K. Tsukamoto, T. Kawamura, T. Takeuchi, T. D. Beard, Jr. and M. J. Kaiser, eds.
Fisheries for Global Welfare and Environment, 5th World Fisheries Congress 2008, pp. 45–56.

Knowledge on How To Achieve Sustainable Fisheries

Ray Hilborn

School of Aquatic and Fishery Sciences
Box 355020,
University of Washington
Seattle, WA 98195-5020 USA

E-mail: rayh@u.washington.edu

I review the state of current knowledge with respect to the requirements for achieving sustainable fisheries. I consider the range of objectives for fisheries and identify conflicting objectives as a major issue in achieving sustainability. Next I review historical and current practice in allocation of fish resources and regulation of harvest and highlight existing knowledge. Evidence suggests that both restriction of access and maintenance of biological productivity are necessary conditions to achieve biological, economic and social sustainability. However, the tools appropriate to achieve these differ greatly across fisheries and societies, and for both elements of fisheries management local solutions are needed in most cases. Attempts to impose standardized solutions to either issue frequently result in ineffective solutions. Evidence also suggests that involvement of consumptive users through appropriate incentives is an essential element in achieving sustainability.

KEYWORDS sustainable fisheries; lessons learned; allocation; harvest strategies; incentives

1. Introduction

As we survey the world of fisheries management in 2008 we can find many notes of optimism and hope, and many of despair. Depending on where we look and the perspective of the viewer, we can find fisheries improving in biological abundance, economic performance and contribution to communities (Hilborn 2007b). Similarly in other places we find fish stocks continuing to decline in abundance, economic performance is poor and declining, and communities are in severe trouble (Pauly 2007).

Even the same fishery, viewed with different disciplinary lenses, may appear to be headed in different directions. For instance, the commercial salmon fisheries of Alaska are widely regarded as examples of well managed fisheries whose biological sustainability remains unthreatened and produces at or near the biological maximum. Yet many of these same fisheries are suffering economically and socially. Economic returns to fishermen poor, many individuals have left the fishery and communities are suffering for loss of income and tax base (Hilborn 2006).

The purpose of this paper is to explore what has been learned about how to manage fisheries well and where this evolution of fisheries management is leading. The question I ask is do we now have enough knowledge to move the world's fisheries to an era of sustainable management? I begin by first exploring many of the conflicts in the definition of "well managed." Can we even move to better fisheries management if we have conflicts in our basic objectives. Then I consider the elements of fisheries management with my emphasis being that fisheries management consists of a broad range of activities, many of which are often overlooked by outsiders. Then I discuss the evolution and lessons from fisheries management in industrial fisheries and small-scale fisheries. Finally I consider what has been learned, and the extent to which we know how to move forwards to more sustainable fisheries and communities.

2. Objectives and Defining "Well Managed"

Before we can consider moving towards a better fisheries future and having most fisheries being well managed, we must recognize the range of perspectives regarding the objectives of fisheries management and what would constitute success or being "well managed." There are a wide range of "stakeholders" who are involved in fisheries, including industrial, artisanal, subsistence and recreational fishermen, suppliers and workers in allied industries, managers, scientists, environmentalists, economists, politicians and the general public (Hilborn 2007a). Each of these groups has an interest in particular outcomes from fisheries and the outcomes that are considered desirable by one stakeholder may be undesirable to another group.

For example, economist often cite the use of individual transferable quotas (ITQ's) and related tools (Pearse 1992; Norse *et al.* 2003) as the key to making fisheries profitable and "successful." Others consider the outcome of ITQ systems that often lead to profitability and wealth for ITQ holders as undesirable, and indeed recently the UN Commission on Human Rights has called the ITQ system in Iceland "unfair" and the Icelandic Green Party has called for abandonment of the county's ITQ system.

Other obvious conflicts in objectives occur between fishing groups who are interested in sustainable exploitation, and conservation groups interested in protecting ecosystems from disturbance. The current controversies over establishment of Marine Protected Areas closed to fishing is the most obvious sign of this conflict. Other examples occur over by-catch of non-target species, where there is no intrinsic interest for fishermen to protect species of little or no value to them, but these species are often highly valued by conservation stakeholders.

Is the purpose of a fishery to make money or to provide jobs? In many places the best way to maximize profit from a fishery appears to be to sell access rights to foreign fleets, or to arrange charter/lease agreements with foreign fleets. In these fisheries the country or quota holders achieve profitability but there is little if any employment generated for the domestic economy.

Within fishing groups there are frequent and long-standing battles over allocation—within the U.S. and in many other countries, recreational fishing groups have repeatedly attempted to have commercial fishing restricted to allow greater access to fish for their groups.

Thus there is substantial disagreement on what we want from fisheries and what would constitute successful management. However, I do believe there are many common elements of success across most stakeholders, including primarily biological and economic sustainability.

2.1. Biological sustainability

The long-term persistence of a fishery depends upon maintaining the productivity capacity of the stocks being exploited. No stakeholder's objectives can be achieved by extirpating the resource. Almost all of the criteria that are currently applied in various forms of fisheries certification, such as the Marine Stewardship Council (Phillips *et al.* 2003), focus on the biological sustainability of the management system. Within the realm of biological sustainability, one does find conflicting objectives when we consider other elements of the ecosystem. For example, in the New Zealand hoki fishery, which is largely mid-water and bottom trawl, there is an incidental catch of fur-seals. To the fishermen the by-catch of seals is unintentional, but of no real consequence, they come up dead and the deck and are thrown overboard. To conservationists this by-catch is a concern, and have repeatedly argued that further efforts should be taken to restrict the by-catch of seals. Several groups objected to the certification of the NZ Hoki fishery by the MSC with one of the issues raised being the by-catch of fur-seals.

Another area of conflict is around the level of ecosystem modification considered appropriate. Fishing often transforms ecosystems. At the very least fishing reduces the abundance of the target species, in the extreme fishing can totally transform the nature of the ecosystem. For example, the overfishing of groundfish in a number of ecosystems has led to major increases in abundance and catch of several invertebrate species such shrimp, crabs and lobster (Worm and Myers 2003). These ecosystems can be thought of as being transformed from a groundfish dominated, to invertebrate dominated. The economic value of the invertebrates is often higher than the groundfish they replaced. While it is not clear that these transformed ecosystems are sustainable in the long term, they may be, and if they are then there is an obvious conflict between the economic value of these fisheries and the fishermen that depend on them, and the traditional objectives of maintaining ecosystem structure and function.

2.2. Economically viability

The economic viability of fishing fleets and communities would be accepted as a desired outcome by almost all stakeholders. Most environmental NGOs say that they support fishing communities. Thus we could evaluate any fishery where the fishing fleets are bankrupt and communities in distress as not successful or well managed. Again however, as soon as we look deeper there are considerable conflicts between stakeholders. Community-oriented groups tend to see any form of large-scale industrial fishing and large firms as an anathema, and their vision of economic viability is small-scale community-based fisheries. Some countries such as New Zealand have made clear decisions to favor economic profitability, and if that profitability is found by a few large firms harvesting the majority of the catch, that is considered consistent with national fisheries objectives.

There is similar conflict on the role of subsidies to individuals and communities. In some places such as eastern Canada, subsidies in the form of unemployment insurance are a major element in the fisheries policy to maintain communities, yet in many other countries (Australia, New Zealand) such approaches would be considered inconsistent with good economic management of fisheries.

3. Elements of Management

In most popular and scientific discussions fisheries management has become almost synonymous with the regulation of harvest and maintenance of stock levels. When one considers whether fisheries management has succeeded or failed, the focus is almost invariably on whether catches have been too high and how and what are the trends in the abundance of the stock.

However, fisheries management is a much more diverse activity, and the other elements of fisheries management are often neglected, or at least undervalued. However, if we wish to consider the success of fisheries management, and indeed the trends in fisheries management in different parts of the world, we must look to a broader range of fisheries management activities. If we look to what fisheries management agencies actually do, the activities they perform, I can identify six types of activity; (1) access to fishing, (2) regulation of harvest, (3) data collection and research, (4) enforcement and compliance, (5) artificial propagation, and (6) habitat protection. Due to limitation of space I am only going to consider the first two elements of fisheries management.

Access to fishing and gear—who fishes with what and where: Fisheries management agencies, by design or default, determine who gets to fish, what gears they can use, and when and where they can fish. We generally call this process allocation, and distinguish between allocating the catch to alternative users, and the regulation of catch levels.

Regulation of catch: Agencies frequently attempt to regulate the levels of catch by a variety of means usually either direct regulation of the total allowable catch (TAC), or restricting the amount of fishing effort, the efficiency of the gear, or the time and space opportunities for fishing.

4. Historical Evolution of Management Practice

In this section I wish to review trends in fisheries management practice comparing industrial fisheries with small-scale fisheries. The emphasis will be on what has been learned.

4.1. Industrial fisheries

This group of fisheries constitutes the high-volume fisheries of the world and includes fisheries in western countries, international waters and some Asian and African countries. The common characteristic of these fisheries is that they involve many vessels, catch large volumes of fish, and are of enough economic value that management agencies can often devote considerable resources to their management. The industrial fisheries of the North Atlantic formed the basis for the modern "theory of fishing" as codified in the classic Beverton and Holt book from the 1950's (Beverton and Holt 1957) and described in Smith (1994). A very large portion of the world's fish catch comes from these fisheries, and most discussion of "state of the worlds fisheries" (Hilborn *et al.* 2003) would focus on these fisheries. However, we recognize that most of the people in the world who earn their livings fishing are in Asia and Africa and most of them depend on the small-scale fisheries described in the next section.

4.1.1. Access to fishing

Almost all industrial fisheries began as open access, where anyone with the ability to purchase a vessel could participate. Within the last 50 years a wide range of mechanisms for providing access have been tried and much has been learned. Open access fisheries have almost uniformly resulted in development of excess fishing capacity to the point where profitability of fishing becomes close to zero. This problem is especially acute when there are cycles in price and abundance. During the periods of high profitability, more participants enter the fishery, and when there is a downturn in abundance, or price, or an increase in costs, most of the vessels operate at a loss.

A common step beyond open access is limited entry, where the number of licenses or vessels is fixed, but the ability of the license-holders to increase their catching power is usually not. In such systems the result is commonly the same as with open access, a highly overcapitalized fishery with poor economic performance. The exception is in fisheries where there are ways to effectively constrain the ability of increased investment to increase the catching power of vessels. In these cases, if the fleet size is capped before it is too large, the tendency of capital to increase catching power and ultimately reduce profits may be controlled and fleets may be profitable for considerable periods of time.

A rarely used alternative to granting of permanent or long-term fishing rights is the sale of short-term fishing rights, either to domestic fishermen or to foreign fleets. Such systems are rare in industrial fisheries, and are generally unpopular with domestic fishermen who almost uniformly argue for fishing rights to be given to them at little if any cost. However, where implemented, such mechanisms have proven to provide considerable revenue to states or management agencies and have avoided the problem of development of excess fishing capacity.

A method that is growing in use is the granting of catch shares to individuals or vessels in systems commonly called Individual Transferable Quotas (ITQ) or Individual Vessel Quotas (IVQ). New Zealand and Iceland have adopted these systems for most of their fisheries, and within the U.S., Canada, Australia, South Africa and Namibia they are now in common use. ITQ systems have long been advocated by economists as a way to prevent, or to reduce overcapitalization. ITQs do this by eliminating any incentives for increased catching power: if a vessel has a fixed share of the catch it cannot increase its catch share by technological means. In ITQ systems the incentives are to reduce the cost of fishing and to increase the quality and price of the product, leading to increased profitability. Another common result of ITQ systems is a reduction in total fleet size, effectively concentrating the harvest to a smaller number of vessels. Such concentration is frequently decried by sociologists and anthropologists because of the loss of jobs and concentration of catch, while economists generally view this outcome as a desirable aspect of economic efficiency. Others object to the fact that ITQ systems often generate considerable wealth in the quota holders, and since the common practice has been to allocate ITQ to vessels largely based on their catch histories, many decry this practice as socially inappropriate.

Another approach is sector allocation, in which a fixed share of the catch is assigned not to individual vessels but to groups of vessels. Perhaps the most common application of sector allocation is in international fishing agreements where nations are granted a certain share of the total allowable catch. Alternatively, in some cases specific fishing fleets in national fisheries are allocated a fixed share. An example of this is the factory trawler fleet for pollock in the Bering Sea (Mansfield 2004). This fleet has a fixed share, and the companies who own the vessels have worked out an agreement on how much of the allowable catch each vessels is allowed to catch, effectively making the system like an ITQ system. The consequences of sector allocation differ markedly. When the size of the sector is small and they have been able to cooperate in how the catch is internally allocated, sector allocation has proven to promote considerable economic efficiency. When the sectors who receive allocation are large, or not well organized, there often remains a competitive race within the sector members and the outcome is not dissimilar to open access.

Experience with industrial fisheries has taught us that the economic performance of the fishing fleet is largely determined by the method used to allocate access to the fishery.

Open access and limited entry have generally resulted in poor economic performance, while ITQ/IVQ systems, and state sale of short-term fishing rights generally result in much more profitable fisheries. Sector allocation has a very mixed track record, but when the groups are small and working together, sector allocation can achieve economic profitability.

The biological sustainability of the resource is much less directly influenced by the allocation method. Numerous fisheries have achieved biological sustainability while remaining in open access or limited entry. The biological success depends much more on the management agencies' choice of harvest levels and their ability to enforce these limits.

Discussion of access in industrial fisheries does always lead to a direct confrontation of the tradeoff between economic profitability, and employment and equity. If you want to make fisheries profitable you always want to use fewer boats and people than would naturally happen in open access.

4.1.2. Regulation of catch

The level of knowledge regarding harvest levels in industrial fisheries has evolved over the last 100 years, beginning with initial debates about whether overharvesting of such fisheries was even possible. Thomas Huxley's viewed these fisheries as one of unending surplus. "... that the cod fishery, the herring fishery, the pilchard fishery, the mackerel fishery, and probably all the great sea-fisheries, are inexhaustible; that is to say that nothing we do seriously affects the number of fish. And any attempt to regulate these fisheries seems consequently... to be useless" (Huxley 1884).

Since Huxley's time much has been learned and it is now widely accepted that there are limits to the potential harvest of all fisheries in the ocean, and that catch levels in most fisheries need to be regulated. There has now evolved in most managed industrial fisheries a process of management that often occurs on an annual basis. The elements of this cycle are (1) data collection and monitoring of the fishery and the stock, (2) assessment of stock status from the data available usually using population dynamics models, (3) determination of catch limits or other regulations for the next year or period of the management cycle, an (4) implementation of the regulations and pursuit of the fishery (Hilborn 2003). Almost all international RFMOs, and governments in Europe, North America, Namibia, South Africa, Peru, Chile, Argentina, Australia and New Zealand, all have processes with these elements for most of their most significant industrial fisheries.

The first two elements of the cycle are highly fishery specific and I won't go into any details. However, in determining the catch limits there are some near-universal themes. In the second phase of the cycle the data are used to estimate the stock size and productivity, from that assessment the catch limits are set usually based on "reference points." One kind of reference points are "targets" which may be as simple as a target exploitation rate (Hilborn 2002; Koeller 2003). From the assessment, one obtains an estimate of the total population size, that is multiplied times the target exploitation rate to obtain the annual allowable catch. In other fisheries, the targets are stock abundance levels, and if the stock is below the target abundance, catches are reduced, if abundance is above the target it might be increased.

A second type of reference point is "limits." Limit reference points are levels beyond which management does not wish to operate. For instance a common limit reference point is a minimum stock size, and if this limit is exceeded, then more drastic management action is taken, either the fishery is closed, or a new set of harvest rules are considered to assure stock rebuilding. There are also exploitation rate limit reference points, exploitation rates which the agency does not want to exceed.

Figure 1 shows a typical harvest rule adopted by the Pacific Fisheries Management Council known as the 40:10 rule. The target population size is 40% of a theoretical "unfished population size" and the limit population size, below which any directed fishing is stopped is 10% of the unfished population size.

A refinement on the cycle of management described above are more formal "management procedures" in which not only is there a fixed harvest rule, but the assessment process is also completely specified. In most management agencies the assessment procedure evolves from year to year as new methods or assumptions are tried, new data become available of staff turns over or staff changes. This can lead to dramatic "revisions" in stock assessments, where estimated abundance changes as much as 2–3 fold from year to year (Parma 2002). In management procedures, the assumptions are fixed for significant periods of time such as 5 years. A major advantage of management procedures is they allow computerized simulation testing of the entire procedure to determine the consequences of using that procedure across a range of assumptions about the true stock biology. Much more extensive discussion of the experience with management procedures is found in a paper in this book by Butterworth (2008).

There are significant exceptions to the annual cycle of management describe above. This process applies primarily to industrial fisheries where an annual allowable harvest is specified. In some fisheries, such as the Maine lobster fishery (Acheson and Gardner 2004), there are no catch limits, but limits on the minimum size, season length, type and amount of fishing gear. These regulatory rules have proved sustainable over many decades and indeed in the Maine fishery yields have risen dramatically in the last 20 years. Systems regulated by effort rather than catch are theoretically more robust to uncertainty in stock size, although they are

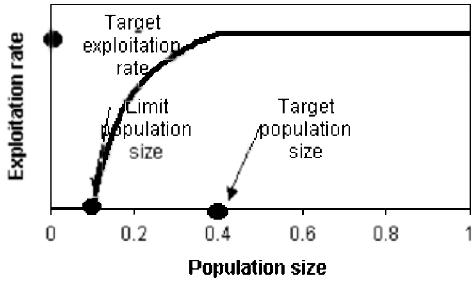

Fig. 1. The 40:10 harvest rule of the Pacific Fisheries Management Council.

vulnerable to increasing technological efficiency leading to growing exploitation rates.

The primary lessons that have been learned in harvest levels are first that overexploitation is possible for almost all stocks and we now have a considerable body of knowledge on what levels of fishing mortality and stock size lead to loss of potential yield (Myers *et al.* 1994). Secondly, when managing by annual catch limits, a feedback management system is required and updates in the allowable catch need to be made in a timely fashion consistent with the biology of the species. I believe there is a broad consensus that application of harvest control rules without implementation in a management procedure leads to highly uncertain outcomes, and harvest control rules should be evaluated in the context of a management procedure.

An outstanding issue is what quantity to have on the *X*-axis of the harvest control rules. The U.S. has been at the forefront of the kind of harvest control rules as described, and commonly the *X*-axis is the stock size relative to the estimated unfished level. This often leads to great complications as the unfished level is often difficult to estimate, and as the importance of systematic environmental changes to stock productivity is more broadly accepted, we recognize that the unfished level in one production regime is different from the unfished level in another production regime. There is considerable active research on how to find robust strategies across production regimes.

A further area of considerable discussion is the appropriate spatial scale of management. The traditional assumption has been the regulation of catch on the basis of the "unit stock" (Hilborn and Walters 1992), a theoretical self-contained population. As we have learned more about the biology of fish stocks we discover more and more structure within stocks that leads to the potential to try to manage dozens, or even hundreds of stock units separately. Management agencies rarely would have the resources or ability to control fishing on such small spatial scales. The best approach with such spatially structured stocks is one of considerable debate, but one promising solution is to think of such fisheries not as large-scale industrial fisheries, but rather as many small-scale fisheries, and move to management methods appropriate for such stocks as discussed in the next major section.

Most of the basic theory of industrial fisheries management has been derived from management of single stocks. Many of the industrial fisheries of the world harvest a mix of stocks, and even many of the large single species fisheries, catch significantly amounts of other species. There remains considerable discussion and debate about how best to manage the non-target species in such fisheries.

4.2. Small-scale and community-based management

At the other end of technology, spatial scale and volume are the many small-scale fisheries of the world. These fisheries employ the majority of the people in the world engaged in fishing, and are the backbone of fishing communities throughout the world, often including industrialized countries. These fisheries have seen an evolution of fisheries management systems very different from the industrial fisheries of the world, and many argue that many of the lessons learned in these fisheries should be applied much more broadly. My personal experience is primarily in industrial fisheries, and I will draw on lessons learned in small-scale fisheries primarily from the Chilean artisanal fisheries (González 1996; Castilla and Fernández 1998; Castilla *et al*. 1998), South Pacific Island nations (Johannes 1978; Johannes 1981; Johannes 2002), and Japanese coastal fisheries (Akimichi 1984; Akimichi and Ruddle 1984; Ruddle 1989, 1994, 1998a, b, c).

4.2.1. Access to fishing

The most important lesson from the small-scale fisheries of the world is that limiting access, usually to local participants, is the key to biological, economic and social sustainability. It is now almost 30 years since Johannes wrote "The Words of the Lagoon" and the lessons he described ring more truly every day.

> The most important form of marine conservation used in Palau, and in many other Pacific islands, was reef and lagoon tenure. The method is so simple that its virtues went almost unnoticed by Westerners. Yet it is probably the most valuable fisheries management measure ever devised. Quite simply, the right to fish in an area is controlled and no outsiders are allowed to fish without permission.
> (Johannes 1981)

> Where such tenure of marine fishing grounds exists it is in the best interest of those who control it not to overfish . . . Self-interest thus dictates conservation. In contrast, where such resources are public property, as is the general case in Western countries, it is in the best interest of the fisherman to catch all he can. Because he cannot control the fishery, the fish he refrains from catching will most likely be caught by someone else. (Johannes 1981)

In his last paper on fisheries management practices in the Pacific (Johannes 2002) Johannes describes how many of the traditional village-based practices that had been abolished under Colonial governments were re-emerging and leading to the re-establishment of village-based tenure and rebuilding of local fish stocks that had been depleted when access was not regulated.

In the Japanese coastal fishery, the access is limited to members in the local cooperatives. Similarly in the Chilean artisanal fisheries, control of the near-shore resources has been granted to local community cooperatives and they can exclude any others from fishing in their areas. Local tenure is not a sufficient condition to ensure sustainability, local people can for various reasons over-exploit or in other ways not effectively use their resources. However, it does appear that for small-scale resources' local control, at least to the extent of being able to exclude others, is a necessary condition for biological, economic or social sustainability.

In Chile, prior to the advent of the local control system, the major fishery for "loco" a valuable snail, was regulated with the traditional methods of industrial fisheries, size limits, season limits and allowable catches. This system totally failed, primarily due to the inability to enforce any of the regulations, and the fishery was legally closed in an attempt to rebuild the resource. Again enforcement of this ban was ineffective, and the system of local control was established which has, in general, been very effective and providing for much better biological and economic performance.

Within small communities across the three areas discussed above, and around the world, there are a multitude of methods used to allocate fish within communities, and I know of no summaries of the relative success and failure of these methods.

4.3. Other elements of management

It is impossible to summarize or describe the other elements of management across the range of small-scale fisheries around the world. Perhaps the most important lesson is that there is no single solution, and what is appropriate in one community for a specific species may be totally different for another species or community. A characteristic of small-scale fisheries around the world is the reliance on local communities for the actions of management such as setting harvest levels, data collection, and enforcement. The top-down approach developed and applied in industrial fisheries simply cannot work at small spatial scales and these systems are by their nature dependent on either local management or co-management where the state organizations simply have a small role assuring that some guidelines are met by the local communities.

Similarly, few of the models of assessment and regulation from industrial fisheries apply to small-scale fisheries. Complex computer models have little role and can be replaced by simple rules of thumb. In small-scale fisheries there is considerable potential for good catch monitoring and fishery independent surveys of abundance to provide the information for harvest rules, but these rules would need to be data based rather than model based.

5. Discussion

I believe the most important lesson learned in fisheries management is that any attempts to achieve biological, economic and social sustainability require limiting access to the resource. This is as true for the large industrial fisheries of Europe as it is for the small-scale fisheries of Oceana. This is true regardless of the objectives of the stakeholder. The appropriate mechanism for limiting access will differ enormously across societies and objectives. A society may chose to have a few individuals take most of the catch of a species, or spread the catch broadly over many users. If economic efficiency is the social goal, then the answer will almost always be for a small number of individuals specializing in their gear and talents for that species. The limitation on access can take the form of legal mandates, or social conventions.

What remains uncertain is how best to achieve limiting access in a wide range of societies given the constraints of their infrastructure and governance. Restricting access always involves winners and losers, and it is often difficult to find a mechanism within a society that can achieve a socially acceptable result. We know we need to restrict access, what we have not yet worked out is how to achieve this in different societies. There is no single solution, and even in the same country we will find a method working well in some fisheries and failing in others. A second lesson is that every fishery needs to be understood as unique and access solutions crafted for the special circumstances of that fishery. We now know of a large "toolkit" of methods for limiting access, and what is needed is a broader systematic understanding of how these work in local circumstances.

An obvious reason for the need for local adaptation of the tools of restricting access is the difference in objectives. There can be no global solutions because there are no global objectives. This is the reason I devoted significant space to objectives at the beginning of this paper. Recognizing the diversity in objectives we must then seek a diversity in solutions.

The second most important lesson is the need to maintain the biological productivity of resources. The use of target and limit reference points as essential elements of a harvest strategy has emerged from the North Atlantic fisheries and is rapidly being adopted in a range of countries, often as a legal requirement. However, these fisheries are in many ways a special case, being some of the most over-exploited and most intensively researched fisheries in the world. This means that there is usually a good idea of what the former biomass was—because the exploitation rates were so high the caught all the fish. There is also both in Europe and Atlantic North America a long history of research surveys. These two conditions are unusual in the world scene, where research surveys are much less common, and exploitation rates may be lower or catches undocumented so we don't know historical biomass. The result is that I doubt that the "reference points linked to harvest strategies" approach is broadly applicable to most of the worlds fisheries. This is especially true when the reference points are defined in terms of an unfished stock size, and it is assumed we know stock size and exploitation rate well enough to base our rules on these quantities.

However, there are many fisheries where this approach is being applied, at least in theory, and one must ask why many of these fisheries remain overexploited. The answer is simply that the consumptive stakeholders have failed to accept the process and resist it through their political power, and through non-compliance. In Europe and New England it has been common for the political process to set the catch limits higher than management strategies would suggest, and in Europe at least, overcatch of quota is common.

Achieving maintenance of the productive capacity of the resource appears to require enough cooperation with consumptive users that they accept and cooperate with the management process. This implies a level of local adjustment of the management process to the circumstances of the local fishery. The measures used to track abundance need to be consistent with the knowledge of the local fishery and accepted by them.

While maintaining biological productivity is essential for sustainability, there is a wide range of ways that productivity can be maintained. Should the ecosystem be managed to maintain a large groundfish population, or should we allow continued heavy fishing on groundfish in order to maintain larger invertebrate populations? Should marine mammals be exploited to reduce their predation on valuable fish? Should large areas of habitat be devoted to various forms of marine aquaculture?

In summary, we have accumulated a great deal of knowledge around the world about how to achieve successful fisheries management. The lessons I see are that access needs to be restricted and biological productivity of the stocks maintained. The best way to do either of these tasks depends greatly upon the local circumstances, particularly the specific objectives of the society associated with the fishery. We have a broad range of tools for achieving limited access and biological productivity and we these tools need to be crafted for local solutions.

In all aspects of fisheries management, including the areas I have not had space to consider, data collection and research, enforcement and compliance, artificial propagation and habitat protection, we see cooperation with local stakeholders as almost universally essential to success. I and others have written extensively about the role of incentives in leading to successful fisheries (Hilborn *et al*. 2005; Grafton *et al*. 2006) so I will not elaborate on this further here. However, if you look around the world for well managed fisheries that are biologically, economically and socially successful you will almost always find these three elements, restricted access, maintenance of biological productivity, and cooperation of stakeholders.

References

Acheson JM, Gardner RJ. Strategies, conflict, and the emergence of territoriality: The case of the Maine lobster industry. *Am. Anthrop.* 2004; **106**: 296–307.

Akimichi T. Territorial regulation in the small scale fisheries of Itoman, Okinawa. *In*: Ruddle K, Akimichi T (eds). *Maritime institutions in the Western Pacific*. National Museum of Ethnology, Suita, Osaka, Japan. *Senri Ethnological Studies* 1984; **17**; 89–120.

Akimichi T, Ruddle K. The historical development of territorial rights and fishery regulations in inshore Okinowan waters. *In*: Ruddle K, Akimichi T. *Maritime institutions in the Western Pacific*. National Museum of Ethnology, Suita, Osaka, Japan. *Senri Ethnological Studies* 1984; **17**: 37–88.

Beverton RJH, Holt SJ. *On the Dynamics of Exploited Fish Population*s. Fisheries Investigations. vol. 2. Her Majesty's Stationary Office, London. 1957.

Butterworth DS. Some Lessons from implementing management procedures. *In*: Tsukamoto K, Kawamura T, Takeuchi T, Beard TD Jr., Kaiser MJ (eds). *Fisheries for Global Welfare and Environment*. 5th World Fisheries Congress. TERRAPUB, Tokyo. 2008; 381–398.

Castilla JC, Fernández M. Small-scale benthic fishes in Chile: on co-management and sustainable use of benthic invertebrates. *Ecol. Apps.* 1998; **8**(Suppl.): S124–S132.

Castilla JC, Manriquez P, Alvarado J, Rosson A, Pino C, Espoz C, Soto R, Oliva D, Defeo O. Artisanal "caletas" as units of production and comanagers of benthic invertebrates in Chile. *In*: Jamieson GS, Campbell A (eds). Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. *Can. Spec. Pub. Fish. Aquat. Sci.* 1998; **125**: 407–413.

González E. Territorial use rights in Chilean fisheries. *Mar. Res. Econ.* 1996; **11**: 211–218.

Grafton RQ, Arnason R, Bjorndal T, Campbell D, Campbell HF, Clark CW, Connor R, Dupont DP, Hannesson R, Hilborn R, Kirkley JE, Kompas T, Lane DE, Munro GR, Pascoe S, Squires D, Steinshamn SI, Turris BR, Weninger Q. Incentive-based approaches to sustainable fisheries. *Can. J. Fish. Aquat. Sci.* 2006; **63**: 699–710.

Hilborn R. The dark side of reference points. *Bull. Mar. Sci.* 2002; **70**: 403–408.

Hilborn R. The state of the art in stock assessment: where we are and where we are going. *Scientia Marina* 2003; **67**: 15–20.

Hilborn R. Fisheries success and failure: the case of the Bristol Bay salmon fishery. *Bull. Mar. Sci.* 2006; **78**: 487–498.

Hilborn R. Defining success in fisheries and conflicts in objectives. *Mar. Pol.* 2007a; **31**: 153–158.

Hilborn R. Moving to sustainability by learning from successful fisheries. *Ambio* 2007b; **36**: 296–303.

Hilborn R, Walters CJ. *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty*. Chapman and Hall, New York. 1992.

Hilborn R, Branch TA, Ernst B, Magnusson A, Minte-Vera CV, Scheuerell MD, Valero JL. State of the world's fisheries. *Ann. Rev. Environ. Resour.* 2003; **28**: 359–399.

Hilborn R, Orensanz JM, Parma AM. Institutions, incentives and the future of fisheries. *Philos. Trans. Roy. Soc. Lond. Ser. B* 2005; **360**: 47–57.

Huxley TH. Inaugural address. *Fisheries Exhibition Literature* 1884; **4**: 1–22.

Johannes RE. Traditional marine conservation methods in Oceania and their demise. *Ann. Rev. Ecol. Syst.* 1978; **9**: 349–364.

Johannes RE. *The Words of the Lagoon: Fishing and Marine Lore in the Palau District of Micronesia*. University of California Press, Berkeley, CA. 1981.

Johannes RE. The renaissance of community-based marine resource management in Oceania. *Annu. Rev. Ecol. Syst.* 2002; **33**: 317–340.

Koeller P. The lighter side of reference points. *Fish. Res.* 2003; **62**: 1–6.

Mansfield B. Rules of privatization: Contradictions in neoliberal regulation of North Pacific fisheries. *Ann. Assoc. Am. Geogr.* 2004; **94**: 565–584.

Myers RA, Rosenberg AA, Mace PM, Barrowman N, Restrepo VR. In search of thresholds for recruitment overfishing. *ICES J. Mar. Sci.* 1994; **51**: 191–205.

Norse EA, Grimes CB, Ralston S, Hilborn R, Castilla JC, Palumbi SR, Fraser D, Kareiva P. Marine reserves: the best option for our oceans? *Front. Ecol. Env.* 2003; **1**: 495–502.

Parma AM. In search of robust harvest rules for Pacific halibut in the face of uncertain assessments and decadal changes in productivity. *Bull. Mar. Sci.* 2002; **70**: 423–453.

Pauly D. The Sea Around Us Project: Documenting and communicating global fisheries impacts on marine ecosystems. *Ambio* 2007; **36**: 290–295.

Pearse PH. From open access to private property: recent innovations in fishing rights as instruments of fisheries policy. *Ocean Development & International Law* 1992; **23**: 71–83.

Phillips BF, Ward T, Chaffee C. Ecolabelling in Fisheries: What Is It About. Blackwell, Oxford, UK. 2003.

Ruddle K. Solving the common-property dilemma: Village fishery rights in Japanese coastal waters. *In*: Berkes F (ed). *Common Property Resources: Ecology and Community-based Sustainable Development*. Belhaven Press, London. 1989; 168–184.

Ruddle K. Local knowledge in the future management of inshore tropical marine resources and environments. *Nature & Resources* 1994; **30**: 28–37.

Ruddle K. The context of policy design for existing community-based fisheries management systems in the Pacific Islands. *Ocean Coastal Manage.* 1998a; **40**: 105–126.

Ruddle K. Introduction to the special issue on a modern role for traditional coastal-marine resource management systems in the Pacific Islands. *Ocean Coastal Manage.* 1998b; **40**: 99–103.

Ruddle K. Traditional community-based coastal marine fisheries management in Viet Nam. *Ocean Coastal Manage.* 1998c; **40**: 1–22.

Smith TD. *Scaling Fisheries: the Science of Measuring the Effects of Fishing, 1855–1955*. Cambridge University Press, Cambridge. 1994.

Worm B, Myers RA. Meta-analysis of cod-shrimp interactions reveals top-down control in oceanic food webs. *Ecology* 2003; **84**: 162–173.