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Viewpoint

Future directions in ecosystem based fisheries management: A personal perspective

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ABSTRACT

This paper provides a personal perspective on the future of ecosystem based fisheries management (EBFM). I begin with the question, "if we did single species management well, would EBFM be necessary." The answer to this is yes, because pure single-species management does not consider impacts on non-target species, trophic interactions among species, and habitat-destroying fishing practices. Pure single-species management conflicts with a range of legislation designed to protect non-target species and habitats within the U.S. and a number of other countries. The most important elements of EBFM are keeping fishing mortality rates low enough to prevent ecosystem-wide overfishing, reducing or eliminating by-catch and avoiding habitat-destroying fishing methods. There is a second phase of EBFM I call "extended EBFM" that consists of considering trophic interactions and area-based management. While there are now models of the trophic interactions for most highly managed ecosystems, and there are area-based management efforts underway in many places, I am not convinced that we are really ready, scientifically and administratively, to apply these forms of EBFM, because they are expensive and require complex trade-offs that are often ill-defined.

1. Introduction

This paper is a personal perspective on EBFM, how we got where we are, and where we may be going. It is based largely on my experiences in the U.S., New Zealand and Canada, and my examples will largely come from those regions, and because the U.S. and New Zealand have been at the forefront of implementing single-species management to reduce overfishing, I assume that the lessons learned there will provide instructive examples for the rest of the world. This paper is the product of the concluding talk from the Bevan Symposium and is not intended as an overall review of EBFM, but rather my thoughts on some aspects of the subject.

The recognition of the need to move beyond single-species fisheries management to a more comprehensive perspective is almost universal in countries that manage fisheries intensively (Garcia et al., 2003; Pikitch et al., 2004; Link, 2002; Francis et al., 2007) and has been an integral part of traditional fisheries management systems for millennia (Johannes, 1982). Nevertheless, EBFM is much like the proverbial elephant encountered by three blind men, different people see EBFM very differently. One view holds that EBFM involves a reasonably simple inclusion of concerns regarding by-catch, forage species and habitat modification into traditional single-species management. A second view of EBFM centers on trophic-connectivity with an ultimate goal of accounting for species interactions using ecosystem models rather than single-species models. The most comprehensive view of EBFM encompasses the broad impacts of society, such as land use, national economic policy and human population growth when managing marine ecosystems. Along this gradient are differing perspectives on how to account for human impacts other than fishing, how to include the response of the fishing industry to regulations, as well as a myriad other elements that may or may not be included in EBFM. These are all legitimate perspectives. Some may be more immediately achievable, while others may be limited by lack of scientific knowledge, cost, and political realities.

This paper will concentrate on the first two views, moving from single-species management to inclusion of ecosystem interactions through trophic analysis and mediation of negative impacts on non-target species or structural elements of the ecosystem. I will not consider the most comprehensive view of EBFM. This is a much larger topic, and while consideration of these broader issues is unavoidable in some areas such as rivers, lakes, estuaries and near-coastal waters where fisheries are often a small component of ecosystem impacts, it is beyond the scope of my experience.

2. The problems with single-species management

Almost every major paper on EBFM begins with a now standard recital of the failure of existing fisheries management practices,

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such as "Many of the world's fish populations are overexploited, and the ecosystems that sustain them are degraded" (Pikitch et al., 2004). The Food and Agriculture Organization of the United Nations estimates that 28% of the world's major fish resources are overexploited or depleted (FAO, 2009), and Worm et al. (2009) estimated a similar proportion for a sample of fish stocks where abundance trends had been estimated. Pauly (2007) called roughly 70% of fish stocks overexploited or collapsed based on an analysis of catch trends. These and other scientific papers and popular articles have quite consistently argued that (1) existing fisheries management practices are failing to protect individual stocks and ecosystems, and (2) fisheries agencies should transition to EBFM from single species management.

EBFM could be as complex, scientifically demanding and more expensive than single-species management. This raises the question "if governments and fisheries agencies have been unsuccessful at implementing single-species management, should we expect them to successfully implement a necessarily more complex EBFM?" Seeking methods of EBFM that are indeed simpler and cheaper than single-species management is highly desirable. The question also arises "Would EBFM be unnecessary if we had implemented single-species management correctly?" That is, if none of the world's fisheries were overexploited, would single-species management be sufficient? Worm et al. (2009) showed that most management agencies that track stock abundance have reduced exploitation rates into the range that would produce maximum sustainable yield on an ecosystem basis, and that at least two regions, New Zealand and Alaska have never experienced significant overfishing. It is then perhaps not necessary to implement EBFM in New Zealand and Alaska and other regions where fishing mortality rates have been lowered and recovery is taking place.

We can conduct a simple thought experiment. Imagine "perfect" single-species management where an agency, a fleet sector or sole owner manages perfectly to maximize the single-species yield across a range of stocks. What might go wrong? There could be by-catch of charismatic, protected, threatened or endangered species and of unproductive fish stocks. In some countries there could be, and already are, conflicts between achieving maximum yield and complying with a range of legislation such as the Endangered Species Act and the Marine Mammal Protection Act in the U.S. as well as the Species At Risk Act in Canada. Other countries could have similar conflicts. There could be ecosystem-transforming fishing impacts through the deliberate or inadvertent reduction of predators and, in some places, use of habitat-modifying gear. It is very clear from legislation passed in many countries, from international agreements and treaties, and from often-reported public opinion that governments and the public care about more than maximization of yield from marine ecosystems. Finally, there may be strong trophic connections and hence significant costs in yield of traditional species if their prey species are depleted to levels consistent with the traditional maximum sustainable yield (MSY) target levels of 30–40% of unfished biomass. We need look no further than to the growing concern about the exploitation of forage fish (Alder et al., 2008; Anonymous, 2007; Tacon and Metian, 2009). Successful single-species management could be a major step forward in many areas but, by itself, it is not sufficient. We have to deal with broader ecosystem concerns.

In any case, successful single-species management demands understanding the ecosystem impacts of factors other than fishing. For example, appropriate management actions depend on understanding how an ecosystem changes whenever fish stocks are affected by regimes of high and low productivity due to climate variation (e.g., Parma, 2002).

Traditional single-species management is exemplified by a strong central government with effective enforcement, by regulating catches and using additional input controls in an attempt to maintain individual stocks at the biomass at which maximum sustainable yield, B_{MSY}, or a related target is achieved. In reality, few fisheries could achieve this ideal without stakeholder cooperation, which, in turn, requires elements of governance such as transparency. A fishery really consists of an ecosystem, a fishing fleet or fleets, and a management system where the role of incentives, compliance, data collection etc. is as important as the fish population itself (Hilborn, 2004).

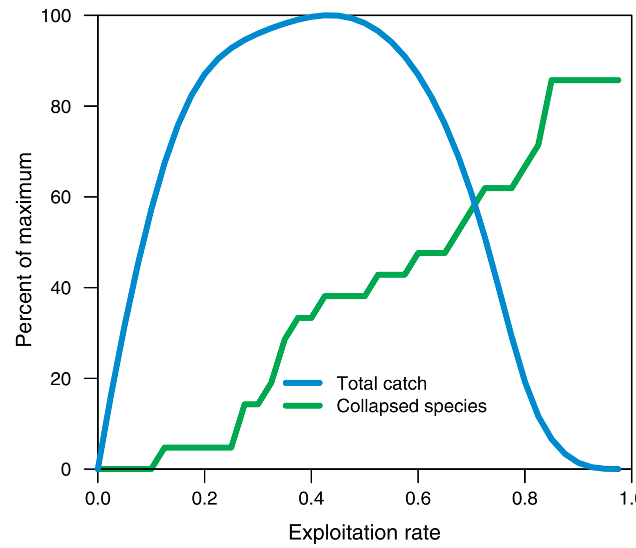

Fig. 1. The sustainable yield, and number of stocks collapsed as consequences of different fishing mortality rates from an ecosystem model.
Figure redrawn from Worm et al. (2009).

3. The core of EBFM

There are "core" and "extended" aspects of EBFM. The "core" consists of three primary features: (a) doing single species management right, i.e., keeping fishing mortality at or below F_{MSY}, and keeping fleet capacity in line with the potential of the resources, (b) preventing by-catch of non-target species, which can be achieved by gear modification, providing incentives for by-catch avoidance, or by area and seasonal closures, and (c) the avoidance of habitat-modifying fishing practices primarily by closing areas or banning of specific fishing methods or gears in sensitive areas. Consideration of trophic interactions and area-based management characterize "extended" EBFM. Most jurisdictions are already engaged in the three core elements, but let us go further than that. Let us consider the broader ecosystem impacts of fishing.

Some "extended" EBFM is easy. Good single-species management reduces ecosystem impacts considerably and we can achieve close to MSY over a range of fishing mortalities—a range called "pretty good yield" or PGY (Hilborn, 2010). That can be obtained for most stock sizes from 20% to 50% of the unfished level, and with varying exploitation rates. Lower exploitation rates that result in higher biomass levels will have much lower ecosystem-wide impacts. Thus, appropriate application of the tools of single-species management can dramatically reduce ecosystem impacts. This is illustrated at an ecosystem scale in Fig. 1, which shows that there is a broad range of exploitation rates that result in ecosystem-wide PGY, and that ecosystem impacts such as the number of depleted stocks, can be greatly reduced by lowering exploitation rates substantially below those that produce maximum yield.

Ecosystem models also show that there are very strong trade-offs between ecosystem impacts and yield (Fig. 1). While there are instances when it is possible to reduce ecosystem impacts significantly with only a little loss of yield, it is generally progressively harder to reduce ecosystem impacts without losing increasing amounts of potential yield. For example, 70% of the potential sustainable yield would be lost if no stocks were to be fished to less than 10% of unfished biomass. Yet there are other ways to reduce ecosystem impacts and not lose sustainable yield that are actually part of the core EBFM elements using the tools mentioned above. While there is considerable research on gear technology to make fisheries more selective, Zhou et al. (2010) argue that a better approach may be to have generalized fishing gears that fish across the ecosystem.

Nevertheless, it is clear that fishing affects ecosystems and there are, at present, no guiding principles, internationally or in national jurisdictions, on the appropriate trade-off between sustainable yield and ecosystem impact. In the U.S., the Magnusson–Stevens Fishery Management and Conservation Act, MSFMCA (USA, 2007) mandates that overfishing of fish stocks should not occur. This could be interpreted as policy guidance that fishing pressure must be reduced so that no stocks are overfished, which analyses, such as Fig. 1, suggest would potentially lead to a dramatic loss of yield. The recent history of the groundfish fishery in the California Current Ecosystem, where fishing mortality rates are now extremely low, and considerable potential yield of productive stocks is being lost (Worm et al., 2009), may be the inevitable consequence of prescriptions to avoid overfishing. I doubt that many of the legislators who voted for the MSFMCA realized that this would be a consequence. Also, I suspect the general public and legislators believe that if we can manage every species to its MSY level, there would be no significant ecosystem impacts. The U.S. has been at the forefront of preventing overfishing without regard to the potential loss of yield, and it is certainly possible that other countries will follow suit.

The question is, how many stocks should be overfished or depleted to low abundance? That is, where on the trade-off curve of Fig. 1 do we want to be? Stock depletion is going to happen for several reasons including: (1) management imprecision, (2) natural variability of recruitment and survival, and (3) unavoidable by-catch in the pursuit of productive stocks. If catch limits were to be set for all species, as is envisaged in the U.S. and New Zealand, many data-poor species with presently imprecise management will somehow have to be dealt with. We would then expect that either many of these species will be depleted, or that exploitation rates will be made ever more conservative and even more potential sustainable yield will be lost. Ecosystem models suggest there will be considerable loss of yield when no stock can be depleted.

4. Elements of "extended" EBFM

EBFM is moving beyond reduction of single-species fishing mortalities, avoidance of by-catch and protecting habitats from destructive fishing practices. There are two elements of "extended" EBFM that are underway. One is founded in detailed studies, as exemplified by wide-scale multi-species data collection on food habits and trophic connections sometimes combined with ecosystem models. The multi-species approach is exemplified by the International Council for the Exploration of the Sea, ICES, multi-species work (Stokes, 1992) and the wider ecosystem approach by data collection and modeling for the Bering Sea ecosystem (e.g., Jurado-Molina et al., 2005). There are now ecosystem models for many ecosystems (see, for example, Worm et al., 2009). Data collection and modeling could lead to modification of single-species control rules to account for ecosystem understanding. It could also lead to protection of forage fish, or deliberate overexploitation of species that prey on or compete with target species, depending on management objectives. Ecosystem data and models could also potentially be used to evaluate ecosystem-based reference points, and lead to modification of exploitation rates to achieve desired ecosystem states.

Forage fish constitute 30% of global landings (Alder et al., 2008). Their reference points are set, and exploitation managed, frequently using the single-species approach. That is, often no account is taken of the ecosystem consequences of reduced abundance of these species. There are many exceptions to this such as concern about fishing of forage species on protected species abundance that has led to restrictions on fishing near Steller sea lion (Eumetopias jubatus) rookeries and haul out sites in Alaska (Giraud et al., 2002) and that the Commission for the Conservation of Antarctic Marine Living Resource explicitly includes ecosystem considerations when setting catch limits (Constable, 2002).

It is possible that ecosystem models will be used to identify "problem" species and potentially direct fisheries to deliberately reduce their abundance. The growing abundance of arrowtooth flounder (Atheresthes stomias) in Alaska has been a concern for a decade, while the recent explosion of Humboldt squid (Dosidicus gigas) off the U.S. west coast and the high densities of spiny dogfish (Squalus acanthias) in New England and the U.S. Atlantic states have led to calls for "ecosystem"-based predator control. Punt and Butterworth (1995) used trophic models to evaluate the potential to improve fish yields by culling seals.

The second element of extended EBFM is area-based management. Certainly area-based management is not exclusive to EBFM and most fisheries management agencies around the world employ some form of area-based management as part of single species management. However, almost all calls for EBFM include area-based management as an important element. Examples of existing area-based management include closed areas to protect spawning stocks, juvenile fish or sensitive habitats (Worm et al., 2009). Spatial exclusion is also driven by aquaculture and other industrial use, as well as to achieve social and customary objectives (e.g., areas set aside for recreational or indigenous use). There is a growing use of area-based management to reduce by-catch, such as short term closures in the eastern Bering Sea and the North Sea (National Research Council, 2003), or the larger and longer closures to protect cod in New England and rockfish off California. There is also the implementation of large-scale systems of marine protected areas in California (Weible, 2007) and major benthic protection areas in New Zealand (www.seafoodindustry.co.nz/bpa, April 2010). Area-based management is currently a reality, and it is certainly going to continue to expand.

I see two major impediments to these forms of extended EBFM. The objectives are uncertain and the cost is high. There was firm policy guidance under single species—the objective was either MSY or "optimum" yield. We could, at least in theory, develop fisheries management plans to achieve these objectives. The legislative frameworks for EBFM are much less clear, and management agencies will have no guidance on appropriate policy unless international agreements and national legislation are made more specific. There is no policy guidance on the objectives for area-based management. For example, the Marine Life Protection Act, MLPA, in California specified that a network of MPAs be established to achieve six objectives (Weible et al., 2004; Weible, 2007). However, those objectives were vague enough that different interpretations could lead to drastically different outcomes. Practical implementation of objectives was left to a science advisory body which, in effect, set the ground-rules that determined what happened. Other forms of area-based management such as set asides for aquaculture or exclusive fishing zones for recreational or commercial gear are also not specified in any legislative frameworks.

The cost of ecosystem models and area-based management is very high. The data demands for ecosystem models in which we would have any faith are far beyond current levels of expenditures for fisheries management. It could easily cost tens to hundreds of times more to monitor all aspects of an ecosystem and have models that are reliable than it does to apply the models used to provide the scientific basis for single-species management. Just doing stock assessments for every species instead of the current practice of the economically important ones will likely require a multi-fold increase in science and management costs. Integrated Ecosystem Assessment (IEA) has emerged (Levin et al., 2009) as one approach to solve the problem, by seeking important indicators of ecosystem condition rather than tracking all species in the ecosystem. Rather than doing single species assessment for each species, simpler ecosystem based indicators could be used in the management control rules. The needed science and political process to implement area-based management is equally intimidating. The implementation of the MLPA failed initially because the State of California had insufficient resources (Weible et al., 2004), but was eventually rescued by funding from private environmental interests.

So while we can see what the second phase of EBFM would look like, it is not clear to me if we are even close to being ready to implement the highly model dependent versions owing to a lack of appropriate objectives and the costs. But simpler implementations of ecosystem concerns and area-based management are certainly possible and being achieved. For instance, area-based management has a tradition going back centuries in the small scale fisheries of the world (Johannes, 1982).

5. The future of ecosystem-based fisheries management

I see two possible futures for EBFM that are not mutually exclusive. The core elements of EBFM, getting single-species fishing mortalities right, reducing by-catch, and protecting sensitive habitats, are widely accepted, being implemented, and are reasonably inexpensive. Further, I believe that single-species management strategies will be modified using ecosystem knowledge. This will mean lowering fishing mortality on all species below the levels that produce MSY and probably lowering even more the exploitation rates on forage species. Various agencies are now using various ecosystem indicators to modify their regulations (Fletcher et al., 2010). I suspect we will also start to use ecosystem models to provide better estimates of unfished biomass. Currently, most single-species assessments for heavily exploited species calculate the unfished biomass based on recruitment estimates projected forward under zero fishing, with no allowance for density-dependent growth or mortality and no ecosystem interactions. Summing these estimates of unfished biomass across species within an ecosystem may lead to values well in excess of what ecosystem models suggest can be supported given the primary productivity of the ecosystem. Essentially, ecosystem impacts of competition and predation are ignored when single-species assessments are used on a stand-alone basis. This aspect of EBFM could significantly modify management since the U.S. and many other countries use estimates of unfished biomass when making harvest decisions.

The second phase of EBFM is true ecosystem-based control rules, supported by ecosystem models and ecosystem indicators. I believe this second phase will not occur for many years because of the cost and lack of ecosystem-based objectives. There is a great deal of science going into this, and implementation using ecosystem indicators (Smith et al., 2007; Fletcher et al., 2010) but I see little sign of implementation and acceptance with ecosystem models replacing current single species models.

EBFM needs to be set in the context of risk analysis. Rice and Legace (2007) discuss the costs of misses (not regulating fisheries in time) and those of false alarms (over-regulating fisheries at considerable cost in yield but with little ecosystem benefit). They contrast the risk aversion of the conservation biologist, who considers a miss as a very serious problem, but a false alarm as much less consequential, to that of the fisheries manager for whom the two types of errors are much more equal. Of course, we cannot really conduct risk analyses until we have objectives that are specified and, as I argue elsewhere in this paper, it is precisely those objectives we do not have. True EBFM involves far more complex forms of risk than single-species management and these risks must be evaluated.

While EBFM is generally perceived as applying a softer touch on marine ecosystems than would occur under single-species management, there is an alternative view. It is quite possible that social objectives might be achieved by numerous forms of ecosystem manipulation if these objectives are the production of goods and services from marine ecosystems, and ecosystem knowledge/models are used to support decision making. One obvious option is deliberate overexploitation of low-value species that prey upon or compete with high-value species. On land, we shot the lions, wolves and bears and plowed up the native habitat to produce much higher return of food production from the land than would be obtained by collecting the native species. We do this in large scale in marine ecosystems with shellfish culture, especially in Asia. Is this type of deliberate ecosystem transformation going to be an increasing part of area-based ecosystem management?

Finally, EBFM does need to take account of the role of people in the ecosystem. Are indicators of community sustainability, income and profit going to be part of EBFM? Much of the current implementation of EBFM relates primarily to the natural ecosystem and regulation of harvest and gears are the key control variables. Another major element of fisheries management is allocation of access to fishing. There is considerable dispute over this area of fisheries management, and allocation often consumes as much management energy as does harvest regulation. Meanwhile, increasing evidence points to an interrelation between how fish are allocated and the ecosystem consequences of fishing (Costello et al., 2008). Is EBFM going to routinely encompass the impacts of fisheries management on human communities as well as aquatic communities, or is EBFM going to be confined to aquatic ecology?

In summary, many fisheries jurisdictions are deeply engaged in EBFM, and there is clear progress to be made for the foreseeable future at improving ecosystems without losing much yield. However, we will have great difficulty in moving EBFM beyond the core components of eliminating overfishing of the main species, reducing by-catch and habitat impact, and protecting endangered or charismatic species without firmer policy guidance regarding the social objectives of fisheries and their impact on marine ecosystems and human communities.

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