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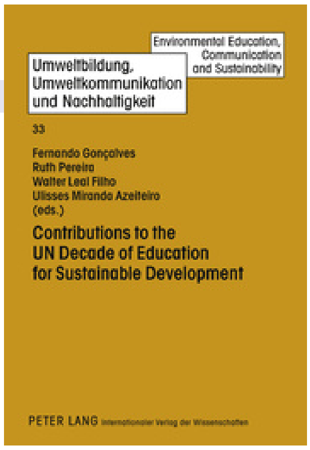

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Book synopsis

This book presents essential learning approaches. It introduces educational and training activities, as well as various innovative methods aiming at the development of practical skills, in order to strengthen the continuous process of environmental education, and in particular the education for sustainable development (ESD). In doing so, it focuses on three dimensions (social, economic and environmental) as a means of achieving an effective change of behaviour and «tries to bridge the gap between science and environmental education by describing a set of projects, initiatives and field activities». A special emphasis is put on teacher training programmes, conception, and implementation, highlighting the problems and barriers, which prevent development as far as integration of sustainability issues in higher education is concerned.

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Sustainability of Fisheries

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Abstract

This chapter reviews the concept of sustainability in fisheries, focussing on fisheries in Europe and paying particular attention to the human dimensions of fisheries. The particular problems presented by fisheries (related to the "Tragedy of the Commons") are introduced, followed by brief accounts of the importance of fisheries worldwide and of their history in Europe. We attempt to summarize the concepts embodied in fisheries management and governance and review the different dimensions (pillars) of sustainability in the context of fisheries: environmental, economic, social and institutional. We describe some current developments in management and governance of European fisheries, including the introduction of property rights, the role of ecological labelling and the concept of demand-led management, participation and co-management, marine protected areas and Integrated Marine Management. We advocate a system of governance under which more attention is placed on achieving the possible than in quantifying the unachievable, a system which delivers successful implementation of sustainability objectives based on holistic (and multidisciplinary) assessments of environmental, economic and social-cultural consequences of proposed actions and which is based on the full and active participation of all relevant stakeholders.

Introduction

In contrast to the terrestrial environment, provision of food from the sea remains largely based on what is effectively a hunter-gatherer system, albeit an increasing technologically sophisticated one. Unregulated marine fisheries provide a paradigmatic example of the Tragedy of the Commons (Hardin 1968), whereby individual fishers do not benefit in the long-term from refraining from catching more fish in the short-term, so long as other fishers choose not to show similar restraint.

It is generally accepted that heavy and poorly regulated exploitation has led to the depletion of a large proportion of the world's fish stocks and has caused some scientists to forecast the imminent end of marine fisheries as we currently know them (e.g. Worm et al. 2006). It is of course human nature to foresee disaster: previous impending disasters, like the feared consequences of human overpopulation (a major focus of popular science in the 1960s), have not always materialized. In addition, at least in the northeast Atlantic, concern about the state of fish stocks is nothing new (see Sims and Southward 2006, who recall the debate occurring in the UK towards the end of the 19th century), and every generation judges the current perceived status of fish stocks against the shifting baseline of its own experience (see Pauly 1995). Nevertheless, and despite the cautious optimism expressed by some authors (e.g. Hilborn 2010; see below), there are profoundly worrying global trends. Zeller et al. (2010) show that a range of indices indicate global scale ecosystem damage due to fisheries, for example a shift from "unstressed" marine communities, dominated by species with large individual biomass but low abundance, towards "stressed" communities dominated by highly abundant species of small individual body size.

The International Council for the Exploration of the Sea (ICES), which is the main organization at European level producing advice on the state of the stocks exploited by the European Union (EU) fleets considers that many fished stocks in European Union waters are currently overexploited (ICES 2010). In addition, wasteful practices such as discarding persist, to the frustration of both fishers and fishery scientists, among others. There may thus be better ways to use limited resources to achieve sustainable fishing. Indeed the present emphasis in Europe on developing an Ecosystem Approach to Fisheries may be counterproductive in the sense that it requires dedication of more resources to obtain the required biological and ecological information, potentially making it even harder to successfully balance competing objectives and ensure effective implementation. These are, of course, also not new ideas. For example, the EU project INCOFISH ("Integrating Multiple Demands on Coastal Zones with Emphasis on Aquatic Ecosystems and Fisheries") was based on the ideas that traditional assessment could be largely replaced by using simple indicators of stock status that could be readily understood by scientists, stakeholders and consumers, and that consumer power could be harnessed to promote sustainable harvesting.

In general, when speaking of fisheries, unless otherwise stated, we refer to capture rather than culture, to commercial fisheries rather than recreational fisheries, and to harvesting of fish, crustaceans, molluscs and some other marine invertebrates (including jellyfish, sea anemones, sea urchins and sea cucumbers). The term can also legitimately be extended to encompass the hunting of marine mammals (e.g. seals, whales) for human consumption although marine mammals are now protected in many countries.

There are many textbooks about fisheries (e.g. Cushing 1975; Hilborn and Walters 1992; Jennings et al. 2001; King 2007, to list just a few), and a huge literature on related topics in scientific journals. Here we will not attempt to cover all the biological and technical aspects of fish stock assessment and fishery management. Our aim is, rather, to provide a short overview of current issues, with an emphasis on the human dimensions of fisheries[1], and to highlight possible solutions to historically persistent problems. It should be self-evident that successful fishery management, the usual broad goal of which is "sustainable" fishing (i.e. meeting the needs of the present without compromising the needs in the future), depends on managing human behaviour. In this sense, while traditional fisheries science encompasses consideration of the economic benefits of fishing (e.g. based on the yield-per-recruit concept, Beverton and Holt 1957), in general the tendency to focus on the (biological) status of fished stocks has led to less consideration of balancing ecological, economic and social objectives, and the implementation of policies, which also require a strong scientific basis. Slightly more radically, there may be a case for developing demand-based fishery management rather than focusing only on regulating the supply of fish.

The Importance of Fisheries

The Food and Agriculture Organization (FAO) of the United Nations estimates that capture fisheries and aquaculture supplied the world with about 110 million (metric) tons of food fish in 2006 of which capture fishery production was about 92 million tonnes. Since the mid-1980s, landings of captured fish have been stable or decreasing, as many stocks become overexploited. In the current context of overall resource scarcity and decreasing catches, aquaculture production assumes a key importance. Aquaculture is a rapidly growing industry, which has experienced an enormous expansion in recent decades, and continues to be the fastest growing animal food-producing sector. It presently contributes about 47% of the marine food supply (FAO 2009), although this figure is misleading in that capture fishery landings include a significant proportion which is not used directly for human consumption, one important use of which is the production of feed for use in aquaculture and to feed other animals. It should also be noted that capture and culture fisheries are not completely separate entities. Apart from the use of wild caught fish in feed, the practice of "ranching" high value wild-caught species such as tuna and octopus (e.g. Volpe 2005; Chapela et al. 2006) is increasingly blurring the line.

Fish and fish products contribute to food security in many regions of the world, in some cases representing staple foods, or at least the main source of animal protein, and elsewhere representing a valuable supplement for diversified and nutritious diets. Overall, fish provided more than 2.9 billion people with at

1 Some basic concepts in fishery management are defined and briefly described in Boxes 1 and 2.

least 15% of their average per capita animal protein intake (FAO 2009). In addition, capture fisheries and aquaculture play, directly and indirectly, an essential role in the livelihoods of millions of people around the world. In 2006, an estimated 43.5 million people were directly engaged (part-time or full-time) in fish production, either by fishing or working in aquaculture. Furthermore, for every person directly employed in fisheries and aquaculture it is estimated that there could be four more employed in related activities (such as fish processing, marketing and services industries) (FAO 2009). In addition to their contribution to worldwide national economic activities and employment, fish and fishery products are important in generating foreign exchange: they are highly traded, with more than 37% (live weight equivalent) of total production entering international trade, as various food and feed products (FAO 2009).

The European Union (EU) is the fourth largest seafood producer world-wide, contributing approximately 4.6% of global capture fisheries and aquaculture production (see table 1 for macroeconomic indicators). In 2006 European capture fisheries and aquaculture supplied the market with 6.4 million tons. Domestic demand for fish products within the EU is high, and per capita consumption of seafood is increasing. In addition, the fish catching, culture and processing sectors provide over 141 000 jobs in the EU (European Commission 2010).

Table 1: Macroeconomic indicators for fisheries in the world and the EU-27

	World	**EU-27**
Total fisheries (= catches + aquaculture)	143.6 million tonnes	6.44 million tons
Capture fisheries (weight)	92.0 million tonnes	5.14 million tons
Capture fisheries (value)	91.2 billion US$	8.2 billion EUR
Aquaculture (weight)	51.7 million tonnes	1.31 million tons
Aquaculture (value)	78.8 billion US$	3.2 billion EUR
Imports (value)	85.9 billion US$[1]	16.5 billion EUR[2]
Exports (value)	85.9 billion US$[1]	2.9 billion EUR[2]
Human consumption	110.4 million tonnes	11 million tons
Per capita annual consumption (kg)	16.7 kg	22.3 kg
Total people employed	43.5 million	141 thousand
Vessels (number)	2.1 million[3]	89 thousand
Vessels (gross tonnage)	–	1.93 million tons
Vessels (engine power in kW)	–	7.06 million kW

Source: EUROSTAT (2009), European Commission (2010), FAO (2009). World data refer to 2006, EU-27 data refer to the 27 EU Member States, in 2007.

Notes: [1] Total value traded worldwide; [2] External trade of fisheries and aquaculture products (trade between the EU and third countries); [3] FAO obtained data on national fishing fleets from 97 countries (slightly fewer than half of those catching fish). Value represents number of vessels powered by engines.

Aquaculture is increasing in importance within the EU, now accounting for almost 20% of fish production. However, total EU seafood production has been decreasing for the past 20 years (European Commission 2010). For some time now, EU fisheries and aquaculture have not been able to meet domestic demand, resulting in the EU being the world's biggest importer of fishery products, at a time when many exploited fish stocks in European waters are at historically low levels. The environmental and socioeconomic sustainability of fisheries and aquaculture within the EU is thus a major current concern.

History of Fisheries Management in Europe

Concerns about the depletion of fishery resources are not a recent phenomenon: 120 years ago, the rise in fish trade and reports about the scarcity of fish from all around the United Kingdom's coasts strengthened widespread concern among fishing communities and scientists prior to the International Fisheries Exhibition in London in 1883 (Sims and Southward 2006). Indeed, fisheries have rarely been "sustainable". Rather, fishing has induced serial depletions, masked by improved technology, geographic expansion and exploitation of previously spurned species lower in the food web (Pauly et al. 2002). As previously mentioned, inevitably our perception of the status of fisheries is informed by our own experiences, i.e. the shifting baseline concept (Pauly 1995). In some areas traditional fisheries continue much as the previous generations might remember them; in others, the fishing has all but disappeared (compare pictures from different parts of Lisbon in the 1940s and in 2010 (fig. 1, 2).

Fig. 1: Postcard of a fishing village (Cascais, Portugal), (a) around 70 years ago. Private collection. (b) same area in 2010

(a)

(b)

Fig. 2: Postcard of the fishing activity in Cais da Ribeira (Lisbon, Portugal), (a) around 70-80 years ago. Private collection. (b) same area in 2010

(a)

(b)

In some parts of Europe, fisheries management has a long history. For example, in the Lofoten islands (northern Norway), laws have existed for more than 200 years to control fishing activity. However, fisheries management as we currently understand it is a relatively new concept (see boxes 1 and 2 on the evolution of concepts in fisheries management). As recently as the 1960s, marine fisheries in Europe were largely unregulated. The first common measures in the European fishing sector can be traced back to the early 1970s, when the then member states of the EU reached agreement on access rights for their fishing vessels and the establishment of a common market for fisheries products. The late 1970s and early 1980s saw the development of a common policy on fisheries and the assumption of the centralized authority, by the EU, for the regulation of commercial fisheries. This culminated in the establishment of the Common Fisheries Policy (CFP) in 1983.

Two decades later, in 2002, the CFP underwent a radical reform and several new concepts were introduced and/or implemented in an attempt to tackle the serious consequences of overfishing (see table 2 for a chronology). This reform saw the beginning of a more long-term approach to fisheries management, with the implementation of multi-annual recovery plans, and the introduction of restrictions on fishing effort and of a precautionary approach to management. It saw the end of aid for the modernization of the fleet and the establishment of measures to support the decommissioning of fishing vessels. It also facilitated the implementation of measures to allow for an increase in stakeholder participation in the decision-making process (with the subsequent creation of Regional Advisory Councils) and aims to progressively implement an "ecosystem-based approach to fisheries management" (EAFM). Further reform is envisaged for 2012. The Green Paper, setting the way for the forthcoming reform of the CFP, indicates that the new policy will focus on addressing the deep-rooted problem of fleet overcapacity, improving the system of governance by giving more power to the fishing industry, developing a culture of compliance, adopting long-term management plans, adopting a regionalized management regime, and integrating fisheries management in the broader maritime policy context.

Table 2: Development of the Common Fisheries Policy (CFP)

Year	Description	Regulation
1976-1982	Set the rules for the CFP, with emphasis on conservation of fish stocks, allocation of fishing rights, regulation of fishing fleets	–
1983	Establishment of the CFP (main areas of activity: Conservation of stocks, vessels and installations, market controls, and external agreements with other nations).	Regulation 170/83
1992	First review of the CFP, resulting in minor amendments (measures to improve compliance, more restrictive regulations and improve monitoring)	Regulation 3760/1992
2002	Reform resulting in a new framework regulation (aimed at ensuring the sustainable development of fishing activities, and improve the basis of the decision-making process)	Regulation 2371/2002
2012	Forthcoming reform of the CFP	–

In order to ensure sustainable fisheries, the CFP introduced various "conservation measures", including rules for total allowable catches, limitation of fishing effort, and technical measures (related to gear and vessel characteristics). However, as in fisheries throughout the world, few of the measures introduced worked exactly as planned. In practice, the CFP has had very mixed success. Some fish stocks, especially those that have been subject to long-term management plans, have remained in a healthy state. For example, among stocks exploited by Scottish fleets, North Sea haddock, North Sea herring, Rockall haddock, and mackerel are all currently doing well. On the other hand, many stocks have been seriously overexploited, including North Sea cod (although biomass is increasing from a historic low point in 2006) and herring (which has gradually recovered since the mid-1970s) (ICES 2010). However, serious concerns remain about fleet overcapacity, exploitation of vulnerable species (e.g. deep-sea fish), wasteful practices such as discarding, environmental degradation (e.g. damage to the sea bed caused by trawling) and effects on non-target species including by-catch mortality of sharks and marine mammals. In short, there is a widely held (if not wholly correct) view that European fisheries are in crisis.

Box 1: The evolving concepts of fishery management in Europe:
A. Fisheries as biological systems

Here we present a very brief (and simplistic) overview of concepts in fishery management. Some of the recent terminology has its origins in the USA but the processes described are increasingly relevant to European fisheries, even if (paradoxically) we have yet to fully engage with the human dimensions of fisheries (see Fig. 3).

In its simplest current form, **fishery management** consists of **stock assessment** (i.e. evaluating the status of a fished population or stock[2], and setting **harvest rules** (e.g. catch quotas, fishing effort limits, specified gears, closed areas) designed to ensure a sustainable harvest. For the system to have any chance of working there must also be **monitoring** of compliance and enforcement of **regulations**, which is where management becomes subsumed within the concept of **governance**. Since this falls outside the remit of traditional fisheries biology, we leave further discussion until Box 2.

Maximum Sustainable Yield (MSY) can be achieved by harvesting the stock so that abundance is maintained high enough to ensure good **recruitment** (i.e. a sufficient number of young fish are produced that can enter the fishery) but not so high that density-dependent regulation starts to restrict population growth. Needless to say, while mathematically easily defined, keeping a fishery at MSY is very hard to achieve in practice, since (a) the precise values will keep changing due to environmental variation, through its effects on environmental carrying capacity and, probably more importantly, on recruitment (i.e. the stock's ability to replace itself) and (b) once a fishery has grown sufficiently to achieve MSY it is very hard to reduce effort again when MSY is exceeded. Reflecting these difficulties, the current focus in EU fisheries is on achieving F_{MSY}, i.e. the fishing mortality required to achieve MSY.

Not all mature fish are equal. Taking into account the effect of body size and condition (and environmental factors) on the number and quality of eggs produced could lead to a better understanding of recruitment and a better estimate of the "optimum" stock size. Large, old females (**megaspawners**) may contribute a disproportionately large number of offspring and it may be useful to take special measures to protect them.

In many modern fisheries, stock abundance is so far below MSY that it becomes important to define "limit" or "precautionary" **reference points** for fished populations. If abundance falls below defined reference points, some kind of remedial management action should be triggered (e.g. fishery closure).

In practice, we never have perfect knowledge of fish abundance, we cannot perfectly control fish catching (if indeed we can control it at all), and the intrinsic variability of natural systems (**stochasticity**) makes us less certain (e.g. the correlation between the number of breeding fish and the number of young fish reared, the **stock-recruitment relationship**, may be very weak). According to the **Precautionary Approach** to management, catch limits should be set low enough to make stock failure (due to any of the above reasons) unlikely.

Many fisheries catch several different species, while the same species may be caught by more than one fishing fleet. In **multispecies** fisheries, we need to consider that optimizing catches of one species could result in too many of another species being caught. Managers must decide on the objective (is it to maximize total yield, to preserve the most vulnerable stock or to identify an acceptable trade-off?) and set harvest rules accordingly. It may be possible to define a "**multi-species MSY**". In **multi-fleet** fisheries, more complicated harvest rules may be needed to ensure that each fleet takes an equitable share of catches.

Fishing can have profound negative impacts on the marine ecosystem. Firstly and most obviously, overfishing of target species can reduce their abundance and disrupt trophic webs. Fishers also catch

2 Although we use "population" and "stock" interchangeably, the first strictly refers to a genetically distinct, reproductively isolated (and usually geographically discrete) grouping of conspecific animals, while the latter is a management unit, often the same as a population but sometimes (e.g. for political reasons) representing only a part of a population or even a mixture of several populations.

species which were not being targeted (**by-catch**), some of which may be vulnerable and/or have a high public profile (**charismatic megafauna**, e.g. dolphins, turtles). Fishers may throw overboard (**discard**) those species and sizes of fish that cannot legally be landed or which are of low value. Trawling can damage the seabed and benthic communities. The **Ecosystem Approach to Fishery Management (EAFM)** envisages use of **Ecosystem Health Indicators** to carry out an "ecosystem assessment" (including the usual stock assessment), possibly leading to the definition of an "**Ecosystem MSY**" for the target fish species (i.e. the MSY is modified to take into account effects on the ecosystem), presumably leading to modified harvest rules.

Even more than multi-species fisheries, EAFM presents a major challenge to fishery scientists and managers by increasing the amount of information needed, to permit a full assessment and define adequate harvest rules, by orders of magnitude. This has resulted in two very different (although not mutually exclusive) trends in methodology: (1) development of increasingly complex mathematical models, sometimes by combining different kinds of models (e.g. traditional fish population dynamics models can be combined with models of ecosystem trophic structure such as ECOPATH and linked at one end to physical oceanographic models and at the other end to bio-socio-economic models (creating "end2end" models), and (2) complex models are replaced by simple indicators which "capture" the pertinent features of the system. It should be also noted that increased model complexity comes at a price, not just in terms of the data requirements to estimate multiple parameters, but because the uncertainty in each one makes it increasingly unlikely that the final estimate will be either accurate or precise.

The foregoing account very much follows a traditional fishery biologist's worldview, focusing on the biological and ecological aspects of sustainability. **Harvest rules** came within the ambit of the fishery scientists only in that they helped to define the currency in which fish stock status is expressed (e.g. tons of fish which may be safely removed). In practice, fishery scientists are increasingly required to provide **dynamic stock assessments** (Hilborn and Walters 1992), in which the future trajectories of fished populations are predicted under different possible harvest rules. Thus, recommendations about harvest rules now fall within the competence of fishery scientists – even if the options to be evaluated are still specified by the client, normally the management/regulatory authority. More recently the fishing industry has also been involved in setting, for example, limits on total allowable catches (TACs), signifying the increasing importance attached to socioeconomic objectives (e.g. market stabilization). Of course, some would argue that the industry has always been involved in setting quotas (and at levels which make sense only in terms of short-term profit), through successful lobbying. As Froese (2011) points out, an industry which in purely economic terms is less important than the sowing machine industry has always punched above its weight.

The increasing amount of information that must be processed and the inadvisability of conducting field experiments on real fisheries have led to the use of "**Management Strategy Evaluation**" (MSE), by which computer simulations (**scenario models**) are used to explore the interactions between the fish-fishery system and management (assessment + harvest rules), allowing much faster and less risky evaluation of options before they are implemented. This approach was developed by the International Whaling Commission for its "Revised Management Procedure" (see Cook 1995). A key component is understanding fisher behaviour in response to different stock status and harvest rule scenarios (Branch et al. 2006). This concept can be expanded to include consideration of effects of fishing (and other human impacts) on the ecosystem, leading to "**Integrated Ecosystem Assessment**" (IEA).

Under **adaptive management**, a feedback loop is introduced such that harvest rules are regularly modified in the light of new evidence about the state of the stock following implementation of existing rules.

Even under this more sophisticated worldview, economic, social and political considerations are simply things that happen to advice after it has left the scientists, and often involve the advice being modified or ignored. This is of course an oversimplification but the **International Council for the Exploration of the Sea** (ICES), the body responsible for assessing many of Europe's marine fish stocks, followed this kind of model for around 100 years (although it is currently undergoing extensive reform).

Box 2: The evolving concepts of fishery management in Europe: B. The human dimensions of fisheries

To state the obvious, fishery management is about managing people. Fish cannot be managed. The concept of the **three (or four) dimensions or pillars of sustainability** emphasizes that fishery management is not (or should not be) designed only to achieve biological or ecological sustainability: this represent just one of the pillars. Two of the other three, to be given equal weight, are social and economic sustainability. **Economic sustainability** captures the value of fishing as a source of income to the fishers, support industries (e.g. processors) and ultimately the contribution to national GDP. It also considers fishing costs (e.g. the capital invested in a boat, and the running costs – fuel, salaries, etc). As noted by Hilborn (2010), economic objectives are often fairly compatible with biological objectives – although there are circumstances under which the "rational" economic decision is to fish a stock to commercial extinction (e.g. the case of whaling, where it may make more sense in economic terms to fish the stock to extinction and live off the interest on earnings, since whale populations grow at too slow a pace to justify waiting for recovery). **Social sustainability** concerns societal benefits of fisheries, such as the provision of jobs, and a major protein source, and maintenance of local communities. As Hilborn notes in the article cited above, social objectives can be difficult to reconcile with economic or ecological objectives.

Some sources (e.g. O'Connor 2006; Valentin and Spangenberg 2000) define a fourth pillar, as **institutional (**or **cultural) sustainability**, which may be thought of as the sustainability of the human system in which the fishery takes place. In particular it is useful to consider this as including governance, i.e. the **implementation** of fishery management, including the monitoring of compliance and the means by which regulations are enforced. In this way it can be seen that the governance system is not a fixed constraint, it is something that can itself be optimized. Indeed, arguably this is the single most important pillar of sustainability: successful implementation of a sub-optimal environmental/biological objective is likely to be less environmentally damaging than an unenforceable optimal solution.

Fishers are more likely to "buy-in" to management decisions in which they have participated, and more likely to be hostile to a **top-down** system in which they have no say. The move toward **fisher participation** and **co-management** is one of the key issues in the current reform of the CFP. Various local and regional bodies (e.g. **Regional Advisory Committees**) have given roles to fishers and other stakeholder groups (e.g. local communities, NGOs) in the decision-making process. In addition to allowing the consideration of non-biological objectives to become a legitimate part of governance, such arrangements can facilitate the inclusion of **fisher knowledge** into stock assessments.

In practice, current fishery governance structures tend to be more or less hierarchical, for example involving (moving from national or European to local or regional scales) (a) provision of advice, (b) strategic management decisions and (c) tactical management decisions, with different combinations of bodies involved at each level. There is of course a risk that such a hierarchy can perpetuate ingrained beliefs that environmental concerns should take precedence over social objectives or vice versa at particular scales.

The increased number of bodies participating in decision-making (each with their own sectoral objectives) and the need to explicitly incorporate objectives related to all four pillars of sustainability, including the need to optimize the management and regulatory (governance) system, has led to development (at least in the USA) of the "**Systems Approach**" to fisheries management (SA, or possibly SAFM), a generalization of the IEA/MSE approach. The key to reconciling different kinds of objectives is to have a common currency, normally the value in $ US. Clearly, issues remain about how social and ecosystem benefits should be valued in monetary terms. Under the SA, the cost of administering the management and regulatory system (governance costs) is included as a component of the model (something that, if done in Europe, might make the present governance system look impossibly cumbersome and costly in proportion to the size of the sector it governs), and it is possible to incorporate "hidden costs" (e.g., the risk of undesirable outcomes).

Results-based management does not involve specific harvest rules but rather passes the burden of proof to the fishers, i.e. requiring them to demonstrate that they are meeting specified targets for stock or environmental status (e.g. reducing by-catch of threatened species). The approach aims to provide incentives for fishers to devise mechanisms to achieve these goals, for example rewarding success by permitting increased fishing effort. This would normally be combined with co-management, such that all proposals are discussed and agreed on by fishers, scientists and regulators, and the success of the measures is regularly monitored. Current examples tend to involve local or regional scale fisheries.

Fishing is just one sector of human activity in the ocean. Others include aquaculture, oil and renewable energy extraction, marine transportation, tourism and marine conservation. Management and governance for sustainability thus becomes a multi-dimensional problem, enshrined in concepts such as **Integrated Coastal Zone Management** and **Marine Spatial Planning**.

Virtually every variant of management we have discussed above is **supply-side management**. However, **demand-side management** also offers options. **Eco-labelling** or **ecological certification** provides a mechanism to use consumer demand to promote sustainable fishing practices. The EU project INCOFISH proposed the slogan "Don't eat babies", and the "fish-ruler" tool, both to promote the use of simple harvest rules (and simple indicators of fish stock health) and to harness public opinion as a driver for sustainable fishing, by stigmatizing the landing of under-sized fish.

Sustainable Fisheries

What is Sustainable Fishing and why is it so Hard to Achieve?

In 1988 the FAO Council adopted its definition of sustainable development[3]. This was defined as

> "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development conserves land, water, plant genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable".

Following this, in 1995, FAO adopted a Code of Conduct for Responsible Fisheries, which offers an integrated comprehensive framework for the sustainable development of fisheries and aquaculture. More recently, it was agreed during the 2005 World Summit that sustainable development requires the reconciliation of environmental, social and economic demands, which became known as the "three pillars" of sustainability.Numerous policies and initiatives implemented in the EU over the last decade have been giving a new direction to fishery management. Concerns about sustainability, including environmental sustainability, are now at the heart of fishery management initiatives. Historical fishery management regimes are being gradually replaced by new regimes covering the eco-

3 Very similar concepts had been formulated previously, for example in the World Conservation Strategy (1980).

system as a whole. There have already been shifts in the nature of fishery management in Europe and further significant changes will follow in the near future (see also section 3 above). Table 3 shows some of the major drivers of current European policy in marine conservation which directly impact on fisheries management. Almost without exception, their aim is to increase sustainability.

Table 3: Some major developments in conservation and fisheries management measures over the last decade which impact on the fishing industry within the European Union (adapted from Pita 2010)

Year	Measure	Scope
2000	EU strategy for sustainable development	EU
2001	Biodiversity action plan for fisheries	EU
2002	Reform of the Common Fisheries Policy (CFP)	EU
2002	Johannesburg World Summit on Sustainable Development (WSSD)	International
2002	EU recommendation for Integrated Coastal Zone Management (ICZM)	EU
2003	OSPAR and HELCOM agreement	International
2004	Convention Biological Diversity (CBD)	International
2004	Establishment of the Regional Advisory Councils (RACs)	EU
2004	Introduction of requirement to monitor and mitigate cetacean by-catches in certain fisheries (although only applying to larger vessels)	EU
2004	Cod recovery plan adopted covering four stocks: (1) North Sea, Skagerrak and Eastern Channel, (2) Kattegat, (3) west of Scotland, and (4) Irish Sea. Effort limits impact other demersal stocks.	EU
2007	Proposal for an Integrated Maritime Policy (IMP)	EU
2008	Move from fisheries policy to maritime policy (EU Directorate General for Fisheries to DG MARE)	EU
2008	Marine Spatial Planning (MSP)	EU
2008	Marine Strategy Framework Directive (MSFD)	EU
2009	Green paper on the 2012 reform of the CFP	EU

However, commercial fishing is arguably particularly difficult to manage sustainably for several reasons. As noted above, marine fisheries are among the very few large-scale economic activities that could be described as “hunter-gatherer” systems. Fishing attracts active, individualistic persons who do not readily accept regulation of their activities. The sea is huge (covering 8 times the area of the world’s land masses) and largely inaccessible and hostile to air-breathing animals. Much of the area of the world’s oceans falls outside national boundaries and, even where national boundaries apply, in coastal waters, most fish species are highly mobile and are not confined by such boundaries, and ownership of these resources is (at least in practical if not legal terms) ill-defined. It is notable that in the EU, where most formerly national waters are now shared between many countries, fishery management has been less successful in achieving sustainability than in countries like Norway and Iceland that retain exclusive rights to their fisheries as far as the 200 NMI limit.

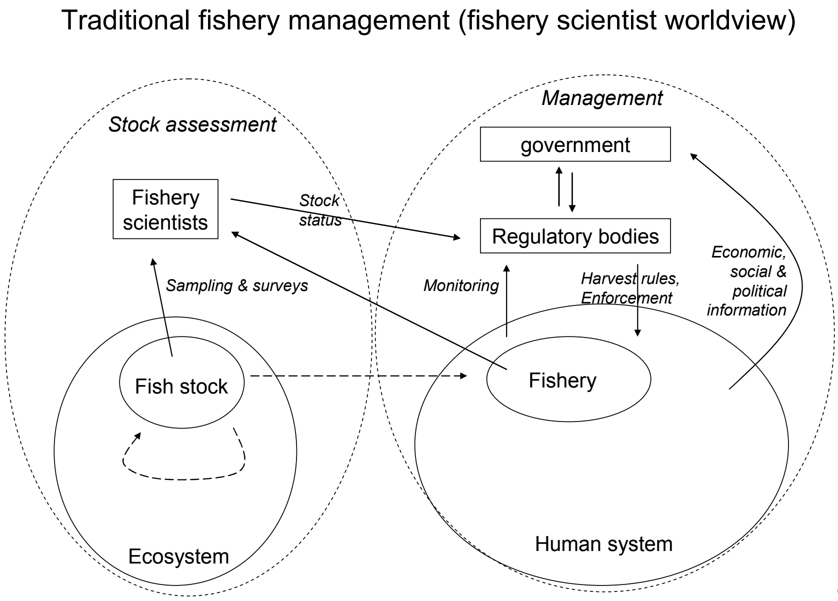
As with exploitation of the great whales, when investment is high and there is little prospect of maintaining a viable fleet if it is inactive, it may make economic sense to keep fishing until stocks are commercially extinct and then live off the interest from the income thus generated (although in times of economic crisis, the low interest rates available may, paradoxically, favour conservation of exploited stocks). Several great whale species were brought close to actual biological extinction, an extreme outcome which is unlikely in most fish species.

History suggests that fisheries are often unsustainable in practice, with many well-known examples of failed fisheries (e.g. North Sea herring, Peruvian anchoveta, and Northwest Atlantic cod), in which the phases of fishery development (from pre-development to collapse, see Csirke and Sharp 1984) were apparently inevitably played out. Evidence of imminent stock collapse rarely resulted in appropriate remedial action: Pauly (2009a) refers to the “toxic triangle” of underreporting catches, ignoring scientific advice and blaming the environment. Yet, while some authors (e.g. Worm et al. 2006) see this as a harbinger of doom, others, notably Hilborn (2007, 2010) are more optimistic, pointing out that, at least in the first world, overfished stocks are usually able to recover given appropriate management (e.g. North Sea and other herring stocks).

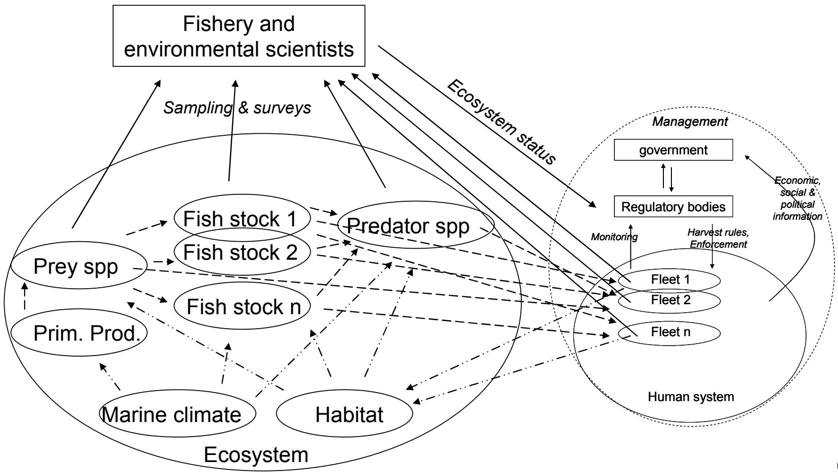
In Europe, great advances have been made in fish stock assessment, taking into account the multi-species and multi-fleet nature of many fisheries, as well as impacts on non-target species and the ecosystem as a whole (see box 1 and fig. 3a, b) and with a longer-term perspective. This has been matched by increasing recognition of environmental issues by policy-makers. Harvest rules have moved from simple Total Allowable Catches (TACs) or quotas to a combination of quotas, effort and gear restrictions, and area closures. However, scientific evaluation of the economic and social dimensions of fisheries has lagged behind and, in any case, implementation has consistently failed: agreed harvest rules may contradict scientific advice (e.g. quotas may be set higher than recommended), may be inherently flawed (e.g. rules about discarding), and may be ignored by fishers and/or not enforced. In principle the latter issue may be addressed by incorporating fisher behaviour into management models (see, e.g. Wilen et al. 2002), i.e. fishers are viewed as part of the system to be managed, and/or by involving fishers as partners in the management/governance process.

European fisheries face several major challenges: reducing fishing mortality to sustainable levels, adjusting fleet size to match the resulting opportunities, eliminating discards and by-catches, and achieving a sustainable system of governance. Once fishers (and other stakeholders) are fully engaged in the process, and it is evident that social and economic objectives are being given full consideration, the prospects of fisher "buy-in" to the regulatory system should be much improved (see box 2, fig. 3).

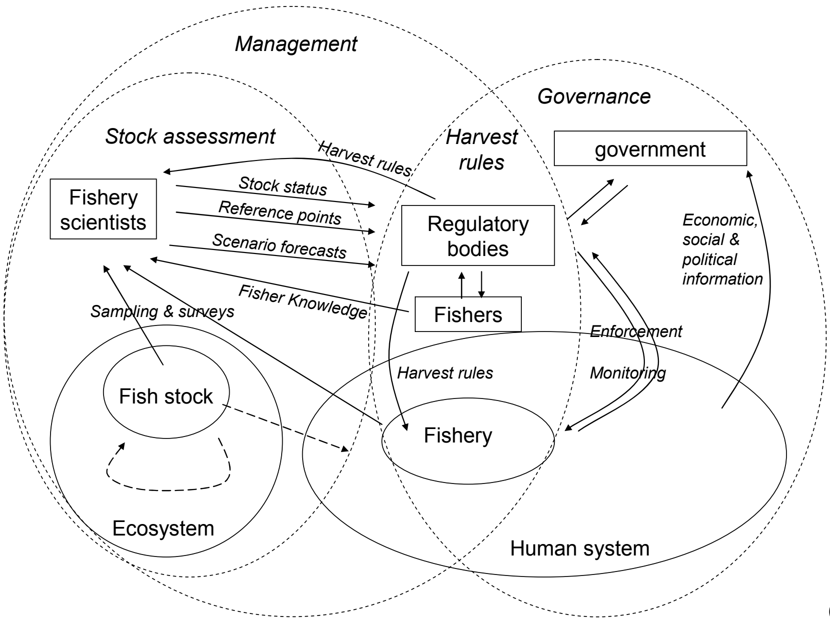
Fig. 3: Different concepts of fishery management: a) a simple system from a fishery biologist's viewpoint; b) the ecosystem approach to fisheries management, incorporating multi-species and multi-fleet assessments; c) co-management and integrated marine management.



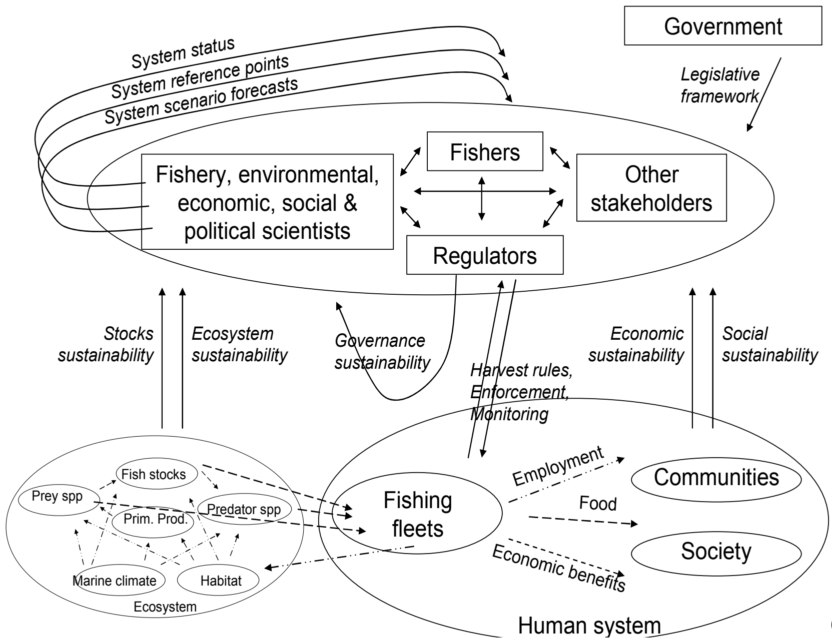
(a)


Fishery and environmental scientists
Sampling & surveys
Ecosystem status
Management
government
Regulatory bodies
Economic, social & political information
Monitoring
Harvest rules, Enforcement
Fish stock 1
Fish stock 2
Predator spp
Prey spp
Fish stock n
Prim. Prod.
Fleet 1
Fleet 2
Fleet n
Marine climate
Habitat
Human system
Ecosystem

(b)


Management
Governance
Stock assessment
Harvest rules
Harvest rules
government
Fishery scientists
Stock status
Reference points
Scenario forecasts
Regulatory bodies
Economic, social & political information
Fisher Knowledge
Fishers
Sampling & surveys
Enforcement
Harvest rules
Monitoring
Fish stock
Fishery
Ecosystem
Human system

(c)



(d)

Environmental Sustainability of Fisheries

Here we briefly review (a) aspects of fishing activity that may have adverse environmental impacts and (b) other anthropogenic factors that may negatively affect fisheries.

Reflecting past policy to invest in fisheries, and "technological creep", European fisheries suffer from *overcapacity*, i.e. the fleet has the capacity to catch more fish each year than can be sustainably removed. It is estimated that over 80% of assessed fish stocks in EU waters are overfished, compared with approximately 25% globally (Pew Environment Group 2009). It is common for fishers to be able to catch their annual quota allocation of fish within a few months (although, to put this in perspective, there are fisheries elsewhere in the world that remain open for only a few hours a year). It is politically difficult to reduce fishing capacity, although some steps have been taken in this direction, and care is needed to ensure that vessels taken out of a fishery (and the associated fishing effort or catch quota) do not subsequently re-enter fishing elsewhere. Another option (albeit increasingly difficult, and clearly not without ecological risks) is to begin exploiting previously unexploited species. One such trend was the move into fishing deep-water fish species, a development doomed to become a very short-term solution by the low reproductive capacity of most such species and the lack of regulation while these fisheries were expanding, as was seen in Scotland (Royal Society of Edinburgh 2004).

Many types of fishing gear are unselective in the sense that they catch species and size-classes that are not being directly targeted (e.g. because they are not commercially valuable or the quotas have already been filled). Such catches are referred to as *by-catch*. By-catches of *charismatic megafauna* such as dolphins, turtles and sharks attract most public attention, while by-catches of commercially important species for which the fleet has no quota (or none remaining) may adversely impact on the state of the fished stocks. Under the current EU system, by-catches of species for which no quota remains must be discarded, i.e. thrown overboard. *Discarding* is almost universally perceived as wasteful (in Norwegian fisheries it is illegal), and enforced discarding of potentially valuable catch undermines fishers' respect for the regulatory system. However, fishers also discard by-catches of species with no commercial value and may discard less valuable species and size-classes if they anticipate that more valuable ones can be caught subsequently (so-called *high-grading*). Based on 1980s data, Alverson et al. (1994) estimated that between 17.9 and 39.5 million tons (average 27.0 million tons) of fish are discarded globally, each year, in commercial fisheries, almost 1/3 of which arise from shrimp trawl fisheries. A more recent estimate based on 1990s data (Kelleher 2005) indicates a much lower, but nevertheless substantial, annual total of 7 million tonnes. Aside from the obvious waste (most discarded fish are dead), such practices distort marine trophic links, increasing the numbers of scavenging species. For example seabird populations have benefitted from feeding on discards (Furness et al. 1988), as have benthic scavengers such as crabs (Catchpole et al. 2005, 2006).

Lost or abandoned fishing gear, including gill nets, trammel nets, longlines and cage traps can continue to catch fish and other marine organisms, as well as representing a hazard for boat traffic. Recent studies in the northeast Atlantic verify that *ghost fishing* by abandoned gillnets is a significant cause of mortality which must be accounted for in fishery management (Large et al. 2009). Dumping of damaged or obsolete fishing gear could be reduced by educating fishers and establishing collection points in ports for unwanted gear. Matsuoka et al. (2005) proposed that such measures should be included in coastal zone development and management policy and that all fishing gears should carry labels to identify the owner.

Mobile fishing gears such as bottom trawls and dredges can cause significant *habitat damage*, something which fishers have been aware of since at least the 14^{th} century (Jones 1992). Bottom trawling impacts on both the physical structure of the seabed substrate and the composition of benthic communities, with consequent effects on the epifauna – including demersal fish – which form part of the benthic food chain. In the English Channel, analysis of trends over 100 years indicated a loss of larger species from the benthic community (Capasso et al. 2010), and there is general concern about loss of biodiversity (e.g. Norse and Waitling 1998). Such damage may be of particular concern in vulnerable marine ecosystems, e.g. coral reefs (including cold-water corals). Bottom trawl nets used to catch groundfish and shrimps can drag along the seafloor, ripping up or scooping out inert material and animals. Dredges, used for capturing bivalves, not only capture everything that is bigger than the mesh of the net but also remove the upper layer of substrate, killing the animals living there and degrading the habitat. These impacts may be reduced by protecting a large proportion of the habitat of concern although, ultimately, the only way to completely avoid such damage is to use other kinds of fishing gear.

Fishing is obviously not the only human activity that can negatively affect marine ecosystems, and fisheries, in turn, may be negatively impacted by a range of other anthropogenic factors. It is estimated that some 10 billion tonnes of *ballast water* (used by ships to ensure their stability in the water) are transferred globally each year, and that 7,000 species are carried around in ballast water every day. Ballast water is responsible for dissemination of microorganisms and different life stages (e.g. eggs and larvae; cysts, spores or resting stages, adults) of plankton, plants and other animals. These newcomers have the potential to disrupt marine communities (Raaymakers 2002) and hence the fisheries that depend on them.

Pollution is another major issue in the world's oceans; indeed, consultation of Web of Science (in 2010) revealed over 41000 published articles on marine pollution. The world's human population is largely concentrated in coastal areas and the sea has become a repository for sewage, agriculture run-off, industrial effluents, oil spills, garbage, etc. A wide variety of pollutants (e.g. heavy metals, pesticides, oil derivates and chemical fertilizers) are then incorporated into the marine food web with potentially harmful results. Some (e.g. persistent organic pollutants and heavy metals) can bioaccumulate and biomagnify through the food chain, ultimately reaching concentrations harmful to marine animals, especially in upper trophic levels, and posing a significant risk to humans who consume marine fishery products.

Heavy metals include mercury, cadmium and lead, which have no known biological function and can be harmful to marine animals at any concentration. One of the best known cases of the links between marine pollution and fisheries occurred in the Japanese town of Minimata in the early 1950s, where many of the human population (as well as cats and fish-eating birds) suffered severe neurological disorders due to eating fish and shellfish that had been contaminated by mercury in factory effluents (Kurland et al. 1960). High levels of mercury are routinely recorded in large predatory fish such as swordfish (e.g. Glover et al. 2010). Concentrations of cadmium in mussels from the Baltic and North Seas are above limits set by OSPAR (Rüdel et al. 2010) and lead is recorded in various marine animals, e.g. octopus (Seixas et al. 2005).

The *persistent organic pollutants (POPs)* include several categories of compounds of mainly anthropogenic origin, notably polychlorinated biphenyls (PCBs), pesticides (e.g. dichloro-diphenylethanes (DDT)) and, of more recent concern, the brominated flame retardants (e.g. hexabromocyclododecane (HBCD) and polybrominated diphenylethers (PBDEs)). In marine mammals, high PCB concentrations – which arise from the fish and cephalopods in their diet – have been linked with immune suppression and reproductive failure (e.g. in seals, Reijnders 1986). The production of PCBs has been banned for some decades, but high concentrations persist in many marine animals. The greatest risk to humans though, arises from eating marine mammals. The traditional human diet in Greenland, which includes seal muscle, seal liver, seal kidney, seal blubber and whale blubber, results in high exposure to both POPs and heavy metals (Johansen et al. 2004). High PCB levels are also found in some fish, for example bluefin tuna (Ueno et al. 2002). HBCD and several of the most abundant PBDEs are biomagnified with increasing trophic position in the marine food web (Sørmo et al. 2009).

Anti-fouling paints, such as tributyl-tin (TBT), widely used to avoid problems of fouling in ships, deserve special attention due to their toxicity to aquatic life (with severe effects on the reproductive capacity of some aquatic organisms). TBT compounds have been included on the Red List of dangerous substances and their control is a priority action for the protection of the marine environment under the OSPAR and Helsinki conventions.

Chemical fertilizers can cause eutrophication, creating anoxic conditions and resulting in mass die-offs of fish. One example is the dead zone in Gulf of Mexico, provoked by chemical fertilizers from the Mississippi river (Turner et al. 2008).

Marine *oil spillages* (caused accidently from ships, oil platforms or pipelines, or intentionally from illegal oil releases from platforms or flushing of ships' tanks) can cause major environmental disasters, strongly impacting the fishing industry. Poly-aromatic hydrocarbons (PAHs) from oil result in contamination of fish and shellfish, potentially making them unsafe for human consumption and resulting in a distinctive taste (taint) (e.g. Whittle et al. 1997). In recent years, several major oil spills have led to temporary closures of fisheries, e.g. in Shetland (UK), Galicia (NW Spain) and, most recently, the Gulf of Mexico. In Galicia, losses in the fishery sector over the 12 months following the "Prestige" oil spill (2002) were estimated at around 76 million euros (Suris-Regueiro et al. 2007).

Social, Economic and Institutional Sustainability of Fisheries

Fisheries have linked social and ecological dynamics. Besides the important ecological and environmental aspects of fisheries, the activity has also *human dimensions* (i.e. the social, economic, cultural and institutional components) which need to be taken into consideration to achieve sustainable and effective fishery management.

Arguably, the more important failings of traditional fishery management in Europe, and elsewhere, relate directly to the lack of integration of the human dimensions into the fishery management process (Hilborn et al. 1995). In summarizing papers presented at the fourth World Fisheries Congress, Chuenpagdee and Bundy (2006) commented that "although the human dimensions of fisheries were recognized, few studies involved stakeholders beyond their roles of objects to study". All fishery management measures have social and economic consequences. In addition, the performance of any management measure (i.e. its successful implementation), depends (at least partly) on fishers' behaviour. For all these reasons, the failure to take the human dimensions of fisheries into consideration may undermine the success of any new fishery management measure. A governance system which does not achieve fisher buy-in is, in short, not institutionally sustainable.

A major contributor to overfishing (and consequent failure to achieve environmental sustainability) in EU waters, the *overcapacity* of the EU fleet, also has major socio-economic implications. Aside from the initial economic cost of subsidizing capacity building, reducing capacity creates the need (or at least the moral imperative) to provide financial assistance to prevent unemployment, both in the catching sector and those sectors dependent on it (e.g. traders, processors), and to mitigate consequent damage to coastal communities or loss of investment. As argued by Clark et al. (2005), the provision of subsidies is possibly the major contributor to unsustainable fisheries worldwide.

Hilborn (2010) observes that social sustainability is often incompatible with environmental and economic sustainability. The logic of market forces may lead to the increasing concentration of ownership of fishing rights to involve a smaller and smaller number of companies operating fewer and larger fishing vessels. This is clearly incompatible with retaining thriving coastal fishing communities, and some governments (e.g. Australia) have elected to accept the social costs of maximizing economic sustainability. Environmental sustainability increases as competition between fishers is reduced (and the tragedy of the commons no longer applies) while institutional sustainability improves as the system becomes less difficult and less costly to manage. One of the main contributors to lack of *institutional sustainability* (i.e. sustainable governance) has been lack of trust between fishers, scientists and managers/regulators, impeding the flow of reliable information and thus (through a positive feedback loop) contributing to inaccurate stock assessments, sub-optimal harvest rules and lack of buy-in by fishers, which, in turn, leads to further distrust. Over the last decade new institutional arrangements within EU fisheries have been aiming at improving the system of governance by increasing the fishing industry's participation in the fishery management decision-making process and, as such, aim to facilitate common understanding, establish trust between fishers and management bodies and researchers, increase fishers' accountability and responsibility, and contribute to more effective enforcement of rules and regulations by increasing the likelihood of compliance (Pita 2010).

There are inevitable differences in perception between fishers and fishery scientists. Again as noted by Hilborn (2010), fishers have more direct experience of real fish abundance than fishery scientists. However, fisher experience is limited to the areas where they fish. Since, broadly speaking, fishers aim to minimize costs and maximize landing value in order to maximize their profit, they are naturally drawn to easily accessible areas with high fish densities. Their observations in these areas of high density can result in an over-optimistic view of overall fish abundance.

There is always *uncertainty* associated with information on the status and trends in fished populations and on amounts of fish caught and landed (or discarded). This arises for numerous reasons, from the patchiness of fish distributions, and the relatively low sampling effort that can be applied by fishery-independent surveys of fish abundance or on-board monitoring, to the inaccurate reporting of their activities by fishers (which is generally more likely to involve under-reporting of catches than over-reporting – unless the aim is to build up a track record of fishing on a particular species). In turn, this creates a risk that even an apparently successfully implemented management action may have unexpected consequences. The environmental risks (principally the collapse of fished stocks) can be reduced by application of a *precautionary approach*, setting catch limits lower than might otherwise be optimal, especially if a stock is known to already be seriously depleted. However, uncertainty is one of the hardest concepts to communicate, since it means different things to scientists (for whom it is a statement of fact) and non-scientists (to whom it often signifies a reluctance to state the facts).

When talking about the economic and sociocultural sustainability of fisheries it is especially important to pay attention to *small-scale fisheries*. Although there is no universally agreed definition of this type of fishery, the European Fisheries Fund regulation defines small-scale coastal fishing as "fishing carried out by vessel less than 12 m in length and not using towed gear"). Such boats constitute the majority of the EU commercial fishing fleet (77% by number), even if their total catching power is relatively low. As is the case in many other regions of the world, these fisheries are important in terms of providing employment and income (especially in rural communities with limited employment opportunities), as well as maintaining traditional practices (Pita et al. 2010a).

To date, the CFP does not make a distinction between small-scale and large-scale fisheries in its system of governance. However, this could change since the Green Paper on the forthcoming reform of the CFP considers the possibility of adopting a differentiated fishing regime to protect small-scale coastal fleets. This would result in considerable changes in the way small-scale fisheries are managed, and several issues have already been identified as challenges associated with this specific treatment of small-scale fisheries, such as issues of preferential access, specific control measures and application of conservation measures.

Several problems surround management of small-scale fisheries within the EU; first, there is the problem of defining what constitutes small-scale fisheries (different member states have different definitions) and small-scale fisheries within the EU (as in other locations) are traditionally data-poor. Methodologies developed for large-scale finfish fisheries may be inappropriate for artisanal fisheries[4], which often exploit shellfish species with very different population dynamics and distribution patterns to finfish. For instance, Freire and Garcia-Allut (2000) argue that the overexploitation of shellfish in Galicia has resulted from a mismatch between management (i.e. assessment and harvest rules) and the biological and socioeconomic nature of these fisheries.

Social research has a key role to play in revealing how fishers may respond to specific management measures (e.g. the creation of protected areas) or different approaches to improve the system of fisheries governance (e.g. the implementation of co-management approaches). One of the most simple and obvious findings of such research is that fishers are more positive towards management measures about which they have been consulted (as opposed to the measure being handed down unannounced by government). By understanding how fishers are likely to respond, it should be possible to devise more efficient harvest rules and monitoring/regulatory systems and, as such, reduce uncertainty about the outcome of management measures. For example, under the Conservation Credits scheme, Scottish fishers are asked to notify the authorities of areas with high concentrations of cod, which (subject to confirmation) are then temporarily

4 However, methodologies developed for large-scale fisheries, for example use of log-books carried by fishing boats, have been successfully applied in assessment of recreational fisheries (ICES, 2009a)

closed to fishing. In return, the fishers are awarded additional fishing days (Anon. 2010).

Social science research in fisheries is still in its infancy when compared to the biological sciences. However, everything points to social sciences playing a more important role in fisheries management in the near future (see Symes and Hoefnagel 2010). Fishery advisory bodies, such as ICES, are starting to integrate economic and social considerations into their traditional scientific advice. ICES, in its revised Science Plan for 2009-2013, considered the understanding of the interactions of human activities with ecosystems as one of its high priority research topics (ICES 2009b). Recent developments in marine policy make it crucial to include social, economic, cultural, political and institutional information into fisheries management. These types of information have the potential to contribute to improve the realism of scenarios, better understand and/or predict the behavioural response of fishers, improve the buy-in of stakeholders, and develop suitable decision processes.

Recent Developments in Fisheries Management (the Way to Sustainable Fisheries)

Several measures have been implemented in recent years with the aim of achieving long-term sustainable management of fisheries resources; we give a brief overview of some of these measures, while also ending on a cautionary note.

Property Rights

As noted above, the absence of property rights in the sea has been one of the major stumbling blocks to delivering sustainable fishing. Competition between fishers, in the absence of property rights, creates perverse economic incentives and encourages expansion of fishing power, leading to excess fishing capacity (Clark 2006). Thus, creating a property rights system has been a major challenge for policy makers (Wilen 2000). Provision of property rights attempts to eliminate the common property problem by establishing private property rights over the fish stocks (Arnason 2002). Property rights in fisheries offer several advantages, such as security or quality of title, exclusivity, permanence (durability) and transferability, although there are both technical and social limitations (Arnason 2000).

Several types of property rights regimes have been employed in fisheries, including Territorial User Rights Fisheries (TURFs), individual catch quotas and community fishing rights (Arnason 2002). TURFs involve allocation of units of space to a state, private firms, cooperatives, fishers, etc. This approach has been successfully applied to fishing on benthic resources in Chile (see Gelcich et al. 2008). Use of individual catch quotas attempts to solve the common property problem not by conferring ownership of the fish stocks themselves but by allocating individual rights to harvest these stocks. Transferable and divisible catch quotas are usually referred to as *Individual Transferable Quotas* or ITQs (Arnason 2002).

Setting catch quotas does not itself define property rights but, for instance, ITQs potentially do so, at least when coupled with an appropriate level of license fee, and adequate monitoring and enforcement (Clark 2006). Several major fishing nations employ ITQs as their primary fisheries management system (e.g. Australia, Denmark, Canada and New Zealand), and many others employ ITQs in some of their fisheries (Arnason 2002). A global survey found that fisheries managed using ITQs, or a close variant, were half as likely to collapse when compared to other management systems (Costello et al. 2008).

Rights-based management (RBM) is discussed on the Green Paper on the forthcoming 2012 reform of the CFP (see COM (2009) 163 final). The Commission argues that transferable rights (individual or collective) to fishing may be a more efficient and less expensive way to reduce overcapacity and allocate more responsibility to the fishing industry. ITQs may offer the most flexibility within a private ownership system and may reduce the "race to fish". However rights-based fisheries management systems, such as ITQs, are not free from controversy, since this system may encourage discarding and high-grading, promote quota leasing, and facilitate privatization and the creation of monopolies (Burke and Brander 2000; COM (2007) 73; Ecotrust 2009). This process has clear social costs, since it will ultimately lead to the loss of vulnerable coastal communities where fishing is the primary source of income, as in the northeast of Scotland.

Eco-Labelling and Ecological Certification

The history of fisheries suggests that supply-led management of fishing has so far failed to deliver long-term sustainability and that management based on consumer demand could represent a viable alternative (Starkey et al. 2008). Some significant measures promoting sustainable seafood products at consumer level are already in place. These function primarily by raising public awareness of the issue and ensuring that it remains it on the agenda of governments and regional fisheries management organizations. A recent development in fisheries is the increase in the use of "eco-labelling". Eco-labelling is a market-based approach, which involves independent third-party certification, to enhance and reward responsible fishing practices (Gardiner and Kuperan-Viswanathan 2004; Roheim and Sutinen 2006). The growing importance of eco-labelling and organic certification in seafood marketing is a reflection of the increasing interest by retail chains in the topic, no doubt reflecting what appears to be a growing consumer, and media, interest in the issue.

Eco-labelling seeks to inform consumers about product attributes other than price, in particular environmental considerations, but potentially also ethical, social and health issues, e.g. “Dolphin safe” labelling with the aim of reducing the number of dolphin deaths in tuna fisheries in the Pacific. Surveys to date indicate consumer willingness to pay a price premium for labelled fish products (see Johnston et al. 2001; Wessells et al. 2001). For producers, the price premium achieved from eco-endorsed products may serve to recompense them for the extra effort required to generate products to the standards demanded by eco-labelling and organic product schemes. In addition, the seafood industry fears that without certification of sustainability it will be unable to sell its products to the world’s major retailers (Roheim and Sutinen 2006). This presents a very real market incentive for sustainable fishing.

The Marine Stewardship Council (MSC) is currently the only eco-labelling organization which provides a world-wide eco-label for wild capture fisheries. The MSC eco-label was created in 1997 by Unilever and World Wildlife Fund (WWF) and the MSC has operated as an independent entity since 1999. Today, over 150 fisheries around the world are certified or undergoing assessment. The MSC eco-label is carried by more than 2,500 seafood products in 52 countries and the market for MSC certified sustainable seafood is estimated to be worth over $1.5 billion (MSC 2009). However MSC certification is not without its critics. The system came under fire in 2004 during certification of the Alaska pollock fishery, with two independent studies criticizing the MSC for lax application of standards.

There are various other eco-labelling schemes such as Friend of the Sea, Naturland and Marine Aquarium Council (Sainsbury 2010). Friend of the Sea provides an ecolabel called the Friend of the Sea Mark and applies to fisheries and aquaculture. Naturland was founded in 1982 for agriculture products, and in 2006 extended certification to marine capture fisheries with the ecolabel Naturland Wildfish. The Marine Aquarium Council certifies wild capture and subsequent treatment of fish for the ornamental aquarium trade.

Co-Management Arrangements

Intrinsically linked to the goal of achieving long-term sustainable management of fisheries resources is the need to ensure greater responsibility and accountability by all individuals involved in the harvesting, processing and marketing of fish. As such, measures have been developed for some years now to increase stakeholders' participation in the fisheries management decision-making process in Europe. The European Commission's (EC) first step for involving resource users in decision-making was the introduction of the Advisory Committee on Fisheries (ACF) in the early 1970s. This measure was reformed in 2000, to include new sectors and interest groups, and renamed the Advisory Committee on Fisheries and Aquaculture (ACFA). More recent measures have included the implementation of a network of Regional Advisory Councils (RACs). The RACs resulted from the 2002 reform of the CFP, meeting the aim of improving the system of governance by increasing the involvement of stakeholders, particularly fishers, in the decision-making process. The RACs have been in operation since 2004 and a total of seven exist within EU waters. Six of these cover specific areas (North Sea, Baltic Sea, Mediterranean Sea, North-western waters, South-western waters and distant water fisheries) while the seventh concerns pelagic stocks. The RACs' main task is to provide the EC with advice on fisheries management in their specific regions/stocks (Pita et al. 2010b). New developments in stakeholder involvement in management are expected with the forthcoming 2012 reform of the CFP. The EC Green Paper setting the rules for the reform identified the need to develop regional co-management arrangements. This will result in a new set of co-management arrangements which will change the face of EU's fisheries management (Pita 2010).

Co-management measures aim at the sharing of authority and responsibility between government and local communities in the management of natural resources. Co-management depends on the willingness and ability of fishers to participate. Since 2000, under the Scottish Shellfish Regulating Order scheme, local stakeholders in some regions of Scotland have been granted the responsibility to regulate and manage sustainable shellfish fisheries. Noble (2003) noted that, while this scheme was successfully applied in Shetland, in another region (Orkney Islands) it was unsuccessful due to opposition by the local fishers. Frangoudes et al. (2008) argue that government investment in training and improving organization of fishing activities, and the empowerment of women, have been key factors in achieving sustainable co-governance of shellfish gathering by Galician women.

Marine Protected Areas

As described above, past fishery management regimes in Europe are gradually being replaced by new management regimes covering the ecosystem as a whole, reflecting a global trend. In this context, Marine Protected Areas (MPAs) have been widely used world-wide as a tool for fishery management, to help to address overexploitation of some fish stocks. MPAs are used, for example, to create area-based restrictions on particular types of gear and/or fishing methods, thus allocating zones for different gear types. Alternatively, closed areas may be established with set time limits, as currently implemented in Scotland to aid the recovery of North Sea cod. These closures are named “Real time closures” and were introduced in 2007 as a voluntary system with the co-operation of the Scottish fishing industry (Anon. 2010; Pita 2010). The primary goals of MPAs are to protect critical habitat and biodiversity, to sustain or enhance fisheries by preventing spawning stock collapse, and to provide recruitment to fished areas. Possible advantages include protection of large mature females (megaspawners) which have disproportionately high fecundity compared to small fish. The increased egg output, and potentially increased recruitment, can benefit the fished part of the stock in adjacent areas. In addition, as protected stocks build up, reserves are predicted to supply local fisheries through density-dependent spillover (movement out of MPAs) of juveniles and adult fish into adjacent fishing grounds (e.g. Amargós et al. 2010).

In addition to MPAs created for fishery management purposes, international obligations and EU legislation have resulted in MPAs also being widely implemented for conservation purposes. This is mostly the result of commitments stemming from the World Summit on Sustainable Development (WSSD) and the United Nations Convention on Biological Diversity (CBD), for the establishment of a global network of MPAs by 2012. At the EU level, various agreements (e.g. OSPAR and HELCOM) reinforce the commitments for the establishment of a network of MPAs within European waters by 2010. This is further reinforced by environmental legislation, such as the Marine Strategy Framework Directive (MSFD), and the Habitats (92/43/EEC) and Birds (79/409/EEC) Directives (Pita 2010). Of special importance is the fact that, under the MSFD, a programme of measures must be implemented to maintain or achieve “Good Environmental Status” in the marine environment by 2020. The Directive specifically requires the implementation of network of MPAs. As such, MPAs will continue to be implemented within EU waters as part of the long-term conservation and fishery management plans.

Empirical evidence shows that no-take MPAs (i.e. areas fully closed to fisheries) can significantly increase species richness, biomass and density of fish although there is considerable uncertainty about the effect of no-take MPAs in temperate waters and several authors have questioned the value of MPAs as a means to address broad conservation and sustainable fisheries objectives (see Halpern and Warner 2002; Halpern 2003; Kaiser 2005; Jones 2006, 2007; Stewart et al. 2009). While there is general consensus amongst the scientific community on the use of no-take MPAs for restoring overexploited ecosystems, it is also suggested that the improvement of conventional fisheries management approaches can be more effective in promoting sustainable fish stock yields (see Hilborn et al. 2004, 2006; Kaiser 2004, 2005; Pauly et al. 2002; Roberts et al. 2005). There is the risk that the implementation of a no-take MPA may merely result in the displacement of fishing effort to other locations (and, worse, to new areas which were not intensely fished before). To avoid this, several authors argue for a combined use of both no-take MPAs and conventional fisheries management approaches (see Greenstreet et al. 2009; Hilborn et al. 2004, 2006; Kaiser 2004, 2005; Roberts et al. 2005; Pita 2010).

The issue of displacement of fishing effort due to the creation of no-take MPAs is yet to be resolved. A recent study by Greenstreet et al. (2009), in the North Sea, concluded that MPAs on their own are unlikely to achieve significant regional-scale ecosystem benefits, because local gains are largely negated by fishing effort displacement into the remainder of the North Sea. To add to the problem of displacement of effort, the whole question of how the socio-economic impact of MPAs will be measured, mitigated and dealt with is a seriously under-developed part of the research into MPA implementation in Europe.

High Seas Marine Protected Areas (HSMPAs) represent a potentially important tool for protecting biodiversity of the oceans. The first six HSMPAs were created in 2010, in the North Atlantic, covering a total area of 285 000 km^2, enclosing a series of seamounts and sections of the Mid-Atlantic Ridge that host a range of vulnerable deep-sea habitats and species. This was the first high seas network beyond the jurisdiction of national governments.

Integrated Management of the Marine Environment

The numerous *policies and initiatives* implemented in the EU *over the last decade*, such as the Integrated Maritime Policy (IMP), ICZM and MSFD, have been giving a new direction to the management of marine space, under which fishing is simply one of many human uses of the seas. Nowadays, the focus is on the integrated management of human activities in the marine environment, which is a reflection of the pressing need for environmental protection and the increasing competition for sea space. Such integrated approaches imply adoption of a common currency to facilitate comparison of the values of biological, economic and social outcomes of management (Pita 2010). They also imply some commonality of value systems and world views. This could be difficult to achieve in practice. For instance, Mee et al. (2008) pointed to the difficulty of defining “Good Environmental Status” due to different concepts of “good” in different European countries.

The IMP sets the broader vision for the integrated management of all maritime activities in the EU according to the economic, social, and environmental dimensions of sustainable development. Historically, coastal management and fisheries management evolved separately, addressing different needs. The result of this was that the fishing industry, until recently, had enjoyed a surprising level of "favoured status" in relation to its use of marine space (Symes 2007). However, the IMP will imply a less influential fishing industry, a new set of decision-making processes and procedures and the development of new management instruments. For instance, the IMP has made ecosystem-based fisheries management obligatory in the forthcoming 2012 reform of the CFP. The IMP has severe consequences for fisheries management and is possibly the most significant change to the institutional framework for fisheries governance since the implementation of the CFP in the 1970s (Symes 2007).

A Note of Caution!

Fisheries are a global activity and achieving sustainability in Europe may reduce sustainability elsewhere, not least because it will almost certainly require a substantial decrease in fishing activity in European waters. Europe's fishing fleets have long plied the world's seas and the lack of enforceable regulations in international waters presents a potentially tempting economic incentive to exploit such waters unsustainably, a phenomenon evident in the plight of bluefin tuna. Pauly (2009a) argues that the European Union has taken advantage of weak governments in Northwest Africa to reach agreements that allow unsustainable fishing in their waters. It has also been argued that one reason for the rise of marine piracy in Somalia has been the decimation of regional fisheries, caused at least in part by foreign vessels exploiting the lack of fishery protection during the civil war (Dagne 2009).

Supermarket chains, currently the champion of eco-labelled fish products have, in fact, been largely responsible for driving consumer demand in the opposite direction over many years by selling cheap, poor quality fish, often imported frozen, and driving traditional fish shops out of business.

Against a background of rising global market demand for seafood, the future of world fisheries will be affected by fluctuations in the abundance of fish and living marine resources, along with factors such as technical developments, scientific discoveries and economic progress. However, a critical issue will be how capture fishing and aquaculture activities are managed. Clearly, trying to predict future world fisheries (say) three decades from now is subject to many uncertainties (Bruinsma 2003). One of the main difficulties encountered in the prediction about the future of fisheries is that it depends on future political, social and economic conditions, prediction of which represents an even higher order challenge (Garcia and Grainger 2005).

We have so far made no reference to anthropogenic climate change, very possibly the "elephant in the room". While subject to much recent public debate, there seems little doubt that climate change is a reality (Anderegg et al. 2010) and that it has the potential to cause profound effects on marine ecosystems. Global warming may lead to increased fishery yields in some parts of the world (Sherman et al. 2010) but a range of climate-related threats to fisheries has also been identified (Brander 2007). As the latter author comments, "*we have low confidence in predictions of future fisheries production because of uncertainty over future global aquatic net primary production and the transfer of this production through the food chain to human consumption*." Alongside global warming, ocean acidification threatens a range of marine organisms and associated fisheries, notably corals reefs (because deposition of calcium carbonate in coral skeletons is inhibited) and reef-associated fisheries (Hoegh-Guldberg et al. 2007).

Conclusion

Historically, scientific advice on marine fisheries in Europe has concerned the biological status of single fished stocks, and selection of appropriate catch or effort limits to ensure that they remain at healthy (sustainable) levels. More recently this has sometimes been expanded to include consideration of consequences for other target and non-target species and the wider ecosystem. Traditionally, fishery scientists then step back and let managers, regulators and politicians get on with the business of deciding if and how to implement recommendations, i.e. stepping back from the task of putting the scientific advice in its social, economic and political context, taking the view (and one long formalized in the system) that the role of scientists is to present facts and not opinions. However, evaluation of the social and economic impacts of proposed fishing regulations is very much within the remit of fishery science, even if not something that falls within the area of expertise of most biologists who participate in ICES Working Groups. Furthermore, it is a highly relevant scientific task to evaluate how implementation of recommendations might work, for example what regulatory, compliance and political issues might arise – and how these will, in turn, affect the fish stocks. Such considerations are currently finding their way into both European Union policy and the way that ICES conducts its business. A key feature of these non-biological components of fishery assessment is that they require engagement with fishing industry stakeholders, for it is ultimately the uptake (compliance) by stakeholders which will secure the achievement of management goals. Less well recognized is the need to engage perhaps the most important stakeholders of all, the consumers. Informing and educating the public about the state of fish stocks could do much to create a backdrop conducive to achieving sustainability and provide greater incentives for all players – fishers, scientists, managers/regulators and politicians – to get it right.

At the time of writing, the EU is starting to address the concept of "MSY variants", whereby "traditional maximum sustainable yield" indicators of stock status are broadened into more general indicators of fishery status by incorporating additional biological, environmental, social and/or economic information. The consequences of using alternative MSY variants can be evaluated following an experimental approach with real fisheries (inherently slow and risky as well as being potentially unrepresentative) or through scenario modelling (and/or "pathway scenario" modelling). Successful multidisciplinary scenario modelling clearly needs a common currency and many strong assumptions – and the latter may lead to scepticism about its validity (e.g. Rose et al. 2010, Schmolke et al. 2010). However, strengths include the possibility to evaluate an almost infinite range of scenarios and options for communication, e.g. visualization of simulation outcomes.

Under this concept, the next step is to "develop an operational framework for the implementation of MSY variants in practical management settings". Arguably this approach, which separates the solution of governance issues from the optimization of fishery status, while realistic in that it implicitly recognizes the inertia of governance systems, is inherently limited. Ideally, the governance system would be treated as a variable alongside those that quantify environmental, social and economic sustainability. In this way inherently unworkable solutions may be avoided, and an achievable sub-optimal target for (say) ecological sustainability may be seen (rightly, in our opinion) as superior to an unachievable ecological panacea.

In the present review we have said little about fishery governance, while implying that governance issues may be amenable to scientific solutions, e.g. by extension of the management strategy evaluation (MSE) approach. It is worth remembering that MSE was developed under the auspices of the International Whaling Commission (IWC). To date, the Revised Management Procedure, designed to deliver sustainable whaling, has not been implemented. Reflecting strong differences of opinion between "pro-" and "anti-whaling" nations, there is no consensus within the IWC about how to proceed. In short, politics trumps science. Jentoft and Chuenpagdee (2009) argue that there are limitations to how rational and effective fisheries governance can be, and that some issues in fishery governance are inherently "wicked", i.e. they have no technical solution, are difficult to define, difficult to solve and likely to recur. In such cases, "governance must rely on the collective judgment of stakeholders involved, in a process that is experiential, interactive and deliberative" (Jentoft and Chuenpagdee 2009).

It is evident therefore that the fishery science of the near future should be inherently multidisciplinary, even if a substantial part of the new work that is needed could still, as currently, be undertaken at least partly by numerate biologists. Good simulation models are likely to be a key feature of multidisciplinary assessments, whether the core is a traditional ecosystem model (e.g. ECOPATH with ECOSIM) or something quite different. Ideas which behavioural and evolutionary ecologists imported from the human sciences, such as optimal foraging theory and game theory, can now be re-applied in something closer to their original contexts, alongside theory derived directly from the fields of economics and psychology (e.g. Clark and Munro 1975; Kahneman, and Tversky 1979), to predict and model the behaviour of fishers and fishing fleets under different management and regulatory regimes. Nevertheless, there is a need to involve economic, social and political scientists in this more broadly defined fishery assessment process. There are inevitable differences in methods and world views across disciplines (see Gould 2003, for a general historical perspective on this theme), and ensuring that they work together efficiently and harmoniously is itself a challenge.

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