# Measuring the biological sustainability of marine fisheries: property rights, politics, and science

Michael De Alessi*

* Michael De Alessi, Department of Environmental Science, Policy, and Management at UC Berkeley, and a Senior Fellow at the Reason Foundation in Los Angeles.
Email: dealessi=a=ix.netcom.com (replace =a= with @)

While nearly everyone favors sustainability, few agree on what the term actually means. In the case of marine fisheries, what first appears simple – exploiting species at a level that does not diminish their productivity in the future – is confounded by the possible inclusion of social, cultural, and economic notions of sustainability, as well as the effects of fishing practices on the wider ecology (that is, on both non-target species and habitats) of the seas. These approaches are all important, but this paper will focus on measuring the biological sustainability of targeted species, which must precede (but certainly not preclude) all other measures of sustainability. While determining what *is* sustainable is tricky, it is not difficult to find examples of biologically unsustainable fisheries.

From the dramatic collapse of the once prolific cod fisheries of New England and Eastern Canada to the decline of subsistence fisheries throughout the developing world, marine fisheries are a classic case where the sustainable development of a resource has been the exception rather than the rule. According to the Food and Agriculture Organization of the United Nations (FAO 2007), worldwide marine fish catches have declined over the last ten years and most marine capture fisheries are now either depleted or hovering at the brink of overexploitation. In the United States, the National Marine Fisheries Service (NMFS 2002) reports that almost one-third of U.S. fish stocks are overfished, or that 75% of U.S. commercial fish stocks are either overexploited or fully exploited. Some academics have suggested that the problem is even worse, estimating in the journal *Science* that since the advent of industrial fishing more than 90% of large predatory fish have been removed from the world's oceans (Worm and Myers 2003). Subsequently, *Nature* published one extrapolation of current trends in loss of diversity and ecosystem function that predicted a global collapse of all commercial fisheries by 2048 (Worm et al 2006).

This research succeeded admirably in raising eyebrows, as well as criticism. Fisheries scientist Ray Hilborn (2007a) depicts the 2048 prediction as "ridiculed by most fisheries scientists", and describes similar studies, including the precipitous decline of large predatory fish, as "either outright wrong or serious distortions of reality" (citing, for example, Hampton et al 2005). In addition, pronouncements from agencies such as FAO that seem dire at first glance – such as listing the majority of fisheries as either fully or overexploited – belie the fact that for many countries, full exploitation is the stated goal of fisheries policy. The list also says nothing about whether overfished stocks are recovering or not. Finally, Hilborn (2003) notes that in the U.S. context, most fisheries classified as overfished are still producing significant catches, so that even if they were pessimistically producing only half of their potential yield, "U.S. production would [still] be at 84% of maximum" – which sounds very different than 75% overfished or fully exploited.

The issue is not whether depletion is a widespread problem, but just how bad things have become, and what might be done to fix the problem. Part of this difference of opinion stems from the fact that fisheries can be managed for economic, biological, or social objectives. Not only are the criteria for success different in each of these cases, but also within similar fields, as is the case with fisheries scientists such as Hilborn and marine ecologists such as Myers and Worm. That social scientists are even less likely to agree on measures, let alone desired outcomes, only highlights the complexity of the issue.

Measuring performance is crucial to understanding which fisheries are being successfully managed. This paper will focus on biological sustainability, as it lies at the heart of the sustainable development of marine resources. It will address the ways that institutional and political causes of depletion and the uncertain nature of fisheries science have undermined measures of biological sustainability; explore ways that success may be better measured; and conclude with a proposal for a new approach to measuring biological sustainability.

## The Tragedy of the Commons and the regulatory response

Understanding what causes depletion under today's complex institutional, political, scientific, and economic institutions is not easy. At its core, however, is a simple explanation, one that has been known literally for ages. Aristotle (*politics ii*) noted that "those things which are owned by the greatest number of people are the least well cared for." Some millennia later, the same idea was neatly encapsulated by Garrett Hardin (1968) when he coined the phrase "the tragedy of the commons." Despite making a semantic mistake in his use of the word "commons" (he really meant open access[1]), Hardin's basic point, that valuable resources free for the taking will inevitably be depleted, was spot on.

Hardin drew primarily on the work of economists writing in the 1950s who modeled the choices faced in fisheries and pointed out the fundamental importance of property rights to resource stewardship and conservation. Property rights define who has the right to do what with a resource, including whether to exploit, conserve or deplete it. As H. Scott Gordon (1954) wrote, "The fish in the sea are valueless to the fishermen, because there is no assurance that they will be there for him tomorrow if they are left behind today." With no incentive to leave fish in the sea, depletion naturally follows. Anthony Scott (1955) expanded upon the notion that no one will maintain a resource unless they have a residual claim to its production (i.e., a property right in the yield of the fishery) and extended the analysis to reflect the idea that the ideal standard of comparison for fishery management should be a sole owner who "has complete control of the asset" (the fishery) thereby eliminating the risk that anything left in the water could simply be caught by someone else.

For most of the twentieth century, however, the blame for the decline of fisheries was laid at the feet of the fishers, which meant that the response from both scientists and management agencies was to devise restrictions and regulations designed to rein in these rapacious harvesters. But traditional restrictions on time (seasons), area, and technology (boats and fishing gear) do not address the underlying incentives that fishers face, and the "tragedy" remains. Under these circumstances, people whose livelihoods depend on fishing find ways around restrictions when it is worth their while to do so. The Alaska halibut fishery of the 1980s is often cited as an example of regulatory extremism. Managers in that fishery attempted to limit catches by shortening the fishing season, reasoning that less time on the water would result in less fish taken out of the water. Fishers responded with increased effort and better technology such as fish-finding sonar, so that in a relatively short period the season was reduced from over nine months to just *two days,* with no real decline in fish harvests (see Christy 1996).

In other cases, depletion has been avoided, but at enormous economic cost, often in duplicated effort and capital resources spent trying to catch fish before someone else does. In the case of the northern lobster fisheries of the United States, the economist Frederick Bell (1972) found that "over 50 per cent of the capital and labor employed in lobstering represent an uneconomic use of factors." In other words, Anthony Scott's hypothetical sole owner of the fishery would have harvested the same amount of fish over roughly the same period of time employing half the labor and capital.

Another problem with fisheries regulation is that it often replaces existing formal and informal institutions such as those that Hardin famously and incorrectly lumped into the commons. Many of these institutions were fragile as they were based on custom and informal rules, so that once destroyed, they are very difficult to recreate. This is a problem particularly in those countries where foreign management regimes were imposed without consideration of the local context. This led the marine ecologist turned ethnographer Robert Johannes (1978) to observe that "If there is an island somewhere in Oceania where marine resources are conserved more effectively today than they were before European contact, I have not heard of it."

It is now well established that most fishers who depleted resources were simply responding rationally to the rules of the game presented to them. And despite the economic waste in the Alaskan and northern lobster examples, they were at least spared a collapse. But other well developed fisheries, most famously the cod stocks of New England and Atlantic Canada, did collapse. Where were the fisheries scientists? Were they well aware of depletion but ignored by fishery managers, or did they miss the boat? A little of both, it appears.

## Fisheries science and uncertainty

For many years and even today, much of fisheries science and management is directed at finding the maximum sustainable yield (MSY) of a fishery. The theory is that a virgin (established but unfished) biomass produces fewer fish than one that is expanding to fill a niche. At the point along the curve of fishery production with the highest rate of increase, fishery harvests can be maximized Perhaps first among many problems with determining this curve and where a particular fish population lies along it, is that fish are hard to count. They are underwater and they move, often over great distances and over great depths.

Even when sampling data show clear trends, multiple interpretations are still possible. To reach MSY, virgin stocks of fish will be fished down for a number of years, which means harvest levels are intentionally unsustainable. Eventually harvests decline and even out as the fishery stabilizes around MSY. Although the theory that fishing down a virgin biomass increases its productivity is generally accepted, there are a number of species where the largest and oldest fish are the most fecund. It is also widely accepted that the exploitation of fisheries lowers the average size and age of a population.

The effects of natural variability on fish reproduction and mortality, and even on the location of fish, are very difficult to parse out from management effects, even after the fact. In its heyday, the Peruvian anchoveta accounted for over twenty percent of the world's marine fish catch. When it crashed spectacularly in the 1970s it drew enormous attention from scientists, academics, and policy makers, yet even today academics still disagree about whether the cause was overfishing or natural variation, in particular the effects of El Niño weather patterns (Pauly et al 2002). Even what seems like the most obvious indicator of sustainability – a stable catch over a number of years – has recently been questioned by fishery scientists who analyzed data on fisheries collapses around the world since the 1950s. They found that one in five collapses followed "a relatively long and stable persistence of high level of catches" (Mullen, Freon and Cury 2005). They also found that nearly one in four fisheries (out of almost 1600 sampled) has experienced some kind of collapse, and that the number of collapses has remained constant since the 1950s.

When the biomass and population dynamics of a fishery are largely unknown, how can one tell whether a decline in harvests is a sign of depletion or just the expected trajectory of a fishery on its way to reaching MSY? As Ludwig, Hilborn, and Walters (1993) point out, the diversity and complexity of fisheries means that "optimum levels of exploitation must be determined by trial and error" for each and every fishery. And this doesn't even begin to address other complicating non-biological factors that can affect harvests, such as changes in technology that make it easier to find or harvest target species, or changes in market prices that make certain species more or less appealing to fishing pressure.

Some leading fishery scientists believe that their profession will "never attain scientific consensus" on most exploited fisheries (Ludwig, Hilborn and Walters 1993).

Why isn't fisheries management improving, or fisheries science getting more accurate? Fisheries modeling is improving, but it is also becoming more data-intensive, and data collection is expensive and complex, which can reduce the effectiveness of newer models (Pinnegar and Engelhard 2007). Another explanation from the ecological and environmental community is the notion of shifting baselines, an idea coined by Daniel Pauly (1995) to describe how each generation of fisheries scientist takes the current state of the world as the norm, instead of more accurately incorporating the past. For example, restoration targets from Atlantic cod to oysters in the Chesapeake Bay of the United States are commonly set at the levels of 20–30 years ago, despite centuries of decline in those fisheries.

Lest this all sound too pessimistic, Ray Hilborn, one of the authors of the pessimistic statement above, and his colleagues (Hilborn et al 2003), have documented a number of fishery success stories where the science and the management are both sound. Notable successes such as West Australian Rock Lobster, Alaska Salmon, and Pacific Halibut, however, are examples of single species management, while most of the world's fisheries are part of a complex of species. They (Hilborn et al 2003) point out that fisheries science and in particular stock assessment have come a long way in the last 100 years, so much so that "harvest guidelines that lead to long-term sustainability are easily calculated." The problem is, safeguarding against collapse is one thing; trying to "identify and reach the population size that provides maximum harvest …requires a much more detailed understanding of fish biology" (Hilborn et al 2003). Maximizing yields from the fishery is more attractive to just about everyone, from politicians courting votes, to managers increasing the scope of their work and the size of their budgets, to ports and cities increasing employment, and, of course, to fishers looking to maximize returns.

## Political economy of fisheries management

When politics collides with science, it provides even greater uncertainty and complication; something that has all too often been overlooked by fisheries scientists in the past. In an oft-cited paper from 1993 in *Science,* the fisheries scientists Donald Ludwig, Ray Hilborn and Carl Walters acknowledged that the short-sightedness of politics was a real problem, but gave the profit motive equal billing, attributing resource collapse to uncertain "scientific information coupled with the promise of large profits."

Many ecologists have discounted politics altogether. Cod is one of the most fecund marine fish species and had been plentiful off the coasts of Atlantic Canada and New England for centuries. After the Newfoundland cod fishery collapsed and was shut down in 1992, postmortems were common. One published by the US National Academy of Sciences likened the ability of the economic models used to manage the cod fishery to hit their targets with the difficulty of "balancing a marble on top of a dome", and proposed basing fisheries management on ecological stability instead of yield (Roughgarden and Smith 1996). To prove the failure of yield-based models, they showed that from the late 1970s to the collapse in the early 1990s, harvest limits set by regulators and the actual harvests of fishers in the Newfoundland cod fishery were roughly equivalent, meaning that the fishery failed despite effective enforcement of the catch limits.

In fact, those limits were not set by the models but by politicians, or at least by scientists pressured by politicians. A Canadian Department of Fisheries and Oceans (DFO) audit in 1992 found that the science surrounding the health and management of the cod stocks "was gruesomely mangled and corrupted to meet political ends" (quoted in Brubaker 1999). The DFO also had a policy called the "50 percent rule", which meant that if the fishing industry bristled over proposed catch reduction, then DFO policy was to split the difference between the current harvest limit and the scientific target (Brubaker 1999). The fact that DFO harvest limits and actual catches lined up neatly therefore says little about the ability of economic models to set sustainable harvest limits[2]. It is also worth noting that by 1990, fishers in Newfoundland received CAD$1.60 in unemployment insurance for every dollar they made from the fishery (Brubaker 1999), so that the tragedy of the commons was further perverted by government benefits to fishers that increased as the fishery became more depleted.

Newfoundland is an extreme example, but it underscores the widespread problem of politicized fishery science. Even the best fishery science is based on sampling, not complete information, so there will always be uncertainty in stock assessments. If the incentives of fishers, processors, scientists, bureaucrats, or politicians are not lined up with conservation and sustainability, then uncertainty gives politicians and interest groups an opportunity to press for their own agendas. In the race for fish, for example, market power is decidedly on the side of fish processors. When fishers are trying to catch as many fish as they can as fast as they can, they fish first and then worry about the prices they can get from fish processors. Management changes that end this race (discussed below) allow fishers to choose not to fish if they don't like the offered price. Needless to say, processors have a vested interest in maintaining a market advantage over their suppliers (see Matulich and Sever 1999). This has had a major impact on efforts to reform fishery management in the United States, and has even resulted in the creation of a special dispensation for processors in one Alaskan crab fishery that forces fishers to take their catch to a specific processor.

The wedge of scientific uncertainty makes it easy to argue against reductions in catch, meaning that catches are easy to raise but tricky to lower. Even if special interests do not take on individual stock assessments, taking more interests into account drastically increases regulatory complexity, making any kind of decisive action that much more difficult (Healey and Hennessy 1998). As a result, more and more scientists and managers are realizing the importance of aligning economic objectives with conservation objectives, and there has been a shift away from the economics of MSY toward the economics of property rights in fisheries discussed by H. Scott Gordon and Anthony Scott. Ray Hilborn, for example, has recently written extensively about the importance of recognizing success in fisheries management, comparing and contrasting management institutions and the incentives that fishers face (Hilborn et al 2003, 2007a, 2007b, 2007c, and Hilborn et al 2005). Others are joining Hilborn to suggest parameters necessary for successful fishery management, such as a recent *Science* article which suggested that "legally enforceable and tested harvest strategies, coupled with appropriate rights-based incentives to the fishing community, [are needed] for the future of fisheries to be better than their past" (Beddington et al 2007).

Many of the fishery success stories, and most serious efforts to reform fisheries management, involve limited access and some kind of harvest rights, such as the provision for the creation of "dedicated access privileges" in the 2006 authorization of the Magnuson-Stevens Fishery Conservation and Management Act (the overarching fishery management legislation in the United States). More commonly, access and harvest rights take the form of Individual Transferable Quotas (ITQs), especially in countries like Iceland, New Zealand and Australia, and some notable examples such as the Alaska Halibut fishery in the U.S. (which has stretched its two day season back to eight months).

## Property rights and ITQs in New Zealand

An ITQ is a harvest right that assigns a percentage of a total commercial catch on an annual basis, and is also sometimes known as an Individual Fishing Quota (IFQ). If fishery scientists determine that a fishery can sustain a harvest of 100 tons in a particular year, the owner of a one percent ITQ then owns the right to harvest (or to sell or lease the right to harvest) one ton of fish for that particular year. At the very least these rights end the race to fish, and in some cases create economic incentives to conserve the resource.

Iceland and New Zealand have the most comprehensive ITQ systems, but New Zealand's Quota Management System (QMS) has adapted and evolved more than any other. Since ITQs were introduced in 1986, a series of conflict resolutions and legislative action have moved ITQs away from access privileges toward property rights (Batstone and Sharp 1999). One such upheaval came after the settlement of a lawsuit over the 1840 Treaty of Waitangi, which guaranteed the native Maori "full, exclusive and undisturbed possession of their fisheries" (see Stewart 2004). In the settlement, government bought quota and a share in one of the largest fishing companies in New Zealand for the Maori, who are still majority owners of Sea-Lord today. As a result, the QMS has the strong support of the politically active Maori.

Subsequently, the 1996 *Fisheries Act* specified that ITQs are "allocated in perpetuity" and created a quota registry modeled on a land title registry. The strength of these rights appears to have created a vested interest in the long-term health of fisheries among quota owners (Batstone and Sharp 1999). Quota markets are functioning well as the rate of return to fish quota is comparable with other financial assets in New Zealand (Newell et al 2005). The 1996 Act also instituted cost recovery, which charges the fishing industry for stock assessments and fisheries science directly related to commercial fisheries. The fishing industry now actively funds both research and scientific review.

There seems to be little question about the improvements in the economics and incentives created by the ITQ system, but evaluating the success of New Zealand's QMS beyond these broad measures is proving difficult, even just for biological criteria. Both the fishing industry and the Ministry of Fisheries tout their commitment to sustainable fishing, but most of the evidence lies in moderately stable catch histories and numerous examples where fishers have imposed catch reductions on themselves (unheard of in traditional fisheries management). The New Zealand Ministry of Fisheries (MFish) prioritizes stock assessments of New Zealand's main commercial fisheries, and states that "Of the 85 stocks for which we have sufficient information to characterise stock status, 72 (85%) are at or near target levels" (MFish 2007). This sounds good, but are those targets really sustainable?

## Measuring biological sustainability

With all of the aforementioned uncertainties inherent in fish stock assessments and population dynamics, it is not surprising that fisheries scientists and others have had difficulties in defining performance indicators for biological sustainability, let alone economic and social indicators which also affect biological sustainability. The New Zealand QMS seems to be a success, but in order to evaluate its effect on biological sustainability, there needs to be better performance measurement.

Common biological performance measures include average catch, variance of catch, average stock size, minimum stock size, or probability of falling below some threshold level, but which one is chosen depends on fishery management objectives (Hilborn and Punt 1997). Comparison is even more difficult between countries, as species, data sets, and classification criteria such as "overfished" invariably differ. Most efforts by non-governmental organizations (notably the Marine Stewardship Council) and inter-governmental bodies (notably FAO) to measure fisheries sustainability set clear objectives but have vague criteria with which to measure them, whether biological, economic, or social. In a document aimed at setting and improving the measurement of indicators in fisheries, FAO suggests evaluating biological sustainability by looking at "catch structure, relative abundance of target species, exploitation rate, direct effects of fishing gear on non-target species, indirect effects of fishing on trophic structure, direct effects of gear on habitats, species biodiversity, change in area and quality of important or critical habitats, and fished vs. unfished area" (FAO 1999). Many of these are difficult to measure in the first place, which is compounded by the difficulties in comparing different standards of measurement across both fisheries and countries which can't even agree on what constitutes "overfished."

The Marine Stewardship Council is a non-governmental organization based in London that certifies fisheries as sustainable with an eco-label. Founded in 1997 by Unilever and the World Wide Fund for Nature, it became independent in 1999. MSC has certified 26 fisheries as sustainable to date, and claims that 7% of the world's edible, wild capture fisheries are either certified or in the process of being assessed (MSC 2007c). The MSC's (2007a) biological criteria (the "primary focus" of the program") for determining that a fishery is sustainable are that:

- it can be continued indefinitely at a reasonable level;
- it maintains and seeks to maximise ecological health and abundance;
- it maintains the diversity, structure and function of the ecosystem on which it depends as well as the quality of its habitat, minimising the adverse effects that it causes.

The MSC further clarifies each of these criteria, for example stating that a "reasonable" level of fishing is one that "does not lead to over-fishing or depletion" or that "demonstrably leads to their recovery" if a fishery is rebuilding. Beyond these efforts at clarification, the MSC guidelines are filled with phrases like "does not threaten biological diversity", "minimise mortality of [non-target] catch" and "implement appropriate fishing methods designed to minimise adverse impacts on habitat" (MSC 2007a). Of course it would be almost impossible to quantify any of these criteria further across broad categories, but words like "minimize", "threaten", and "appropriate" leave open a very wide array of interpretations and subjectivity.

Some fisheries scientists and economists have suggested the price of access to a fishery could be used as a proxy for biological data because it conveys information about the marketplace's long-term outlook for the fishery (Hilborn et al 2005). With its secure, transferable rights and active quota market, New Zealand should be a good testing ground of the theory that quota prices capitalize the expected future health of the fishery, and indeed, some economists have suggested that quota prices may be used as a guide to set limits on commercial fish catches (Batstone and Sharp 2003). New Zealand exports 90% of its fish, so factors such as foreign exchange rates and the volatility of international fish prices, as well as the small size of many of New Zealand's fisheries are likely to affect asset value in ways unrelated to biological health. And indeed, comparing recent asset values to harvest limits for three different species shows that as harvests in each fishery fell, asset values for paua (abalone) rose, asset values for snapper remained relatively constant, and asset values for hoki dropped (Statistics NZ 2007). On the other hand, a more specific study of the Gisborne rock lobster fishery demonstrated the link between asset value and biological health, as fishers purposefully increased their asset values by reducing their catches (Breen and Kendrick 1997). Trends in asset values should be easier to measure and compare across fisheries and countries, but the information they contain is still subject to significant noise from changes in regulations, export markets, and consumer preference, among others.

## Using the likelihood of sustainability to measure performance

Fisheries management is a form of decision-making under uncertainty, but to date, the disciplines of decision analysis and management science, which deal with exactly this problem, have made few inroads into fisheries science[3]. One of the insights of decision analysis is to assess the quality of *decisions* as much if not more than outcomes. The difficulties of measuring results in fisheries short of total collapse mean that outcomes are very difficult to ascertain. Measuring the *likelihood* of biologically sustainability instead could be more practical and widely applicable/comparable. Thus, biological sustainability could be measured by looking at attributes of the inputs (harvest models) instead of the outputs (uncertain stock estimates that depend on uncertain population dynamics).

Measuring inputs means evaluating how harvest models incorporate uncertainty, risk, and past performance. All three of these measures can be quantified or at least identified in the models, which would reduce the subjectivity of criteria setting. All fisheries modeling has to deal with uncertainty in some form or another, whether by simply taking a midpoint estimate or by incorporating more information about the possible variation around that midpoint. As the number of points incorporated into the model increases, or as the distribution moves from discrete to continuous, there will be more information used by the model, both about the level of uncertainty and the value of investing more time and effort in refining that variable (for example, one might find that recommended harvest levels are unchanged by reducing the uncertainty of a particular estimate, so there would be no point in refining that data point).

Risk tolerance is also an important part of fisheries management and the evaluation of possible outcomes.

In other words, how willing are managers and fishers to accept a chance that a particular harvest level will be unsustainable? The more explicitly risk averse a model is, the more likely the harvest is to be sustainable. A third indicator of the likelihood of sustainability is the incorporation of Bayesian statistical analysis into harvest models, which, simply put, incorporates past performance (outcomes) into the model. This has already been suggested and used by a number of fisheries scientists (Punt and Hilborn 1997), but seems rarely to be put into practice. But the individual nature of each fishery, and therefore the trial and error necessary to refine fishery models, suggests that historical comparisons are vital to model refinement.

If the relationship between property rights and biological sustainability is significant, then one would expect to find that harvest models in New Zealand quantify risk attitude and are more risk-averse, use continuous probability distributions, and incorporate historical precedent more than fisheries elsewhere. One would also expect these attributes to be extant and better defined in fisheries where the property rights are more clearly defined. Indeed, Hilborn and Punt's (1997) example of a Bayesian approach to fisheries management used the New Zealand hoki fishery as their model and data source. More research is needed, particularly in quantifying the risk, uncertainty, and incorporation of history in New Zealand's fisheries models. Given the uncertain nature of just what's going on underwater, however, more attention needs to be paid to the *likelihood* of sustainable harvests as a comparative, empirical tool for understanding the effects of management institutions on biological sustainability.

## Conclusions

The history of fisheries management is replete with failures to sustain yields of fish harvests, let alone the marine environment, coastal communities, or the economic viability of the fishing industry. What Garrett Hardin loosely described as the tragedy of the commons appears to have been a major factor, and as a result, limited access and quota management are common fishery management tools today. Fisheries science has also grown in sophistication in recent years, but much uncertainty remains even in population estimates of target populations. Better measures of biological sustainability are crucial for evaluating management changes in places like New Zealand. Natural variability combined with other scientific (for example simply finding fish underwater) and economic (such as the influence of foreign market demand) variables mean that there will always be a great deal of uncertainty surrounding population estimates. On the other hand, fishery models are easily measurable, as are their treatments of uncertainty and history. This paper suggests that rather than relying on biological data alone, measures of biological sustainability include the treatment of uncertainty and the influence of history (i.e. Bayesian priors) to determine comparative measures of the *likelihood* of biological sustainability. This would offer meaningful comparisons between management regimes and fisheries, in particular the ability to say which are more likely to be sustainable.

## Notes

1. Research has shown that from the actively managed open fields in England to the rigidly defined, and often formally recognized marine tenure arrangements in the South Pacific and elsewhere, "commons" often have clearly defined boundaries and exclusive access for a well-defined group, and are often quite successful at mitigating depletion (see Johannes (1981), Cordell (1989), and Ostrom (1990)).
2. See McCay and Finlayson (1996) and Milich (1999) for more on the political economy of DFO policy before the Newfoundland cod collapse.
3. For a notable exception see Hilborn and Punt (1997).

## Acknowledgements

The author would like to gratefully acknowledge research support from the University of California Pacific Rim Research Program and the Alex C. Walker Foundation Educational and Charitable Foundation.

## References

Aristotle. *Politics – Book ii*.

Batstone, C.J. and B. Sharp. 1999. "New Zealand's Quota Management System: the First Ten Years" *Marine Policy*, 23: 177–190.

Batstone, C.J. and B. Sharp. 2003. "Minimum information management systems and ITQ fisheries management" *Journal of Environmental Economics and Management*, 45(2): 492–504.

Beddington, J.R., Agnew, D.J., and C.W. Clark. 2007. "Current Problems in the Management of Marine Fisheries" *Science*, 316: 1713–1716.

Bell, F. 1972. "Technological Externalities and Common-Property Resources: An Empirical Study of the U.S. Northern Lobster Fishery" *Journal of Political Economy*, 80: 148–58.

Breen, P.A. and T.H. Kendrick. 1997. "A fisheries management success story: the Gisborne, New Zealand, fishery for red rock lobsters (*Jasus edwardsii*)" *Marine Freshwater Research*, 48: 1103–1110.

Brubaker, E. 1999. "Cod Don't Vote: Filling fisherman's quota's with paper fish" *The Next City*, 4(2): 34–41 and 56–57

Christy, F. 1996. "The Death Rattle of Open Access and the Advent of Property Rights Regimes in Fisheries" *Marine Resource Economics*, 11: 287–304.

Cordell, J. 1989. *A Sea of Small Boats.* Cambridge, MA: Cultural Survival, Inc.

FAO Fishery Resources Division (FAO). 1999. "Indicators for sustainable development of marine capture fisheries" *FAO Technical Guidelines for Responsible Fisheries*. No. 8. Rome: FAO.

Gordon, H.S. 1954. "The Economic Theory of a Common-Property Resource: The Fishery" *Journal of Political Economy,* 62:124–42.

Hardin, G. 1968. "The Tragedy of the Commons" *Science*, 162: 1,243–48.

Healey, M.C. and T. Hennessey. 1998. "The Paradox of Fairness: the impact of escalating complexity on fisheries management" *Marine Policy,* 22(2): 109–118, 1998

Hampton, J., Sibert, J.R., Kleiber, P., Maunder, M.N. and S.J. Harley. 2005. "Fisheries: Decline of Pacific tuna populations exaggerated?" *Nature,* 434: E1–E2.

Hilborn, R., Branch, T.A., Ernst, B., Magnusson, A., Minte-Vera, C.V., Scheuerell, M.D., and J.L. Valero. 2003. "State of the World's Fisheries" *Annual Review of Environment and Resources*, 28: 359–399

Hilborn, R. 2007a. "Moving to Sustainability by Learning from Successful Fisheries" *Ambio*, 36(4): 296–303.

Hilborn, R. 2007b. "Defining success in fisheries and conflicts in objectives" *Marine Policy*, 31: 153–158

Hilborn, R. 2007c. "Managing Fisheries is Managing People" *Fish and Fisheries*, 8: 285–296.

Hilborn, R. and A. Punt. 1997. "Fisheries stock assessment and decision analysis: the Bayesian approach." *Reviews in Fish Biology and Fisheries*, 7: 35–63.

Hilborn, R., Orensanz, J.M. and A.M. Parma. 2005. "Institutions, incentives and the future of fisheries" *Philosophical Transactions of the Royal Society B*, 360: 47–57

Johannes, R. 1978. "Traditional Marine Conservation Methods in Oceania and their Demise" *Annual Review of Ecology and Systematics*, 9: 349–64.

Ludwig, D., Hilborn, R., and C. Walters. 1993. "Uncertainty, Resource Exploitation, and Conservation: Lessons from History" *Science,* 260(5104): 17, 36.

*Magnuson-Stevens Fishery Conservation and Management Act*, 16 U.S.C. §§ 1801–1884.

Marine Stewardship Council (MSC). 2007a. "MSC Principles and Criteria for Sustainable Fishing." Downloaded from http://www.msc.org/html/content_504.htm on Nov. 26, 2007

Marine Stewardship Council (MSC). 2007b. "MSC Principles and Criteria for Sustainable Fishing: Guide to Principles, Criteria, Sub-criteria and Performance Indicators." Downloaded from on Nov. 26, 2007.

Marine Stewardship Council (MSC). 2007c. "About MSC." Downloaded from http://www.msc.org/html/content_462.htm on Nov. 26, 2007

Matulich, Scott and M. Sever. 1999. "Reconsidering the Initial Allocation of ITQs: The Search for a Pareto-Safe Allocation between Fishing and Processing Sectors" *Land Economics*, 75(2): 203–219.

McCay, B.J. and A.C. Finlayson. 1996. "The Political Ecology of Crisis and Institutional Change: The Case of the Northern Cod" presented to annual meeting of the American Anthropological Association, Washington, D.C., November 15–19, 1995. Published electronically in *Arctic Circle*, January 15, 1996, available online at http://arcticcircle.uconn.edu/

Milich, L. 1999. "Resource Mismanagement Versus Sustainable Livelihoods: The Collapse of the Newfoundland Cod Fishery" *Society & Natural Resources*, 12: 625 642.

Ministry of Fisheries, New Zealand (MFish). 2007. "Status of Fisheries." Downloaded from http://www.fish.govt.nz/en-nz/SOF/default.htm?WBCMODE=PresentationUnpublished%2cPresentationUnpublished on November 6, 2007.

Mullon, C., Freon, P., and P. Cury. 2005. "The dynamics of collapse in world fisheries" *Fish and Fisheries*. 6: 111–120

National Marine Fisheries Service (NMFS). 2002. *Annual Report to Congress on the Status of U.S. Fisheries--2001*, Silver Spring, MD: U.S. Dep. Commerce, NOAA, Natl. Mar. Fish. Serv. 142 p.

Newell, R, Sanchirico, J. and S. Kerr. 2005. "Fishing Quota Markets" *Journal of Environmental Economics and Management*, 49(3): 437–462.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge: Cambridge University Press.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., and D. Zeller. 2002. "Towards sustainability in world fisheries" *Nature,* 418: 689–695.

Punt, Andre and R. Hilborn. 1997. "Fisheries stock assessment and decision analysis: the Bayesian approach" *Reviews in Fish Biology and Fisheries*, 7: 35–63.

Roughgarden, J. and F. Smith. 1996. "Why fisheries collapse and what to do about it" *Proceedings of the National Academy of Sciences of the USA*, 93(10): 5078–5083.

Scott, A. 1955. "The Fishery: The Objectives of Sole Ownership" *Journal of Political Economy*, 63: 63–124.

Statistics New Zealand. 2007. "Fish Monetary Stock Account: 1996–2006." Downloaded from http://www.stats.govt.nz/analytical-reports/fish-monetary-stock-account-1996–2006.htm on August 5, 2007.

Stewart, C. 2004. "Legislating for Property Rights in Fisheries." *FAO Legislative Study 83*. Rome: FAO.

Worm, B. and M. Ransom. 2003. "Rapid worldwide depletion of predatory fish communities" *Nature,* 423: 280–283.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J., and R. Watson. 2006. "Impacts of Biodiversity Loss on Ocean Ecosystem Services" *Science*, 314: 787–790.