CHAPTER 14
THE ROLE OF MARINE SCIENCE IN PARTICIPATORY FISHERIES GOVERNANCE

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Abstract

In the North Atlantic, formal international agreements to provide a co-ordinated response to the requirement for marine science to underpin fisheries governance have been in place for over 100 years. In this chapter, I consider how marine science has been used during that period, and the extent to which failures in fisheries management result from deficiencies or misuse of the science. My analysis of our failures in the past leads me to a consideration of ways to avoid such failures in the future, including an account of the possible role for marine science in an objective-based management regime, such as the 'ecosystem-based approach to fisheries management'. This role will include a significant element of prediction of the ecosystem effects of management scenarios, and also much greater dialogue with industry stakeholders and society to allow the informed selection of management objectives. The traditional fisheries science sector is inadequately prepared for this task, and much greater use of the wider marine science community will be required. In addition to the scientific challenges, the development of effective communication mechanisms between marine scientists and fisheries scientists, and between the science sector and society, must be acknowledged as necessary conditions for the success of these initiatives.

14.1 Introduction

Marine science as a discipline is often traced back to the oceanic voyages of exploration in the late nineteenth century. However, 'science' has been involved in fisheries governance for probably as long as there has been fisheries governance. In early times, this input came from 'advisors' who included stakeholders, such as fishers, resource 'owners' such as the Crown, and learned men. With the development of what we would now describe as the 'scientific approach', there was scope for its application to fisheries problems. This was seen most in freshwaters where scientific investigation led to great advances in our understanding of, for example, salmon lifecycles. However, the continued increase year on year in marine catches, and the extent and richness of life in the oceans as revealed by the early research surveys, meant that most people, including many early scientists, believed that the oceans' bounty was so vast that it could not be impacted by anything man could do. As late as 1884, Thomas Henry Huxley, President of the Royal Society, stated "The cod fishery, the herring fishery, the pilchard fishery, the mackerel fishery, and probably all the great sea fisheries, are inexhaustible". However, by the turn of the last century this view was being challenged and it was recognised that a coordinated international programme of research was required. It was this that led to the establishment of the International Council for the Exploration of the

T. S. Gray (ed.), Participation in Fisheries Governance, 231–247.

Sea (ICES) in 1901, which brought together marine science in the North Atlantic. Similar agreements were established subsequently, covering the Baltic, Mediterranean, North Pacific and other regions.

The aim of this chapter is to provide an analysis of the role of science in current governance, using the NE Atlantic as a case study, and to consider the science needs of an alternative governance framework – that of ecosystem management.

14.2 The role of science in fisheries governance

Science is defined by the Oxford English Dictionary as the "systematic study of the structure and behaviour of the physical and natural world through observation and experiment". It therefore provides a body of knowledge and a mechanism for answering questions posed by society. In the context of fisheries, these questions are likely to concern the possible configurations of the exploited system and how to manage the system in order to arrive at the condition desired by society and expressed by their democratic choices. This leads us to answer questions such as:

- How many fish are in the sea?
- How many fish can be removed without compromising the stock (i.e. what is the Total Allowable Catch (TAC))?
- What impact will this removal have on the habitat and other parts of the ecosystem?
- What is the level of annual recruitment, and how does it relate to size/age and number of adults?
- What should be the minimum size/age of the fish we catch?
- What are the options for technical measures to limit exploitation (such as restrictions on fishing methods or the imposition of marine protected areas (MPAs))?
- What impact will these options have on fishers?
- What impact will the measures have on the exploited stocks?

It is immediately apparent, then, that the central question for fisheries science is 'how many fish can we harvest without impacting on the ability of those that remain to maintain the population'? Population models would seem to offer a solution, as they can allow us to predict future population size, based on a limited number of measures of the current situation and some knowledge of the biology of the organisms. Fish, like all living organisms, have the capacity to produce an excess of offspring. That is to say, each pair of parents can produce more than one pair of offspring. In a stable population, disease, predation and other natural processes, mean that within a generation each pair of parents replaces itself. However, if we remove a proportion of the offspring produced, we reduce the amount of competition for food, and the size of the population may show no effect of the harvesting. In other words, the number of individuals we took as a harvest would have died later of natural causes anyway. Given that an adult fish like a cod can produce in excess of two million eggs each year, and may have a reproductive life of ten or more years, there would seem to be a massive scope for the harvesting of the excess production.

As it has long been known that mortality varies between individuals in a population, in large part due to their age/size, fisheries models try to model the population using just three basic input parameters; recruitment, growth and mortality. Recruitment provides an estimate of the number of young fish entering the adult stock that year; this subsumes all the mortality and losses at the egg and larval stages. This obviates the need for much data gathering and the need to model the full life cycle. Growth functions are then required to allow the movement of individuals from one size group to another to be modelled, while mortality terms describe the natural and fishing mortality on each size class.

For many years, the optimum harvest was seen as the maximum yield that could be removed without reducing the population in subsequent generations. This is known as the Maximum Sustainable Yield (MSY). The approach used in many contemporary fisheries management schemes to assess the state of stocks and provide advice on the amount of harvest, is Virtual Population Analysis (VPA). This seeks to estimate fishing mortality (F) and the numbers at age in a stock from catch at age data and estimates of natural mortality only.

14.2.1 VIRTUAL POPULATION ANALYSIS (VPA OR COHORT ANALYSIS)

In order to estimate fishing mortality (F) and the numbers at age in a stock from only catch data, VPA must assume that natural mortality (M) is constant at any given age. For example, consider the total number of five-year old fish in the stock, which is the number of fish reaching the age of four the previous year minus the number of four year olds dying (total mortality Z_4). The total mortality of four-year old fish is composed of fishing mortality (F_4) and natural mortality (M_4). We assume natural mortality is constant over years but can vary for different age groups. The number of fish of a particular age class caught is a proportion of the total number dying. These two relationships can be combined into a single equation containing natural mortality (M), numbers at age plus 1, and catch and fishing mortality at age. If M, numbers at age plus 1, and catch at age, are known, then F can be calculated. The actual equation is complex, so solving for F is done by computer iteration. The iterations begin with the oldest cohort (as the total mortality is then 1, none survives to the next year) and assume a value for F for the oldest cohort. This iteration can then be used to calculate the numbers in the cohort one year younger. The procedure can then be repeated, using the appropriate catch data, to get a value of F for the next cohort and so on until all the cohorts have been modelled.

A big assumption of VPA is that M is constant across years and is known. M can be calculated if total mortality and fishing mortality are known, but if F is known then VPA is unnecessary! It is relatively easy to include age specific rather than constant natural mortalities into the model but it is not easy to incorporate inter-annual variability in M or density dependence. Density dependence is the term used to describe when the values of a parameter vary depending on the population size; more fish are likely to starve when the population is large than when it is small, for example.

Unfortunately, in using VPA as a basis for management measures, the least reliable estimates of F are those for the older age classes, that is, those parts of the stock most heavily exploited. Considerable effort has gone into developing more accurate VPA, including multi-species VPA (MSVPA) and more recently the 4M package (Multi-species, Multi-fleet, Multi-area Modelling-package). These multi-species models contain inter-specific interactions such as large cod predation on small whiting.

The MSVPA has its origins in a multi-compartment production model of the North Sea (Anderson and Ursin 1977). However, this model was too complex, containing too many inestimable parameters to be useful in fisheries management. ICES, therefore, developed a simpler model that focused on the predatory interactions between the commercially exploited fish stocks. For those stocks for which catch-at-age data were available, and assuming constant, instead of food dependent, individual food intake and growth, it was possible to construct a multispecies model, MSVPA, with only three equations. These were the catch and stock number equations of the single species VPA plus an equation describing how predation mortality, M2, depends on the biomass of the prey and the total food intake of the predator.

In order to gather information on predation and diet for the model, a major international programme of fish stomach sampling was carried out. The so-called 'Year of the Stomach', 1981, saw co-ordinated sampling by research cruises across the North Sea during which approximately 60,000 stomachs from five commercially exploited fish species (cod, haddock, whiting, saithe and mackerel) were collected. These five species were assumed to be the major fish predators in the North Sea. The stomach contents were analysed to provide estimates of the average food composition and total weight of stomach content by predator age, prey age and quarter of the year. In 1984, the first quarterly North Sea MSVPA was produced. The model was further refined and additional fish stomachs were collected in 1985, 1986 and 1987 for some of the predators. In 1991, the second 'Year of the Stomach' saw additional food composition data collected for all of the MSVPA predators as well as for a suite of other predators expected to prey on commercially important fish species. The total food composition database for the North Sea now contains the results from analysing approximately 200,000 fish stomachs (Greenstreet *et al* 1997).

Over the period from 1984 to 1997, ICES has performed sensitivity analyses of the MSVPA, examined the assumptions, the difference between single and multi-species, long- and short-term predictions of effort and mesh changes, added additional 'other predators', developed alternative, simpler models and tried to reduce the parameters of the model describing the food selection of the major fish predators (Pope 1991; ICES 2002a:82). The major conclusion of the work is that natural mortality is much larger for the younger ages of the species exploited for human consumption than previously assumed. The MSVPA was found to be quite robust to changes in input parameters. Most importantly, it was found that the long-term predictions arising from a multi-species approach differed significantly from single species predictions.

Outside the North Sea, the MSVPA has been applied in the Baltic, in the Barents Sea, Georges Bank and in the Bering Sea. The development of MSVPA centred on biological interactions between fish, their prey and their predators. However, from a management point of view, technical interactions between fleets and species are also important. This has prompted the development of the, so-called, 4M model (Multi-species, Multi-fleet, Multi-area Modelling-package). Within the 4M model the impact of technical interactions can be evaluated. However a lack of data disaggregated by fleet, has so far prevented it being used operationally.

Table 14.1. List of stocks used in the analysis of the effectiveness of ICES fishery advice

Fishery	*Species*	*Area*
Flatfish	Plaice	Division VIId (Eastern Channel)
		Division VIIe (Western Channel)
		Sub-area IV (North Sea)
	Sole	VIId (Eastern Channel)
		Division VIIe (Western Channel)
		Sub-area IV (North Sea)
Industrial	Norway pout	Sub-area IV (North Sea) and Division IIIa (Skagerrak – Kattegat)
	Sandeel	Sub-area IV
Pelagic	Herring	Divisions VIa (South) and VIIb,c
		Sub-area IV Division VIId and Division IIIa (autumn spawners)
	Mackerel	combined Southern, Western & N.Sea spawn.comp.
Roundfish	Cod	Division VIa (West of Scotland)
		Sub-area IV (North Sea), Division VIId (Eastern English Channel) and Division IIIa (Skagerrak)
	Haddock	Division VIa (West of Scotland)
		Division VIb (Rockall)
		Sub-area IV (North Sea) and Division IIIa (Skagerrak – Kattegat)
	Saithe	Sub-area IV (North Sea), Division IIIa (Skagerrak) and Sub-area VI (West of Scotland and Rockall)
	Whiting	Sub-area IV (North Sea) and Division VIIId (Eastern Channel)

14.3 Performance of science advice in North Sea fisheries governance

The current management objective for fish stocks (Table 14.1) is to keep the spawning stock within ‘safe biological limits’ – that is, where there is a high likelihood that the stock will not suffer a catastrophic decline and that sufficient fish are available to replace losses. However, ICES produce advice on the status and levels of exploitation for only a limited number of species and stocks. There were many other species exist in the North Sea. A number of these are fished commercially, but they are not assessed, and estimates of spawning stock biomass (SSB) are not available for these. It is therefore impossible to ascertain if these stocks are within safe biological limits.

Management advice is given in a precautionary framework and with respect to the desired biomass of fish in the sea (B_{pa}) and the level of fishing mortality that matches this biomass (F_{pa}). Three criteria can be used to determine whether a stock is within these limits and hence whether the objective was met:

- SSB was above the desired level ($SSB>B_{pa}$);
- F was below the desired level ($F<F_{pa}$);
- Both of the above ($SSB>B_{pa}$ and $F<F_{pa}$).

In order to evaluate the performance of science advice to fisheries managers, ICES carried out an evaluation of its past advice (ICES 2003). For each stock for which advice was produced, both the actual annual management advice given and the action taken was assessed, using the observations tabulated in the “Catch Data” and assessment output tables from the 2002 round of fisheries advice (ICES 2002b). The evaluation identified four possible scenarios:

1. **Stock does not meet the objective, correct advice**: the estimate of SSB and/or F *in the assessment year* led to advice to reduce catch, when the estimate of SSB and/or F *in the 2002 assessment* now indicates that the stock did not meet the objective (i.e. respectively SSB < B_{pa} , F > F_{pa} or SSB < B_{pa} and F > F_{pa})
2. **Stock does not meet the objective, *incorrect* advice**: the estimate of SSB and/or F *in the assessment year* led to advice for status quo or increased total allowable catch (TAC), when the estimate of SSB and/or F *in the 2002 assessment* now indicates that the stock did not meet the objective.
3. **Stock meets the objective, *incorrect* advice**: the estimate of SSB and/or F *in the assessment year* led to advice to reduce catch, when the estimate of SSB and/or F *in the 2002 assessment* now indicates that the stock met its objective
4. **Stock meets the objective, correct advice**: advice for *status quo* or increased TAC, when the estimate of SSB and/or F *in the 2002 assessment* now indicates that the stock did meet its objective

Signal theory was applied to these scenarios to determine the proportion of Hits (1 and 4), Misses (2) and False Alarms (3) per year as the proportion of the stocks for which the respective scenarios applied. If the analysis shows a high Hit rate and low rates of Misses and False Alarms, it is support for the view that precautionary reference points are a robust basis for fisheries management advice, generally advising managers to take actions that would move the stock in the proper direction. High Miss rates would suggest that precautionary reference points, as currently used, do not lead to advice that is sufficiently restrictive to ensure stocks remain within safe biological limits. High False Alarm rates would indicate that precautionary reference points, as currently used, lead to overly intrusive management advice. The actual performance of B_{pa} and F_{pa} as objectives and as guides to fisheries management is presented in Table 2.

Overall, the main difference between the criteria used, is that using only F, will result in relatively low False Alarm rates, but high Miss rates. Using only SSB, results in a decrease in Misses but a higher proportion of False Alarms. The best results were achieved using both criteria with a 53 per cent Hit rate, 23 per cent Miss rate and 24 per cent False Alarms.

Tables 3 and 4 give a quantitative indication of the true impact of the advice depending on the scenario, not just what advice was provided, but how management actually responded to the advice and the indicator. This also shows that in general the advice was appropriate. If the objective was not met, a reduction in TAC of about 18 per cent was suggested in case of a correct advice (Hit), whereas there was an increase of TAC averaging between 10 per cent (SSB) and 15 per cent (F) in case of a Miss. If the objective was met, correct advice resulted in a suggested increase of the TAC between 26 per cent (SSB) and 16 per cent (F), whereas in the case of a False Alarm, the TAC was suggested to decrease between 9 per cent and 18 per cent. Overall, the advice using SSB appears more appropriate with relatively small changes in case of a Miss and False Alarm but relatively higher changes of TAC in case of Hits.

Table 14.2. Proportion (%) of Hit, Miss or False Alarm depending on the criteria used (i.e. respectively SSB > B_{pa} , F < F_{pa} or SSB > B_{pa} and F < F_{pa}) and the type of fishery (from ICES 2003)

Criteria	*Fishery*	*Hit*	*Miss*	*False Alarm*
F	All	49	44	7
F	Flatfish	52	43	5
F	Pelagic	27	63	10
F	Roundfish	52	40	8
SSB	All	51	25	24
SSB	Flatfish	52	18	30
SSB	Industrial	16	21	63
SSB	Pelagic	57	26	17
SSB	Roundfish	56	29	15
F & SSB	All	53	23	24
F & SSB	Flatfish	50	17	33
F & SSB	Pelagic	57	26	17
F & SSB	Roundfish	55	25	20

Table 14.3. The average change of the TAC (%) that was actually implemented for various scenarios: i.e. the objective (SSB> B_{pa}) is met (1) or not met (0) and advice is correct (1) or incorrect (0) (from ICES 2003)

Scenario	*The objective*	*Advice*	*Flatfish*	*Industrial*	*Pelagic*	*Roundfish*	*Total*
1	0	1	-11.8		-37.7	-21.5	-18.8
2	0	0	9.6	0.0	8.7	12.2	10.3
3	1	0	-6.0	-2.4	-13.1	-17.7	-9.4
4	1	1	23.9	11.4	10.8	38.9	26.1

Table 14.4. The average change of the TAC (%) that was implemented for various scenarios: i.e. the objective (F<F_{pa}) is met (1) or not met (0) and advice is correct (1) or incorrect (0) (from ICES 2003)

Scenario	*The objective*	*Advice*	*Flatfish*	*Industrial*	*Pelagic*	*Roundfish*	*Total*
1	0	1	-11.7		-34.5	-20.9	-18.1
2	0	0	11.5		10.2	20.8	15.5
3	1	0	-7.3		-4.3	-26.4	-17.5
4	1	1	17.0		5.6	17.4	16.3

14.4 Marine science and fisheries management tools

There are a number of approaches to fisheries management, involving control of fishing effort and/or catches, and a wide range of other technical measures. Traditionally, the approach has focused on conservation of the target stocks with measures such as catch quotas and controls on size/age at capture (mesh size controls). In recent years, the effectiveness of much of the management effort has been questioned – after almost 100 years of fishery management in the North Sea, more stocks were listed as endangered (outside ‘safe biological limits’) than ever before! This, along with growing recognition of the need to manage fisheries in the context of the wider ecosystem, has led to developments of other management approaches including effort controls, technological changes to provide better selection of the target species, and closed seasons/areas to minimise habitat damage.

14.4.1 CATCH QUOTAS

The most simple and intuitive means of ensuring sustainability of fisheries is to limit the catch to a level that removes only the surplus production. This is the basis of most fisheries regulations worldwide, and also the source of many of the problems of over exploitation. However, there are two major problems in applying this approach: first, the difficulties of calculating, in real time, the levels of this surplus production; and second, how to match the effort of the fleet to this level of production in space and time.

Science is the key tool in estimating the size of stock a year in advance through modelling the population (see above). The scientists are then able to advise on both the TAC and also the amount of fishing activity likely to result in this take. However, it is managers that use this information and convert it into management measures. TACs are usually set to reduce the total fishing effort on a stock in order to limit the rate of fishing mortality. TACs are then translated into quotas that restrict landings of individual fishers. Such restriction of landings is supposed to restrict fishing effort, but the link is not direct. For example, fishers can continue to fish, but discard excess catches, and this is recognised as one of the problems of managing using TACs and quotas. In theory, however, there is no fundamental difference between control of effort and control of catches.

The managers have to balance the biological and social aspects of the fishery in setting the quota. Fishers' livelihoods, their families' welfare, the investment in infrastructure, both in fish capture but also post-capture processing, have to be considered. This results in reductions in quotas often being less than those recommended by scientists. If the quota set is so small that the quota for each vessel fails to provide enough legitimate catch for the fisher, then either the fisher will behave illegally or the economics of the whole fleet will collapse.

Fishers in the European Union (EU) have learned to live with a quota-based system, but, generally, they regard it as 'unfair' (Hatchard, this volume). The quotas recommended are regularly challenged and are always set too low, according to the industry. Fishers complain that the TAC is not allocated into quota according to the 'best' algorithm, and they denounce the need in mixed fisheries to discard species for which the quota has been filled, while still pursuing other species.

14.4.2 FISHING EFFORT REDUCTION

Currently, fishing vessel and fleet capacity are widely considered to be excessive and not in balance with the resources (ICES 2002b; FAO 1998). The relationship between the fleet size and its ability to impose a particular level of mortality on a stock is a complex one. Efforts to develop models such as the 4M, which incorporate these relationships, are severely handicapped by a lack on data on these relationships.

The European Commission has in place a programme, whereby fishing vessel de-commissioning targets are set for each Member State, in an attempt to reduce the overall fishing effort in EU waters, thus reducing the pressure on stocks. However, vessel de-commissioning is likely to be more attractive to those skippers with the least economically successful vessels. For instance, in a UK shrimp fishery consisting of 98 vessels, seven of these vessels were responsible for 49 per cent of the total fleet effort, and the combined effort of a further fifty-six vessels was estimated to be only 6 per cent of the total effort (Revill 1996). This implies that a programme that cut the fishing effort, in terms of the number of vessels, by around 55 per cent, might only actually reduce effort on the stock by 6 per cent!

Such programmes also fail to deal with the issue of ‘technological creep’. It is estimated that the ability of the fleet to catch fish (the efficiency of the fleet) increases by 7-8 per cent every year as a result of new vessels replacing old ones and changes in technology on the existing vessels. This implies that even if the fleet size were reduced by 40 per cent immediately, there would be a need to make a further cut, of the same magnitude, in the fleet every 12.5 years! Thus science can advise not only on the need and extent of effort reductions, but how these can be targeted effectively. However, lack of information about the scale of the vessel, usually withheld in order to provide anonymity, has prevented this in most cases.

In the EU, an additional restriction has been applied, which limits effort during periods of low stock size and hence low quotas. Known as the ‘days-at-sea’ regulations, they restrict the number of days per month an individual vessel can fish without removing the vessel permanently from the fleet. These measures have been a key element of the European Commission stock recovery plans, but they are unpopular with fishers, whose costs remain the same, but their opportunity to earn is restricted. Days-at-sea restrictions also force vessels to sea in poor weather if quota is not used up and there are days remaining in that month. Moreover, they encourage the race to fish, and lead to further high grading (and black fish landings) on the days when the vessel is at sea.

14.4.3 SIZE/AGE AT CAPTURE RESTRICTIONS

Technical conservation measures such as minimum mesh sizes affect the composition of the catch, but do not restrict the total quantity of fish caught. For this, direct conservation measures such as catch or effort controls are required. The simplest technical measure to apply is one based on the size (age) at which individuals are caught – a Minimum Landing Size (MLS). This can be set to ensure that all individuals spawn at least once before becoming available for capture. Selection may occur post-capture with small individuals being returned to the wild or, in net fisheries, through alterations in the gear, such as the mesh size of the net.

In fisheries targeting individuals, it is easy to enforce minimum landing sizes. In net capture fisheries, it is usual to apply a mesh size to the net; fishers still have to comply with a MLS but the number of small fish caught that have to be sorted and then discarded is reduced. The mesh size used should ensure that most of the time, individuals below the desired size escape. However, selection will never be 100 per cent: as a net fills with fish then the fish in the net ‘blind’ the mesh openings, preventing the escape of smaller individuals, while a heavy catch being towed through the water will stretch the net causing the mesh to deform.

When fishing for a variety of species that differ in morphology (round fish versus flatfish) and life history (early breeders versus late developers), the selection of an appropriate mesh size is a compromise. The small individuals in the catch, below the species' MLS are discarded, but this is of little use if by that time they are dead. There are now efforts directed at developing gears that sort the species in the water by criteria other than size.

14.4.4 SORTING THE CATCH BY SELECTION IN THE WATER

Fishing gears are size selective. However, fishing gears can be made more selective towards the target species by altering the geometry of the gear. This would reduce post-capture discarding. The mesh sizes of the netting in fishing gear, and in particular the cod-end mesh size, is influential in determining the selective properties of towed demersal fishing gear (Anon 1996). The minimum cod-end mesh size is widely legislated for in EU waters and is specific to each target fishery. In many fisheries, however, the demersal fishing grounds are multi-species in nature and by-catch and discarding are common resultant features, due to poor cod-end selection (Evans *et al* 1994). The twine diameter (thickness) of the meshes in the cod-end is also known to affect the selection process in the cod end, as are seasonal processes such as spawning status that may affect the overall shape of the fish.

Research into the incorporation of selectivity devices such as square mesh panels, funnels (sieve nets) and separator grids into towed fishing gears to enhance their overall selectivity is becoming more widespread, and, as a result, their use within fishing gears is gaining acceptance as a management tool. Legislation requiring the use of selectivity devices is being implemented in many instances; for example to allow turtles to escape. However, while such technical measures as mesh size and sorter nets go some way to addressing the problem of by-catch, they will never completely solve it.

14.4.5 CLOSED AREAS

Technical conservation measures such as closed areas, which prohibit or restrict fishing activity from an area, are also common, but need to be supported by direct management limiting catch or effort. In some cases, these spatial restrictions may be related to the need to protect military, oil and gas installations or sites of special scientific or historical interest (Rogers 1997). In other cases, fishing is restricted or prohibited in order to protect the fish stocks (usually juveniles) themselves from over-exploitation. For example, in the North Sea, much of the North Yorkshire (NE England) inshore coastal waters (inside 3 miles) are closed to all towed forms of fishing in order to protect the juvenile codling and other gadoid species that aggregate in these waters (Rogers 1997). In other areas, the marine protected areas (MPAs) may be established to segregate recreational activities, including tourism, from fisheries.

14.4.5.1 *The 'Plaice Box'*
One of the largest restricted fishing areas in the North Sea is the 'plaice box'. This is a nursery ground for large numbers of juvenile commercially important flatfish species, such as plaice and sole (Anon 1994). The plaice box is closed to fishing vessels with engine powers above 300 horsepower, and therefore excludes the large whitefish beam trawling fleets from accessing these grounds, and thereby inflicting mortality by discarding juveniles. The plaice box has been in existence for over ten years, but only recently has been closed for the entire year. However, few beneficial effects on the flatfish stocks have been identified, though it is postulated that environmental factors (such as climate change) may be affecting the structure of the fish stocks and overshadowing the beneficial effect resulting from the existence of the 'plaice box'. In addition, the efficacy of the closed area may be compromised by the continued use of the region by small (below 300 horsepower) vessels.

14.4.5.2 *The 'Cod Box'*
The 'cod box' was a temporary closure imposed because the North Sea cod stock was considered by ICES to be outside safe biological limits and at serious risk of collapse (ICES 2001). On 14 February 2001, an area of more than 40,000 square miles of the North Sea, almost a fifth of its entire area, was closed for 75 days to fisheries likely to catch cod (Figure 14.1). The areas closed included some of the main fishing grounds for the international North Sea beam and otter trawl fleets. The aim of the emergency closure was to reduce fishing mortality on spawning cod, but the wider consequences of this closure were not considered at the outset.

Since the beam trawl fleet was allowed to continue fishing during the period of the closure, but could not fish in the closed area (the activities of the beam trawl fleet could be effectively monitored and enforced through the satellite Vessel Monitoring System (VMS)), the fleet sought alternate fishing grounds. Many of the grounds to which the vessels were displaced were not the grounds that the fleet usually fished (Rijnsdorp *et al* 2001). Modelling suggests that the closure led to a different spatial distribution of trawl effort than in normal years, with slightly greater cumulative impacts on the production of sea floor living animals. This effect occurred because the effects of a given trawl impact are relatively greater when habitats are impacted the first time, than when they are fished frequently. Organisms that are less vulnerable to impacts will inhabit an area that is regularly impacted. Some of the trawling effort was displaced to areas that had never been trawled before, and recovery of the seafloor communities in these areas was expected to take decades. Thus protection of spawning cod for 75 days leads to impacts on other ecosystem components that may persist for several decades.

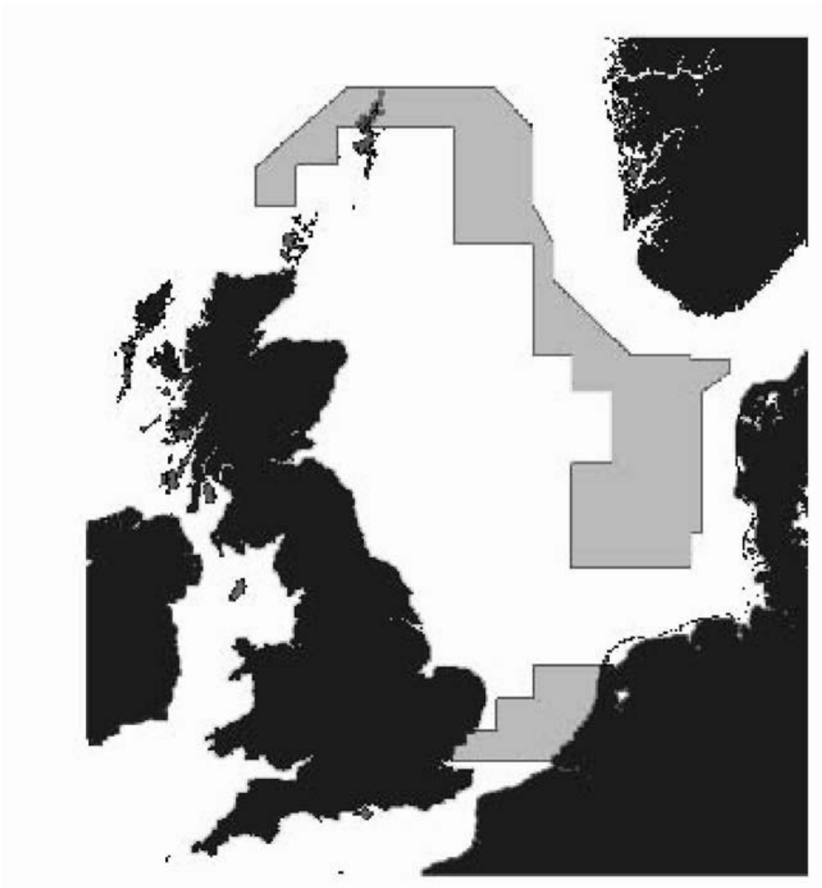

Fig. 14.1. The area of the cod box closure from 14 February - 31 April 2001: stage 1 of the North Sea cod recovery plan.

14.5 Ecosystem-based management

As noted above, to date, fisheries management has focused on providing a sustainable stock of fish. However, various international agreements, including the Convention on Biological Diversity (CBD), now require protection of the ecosystem. Ecosystem management schemes are in their infancy, and considerable effort is being directed at developing appropriate measures for ecosystem status (health) and function.

One example of an ecosystem level management scheme that has been implemented is the sandeel fishery off the east coast of Scotland and NE England. A number of internationally important seabird colonies occur in this area, including the Isle of May and the Farne Islands. The Isle of May alone hosts around 70,000 pairs of breeding seabirds per year. While these birds range far and wide and take a variety of prey outside the breeding season, sandeels are a very important component of the diet of adults and young during breeding. During the breeding season, the birds' foraging is also restricted to sites relatively close to the breeding grounds. In the 1980s, a number of inshore areas were exploited for the first time by industrial fisheries targeting the sandeels. At this time, many spectacular breeding failures by the seabirds. For example, 4,300 pairs of kittiwakes in the Isle of May in 1998 raised less than 200 young (a pair normally raises 1 or 2 chicks from a clutch of 3 eggs). While the evidence of a fishery-seabird interaction is only circumstantial, it was sufficient to prompt a precautionary response. Industrial fishing in the 'sandeel box' (which covers the inshore area from eastern Scotland down to NE England) is closed if the breeding success of kittiwakes in the nearby colonies falls below 0.5 chicks per pair for 3 successive years. The fishery does not reopen until breeding success has been above 0.7 for 3 consecutive years. Thus management of this fishery is based on an ecosystem objective (seabird population health), is precautionary (the link is not yet proven) and uses the kittiwake breeding success as a biological indicator of the ecosystem effects of the fishery.

14.5.1 THE ECOSYSTEM – THE EMERGING CHALLENGE

With the adoption of the Convention on Biological Diversity (1992), managing the environment in an ecologically sustainable manner has shifted from being an option to a legal necessity – sustainability is now the goal of management policy. Given that reproduction and adaptability are fundamental biological attributes, the real challenges for managing the system are two-fold: first, determining the key limits – that is, what are the ways and rates which can be sustained; and second, setting in place policies to obtain society's goals for the marine ecosystem. The latter is a socio-political issue, while the former is very much a scientific issue and may be the greatest challenge facing ecologists in the third millennium.

14.5.2 THE ECOSYSTEM APPROACH TO ENVIRONMENTAL MANAGEMENT

The ecosystem approach has been defined as:

> (T)he comprehensive integrated management of human activities based on best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of the marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity. (Danish Presidency 2002)

The ecosystem approach is seen as requiring the setting of clear objectives covering ecological, social and economic goals (Koge Conference 2002). From these objectives, it is possible to develop appropriate metrics of each class of objective and to develop management measures that aim to ensure the objectives are met.

14.5.3 THE MARINE SCIENCE REQUIREMENT FOR AN ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT

Science has to contribute to this process in two distinct ways: first, in clearly communicating with all stakeholders about possible configurations of the ecosystem – the **educator** role; and second, the provision of clear advice to managers – the **advisory** role.

The educator role will essentially focus on informing stakeholders of 'What it is feasible to wish for?' This will involve explicitly predicting possible ecosystem scenarios – for example, this many seals in the North Sea will mean a maximum catch of this many salmon and this much cod, and will also mean this many birds. Or, if we can catch this many cod and this many sandeels, we would then expect this many porpoise to be killed each year in our nets and only this many birds to breed. This task requires a major shift in the attitudes and behaviour of scientists. The fisheries science community is not used to communicating directly with society. This approach would also necessitate a massive advance in our predictive capabilities. There are presently no models that can do for the ecosystem what MSVP/4M models do for the ten or so species of fish and their predators modelled. Given the complexity of multispecies systems and the recognised importance of climatic variations in driving marine productivity, ecosystems modelling is a massive undertaking. Also, we need to identify aspects of the ecosystem which can be used as measures of the success of a management scheme in achieving a particular configuration.

After society has been informed by the science through the educator role, it will be expected to express a preference for the state of the ecosystem. This will lead to the setting of clear objectives. Science now has to fulfil its advisor role in advising managers on the steps to be taken to meet the objectives, and in monitoring the system, to continue to provide advice in response to the observed status. This role is similar to that currently fulfilled in fisheries management, although the broader, ecosystem, basis of the management objectives presents greater challenges.

14.6 Marine science and governance models

The most obvious way of governing or managing social activity is through government regulation and enforcement - what is known as 'hierarchical governance'. But there are at least two other ways of governing social activity: 'market governance' and 'participatory governance' (Gray 2003). In the case of fisheries, market governance could mean a system of Individual Transferable Quotas (ITQs), while participatory governance could mean a system of co-management. In practice, we are unlikely to find a pure form of any of these three alternative modes of governance – virtually every kind of fisheries management system is likely to have some elements of all three modes. What differentiates one system from another, therefore, is the proportion of the three elements that they respectively embody.

Most commentators would probably regard current EU fisheries governance as being dominated by the hierarchical model. Science input to the governance process tends to be at a high level in this hierarchy. I would suggest that this is historic. ICES was established as an intergovernmental organisation, and so ICES advice flows to governments (and supra-governments such as the EU). One must acknowledge that certain individual scientists (such as Shepherd 1993:19), and, increasingly, scientific institutions, have made great efforts to inform the industry of the science behind the advice. So would a different governance regime require different science?

14.6.1 IS MARINE SCIENCE USED DIFFERENTLY DEPENDING ON THE GOVERNANCE REGIME?

In many ways, the science required to answer the questions posed at the beginning of this chapter is probably required by whatever governance regime is being used, although the importance of the various questions may vary. However, it appears to me that the adoption of a true ‘ecosystem approach’, as opposed to merely carrying on as before but paying lip service to the ecosystem, is inherently linked to more participatory governance. This will involve marine science in new roles. For some scientists playing the role of informed advocates, and entering into a debate about possible objectives and management schemes, may be an uncomfortable experience.

What is clear is that participatory management involves much greater ‘education/communication’ and much greater openness in terms of data exchange, both from scientists to stakeholders and from stakeholders to scientists (for instance, on fishers’ behaviour in response to management measures). An ‘ecosystem based approach’ also requires a much wider range of science than traditional fisheries management, hence the title of this chapter. It is no longer **fisheries** science but **marine** science that needs to inform fisheries management.

14.7 Conclusion

Technological advances are in part responsible for the perilous state of our fisheries. Improvements in vessel design, gear efficiency, gear handling, catch processing and navigation have all helped us to impose a greater mortality on fish stocks than ever before while using fewer vessels and fishers. Technology does not provide a solution to this problem, but the priority action must be to adjust national fleets so that with the available, and still developing, fish catching technology, the level of exploitation reflects the biological reality of fish stock production. This is the challenge for politicians and policy makers.

In realising the potential sustainable yield from fisheries, we must also have regard for the sustainability of the ecosystem, both because it ultimately supports the fish stocks, and because of society’s desire to maintain healthy and natural ecosystems. Closed areas are a very efficient means of protecting key habitats or vulnerable species, but as the scales applied to date they are unable to provide an effective mitigation against the direct mortality of fishing. Given that closed areas often, in reality, merely redirect effort into open areas, which then suffer higher levels of fishing, their role in ecosystem management is really restricted to protection of key species or habitat features. Rather than closing areas to fishing, we should seek ways of catching fish that do not do collateral damage to non-target species or ecosystem/habitat features. This will involve a move to more selective and lighter gears and possibly a return to static traps in place of towed gears. This may lead to financial hardships for the fishers in the short term and society should be willing to pay compensation to fishers for playing a stewardship role. Development of such 'ecologically friendly' fishing gears is the challenge for technologists.

We know much about fish biology, but predicting the size of a stock, even a couple of years in advance, remains difficult. A reduction in effort will make year-to-year fluctuations in stock size (and catch and market price) less marked, but it is still important that we develop a better understanding of the relationship between the environment and fish stocks and between fish stocks and the rest of the ecosystem. This is needed to underpin any attempt to provide a holistic ecosystem approach to coastal management. This is the challenge for marine scientists.

For marine scientists, the tools that need to be developed include both better ecosystem models and ways of predicting and incorporating the role of extrinsic drivers, such as climate into our predictions. These may seem to reflect the views expressed by some of the stakeholders. Trade papers and meetings frequently feature the assertion that the perilous state of the fish stocks is the result of external factors – the climate, and seal predation, being two that are widely cited. These extrinsic and ecosystem effects can be important, particularly when stock sizes are low so that there is little buffering capacity. However, focusing on them as the cause of the state of fish stocks ignores two important facts: first, fishing effort/mortality on the stocks is at an all time high; and second, we cannot manage the climate or the ecosystem, but we can manage fisheries. If we wish to rebuild stocks, then it can only be achieved through management measures imposed on fishing. Our poor record over the last 100 years of fisheries science and management, and the current need to incorporate ecosystem issues, including predators and climatic drivers, into our management, argue very powerfully that we need a new approach.

Marine science should fulfil two important roles in this new, participatory approach – an educational and an advisory role. To do so, requires some radical thinking within fisheries governance institutions and a redirection of resources by government and other advisory customers.

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