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A review of fisheries management past and present and some future perspectives for the third millennium

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Abstract

A broad-brush review is provided of key issues and events of science-based fisheries management from historical times to the present. Key trends in fisheries assessment, control and surveillance, capacity and its relevance to marine fishery ecosystems are described, particularly those issues where FAO has played a key role. The paper also considers social and institutional issues of relevance. A perspective is offered for the evolution of possible fishery management paradigms that may apply at the start of the third Millenium.

1. Introduction

At the turn of the last century, the great debate in fisheries centred on whether or not the apparently boundless fish resources of the oceans could be depleted by fishing. We have come a long way since then. Technological advances applied to fisheries have fed the increasing global demand for fish products by a growing human population and led to a global network of international trade in fish and fish products. The concept of fisheries management science, incorporating biology, economics and social and institutional issues [1] has made progress, and fisheries management now is far more holistic, self-critical and intensive than it was even 10 years ago. Despite this apparent "progress" however, the great debate at the close of the century and start of the Millennium, is whether or not we can save many of our

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resources from commercial extinction, and the answer to that question at the time of writing is far from clear.

Why is it, that over the last 100 yr, despite undeniable progress in our ability to monitor and assess the state of fish stocks and understand the economic and social forces that underlie ecosystem change, the status of fishery resources has deteriorated? Our slowly dawning awareness that managing fisheries is more to do with managing the people involved in fisheries than it is with managing the resources is one element of the answer, since rarely have issues of equity been resolved. The reasons for the failure in the narrower sense, of resource management is not just a question of maintaining fishing mortality within sustainable limits for a series of target species, but recognising the interconnectivity of ecosystems and the so far intractable problem of management of complex systems. These issues have been widely discussed in recent years [2–7]. Cochrane [8] with studies concluding that the primary reasons for the failure of management can be summarised as: high biological and ecological uncertainty as to resource dynamics, the conflict between social and economic priorities, and the lack of definition or observance of constraints imposed by the limits to production of the resources. Poorly defined objectives and institutional weaknesses, particularly relating to decision-making and co-responsibility also play a key part, as has general public ignorance as to the interconnectivity of marine ecosystems.

This paper provides a necessarily coarse-grained overview of some key developments in fisheries and fisheries management this century, tracing developments thought to be mainly responsible for the failure of fisheries management, and suggests ways for improvement. It considers the status of fisheries management at the end of the millennium and provides the authors' personal prognosis on the range of management paradigms that seem likely to apply to fisheries management early in this century.

2. Fishery management before 1900

A common fallacy of the late twentieth century is that we are the first generation to have encountered the difficult problems of natural resource management, and the rapid advances in technology that have caused many of our problems will soon be applied to resolving them. Certainly, the widespread application of science to human endeavours since the start of the century will need to be focused more on methods of control than as to date, on improving harvesting efficiency. We have much to learn from the past, however, though it is now rare to encounter citations of early experience in fisheries management in publications issued over the last two to three decades.

The current view tends to assume that before computers, the use of radar and electronic communications for monitoring control and surveillance of fishing fleets, multi-criteria decision making etc, there was only darkness. The reality of course, is that fisheries management has a rich and important history, some of whose lessons have only been rediscovered in the last 20 yr. As noted by Caddy [7], new paradigms often emerge from methodologies discarded early on, but renovated through application of new knowledge or technology. The use of closed areas is one example here. This ancient methodology, being re-emphasised in coastal areas after decades of neglect [9], is difficult or expensive to enforce distant from the coast. Satellite monitoring of fishing vessels equipped with transducers as a requirement for licensing, not only makes such measures feasible in the open seas and oceans, but opens the door to the possible leases or exclusive access rights for resources of specific ocean areas. Predicting which new approaches will be made feasible by future technological change is of course largely impossible: only a range of options can be suggested, and in searching for these options one needs to look not only forwards, but backwards as well.

Fishing itself is as old as mankind. Extensive shell middens reflect the early concern with marine resources of prehistoric coastal settlements. One of the oldest fishing implements known is a copper and bronze fishing hook from Mesopotamia, believed to date from about 3500 B.C. and by that time salt fish was already an important commodity in Mesopotamian and Mediterranean trade [10]. In 10th Century Sicily, according to Arab sources quoted by Spalanzani writing in the 18th Century, precious red coral was fished by rotation over a 10 yr cycle between 10 zones established near Messina, which corresponds fairly well to the time needed for the colonies to reach commercial size.

With growing participation in fisheries on the high seas during the early part of the second millennium came conflicts, crises, and the forerunners of management decisions. Nicolson [10] wrote of the petition to Edward III in 1376, expressing concern about a new type of fishing gear, which appears to have been an early type of small mesh beam trawl. The petitioning fishermen were concerned about the damage done to the substrate (it "destroys the flowers of the land below the water"), as well as damage to spat of oysters and mussels, and were concerned about the effect of excessive catches of small fish. A commission investigated the matter and advised that the gear should be used only in deep water, but legislation to this effect was never enacted.

Despite this failure, fisheries management organisations appear to have been common features of many fisheries in the past. In France, local regulatory boards associated with fishing harbours, known as *prud'homies* (or 'wise men' of the port) predate the French Revolution. The functions of these bodies included, and still do today, ensuring fair allocation of resources within the local jurisdiction of a *prud'homie*, protecting the territory from outside intrusions, and protection of the resources through regulation of e.g. mesh sizes and fishing seasons [11]. The *cofradías* of Spain were similar in purpose, and many coastal communities world wide have systems of taboos, access rights and traditional practices which effectively protect the status quo. In Japan, fisheries management also has a centuries-old history, thus Kalland [12] reported that during the Tokugawa period, from 1603 to 1868, fishing territories were established, and coastal waters were considered to be extensions of the land and thus a part of the feudal domain. The feudal lords partitioned the coastal waters and allocated areas of fishing ground to local fishing communities under the control of the village heads. This system remains largely intact today, although during late last century, authority for managing the coastal territories shifted from village heads to fishing cooperatives. Such community approaches to management were widespread, and McGoodwin [13] refers to similar practices in the Philippines, Occania, the Pacific coast of North America and Mexico. McGoodwin suggested that the existence of controls itself indicates that the communities knew the value of these resources and the importance of conserving them. Scott [14] records the existence of explicit fishing rights in Mediaeval times, and the similarities and differences between these and conventional property rights on land. Unlike the latter, these local fishing rights were not developed further within the common law of property, and in many cases were subsequently lost or superseded.

Although there is danger in over-romanticizing the 'equilibrium' between pretechnological cultures and their resources, it is probably true to say that prior to industrial-scale exploitation, fisheries managed using traditional knowledge and early technology and practices were largely sustainable, even without scientific information about the marine ecosystem. A major challenge to 'traditional' small-scale fishers and their rights was probably inevitable however with the development of a market economy for fish, such that the price of a commodity, and hence the incentive to harvest, no longer declined when local demand was satisfied. The development of large motorised fishing vessels that followed the industrial revolution was an inevitable result not only of technological advance, but of the wider market and the means of storage, processing and transportation of fish that developed to satisfy it. Since these new developments required substantial investment, the centre of decision-making shifted from coastal communities to the business community, banks, cities and central government.

On a global scale, beyond coastal waters, in terms of national economies fisheries are secondary in importance for most countries to other national interests (the three mile 'territorial sea' marked initially the range of coastal cannons). The early role of shipping for trade and territorial protection and expansion has had enormous implications for fisheries that are still being confronted today. An early manifestation of this overriding of local rights in favour of national policy was the declaration by Queen Elizabeth I of England to the Spanish ambassador, that she claimed the freedom of the seas, as being "common to all". The concept of the seas and oceans as common property became firmly entrenched with the work of Hugo Grotius, an attorney working for the Dutch East India Company. His contribution took the form of a pamphlet entitled "*Mare Liberum*" published in 1609, in which he claimed that "the sea....cannot be attached to the possessions of any particular nation". This was an aspect of the legal context that European countries required to justify their colonial expansions, and the doctrine was quickly accepted [13]. The consequence, as described by McGoodwin, was that "The indigenous peoples who survived and adapted to the new colonial regimes were acculturated to the ways and mentalities of the conquerors. As a result a wealth of native knowledge about the managing and conserving of natural resources...was forgotten".

Earlier fishery regulations applied in the marine environment tended to reflect the original practices and established rights in husbandry of freshwater fisheries; for example by monasteries, where the ban on consumption of meat on Fridays led early on to the need for cultivation and conservation of fishery resources. Regulations such as closed seasons to protect spawning, minimum sizes, and bans on different types of gear which were believed to be destructive, have all been around a long time, even though the origin of these measures is not easily documented, and they almost certainly were reinvented in different areas. A total allowable catch (TAC) based on scientific analysis is a concept that dates from the 1960s, but the use of bag limits and limited access are measures that have a much longer history. Many early size limits reflected other than biological concerns; thus the strict size regulations controlling the Dutch herring fishery were initially based on product requirements of a curing method developed in the 14th century. These regulations, designed to ensure high quality of the product, also specified mesh sizes and seasons (no fish were to be caught before 24th June each year).

With respect to the control of fishing effort, this was initially largely by a control of access. Territorial User Rights in Fisheries (TURFs) were widespread and controlled the number of entrants to a fishery [15]. Berkes et al. [16] discuss traditional access rights as they applied to inshore fisheries.

Has the twentieth century been an age of discovery and progress for fisheries management or has it, where it has made progress, been an age of rediscovery? In documenting some of the key developments in fisheries management over the last century, our paper will keep this question in mind.

3. Global policy issues in fisheries and the international legal instruments developed since World War 2

The development of fisheries since the Second World War has been dramatic. In 1948, the reported global marine catch was 18 million tonnes. By 1996, it had reached 87.1 million tonnes and the following year was only slightly below this at 86.0 million tonnes [17]. It has been this period of expansion, driven by increasing human demand and the technology used to satisfy that demand, that has really tested fisheries management. One gauge of how management has attempted to meet these challenges comes from following major policy developments during this period, which are reviewed by Garcia [18] and Garcia and Newton [19]. They divided up the post-war period according to trends in the global landings, and these periods, as labelled by Garcia [18], will be used in this discussion.

From 1945 to 1958 was a period of "Construction and Reconstruction", following the Second World War, and landings increased over this period from 18 to 28 million tonnes [18]. The mandate given to FAO, founded in 1945, was to assist in the reconstruction of European economies, including the fisheries sector. In the UN International Overfishing Conference [20] and the first FAO Technical Committee [21], the key problems that face fisheries today had already been identified. These included overcapacity, overfishing and the depletion of resources which they were expected to lead to, discarding, and the lack of data for management of resources on the high seas (then beyond the 3 mile limit).

The FAO Technical Committee drew attention to the existence of under-utilised stocks in the Southern Hemisphere and, despite their primary concern for the development of local fisheries, which effectively resulted in the rich and powerful countries of the north using their technological superiority to exploit the resources of the south. In response, in 1947, Peru claimed jurisdiction over seas within 200 miles of its coastline, and this measure was included in the Santiago Declaration by Chile, Peru and Ecuador in 1952 [18]. The extent from shore of national sovereignty was discussed further at the United Nations Conference on the Law of the Sea (UNCLOS) in 1958. Burke [22] suggested that this conference resulted in acceptance of the principle of separating the concept of jurisdiction over fisheries from that of national sovereignty, but no agreement was reached on extended territorial limits.

Garcia [18] and Garcia and Newton [19] characterised the period from 1959 to 1972 as one of further "Expansion of fisheries and an intensification of research" in support of fisheries development. During this period, the reported global landings increased from the 28 million tonnes of 1958 to 60 million tonnes by 1972. Attention was focused, particularly by countries with extensively developed industrial fleets, principally at that time from Europe, Japan, USA and former communist countries, on expanding their areas of operation. In most cases, these expansions were supported by subsidy schemes. This expanding fishing power was also boosted by technological developments such as the development of synthetic fibres for improved fishing gear.

The second meeting of UNCLOS was held in 1960. Burke [22] stated that the key problem at this Conference was to agree on separate limits for territorial seas and fisheries jurisdiction. He reported that "agreement narrowly eluded the conference", but that it created the atmosphere for subsequent success. After UNCLOS II, several nations attempted to extend their territorial seas to the 12 mile limit and in some cases to extend their fisheries zones beyond this limit. Before 1975 the latter unilateral claims were generally rejected by the international community. During this period almost all the new developments in fisheries assessment and management theory were aimed at high seas fisheries.

A second key event during this period was the UN Convention on Fishing and Conservation of Living Resources of the High Seas, which was adopted in 1958 and is currently still in force for 36 States [22]. Included in its provisions are the rights of mankind to a healthy environment. During this period concern for the status of whale stocks became of global concern, and at the World Conference on Human Environment in 1972 [19], a call for a 10-year moratorium on commercial whaling was adopted. However, whaling continued, with catch limits for whaling, starting in 1974, being determined by a scientifically established set of rules called the New Management Procedure, which marked the first attempt to design a fully scientific management procedure for marine resources.

This leads us into the next period in the modern development of fisheries, from 1973 to 1982, labelled by Garcia [18] as a period of "New Economic Order and Stock Variability". Reported global landings increased from 60 to 68 million tonnes, something of a slowdown that was probably influenced by rising fuel prices, although other problems stemming from resource depletion also increased. At the

1973 FAO Technical Conference on Fishery Management and Development, among important issues that were discussed were the failure of fisheries management, over-capitalisation, subsidies and economic inefficiency, problems related to open access fisheries, and the need for precautionary management. It was in this period that electronics applied to navigation and fish-finding, and at-sea catch processing and refrigeration systems, began to be widely used, with considerable, but largely unmeasured increases in fleet efficiency. It was also in this period that the concept of 'limited entry' began to gain wide diffusion [23].

From 1975 onwards some countries unilaterally extended their jurisdiction to 200 miles, a practice which was formalised in 1982 when UNCLOS III, included the provision for an exclusive economic zone (EEZ) which was not to extend beyond two hundred miles, was presented for ratification [24]. The 60 ratifications necessary for the Law of the Sea (LOS) to enter into force were only achieved in November 1993, and it entered into force on 16 November 1994, but its provisions dealing with fisheries had become international customary law since 1982. Declarations of a 200 mile limit now give countries exclusive control over fisheries in their own EEZs. While the LOS does not solve the problems of many high seas fisheries, where both straddling and purely high seas stocks are not catered for, it was generally seen as providing the legal framework for countries to manage their stocks for their own benefit. The underlying presumption was that this would be achieved in a wise and sustainable way. History has not so far borne out this optimism [25], but perhaps one consequence of the negotiations leading up to final agreement has been that fishing vessel licensing became a widespread practise in the 1970s in an attempt to limit the sizes of fleets.

Although positive, limited licensing in turn led to other problems for management, such as industries' search for technology to increase the fishing power of an individual fishing vessel. In fact, a cycle was commonly initiated, of new regulations aimed at in some way limiting the growth in fishing power, followed by evasion of their provisions, reflecting the adversarial stance that has developed in some fisheries between regulators and participants. This is probably an inevitable consequence of 'top–down' management, and has been one of the main factors leading to the introduction of individual transferable quotas (ITQs). These, as for community-based management, place more of the responsibility of management on the shoulders of stakeholders.

At first an apparent breakthrough in resource management, the 'New Management Procedure' for setting catch limits for whales had appeared to work well, but Kirkwood [26] noted that problems with widely fluctuating catch limits started to emerge in the late 1970s. By the early 1980s, the Scientific Committee of the International Whaling Commission (IWC) found it almost impossible to reach agreement on catch limits for commercial whaling. In part as a consequence of these difficulties, in 1982 the IWC agreed on a 10-yr moratorium on commercial whaling, which was finally implemented in 1988.

The years from 1983–1992 saw another growth spurt, with recorded landings increasing from 68 to 85 million tonnes. This period was marked by a growing concern for environmental conservation and the sustainability of fisheries resources.

Countries were also finding that the establishment of the 200 mile EEZ had not solved all their problems [25], and with a few exceptions, there was no noticeable improvement in the general status of the world's resources. As discussed below, the establishment of jurisdiction within their two hundred mile limit required countries to address the issue of access to resources by groups of national stakeholders, and concepts such as ITQs and TURFs began to be explored and implemented.

Manifestations of growing concerns with environmental issues included a move to prohibit large-scale pelagic driftnet fishing, which again placed high seas fisheries on the UN agenda. The important role in this campaign of environmental lobbies, the general public and the media, may have marked the effective start of what was to be a growing role of 'non-exploitive users' in the fisheries sector. i.e. those sectors of society without access rights to catch fish resources, who may or may not be consumers of fish, but were alarmed at the degradation of the largest group of wild living resources on the face of the planet. In 1991, the problem of large scale drift netting reached the UN General Assembly, which adopted a resolution recommending that the use of such large oceanic drift nets be terminated, although Burke et al. [27] suggested that there was only weak scientific evidence to support this decision. During this period, there was also a unilateral move by the USA, under pressure from environmental lobbyists, to prohibit the importing of tuna which did not comply with their own "dolphin safe" requirements. The move was designed to force the tuna fishing nations to make more rapid progress in reducing dolphin by-catches. A similar process has been followed by the USA with respect to imports of shrimp, and measures taken by shrimp fishing nations to reduce by-catch of turtles. Recently, this trend has led to the application of Eco-certification or Eco-labelling [28], which may be seen as an active response by consumer representatives to fisheries practices that are not sustainable.

These environmental concerns were all brought to the table in the UN Conference on Environment and Development (UNCED) in 1992. This conference led to the adoption of Agenda 21, with a full chapter (Chapter 17) dealing with fisheries. The implications of Agenda 21 for fisheries management are profound [29], and include growing emphasis on ecosystem management, the application of the precautionary approach, the need for participation of all concerned citizens in environmental issues, and others. While very few, if any, of the concepts were new, UNCED gave their implementation renewed impetus and increased authority.

Finally, this period was marked by an important national event; one that has spread alarm to fishery scientists, managers and environmental groups around the world. This was the collapse of the Canadian Atlantic northern cod fishery, which was closed down in July 1992, after a decline from landings as high as 800,000 t in the past [30]. What made this event particularly significant, was that the Canadian approach to fisheries assessment and management was seen by many as being among the best in the world. Subsequent thorough and unmerciful self-criticism of the causes of this collapse revealed both technical and political failings [30]. The fact remained that if a developed and wealthy country with such an intensive and well-developed fisheries management system could fail, what hope was there for fisheries around the world? The lessons from this event are still being considered and digested by many, and have provided a strong impetus to the Precautionary Approach to fisheries which has been promoted by FAO [31] and its implications and requirements are being seriously considered by many national and regional agencies.

Gracia [18] labelled 1993–2000 as the period of the "Sustainability Challenge", but we would add that it has also, to date, been a period of consolidation where several global initiatives have begun to digest the lessons that had been learnt in the negotiation of new international agreements and laws. The most all-encompassing of these new international instruments has been the FAO Code of Conduct for Responsible Fisheries [32], first proposed at the 1991 meeting of the FAO Committee on Fisheries. The need for such a code was endorsed by both the May 1992 International Conference on Responsible Fishing in Cancún, México, and in the following month by UNCED. The Code was developed by FAO in consultation and collaboration with member countries and non-governmental organisations, and was adopted by the FAO Conference, made up of representatives of its member countries, in October 1995. The Code is voluntary, but it includes provisions that have already been made binding or obligatory in many national legislations. It sets out the principles to be adhered to in all aspects of fishing, to ensure responsible and sustainable practices.

Preceding the Code, was the Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas (the FAO Compliance Agreement). This Agreement attempts to prevent vessels transferring their registration to other flag States in order to avoid having to comply with international conservation provisions and management measures. The Agreement addresses this issue by setting out the obligations and the responsibilities of flag States to ensure that their vessels adhere to the relevant internationally agreed instruments [22]. The FAO Conference approved this Agreement on 24 November 1993 and it will enter into force on the date of deposit of the 25th instrument of acceptance.

The second legal instrument developed during this period of consolidation is potentially very important. This was the 'Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks'; usually abbreviated to the more manageable title of 'UN Fish Stocks Agreement'. This instrument sets out provisions to ensure the long-term conservation and sustainable use of straddling and highly migratory fish stocks. The primary way it does this is by obliging states fishing in the high seas to cooperate through "appropriate subregional or regional fisheries management organisations or arrangements" [24]. The Agreement was adopted by the UN Conference and opened for signature on 4 December 1995. At the time of writing, this agreement is close to being ratified by the required number of State signatures to become operational, and its provisions are already entering the legislatory framework of a number of countries.

Overall, therefore, as the twentieth century closes, the international community is well aware of the crisis facing fishery resources and fisheries, and has taken a number of important international steps towards an improved global management system for fisheries. Through UNCED and the Code of Conduct, they are aware of the steps necessary to implement sustainable and responsible fisheries within national EEZs and on the high seas. Through UNCLOS, the FAO Compliance Agreement and the UN Fish Stocks Agreement, the legal instruments necessary to enforce responsible high seas fishing are largely in place. The problem for the 21st century is to implement these successfully, and in particular, to translate policy at the national level and agreements between States to the level of implementation by the stakeholders: skippers, vessel owners, fishing companies, small-scale fishers and their coastal communities.

This may be the key to the next phase, starting in this new millennium, and which we label the period of the "Confronting Rights and Responsibilities" that is now beginning, in that it completes the cycle, taking us back to before industrial fisheries and high seas inter-governmental negotiations of the current framework began, as described at the start of this paper. Perhaps we are now seeing fisheries issues returning to the national and local arena, with revived emphasis on the rights and responsibilities of individual fishers, their communities and other stakeholders through rights-based fishery management. The idea that fisheries management involves managing fishers rather than just the resource was considered innovative as recently as 1988 [33], but is now axiomatic.

The inevitable inclusion of fisheries resource issues in the multi-sectorial context of Integrated Coastal Area Management will hopefully see marine resource and environmental conservation issues recognised outside the fishery sector. With formalisation of user rights we may also see stakeholders seeking legal redress for damage to the marine or estuarine ecosystems and their components.

4. A short history of advances in fishery assessment, management, and fishery control measures

There is a tendency on the part of fishery biologists to forget that industrial fisheries have developed at the same rate or even faster than other industries, and that the fishing power of fleets and their range of action and versatility have increased dramatically. Of course, the conversion from sail to engine power and associated hydraulic systems began before the first World War and allowed the use of large otter trawls and seines. The pace of change has picked up dramatically since the Second World War however [34]. The invention of synthetic fibres in the 1950s was a precondition for modern technologies such as seining with the power block, which began in the 1950s and spread rapidly. The widespread use of the mid-water trawl in the 1960s and 70s, gill netting which is now a predominant fishing method in many developing countries, and also modern long-lining techniques all depend on synthetic fibres for their effectiveness. (See Valdemarsen, Ocean and Coastal Management, this volume). The invention of radio positioning and communication systems and later, positioning by satellite, together with other technological advances such as progressive computerisation of ship systems, all potentially increase fishing power. Improved freezing and at-sea processing technology have also contributed to the extension of the range and duration of trips by large powerful vessels capable of exerting considerable fishing power distant from port. This section will not attempt to track the repercussions of each of these methodologies. Clearly however, the increase in world landings from the 1960s to the 1980s cannot be discussed without an understanding that these reflect an increase in fishing power and pace of technological change whose consequences for marine ecosystems and fishery management we are just beginning to understand; usually only in retrospect. As noted by [7], technological advances may lead to revival in a modern form of old methodologies (e.g. rotating harvest schemes, used earlier in the history of fishery management).

The implications of technological change and improved methodologies for resource assessment and management of stocks can only be considered here as an ensemble, but the following, in our view, are some of the main milestones marking progress in fisheries assessment and resource management.

4.1. Fisheries assessment

The debate between those who felt that ocean productivity is limitless hence, there was no need for management of ocean fisheries, and those that held the opposite view came to a head in 1884, and can be encapsulated in two quotations: "Probably all the great sea fisheries are inexhaustible" [35] and the reply "It is a mistake to suppose that the whole ocean is practically one vast store house" [36], with the debate tipping shortly afterwards in Lankester's favour [37]. The founding of ICES in 1902 was a milestone in the explicit scientific investigation of marine populations with a view to better understanding that might eventually lead to improved fisheries management. The first applications in the North Sea and North Atlantic were technical measures: i.e. the application of studies of growth to the concept of minimum mesh sizes. These technical measures were the first internationally agreed fishery regulations in the north east Atlantic, but proved inadequate for controlling fleet capacity or the evolution of catching power.

An early focus to the question of limiting population size was provided by the concept of the unit stock. Gilbert [38] showed that salmon populations of different rivers were each distinct, and this and other works led to the unit stock concept. However, the genetic diversity of fish populations and the selective pressures on genotypes imposed by fishing are being investigated only now.

Baranov [39] first provided a numerical framework for calculating yields, but his efforts remained in obscurity, perhaps in part because they had run ahead of the capacity for application. They were further elaborated after the Second World War by Beverton and Holt [40] and Ricker [41], aided by the enforced cessation of fishing during the World Wars which provided one of the few early opportunities to test the effect of changing fishing pressure on population growth and size/age structure. The approaches developed by these pioneers can be described as outgrowths of Baranov's analytic, yield-per-recruit calculations.

Another line of investigation that eventually came to have fisheries applications started with the pessimistic view of Malthus [42] as to the uncontrollable exponential growth of (human) populations. Later, Pearl and Reed [43] realised that there must be limits to population growth, and modified the exponential to a logistic formulation. This simple model of population growth was picked up by Graham [44] and formed another 'mathematical strand' of what has come to be regarded as stock assessment theory. As noted by Smith [37], the third of 'the three partial theories of stock assessment' was provided by Ricker [45]. Ricker, and independently, Beverton and Holt [40], showed that reproduction and renewal of a unit fish population was in part self-controlled, and that a number of density-dependent factors reduce reproductive success if the population of spawners is too large. Again, this contributed to the concept of limits to the growth already developed outside the fisheries arena.

In discussing the 'evolutionary tree' of concepts that led to what we now think of as the solid edifice of stock assessment theory, Caddy [7] pointed out that despite their recent convergence into a practical body of methodologies, these three 'partial theories' have until recently tended to remain distinct components of the 'fisheries management paradigm'. With some exceptions, these three 'strands' have been furthest applied in the geographical and cultural areas that gave rise to them, and where data sources suitable for their first development were available. Thus, Baranov's and Beverton and Holt's bionomic analytical theories of 'yield per recruit' were well adapted to the North Sea where age-structured data were easily available. Here, however, a lack of standard effort units and common economic information for a diversity of multi-nation fleets, made application of production models difficult (despite Graham's local pioneering work). Production modelling found more easy application in fisheries of the Pacific coast of North America and for tunas, where detailed biological information was not available. The logistic model also provided a basis for the development of the theory of fishery economics [46]. The great salmon runs of the Pacific Northwest of North America led to early application of the stock-recruitment theories of Ricker [45], which only later were widely applied to purely marine fisheries.

In general, these three strands of classical bionomic theory have been broadly paralleled by three modes or objectives of biological management of stocks; namely, to maximize yield, to optimize fishing effort and mortality, and to maximize escapement to spawning, or of spawning biomass. Of course, technical measures and area and season regulations provide further qualification to each of these classical approaches to fish population control.

Many of the earlier management applications of fish stock assessment followed the lead of Schaefer [47], in applying production modelling and its later outgrowths to time series of catch and standard fishing effort, or related commercial catch rates. The most serious defects of this approach with its apparently low information requirements and limited number of parameters, emerged during the period of expanding fishing effort, notably from 1950s onwards. During this main expansion phase for industrial fisheries, total effort increase coincided with continual increases in both fishermen's skills and technological development of the means of harvesting. Calibration of fishing power by class of boat, age of construction, etc. therefore proved to be difficult, and was rarely attempted in many cases, leading to obvious biases in assessment conclusions. Later data sets where the dynamic range of the effort data was reduced once MSY was reached after only a few years in new fisheries, also made the statistical curve-fitting process unreliable.

In other areas where age-structured data are laboriously analysed, the main assessment approach has been the use of Virtual Population Analysis or Cohort analysis, and its later outgrowths such as ADAPT [48]. Here the problems of fitting the model to the data relate more to misreporting of catches, and density-dependent biases such as changing growth and natural mortality rates.

The defects of both of the above schools of practice have led to increased reliance, where this is feasible, on direct assessments from surveys or by use of hydroacoustic equipment. The high level of variance, and the likelihood of bias [4], around most estimates of biomass or stock size still remains however, and technology does not offer any obvious rapid solutions to informational uncertainty.

A difficulty faced with most existing models is the intractability of modelling systems with many parameters and state variables. At the frontier of stock assessment theory and practice is the problem of dealing with the multispecies fishery question, and the issue of spatial information. In the first case, conceptual breakthroughs in modelling complex ecosystems have been made [49], and in the second, the growing use of GIS techniques and spatially disaggregated models is beginning to allow fleet strategies, migrations, and costs and times of travel to the grounds, to be specifically taken into account. However, incorporating this information into a management framework where there are fishers with species- and area-specific rights and gears with different species and size selectivities, is difficult. This illustrates the limitations of an 'analytical approach' where a problem has to be understood in full before solutions can be proposed. Empirical solutions, especially those coming under the 'precautionary approach', seem inescapable and are urgently required [31,50].

4.2. Fisheries management

Recent fisheries agreements now recognise that there is a high risk of wrong management decisions based on uncertain data [51]. This has recently led to a conceptual revolution towards the concepts of using Limit Reference Points in fisheries management [52]. Limit Reference Points combined with the precautionary approach remove the need for scientists or "representatives" for the stock to provide the burden of proof that stocks are being depleted by current fishing management measures, towards one requiring immediate action to curtail possible overfishing or stock depletion, when certain preagreed precautionary LRP's are approached or passed. Recent international instruments such as the Code and UN Fish Stock Agreement follow UNCED in requiring that such precautionary approaches be adopted when stock status is uncertain.

Control of fishing effort is a basic tool of fisheries management and fisheries theory tends to treat fishing effort as a continuous variable that can be controlled indirectly through quotas or even by controls on fleet tonnage or vessel/gear characteristics. An examination of fleet replacement strategy however, shows that new vessels commonly enter a fishery as 'pulses' of new capacity whose fishing intensity is then difficult or impossible to control by indirect measures. Given the long useful lifespan of most industrial vessels and their low rate of decommissioning (of the order of 5% or less per year—[53]), decisions on increasing capacity in one fishery can have knock-on effects on other fisheries which then receive a 'spill-over' of excess fishing capacity. This phenomenon has been observed in recent years, where fisheries of developing countries are often carried out with vessels originally built for developed country fisheries. The higher rates of decommissioning and generally shorter life spans of artisanal vessels reduces this 'management time lag' for local near shore fleets, thus providing a more flexible response to changes in stock abundance.

Even while fisheries management struggles to get to grips with single-species issues, it is increasingly being called on to take a multispecies and ecosystem perspective. However, there are still few case studies with more than a few years duration which illustrate how these concepts have to be applied, and the difficulties are already apparent to all. One of the best known cases is that of the Commission for the Conservation of Antarctic Marine Living Resources, which embraces an ecosystem approach in its resource management [54]. However, it is still too early to determine how successful this has been. Added to these problems was the late realisation in the 20th Century that computer models as systems of non-linear equations parallel natural systems in being characterised by highly unpredictable behaviour. The conclusion may have to be that 'forecasting' specific levels of species harvest within a multispecies harvesting scheme is likely to remain an empirical exercise for the immediate future. We may need to be satisfied with management systems that are reactive and adaptive, but reduce the risk of stock collapse by not seeking to maximise yields, since this apparently increases the accompanying risk of radical ecosystem change. With respect to multispecies fishery management, where different fleets specialise in harvesting tropically linked components of the same food web, quota-setting has begun to take this into account. Examples here include consideration of predator–prey interactions between cod and capelin in the setting of capelin TACS in the North Atlantic waters of Canada [55], and the implicit setting aside of a component of the production of the prey species, krill, to cover the food requirements of birds, marine mammals and other dependent predators in setting the krill TAC in waters under CCAMLR jurisdiction [54].

Some food webs are extremely complex however, and our understanding of their dynamics remains rudimentary. Despite tools such as ECOSIM [49] which allow for simulation of dynamic change in a food web with multiple exploited components, 'balancing' exploitation rates between different fleets harvesting different components requires judgements on complex and often conflicting socio-economic issues [56]. This type of resource negotiation aimed at ' balancing' extraction rates of different species from the same food web has hardly been addressed in practise. As noted by Tschirhart and Crocker [57], one problem with integrating ecosystem principles into economic analysis is in assigning values to changes in ecosystem components resulting from human intervention. Such quantitative changes are an inevitable consequence of exploitation, but do not necessarily (or usually) put individual species at risk of extinction. Thus, while the concept of 'Ecosystem Management' offers major operational complexities, more simply, a consideration of species and habitat interactions may suggest some simple empirical approaches. One such approach which seems to gain in popularity as a result of the evident difficulties in predicting impacts of fishing strategy on the ecosystem, is the growing use of season and area closures. In this way 'sensitive marine areas', high in biodiversity, or 'critical habitats' for keystone species [58], are closed temporarily or local key areas are closed permanently. Predicting and modelling the consequences of these closures is in its early stages, but is consistent with the growing recognition of area-based user rights and the need for more robust management measures. In the near-shore area, community-based management and other local area-based systems of limited access are also becoming a popular theme.

Good technical advice is only one component of a precautionary management system. The lack of a clear division of powers within the infrastructure implementing a management strategy can be seen as increasing the risk of dangerous decisions being made. For example, in the current 'standard format' scientists provide assessments of the stock and may even make evaluations of the risk of different quotas being chosen. The fishery management authority at the political level takes the final decisions however, which may not always be precautionary. Reviews of management decisions at all levels, and 'fail safe' procedures, will have to be built into the management cycle, which like all real-world management systems require explicit checks and balances to be built in [59].

The key problem in achieving effective fisheries management, however, remains in the problem of dealing with conflicting objectives, coupled with the widespread tendency to give priority to social and economic demands over sustainable utilisation of resources [8]. As long as the decision-makers perceive themselves to be constrained by a lack of alternative options to address short-term human requirements, there can be little hope for sustainable fisheries management. Solving this problem requires promoting the political will to set and strive for long-term goals that inevitably must include sustainable resource utilisation, and this may require finding alternative sources of employment and livelihood for many of those currently dependent on living marine resources. A major part of the solution to failures in fisheries management therefore may require solutions from outside the sector.

4.3. Monitoring, control and surveillance (MCS)

One theme that has been raised elsewhere [7] is that the application of technology to increasing fleet fishing power has not been balanced by similar technological applications to MCS, or to efficient gathering of data needed for reliable estimates of the state of stocks. We can expect that technological applications, involving direct monitoring via satellite of fishing operations by telemetric (black box) systems installed on fishing vessels, will progressively become a condition of licensing. Such systems are already in use in the Southern Hemisphere, and with the fall in price of technology, will become widespread. Perhaps less evident is the potential of such systems to measure directly fishing effort exerted, and to support area-based rights systems. As noted by Caddy [7] few of the potential fishery management measures can be enforced distant from the coast by conventional means, except at great cost, unless such technologies are in widespread use. The advantage of telemetric systems is twofold if all vessels are so equipped with tamper-proof equipment. In addition to MCS functions, they also protect exclusive access rights to time-area windows, opening the possibility of recovering revenue from leasing or auctioning such access rights, or applying rotational harvest schemes for non-migratory resources.

5. Science and fisheries management–some recent concerns

In recent years, attention has been focused on the uncertainties inherent in stock assessment, leading to the concept of risk assessment and, as a consequence, the need for risk management [60]. The old reference points were commonly estimated as point estimates and this led to the promulgation of management advice as a single number corresponding to, e.g., an F_{MSY} or $F_{0.1}$ strategy. Failures in this advice have resulted in greater attention being focused on the uncertainty surrounding estimates and advice, and it is now accepted that decision-makers must be provided with a range of options, in which the uncertainty is clearly conveyed [6]. One formal manner in which risk assessment and risk management can be combined is in the use of management procedures, as was first developed by the IWC for management of whale harvests. These are decision rules developed in full consultation with interest groups, through the application of simulation models of the fishery, incorporating uncertainty [61]. Once a set of rules has been developed which comes closest to satisfying the objectives for the fishery, that set of rules is applied to set e.g. catch limits over a period of years, until a revision is undertaken. The application of management procedures to fisheries has perhaps been taken furthest in the fisheries of South Africa, where they have been applied to several key resources [61].

More recently, the focus has been on how to close the gap between fish population theory and fishery management measures. In this debate, as we will see in the following section, we suggest that eight population themes must be taken into account that were given relatively little attention in international fisheries management until recent decades, but cannot be ignored if a practical fisheries management regime is to be developed.

These themes are:

5.1. Considering spatial distribution

The issues of geographical/spatial distribution of resources and their migration and sharing between jurisdictions and the integration of spatial information on fleet fishing strategy into management theory needs consideration. Beverton and Holt [40] devoted one of their later chapters to spatial issues, but in an era prior to the availability of cheap computing power, integrating calculations over a non-homogenous stock area was a largely intractable problem. The mathematical convention of the 'dynamic pool' was a necessary oversimplification allowing estimates of 'average' stock status at fixed points in time in the absence of spatial and within-season information. The dynamic pool assumption supposes that all inputs and outputs over the whole stock range during a year are integrated into single estimates of biomass, age composition and mortality rate. Such an assumption is required in order to calculate optimal effort and/or yield for the coming season using single 'mean' values for e.g. fishing and natural mortality, growth, etc. It has obvious defects where population mixing by dispersion and migration is not instantaneous, and fleets have a tendency to fish those areas or stock components that are more readily available. In practise, fishing vessels harvest components of the stock where conditions are most favourable and risks lower(i.e. grounds nearer to port), and/or returns on investment higher. Working models that incorporate fleet and fisher strategy in a spatially heterogenous environment are still not used operationally in many fisheries, however.

5.2. *Conflicts in access*

One other geographic issue, namely the recognition with the Law of the Sea that coastal States have exclusive access to the resources of their EEZ would seem to have solved the question of access. In fact it has led to other complications, not only in internalising competitions between e.g. inshore and offshore fleets, but also in negotiating national shares of, and managing, so-called 'trans-boundary stocks'. As noted in FAO [25], the problem of stocks exclusive to national zones is now an issue of domestic politics, requiring conflicts to be resolved between fishermen of different ports, or between artisanal inshore and industrial offshore fleets exploiting the same unit resource, or between the green movement and the fishing industry. All of these are vexing questions with no easy solutions. With respect to 'shared stocks' lying across, or migrating across the boundary between contiguous EEZ's, Caddy [62] noted that more than 500 such boundaries exist, but relatively few formal negotiations between adjacent states have been registered with FAO on the resource-sharing agreements in effect within such boundary zones. A similar situation exists with respect to straddling stocks; the UN Fish Stock Agreement has yet to be ratified by a majority of participating countries, and hence is not yet in force. For obvious reasons, a limit to possible new entrants for high seas fisheries, or a hypothetical 'High Seas Fisheries Authority' are not in sight, and in fact distant water fishing vessels may move between two or more jurisdictions in a single trip, making data monitoring and assessment very difficult. Again, the existence of satellite telemetry systems could now provide the technical impetus for future international agreements on offshore resources.

Management of ocean fisheries is also currently hampered by the limited powers of international fisheries commissions with respect to enforcement of their regulations, especially on non-members but also on members, since individual States prefer to keep such enforcement rights at the national level. Considerable progress has been made by a number of fishery commissions (e.g. ICES, NAFO, IATTC, ICCAT and others) in developing precautionary management approaches such as Limit Reference Points, but their application and enforcement in practice is at the discretion of member countries, since few commissions have an explicit role in enforcing the regulations they develop.

5.3. Application of economic theory

The slow application of economic theory to international fisheries management is worthy of comment, in that subsidies and overcapitalisation are still major issues. Questions of the costs and benefits resulting from fishing were not dealt with by Beverton and Holt [40], and in many areas the separation between stock assessment and economic analysis is still evident, despite the growing interest in bioeconomic theory [63]. Reaching agreements on an economic basis or by national allocation, particularly between states with different economic models or at different states of development, has been more difficult than agreeing on an overall level of harvest which is believed to have certain biological consequences. De facto, it is evident that with respect to resources of international waters, maintaining access rights to a resource can have implications that go beyond maximising economic yield.

The role of economic considerations in developing rules for international fisheries was largely left implicit in the FAO Code of Conduct, since the negotiating countries appear to see defining economic optima as a national policy issue. Economic analysis of fisheries has made considerable strides however, and much of the theory summarised in Clark [64], Hannesson [65], Seijo et al. [63] and others is currently finding application in national fisheries management. Problems and differences of view are evident however, and these include the need to define best economic strategies for non-equilibrium situations (already confronted in recent stock assessment developments), discards, multispecies fisheries, and the definition of fleet overcapacity. Assigning economic values to the habitat and environment, and the indirect impacts of fishing on the ecosystem seem to be challenges not yet fully tackled by fishery economics. The approach suggested by Costanza et al. [66] of calculating the value of goods and services provided by the natural world seem applicable to fisheries also. There will also be a need to estimate the economic implications of optimal stock recovery strategies which are now a top priority for many depleted resources.

5.4. Multispecies fisheries

The vexing problem of managing multispecies fisheries and avoiding irreversible impacts on marine biodiversity raises major difficulties that are frequently intractable with current management measures, especially where a suite of different species are taken in several gear types. This is particularly the case for trawl fisheries, and tropical fisheries using fish traps and trammel nets. Managing these fisheries may require considerable technical changes to the gear and fishing areas and seasons so as to increase selectivity and minimise impacts on other species. It may also be necessary to close permanently or seasonally certain critical habitats of importance to key species. This will have obvious economic and social impacts, but it seems unlikely in future that the prior assumption of free access to a resource in all areas and seasons will continue to be feasible. It is slowly being replaced by access to established 'windows of opportunity' when resources can be exploited with minimal impacts on ecosystem continuity. The bottom line for those gears producing mixed species catches is that if exploitation rate is not adjusted to that sustainable for the longest-lived, slowest growing and least found species in the catch, these latter species will disappear. The alternative, of course, is a rate of exploitation for the short-lived, fast growing species that is much less than they could comfortably sustain. The scene seems to be set therefore for more selective harvest methods if all components are to be moderately harvested but biodiversity is to be conserved. A related question treated by several recent symposia (e.g. the ICES/SCOR symposium on System Effects of Fishing, Montpellier, March 1999) relates to the physical impact of the fishing operation on the habitat. Increased concern with indirect impacts on living resources is important also for shipping and coastal development. An approach to addressing this could involve user rights assigned to coastal communities so that they could seek recourse in law against damages to productive ecosystems within their assigned jurisdictions.

5.5. *By-catch*

A growing concern, not least on the part of 'non-exploitive users' and the public-at-large, is with by-catches, particularly of 'charismatic' species such as marine mammals and turtles. A range of technological solutions have been proposed here, including TEDs and By-catch reduction devices (BRDs), and in some cases, quota management systems which set aside part of the biomass of a target species as food for marine mammals. It remains to be seen, however, what solutions will be found to the problem of growing populations of some protected species in the next century. Although the competition between humans and marine mammals for food species may have been exaggerated, the current moratorium on harvesting or culling these species, could at some point lead to imbalances in the food web, and higher mortalities of populations of apical species following stock recovery, due to food shortage caused by more explicit competition with fisheries.

5.6. *Utilisation of discards*

The current problem of discarding of non-commercial species presents a challenge with two possible solutions. The first of course is a move towards more selective fishing, including the areas where unwanted by-catch is minimised. This is a demanding option, and there has been a tendency to seek the line of least resistance. When stocks of high-priced, long-lived 'apical' species such as halibut or groupers are depleted, and most of the catch consists either of juveniles or their food organisms and non-commercial species, the temptation can be to avoid the fatigue of catch sorting and to treat the mixed catch as a chemical food stock. This may be transformed by the processing industry into saleable products such as fish meal, surimi etc. This second option inevitably degrades the ecosystem. It remains to be seen which of these two options will predominate in the next century.

5.7. *Effects of fishing on genetic diversity*

The question of genetic diversity and the selective effects of fishing on the genetic make up of harvested species is already beginning to receive attention. The statement that few species extinctions in the marine environment have been caused by fishing is generally true (exceptions being long-lived, low-fecundity species such as marine mammals and sharks and species confined to habitats at risk). This generalisation may not apply however for genetically isolated breeding populations or stocks such as individual salmon runs. Long-term effects of fishing such as the selection of individuals that mature earlier and at smaller sizes, will come to influence our views on the importance of maintaining the genotype intact.

5.8. *Effects of the environment*

The effects of environmental change on resource production were undervalued during the expansion phase of fisheries when fisheries theory was being developed, when it seemed obvious that fishing effort was the key controlling variable, and in fact the only variable that man could control. The realisation had grown towards the last years of the second millennium, that oceanic fisheries have reached, and in some cases passed, their peak of production. It seems more likely now that if gross overfishing can be slowed and reversed, the key variable dictating the level of production of a moderately well-managed fishery in future, will be the environmental conditions prevailing. The realisation has also grown that there are long and shorter term production cycles, often tied not only to spawning stock size but also regional or global phenomena such as el Niño events [67], and these show up through annual changes in recruitment and availability of stocks. Other long-term unidirectional anthropogenic as well as natural trends such as human-induced climate change, eutrophication and degradation of coastal ecosystems, are at least potentially, within human capacity to control [68]. These factors must now be added to the previously narrower definition of the scope of fisheries management (namely to control fishing effort) and clearly fisheries and environmental management must be combined in some way in the future.

6. Some social, economic and institutional aspects of fisheries management

As discussed in Section 2 above, inland and coastal fisheries have been managed for centuries, and local communities in many parts of the world had formal or informal mechanisms and structures for regulating access and avoiding over-exploitation of their resources. The efficacy of their attempts to regulate exploitation should not be over-estimated and [69] discusses their weaknesses and failings. Nevertheless, they did play an essential role in reducing conflicts, engendering a sense of stewardship in the users of the resource, and in maintaining some control on effort or destructive fishing practices. However, the rapid advent of industrialisation on fisheries at the end of the last century and beginning of the 20th century changed the emphasis in fisheries management.

McGoodwin [13] suggested that a preoccupation by the public at large with large-scale industrial fisheries has persisted through much of this century, and has been encouraged by the greater homogeneity of large-scale fishing enterprises. This made it easier for bureaucrats to communicate with the leaders of the industry than with the dispersed and culturally heterogenous group of small-scale fishers. Whatever the reason, fisheries management in this century has so far been largely focused on industrial scale commercial fisheries and in many countries these industries have close working ties with centralised government departments. Allocations of exclusive fishing rights by government to enterprises operating primarily in offshore areas, is a fairly common phenomenon [70], but one that in some countries has led to their encroachment on inshore fishing areas and to conflicts with artisanal fishers.

As the science of fish stock assessment developed, assessment expertise was incorporated within national Departments of Fisheries or their equivalent, and natural scientists rose to ascendancy as the influential group within government that could claim to provide quantitative options to managers. Fisheries management became less the process of solving the day-to-day problems of fisheries constituents than the medium- to long-term process of realising scientifically defined objectives such as the effort level corresponding to maximum sustainable yield (MSY) or the catch or effort corresponding to an $F_{0.1}$ level of mortality.

The economists were soon drawn in, and one of the earlier economic studies was undertaken by the same Graham who developed the model of population growth referred to earlier. A key observation in his study was that "Fisheries that are unlimited become unprofitable" (quoted in Ref. [71]). This axiom was incorporated in mathematical models and used to define a maximum economic yield (MEY) for a fishery. It was quickly pointed out, however, that in an open access fishery, MEY would soon be exceeded, and that the real point of equilibrium would only be reached when fishers were only breaking even economically. The lack of stability or automatic convergence on the MEY reference point has had profound impacts on fisheries, and acquired its rallying call in the publication "The Tragedy of the Commons" by Hardin [72]. In this publication, Hardin predicted that biological over-exploitation and economic collapse are inevitable for any natural resource exploited as a common property. He has been rightly criticised for confusing "common property" regimes such as those shared by a limited number of shareholders, with fully open access regimes [13], but the basic need to limit access to ensure sustainability is evident and in the last few decades is apparently being heeded. All of which suggests that the pronouncements of Queen Elizabeth I and Grotius made several hundred years ago are finally being reversed.

One of the most publicised consequences of the growing awareness of the need to limit access has been the wide adoption of individual transferable quota schemes, with perhaps the longest track record with this mechanism being fisheries in New Zealand [73] and Iceland [74]. ITQs, through resource ownership and transferability, encourage economic efficiency, but without adequate controls, may encourage the development of monopolies and there have been fears expressed that they could lead to alienation of local small-scale fishers. They are also, in their current applications, essentially a single-species tool, and generate problems in multispecies fisheries, including discarding and high-grading [75]. They are still seen by many however, as the current frontier in the progression of industrial-scale fisheries away from common property systems. In other respects however, their analogy with food production systems on land should be more with pastoral transhumance systems than with agriculture. We may expect to see parallel developments as extensive aquaculture moves towards sea ranching systems within a more territorially based management modality.

There has been some resistance from small-scale fisheries against the pressures of modernisation and industrialisation, and in many countries the two sectors have remained separate and parallel. McGoodwin [13] noted that comprehensive studies of small-scale fisheries started to appear in the literature in the 1950s, at much the same time as the dangers of open access were being debated. Some of these studies drew attention to the traditional regulatory systems that had existed before being overruled by centralised bureaucratic control which favoured the industrial sector. He also drew attention to the consequent alienation of the small-scale sector from 'top down' management systems, giving rise to low levels of compliance, conflicts and other inefficiencies [76]. Out of this has resurfaced the concept of user participation in management, community-based or fisheries co-management. That the revival of interest in traditional community-based management practices is very recent shows up in the literature: the vast majority of the 176 papers in the annotated bibliography of Flood [77] on this subject were published after 1988.

The options for user participation are now being widely discussed, often drawing on traditional models [76,78,79]. These include TURFs, based on traditional systems from Africa and the western Pacific [71], and Pacific basin [80]. These examples provide a number of models showing how the right to fish can be allocated to and administered by communities or cooperatives.

The replacement of traditional right systems in some areas by industrial fisheries developments, with more recently, the partial move back to recognition of user rights (e.g. the recently recognised rights of Maoris, North American West Coast Indians and other indigenous or tribal groups), are examples of the legislative trend towards restoration of traditional access rights. This is based on natural justice, but also on the recognition that usurping these rights contributes to social unrest, endangers food security and employment, and leads to unwanted migration of the unemployed to large urban centres. Implied here is a move to local rights-based systems for inshore resources, and at least partial delegation of management from the national to regional/local levels. Such a delegation of rights allows local communities to seek legal recourse for damages to coastal resources, e.g. from pollution by other marine activities [81].

7. A perspective on fisheries management measures in the third Millennium

Despite the emphasis in recent literature on fishery management by input or output control, a modern suite of technical measures will play a key role in making these key control measures effective. Technical changes have been occurring slowly that make fisheries more selective and less destructive, including use of square meshes, Turtle Excluder Devices, systems to avoid incidental capture of marine birds and mammals, etc. and to reduce unwanted by catch.

The ongoing debate between selective fishing to avoid discards, and a search for their effective use, is going to determine the direction taken by industrial fisheries after 2000. Selective fishing and stock restoration of long-lived species could lose out to the promotion of by-catch utilisation and to the industrial transformation of small forage fish. Examples here are the North Sea sand eel fishery and the small mesh trawl fishery in the Gulf of Thailand. This modality risks having ecological repercussions on marine biodiversity. The technology already exists to use mixed fish as a protein base and produce a variety of surimi and synthetic products, and this seems the path of least resistance where short-term socio-economic priorities prevail.

The question of what fisheries management will look like in the next century and beyond requires an understanding that we can only start to address if first we decide what frames of reference or paradigms are likely to apply [7]. At the most abstract level Charles [82] points to three sets of 'world views' that are competing for influence: the conservationists, the rational users of resources, and those who would design a management system around social criteria. The mechanisms proposed can range from privatisation of the resource, government intervention or community-based local management. These approaches will depend on the local political context and the nature of the resource and environment, but in general, community based approaches will tend to be applied more inshore, with some or all management responsibilities for inshore resources being explicitly ceded by national governments to local entities.

However, it is not at all certain that management by the private sector will be similarly confined to inshore areas. Certainly, most management approaches can only be extended offshore in a cost-effective fashion by the application of new technologies for position-locating of vessels and grounds, and this might be the case in future years if governments can agree on international frameworks for action.

At the time of final writing (January 2001), the UN Fish Stocks Agreement had been ratified by 28 countries and was hence very close to the 30 required for ratification of the Agreement. However, the recent establishment of a new fishery commission which covers waters beyond 200 miles in the Southeast Atlantic (and excludes the EEZs of coastal states), suggests that the requirements of the Agreement are already being put into effect. Such solutions to urgent resource management deficiencies appear to provide one of the few solutions open to conserving the deep-water, slow-growing, fishery resources of the continental slopes, ridges and sea mounts, that are currently facing largely uncontrolled exploitation.

As access to resources is increasingly limited to long-term stake holders, the key question is whether the recipients of these rights of access or ownership will perform in accordance with the theory, and demonstrate long-term stewardship over the resources, resulting in sustainable fisheries. At present we have no general answer to this question, and the attitude to conservation within different fisheries management bodies will be determined by factors such as the degree of dependency of the fishers on the resources [8] or the appropriateness of the specific rights allocation and system for the bio-political context of the fishery. Adverse environmental trends and variability, especially where adverse conditions occur over lengthy periods, also increase the likelihood of over-exploitation, especially where the management system is weak. One can only hope that in practice, over-exploitation of fishery resources will be constrained by the application of the legal instruments and guidelines developed during the 20th Century such as the UN Law of the Sea and Fish Stocks Agreement, and the FAO Code of Conduct for Responsible Fisheries and Compliance Agreement. It is certain that pressures to over-exploit will increase in an attempt to satisfy expanding global markets for fish and the further upward movement of fish prices this will entail. Under these circumstances a management vacuum or ineffective measures will inevitably lead to stock depletion.

Some other developments which may help to counter the pressure of demand include eco-certification which seems poised to become more influential [28], and will lead to consumer pressure on fishers and fishery managers. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is another mechanism which can act through regulation of the global trade in fish, and is currently examining several marine species for possible listing as endangered species for which trade restrictions could apply. This attention by governments, consumers and NGOs to the management of marine resources is destined to grow and will put pressure for more precautionary measures where data sources (as inevitably in many fisheries) are poor. The world community has become more aware of the dangers facing marine ecosystems and perhaps belatedly now appears anxious to conserve this last wild frontier of our planet.

These societal concerns are also likely to lead to managers having to move away from reliance on single-species approaches to ecosystem-oriented approaches to fisheries management. Although application of an ecosystem model has been formally mandated within the 'Comprehensive United States Ocean Policy and Law of the Sea' [83], in practice, the international community is still seeking precedents for how ecosystem approaches should be implemented. With our present poor state of knowledge of the dynamics of ecosystems and the resulting escalation in uncertainties which need to be considered, this will require precautionary management measures which are more comprehensive, robust and conservative than existing approaches. If successfully applied in conjunction with the necessary standard measures required in each case, such as effort reduction and limited access, there should be medium to long-term rewards for short-term sacrifices made principally by fishers, in the form of recovery of many ecosystems and consequent improved yields over the long term [9].

In response to growing awareness of the failures of fisheries management, there have been widespread attempts to improve its performance, most notably by greater emphasis on assessing the uncertainty in stock assessments and management systems and considering these in decision making; and through attempts to involve fishers and other interest groups in the management process. These attempts have undoubedly had their benefits, but have brought with them escalating complexity in the management process, resulting in increased expenditure and demands on the time of all participants in management. There have been as yet few rigorous comparisons of the costs and benefits of the different components of modern management systems. Such studies carried out to date cast doubt on the genuine reductions in uncertainty in management achieved through more intensive and expensive stock assessments and consultations [84,85]. The challenge for the immediate future is to evaluate the effectiveness and cost-effectiveness of existing management systems, and develop systems that are both cost-effective and robust to the full uncertainties inherent at all stages of the fisheries management cycle.

Who will be the stakeholders after 2000? From what we have written so far, we may ask if fishers will come to acquire exclusive geographical use rights similar to those that applied in traditional coastal fisheries earlier in the last Millennium. In other words, will we see a repetition of those events that led to the enclosure of the US prairies in the 1800s [86] whereby governments ceded geographical or resource-specific rights to 'first comers'? Alternatively, will governments retain rights over resources, or lease or cede them to local communities and the private sector? The criterion of extracting rent from the fishery is common to most economic theories, but is rarely achieved in practice and this objective itself may not be compatible with societal concerns, historical rights or equity. Obviously no single solution will emerge.

As we have noted, a basic paradigm change may be in the wind here from the present system with its echoes of 'freedom of the seas' to a situation where a resource is not seen as being available to harvesting everywhere and year round, except when otherwise specified. We could be seeing 'exploitation windows' or the evolution of 'space-time leasing systems' whereby specific season-area rights if not already established by custom are, for example, leased or auctioned to the highest bidder. A further development of rotating harvest schemes for territorial or sedentary species could similarly see periodical opening of 'windows of opportunity' auctioned or leased by the management authority. Extracting rent from the fishery will be needed to support research, and control and surveillance systems, which once exclusive rights have been assigned, may no longer be available cost-free from the public sector.

According to Larkin [33] 'over the next 50 yr aquaculture production will equal, if not surpass, wild production of fish'. Whether this can be achieved without' double-counting' of wild harvests used for the fishmeal which underly much current mariculture production, and given the environmental impacts of escalating mariculture, remains to be seen. Almost certainly however, we are going to see a further proliferation of mariculture and sea ranching. It seems very likely that fisheries regulations for so-called wild resources will come to resemble those for extensive aquaculture, with area-specific access rights gaining ground.

Some forces still oppose allocating exclusive rights over marine resources to a favoured few in the fishing industry. In some developed countries this is rapidly coming down to the question of whether the green movement and/or consumers will have the controlling vote on resource policy via new mechanisms such as eco-certification. The other basic question is whether it will be possible to reconcile the ongoing debate between the conservation movement and those following the sustainable development theme pronounced at UNCED. The first of the seven principles for enlightened conservation of exploited resources proposed by 42 eminent experts in the field of marine resources [87] states: " Maintenance of healthy populations of wild living resources in perpetuity is inconsistent with unlimited growth of human consumption of and demand for those resources". There seems no doubt as to the veracity of this proposition, but human populations continue to grow and the demand for fish seems highly likely to exceed production for the foreseeable future [17].

Humane considerations as they relate to marine mammals and their harvesting, and a growing appreciation of the importance of marine biodiversity, have gained ground in recent years, aided by extensive exposure in the media. Whereas previously 'environment issues' referred exclusively to the biotic and abiotic milieu supporting living marine resources, these now include the whole marine sector. Marine mammals and other 'charismatic' resources such as sharks and sea birds, unexploited resources and even coastal communities and their harvesting activities are progressively seen as 'environmental' as opposed to resource issues.

How the debate over the utilisation of marine mammals will proceed in the future is difficult to predict. Current stalemates at the International Whaling Commission on decisions to reopen fisheries where there is some evidence of stock recovery could lead to the inauguration of new regional or subregional bodies with more proactive approaches, although these will be opposed by some conservation interests. What will be the acceptable method of population control for marine mammals when full stock recovery is realized at some time in the future? What will be the consequences of this for food security? 'Non-exploitative uses' of marine mammals are increasing in popularity, with increased revenues from eco-tourism, but if marine mammal populations eventually recover to their virgin stock size, will it be reasonable to set aside a large share of ecosystem productivity and potential fishing grounds for supporting marine mammals and other 'charismatic' species? We can only await societal development and changing cultural views to see the results of this debate, which may have significant consequences on the level of marine harvest that can be set aside for man.

Governments are going to retain a key role particularly with regard to transboundary and offshore resources, but how is the shared stock and straddling stock problem going to be solved? So far, very little progress has been made, and relatively few joint commissions like the Comisiòn Tècnica Mixta Marìtimo set up between Argentina and Uruguay for managing the shared resources of the River Plate and its seaward extension have been established. One possible solution to shared resource problems [62] may be the relegation of fishing rights by all parties to a joint multinational company in exchange for shares and rent recovery to each national party. Certainly, theoretical studies of shared resource situations [88] suggest that in practise, reaching an agreement that also conserves the resource is not necessarily a foregone conclusion, and this is an area where innovative thinking and working precedents are urgently required.

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