing sector	0	0	0	0	0	0	0	All scorers agreed for all gears.
Soc: Environmental knowledge	1.3	1.3	1.3	1.3	1.3	1.3	1.3	Each scorer allocated the same score for all gears but these were different for each scorer (1, 1.5 and 2). I used a value of 1.3.
Soc: Education level	1	1	1	1	1	1	1	No gear was the same from all scorers so I opted to use the scientist's scores.
Soc: Conflict status	1	2	1	2	2	1	1	No gear was the same from all scorers so I opted to use the scientist's scores.
Soc: Fisher influence	1	1	1	1	1	1	1	Two scorers allocated 1 and the other 2. I opted for 1.
Soc: Fishing income	1	2	2	2	1	1	1	No gear was the same from all scorers so I opted to use the scientist's scores.
Soc: Kin participation	1	1	0	1	1	1	1	No gear was the same from all scorers so I opted to use the scientist's scores..

Table A4 continued:								
Field/attribute	Score							Origin of score
	Ott trawl	Bm trawl	Midw trawl	Dredge	Net	Pot	Line	
Tech: Trip length	0	2	4	2	0	0	0	Although the values for each gear were very similar for each gear they were different by about 0.5 for all gears. I opted to use the scientist's scores.
Tech: Landing sites	0	1	2	1	0	0	0	No gear was the same from all scorers so I opted to use the scientist's scores.
Tech: Pre-sale processing	1	1	1	0	1	0	1	No gear had the same value from all scorers so I selected the entered values.
Tech: On-board handling	0	0	1	1	0	0	0	Scores were the same for potting and lining.
Tech: Gear	1	1	1	1	0	0	0	Values were the same from each scorer.
Tech: Selective gear	0	0	0	0	0	1	1	Only dredging received the same value from each scorer so the scientist's scores were used for the other gears.
Tech: FADs	0	0	0	0	0	0.5	0.5	Values were the same from each scorer.
Tech: Vessel size	2	4	4	3	1	1	1	Values were based on averaged data from [Tetard <i>et al.</i> , 1995 #33].
Tech: Catching power	1	1	1	1	1	1	1	Values were the same from each scorer.
Tech: Gear side effects	1	2	1	2	0	0	0	Values from each scorer were similar but only beam trawling was identical. The other scores were based on the scientist's values.
Ethic: Adjacency & reliance	2	2	1	2	3	3	2	Values were the same from each scorer.
Ethic: Alternatives	2	1	2	1	2	2	2	One SFC scored 1 for all gears while the other scored 2. I opted to use the scientist's values.
Ethic: Equity in entry	2	2	2	2	2	2	2	Values were the same from each scorer.
Ethic: Just management	1	1	1	1	1	1	1	One SFC scored 2 for all gears while the other scored 3. I opted to use the scientist's values.
Ethic: Mitigation of habitat destruction	0.5	0	1	0	1	2	2	One SFC scored 4 for all gears. The other scorers allocated values between 0 and 2. There were identical values for otter trawling, nets and pots and I entered the scores for the other gears.
Ethic: Mitigation of ecosystem depletion	0.5	0	1	0	1	2	2	All scores were different so I selected the entries.
Ethic: illegal fishing	1	2	1	1	1	1	1	One SFC scored 0.5 for all gears while the other scored 1. I opted to use the scientist's values.
Ethic: discards and wastes	1.5	2	1	2	1	0	1	Only dredging was scored the same by each person and I selected the scores for the other gears.

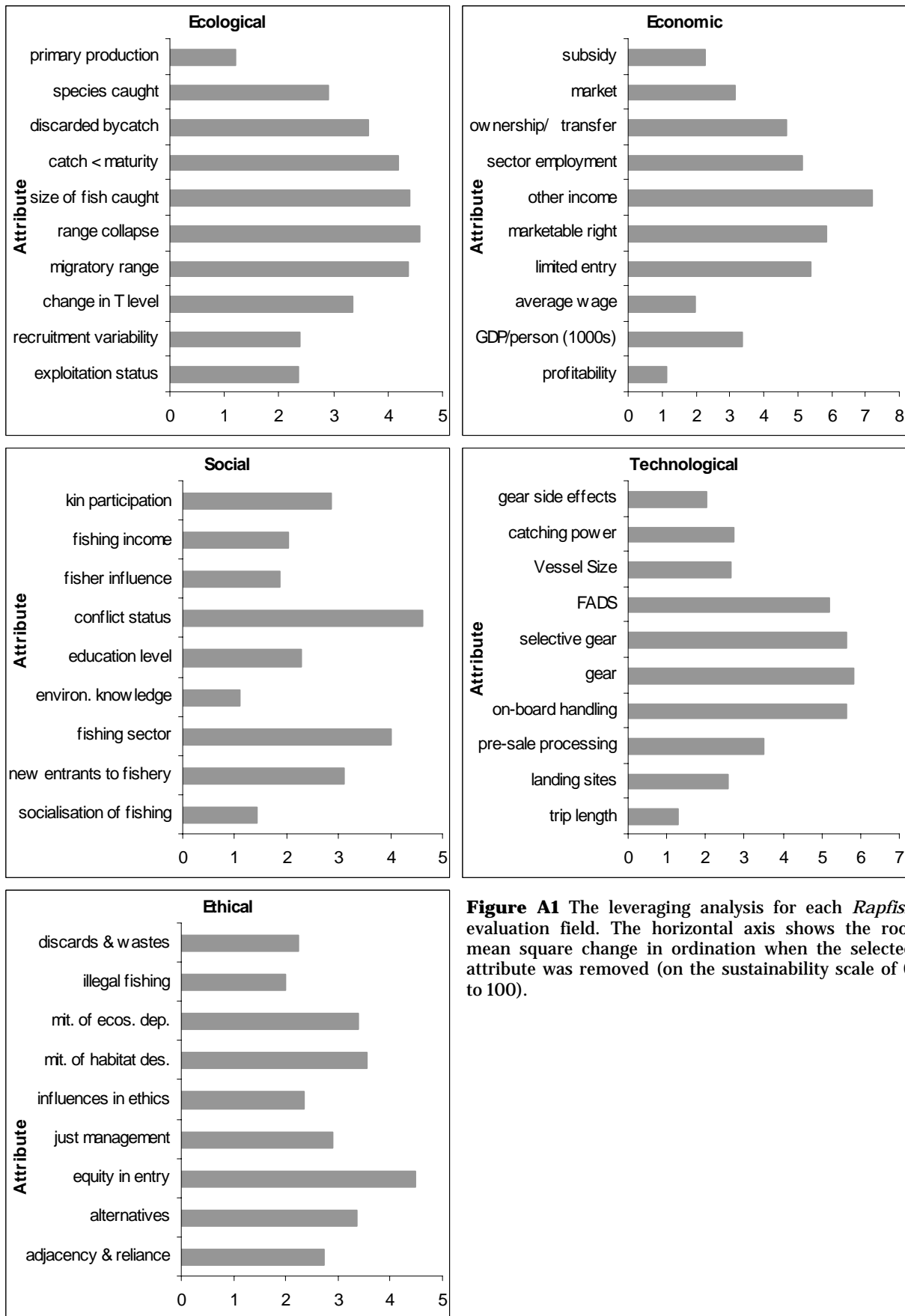


Figure A1 The leveraging analysis for each *Rapfish* evaluation field. The horizontal axis shows the root mean square change in ordination when the selected attribute was removed (on the sustainability scale of 0 to 100).

	Biomass	P/B	Q/B	Diet	Catch
Prim. prod	3	3			1
Zooplankton	3	6	6	6	
Carn. Zp.	3	2	2	6	
Dep. feeders	5	1	6	6	
Sus. feeders	5	7	7	3	
Shrimps	8	2	7	8	3
Whelk	5	1	7	3	3
Echinoderms	5	4	2	3	3
Bivalves	5	1	6	6	3
Scallops	5	3	6	6	3
Crab	5	4	6	8	3
Comm. crab	3	2	6	8	3
Lobster	5	1	6	5	3
Sm. dem.	8	5	5	1	3
Sm. gads	8	5	5	1	3
Mullet	8	5	5	3	3
Sole	3	1	5	3	3
Plaice	3	1	5	3	3
Dab	5	1	5	3	3
O. flatfish	3	1	5	3	3
Gurnards	5	1	5	3	3
Whiting	3	1	5	3	3
Cod	3	1	5	3	3
Hake	3	1	5	3	3
Rays/dogs	3	6	5	1	3
Pollack	3	1	5	3	3
Lg. bottom	3	1	5	3	3
Seabream	3	1	5	3	3
John Dory	5	5	5	3	3
Sandeels	8	5	5	5	
Herring	5	1	3	3	3
Sprat	5	6	3	3	3
Pilchard	5	2	3	5	3
Mackerel	3	5	5	3	3
Overw mac.	3	5	5	3	3
Scad	3	5	5	1	3
Bass	3	2	5	5	3
Sharks	5	5	5	5	3
Basking Shks	5	5	5	5	3
Cephalopods	3	5	6	5	3
Seabirds	3	6	5	5	
Toothed cet.	5	6	5	5	7
Seals	3	6	5	3	
Juv bass	5	7	5	3	5
Juv sole	5	7	5	3	5
Juv plaice	5	7	5	3	5
Juv cod	5	7	5	3	5
Juv whiting	5	7	5	3	

Figure A2 EwE model pedigree. The different colours and numbers refer to confidence limits (+/- %) as follows: 1=10 2=20 3=30 4=40 5=50 6=60 7=70 8=80. Hence blue shades (6,7,8) indicate data that are less trustworthy. Blank rectangles refer to places where there were no data.