ECOSYSTEMS AT RISK: THE CONTRIBUTION OF ECOSYSTEM APPROACHES TO FISHERIES TO IDENTIFY PROBLEMS AND EVALUATE POTENTIAL SOLUTIONS

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ABSTRACT

The wide expanse of the sea, the inter-linkages among, and the productivity of its resources have until recently led most researchers to consider it unrealistic that humans could have more than local impact on marine ecosystems and their biodiversity. This perception is changing, however, as more evidence of the scale of impact becomes available. An enabling factor for this has been a change in focus from local-level studies to increased emphasis on meta-analysis of global or regional-level analysis of fisheries impact. Results include that the world's total fish catches are no longer increasing, but rather have been decreasing over the last decade or more; that larger, predatory fishes (table fish) are becoming increasingly scarcer; and that we are appropriating the ocean shelves' primary productivity to the same level as we are for terrestrial ecosystems. Ecosystems are being eroded in countries throughout the world, and though one might get the impression from the IUCN Red List that it is mainly a developed-country problem, it is alarming that the impact of severe overfishing may be at an even larger scale for developing countries. We describe aspects of the risks overfishing poses to marine ecosystems, and point out how ecosystem approaches to fisheries can be used to evaluate the potential impact of alternative fishing policy scenarios.

Keywords: Ecosystem based management of fisheries, ecosystem modeling.

Roll on, thou deep and dark blue ocean – roll!
Ten thousand fleets sweep over thee in vain

INTRODUCTION

Lord Byron wrote these lines a couple of hundred years ago, at a time where humans indeed had no control of, and but little impact on the oceans. That view was still dominant a century later when Sir Thomas Huxley, President of the Royal Society, at the opening of the 1882 London Fisheries Exhibition stated that "the most important sea fisheries, such as the cod fishery, the herring fishery, and the mackerel fishery, are inexhaustible … the multitude of these fishes is so inconceivably great that the number we catch is relatively insignificant". In the beginning of the 20th Century when the North Atlantic fisheries became mechanized perceptions gradually started to change, and evidence of declining catch rates led to the creation of fisheries research institutions throughout the North Atlantic area; institutions created with emphasis on studies of marine production systems (Rozwadowski, 2002).

The 1960s saw industrialized fisheries spreading through the developing world as part of 'development' projects, quickly followed by major declines in catch rates for the longer-lived fish species, notably of the larger sharks, rays and bottom fishes (Pauly, 1979). Hand in hand with this, increased fishing pressure in many places led to a break-down of traditional management structures where such were established, followed by open access to the fisheries and further effort expansion. In the decades to follow, many fish

stocks crashed due to overfishing, often with devastating impact on local fishing communities (Perry and Ommer, 2003).

Yes, many fisheries scientists will argue, still today, that things are fine with the oceans; what we observe (to paraphrase Lord Byron) are merely rolling waves on the ocean surface; natural succession will let species in- or decrease, and even if we fish one species down, another will pop-up from the food web, and replace it in the ecosystem. In some cases it may even be economically beneficial (when not considering social costs) – extensive shrimp fisheries appearing as cod were depleted for a while made landings in eastern Canada exceed the value from when cod-fisheries were dominant. Nature is resilient, we do not control it, and what's more, the control on fishing practices put in place in notably developed countries since the 1970s is beginning to have an impact. Things are fine apart from a few, unfortunate cases, where stock may have plummeted. And what's more, some of these unfortunate cases are indeed not the deed of humans, but rather an act of God or Gaia through environmental variability.

We are facing two major issues when considering this point-of-view,

- What is the evidence for fisheries having had major impact on species abundance at the ecosystem level? Does the impact of fisheries go beyond local impact on individual species?

- What is the relative role of fisheries and of the environment for the population trends of species of concern (typically threatened charismatic species, or depleted commercially-important fish species)?

We will present results from a series of recent studies conducted at the regional and global level and with the purpose of evaluating how ecosystems have been impacted by humans through fisheries. We further consider how ecosystem modeling can be used to evaluate options for ecosystem recovery, notably by incorporating ecological, economical and social considerations.

Further, we will describe how recent developments in ecosystem modeling have enabled studies aimed at evaluating how ecosystems components are impacted by changes in system productivity and fishing pressure. The ecosystem modeling in question is an important tool for the movement toward ecosystem-based management of fisheries that is currently taking place in countries throughout the world as a consequence of the international agreements reached in Kyoto, Johannesburg, Rome and Reykjavik. We will describe some of the key assumptions behind the ecosystem modeling, as well as the capabilities of the modeling. Notably, we focus on how ecosystem modeling can be used to evaluate alternative scenarios for fisheries management, both in the context of current management practices and for global outlook related to food supply and security.

The studies we refer to are drawing heavily on results from the *Sea Around Us* project at the University of British Columbia; a project that the current authors either participate directly in, or cooperate with.

HUMAN IMPACT ON MARINE ECOSYSTEMS

There are surprisingly few analyses of the global status of fish and fisheries. Prospects for the potential fish production from the oceans have varied widely, from levels of around 70 million tons up to several times higher (Pauly, 1996). For as long as the fisheries were expanding and catches kept increasing, estimations were essentially a guessing-game, and indeed they have never reached any noteworthy level of sophistication. Unfortunately, this situation has changed; unfortunately because the world's fish capture production has stopped increasing and has leveled off at around 70-80 million tons annually; indeed, it may have been decreasing since around 1990 (Watson and Pauly, 2001). The implication of this is that if we do not improve management of our fish resources, we must expect catches to decrease in the future, not increase (Hilborn *et al.*, 2003).
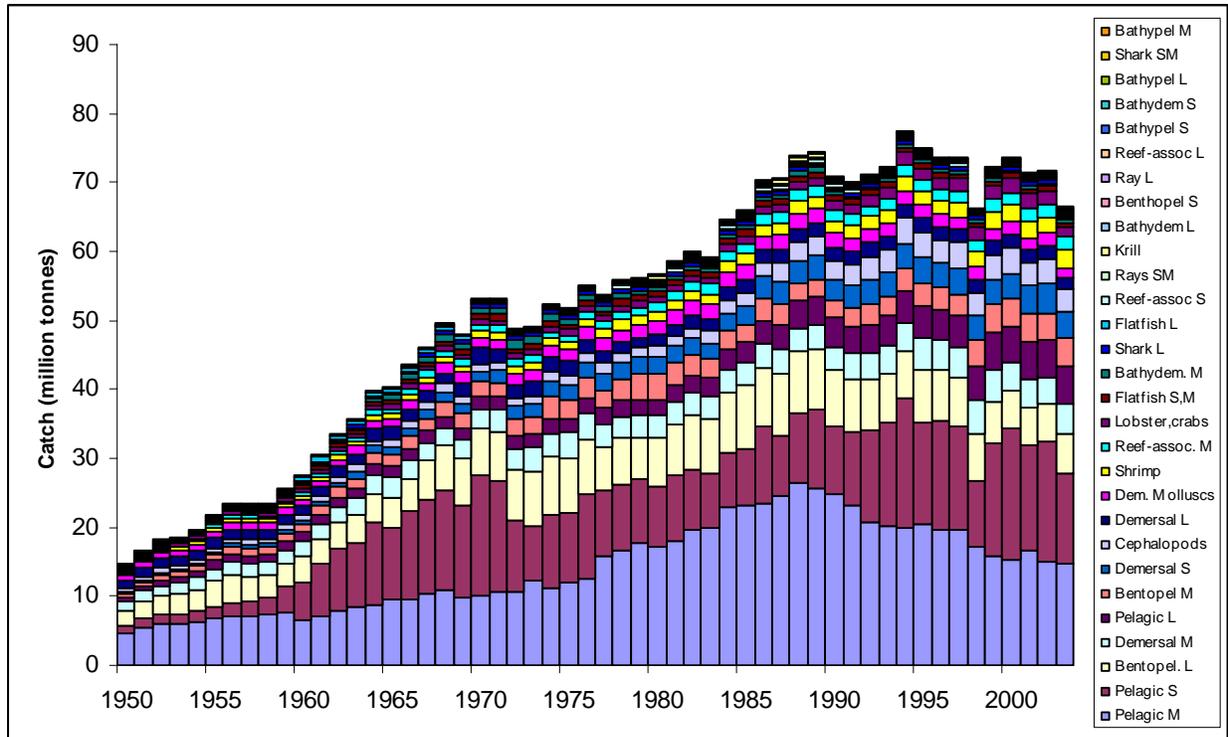
Figure 1. Trends in global catches by catch categories since 1950. Catches increased through the first three to four decades, stagnated, and have been declining since. S, M, and L are small, medium and large, with cuts at L$_\omega$ of 30 and 90 cm. Data source: www.seaaroundus.org.

Aquaculture has often been heralded as the savior for the world's fish supply. We fear though that as long as aquaculture keeps emphasizing the farming of high-trophic level species (Pauly *et al.*, 2001), and as long at suitable replacements for fish-based feeds have not been found, the contribution of aquaculture will rather be more toward habitat-degradation and privatization of public resources than to food security.

One can question if the decreasing catch levels are due to fisheries management finally being successful at controlling fishing effort, i.e. if what we observe is a reduction in fishing effort at the global level as part of a rebuilding of fish populations. While global attempts at evaluating fishing effort are sparse, a new study indicates that global nominal effort levels (measured in horsepower-days) for port-based fisheries (excluding tuna and distant water fleets) annually increased with 2.8% in the 1970s, with 3.0% in the 1980s, and with 1.5% in the 1990s (Gelchu, 2006). Estimating effective effort the increases are even more pronounced at 7.5%, 7.6% and 6.1% annually for the three decades, respectively. We may conclude that the decreasing catch levels are highly unlikely to be caused by reduced effort in the fisheries, every indicator we know of tells us that it is business as usual in the world's oceans. Effort keeps increasing and stocks decreasing.

Fishing down marine food web

As fisheries develop in an area their target species change. During their initial development, the focus is usually on higher-trophic level species. As these become more scarce attention changes toward the more abundant prey species, and ultimately concentrates on lower-trophic level species, e.g., shrimps and squids (Pauly, 1979; Christensen, 1996). This process, now known as 'fishing down the food web' (Pauly *et al.*, 1998), and its global nature has been demonstrated in numerous studies throughout the world.

Fishing down the food web results initially in increasing catches, but catch levels eventually stagnate or decline, while the trophic levels of the catches continue to decline. The effect is clearly distinguishable on a decadal scale, and the trends are so pronounced that they raise considerable concern for the sustainability of today's fisheries under present management regimes.

Fishing down the food web leads to loss of diversity at the ecosystem level. In many systems, top predators are now very much depleted due to targeted fisheries and the limited ability of long-lived top predators to withstand high fishing pressures (Myers and Worm, 2005).

In most developing countries there is limited capacity to consider long-term biodiversity issues – the immediate welfare and nutrition of the population take precedence. The dilemma made apparent through the fishing down the food web studies, however, has direct implications for what can be extracted from the seas: overexploitation leads to dwindling catches, and the catches are of a lower value, as trophic levels and prices often are correlated.

The Conference of Parties of the Convention on Biological Diversity in 1995 drew up the Jakarta Mandate, which outlines actions for preservation of biodiversity and, in agreement with the Kyoto Conference on Food Security, places emphasis on the need for integrated approaches for management of marine and coastal ecosystems. With the recent Johannesburg Declaration on Sustainable Development a commitment has been reached to rebuild stocks by 2015, and together this calls for development of ecosystem-based approaches to fisheries management.

Threats to biodiversity

The Johannesburg Plan of Action recognizes overfishing as a major global problem calling for swift action aimed at restoration of depleted resources and sustainable exploitation. Overfishing and other anthropogenic impacts in turn raise concerns for biodiversity. Loss of biodiversity is related to overexploitation and habitat degradation, both of which are widespread problems in the coastal zones of the world. It has been estimated that half the world's salt marshes may have been lost, one third of the world's mangroves lost (Alongi, 2002), and 20% of corals reefs destroyed and of the remaining, half are under threat of destruction (Wilkinson, 2004).

Where it has been a general assumption among scientists that extinction of marine species due to exploitation is unlikely (Malakoff, 1997), growing evidence points to a need for revision of this assumption (Dulvy *et al.*, 2003). Extinction has been reported for a growing number of fish populations (Myers and Worm, 2005), and there is fear that even species diversity may be at risk for a number of species with limited ranges (Roberts *et al.*, 1998). As a fishery develops, mean size and age of fish decline in the exploited populations. There is selection for early maturity and for small females, which can lead to genetic change, including loss of genetic diversity within – case studies indicates effects within 10-20 generations (Smith, 1999).

The greatest threat to diversity among fishes is for freshwater species. Many species have been lost in recent decades, notably through habitat degradation rather than through fishing. As a result, 90% of the fish species on the IUCN Red List of endangered and threatened species are either freshwater or estuarine, and freshwater fish species are ten times more likely to be threatened than marine species (Froese and Torres, 1999).

The minimal representation of marine species on the IUCN Red List in large part reflects our level of knowledge about the threats to marine life. Of the marine fish species that are actually included on the Red List around half occur in the U.S.A. Continental States. This overrepresentation further highlights the necessity of conducting biodiversity research at the global scale.

Trends of marine fish abundance

One aspect illustrated through the above discussion on biodiversity is that spatial information is needed. The tool for this, GIS (Geographical Information System) was initially developed for national land inventory during the early 1960s, and it was not until the 1980s that this application was demonstrated to be useful in aquatic systems (Valavanis, 2002). Since then, GIS has become a major tool in oceanography, fisheries and marine ecology providing not only descriptive but also predictive images once coupled with other techniques such as geostatistics and generalized additive models (Matheron, 1971; Rivoirard *et al.*, 2000). It has resulted in considerable contributions in fisheries management in terms of predicting stock distribution, abundance, habitat preferences and productivity assessments (Fisher and Toepfer, 1998; Wright, 1999; Rivoirard *et al.*, 2000).
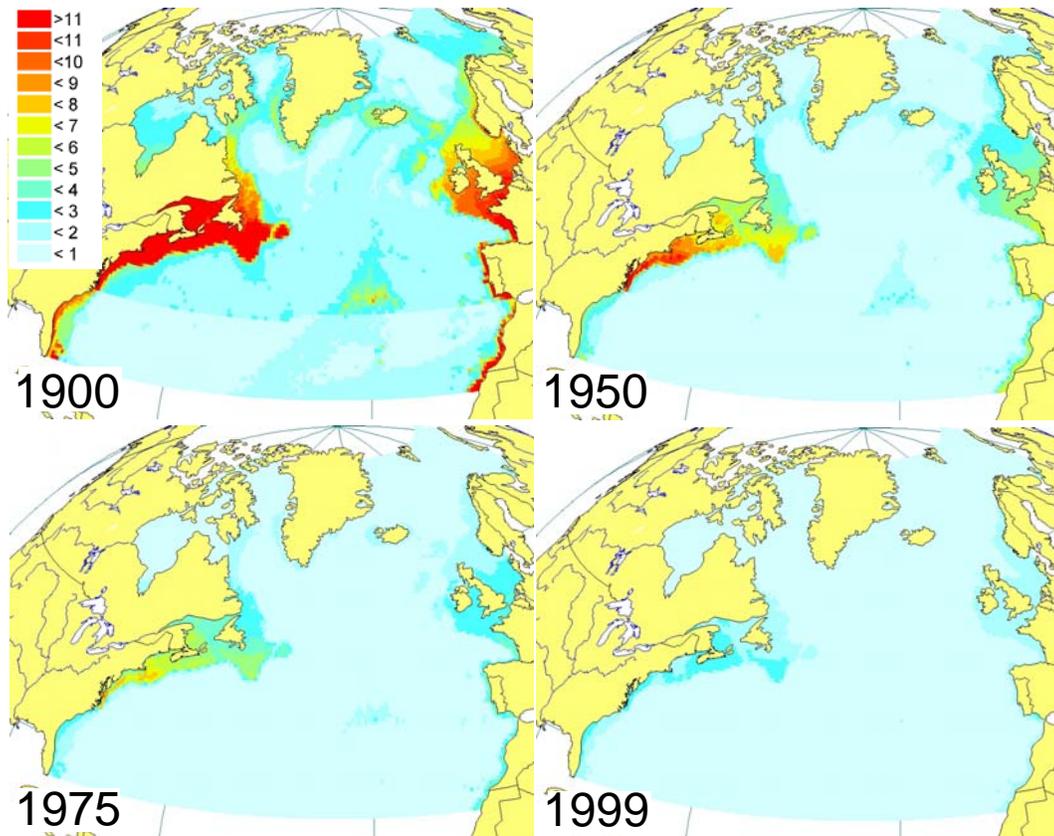
Figure 2. Spatial estimates of combined biomass of high-trophic level fishes ('tablefish') in the North Atlantic through the 20th Century. Unit for legend in t · km^{-2}. (Christensen *et al.*, 2003b).

Recently, global mapping of fish abundance implemented by the *Sea Around Us* project, and made available online at www.seaaroundus.org focused on combining GIS application with predicted distributions in spatial models to determine "how much fish is still left out there?" The massive decline in biomass of high trophic-level fishes over time in has been illustrated by the analyses of Christensen *et al*. (2003a; 2003b; 2004) for the North Atlantic (Figure 2), the South China Sea and West Africa. Fisheries in the northern Atlantic represented in Figure 2 reached their maximum production levels several decades ago and are now showing a declining trend in total catches (Pauly *et al.*, 2002). The declining catches and the biomass trends indicated by the figure are consistent with observations that these areas have the highest incidence of overexploited, depleted or slowly recovering stocks that have been depleted by overfishing (Pauly and Maclean, 2003). In fact, this phenomenon is not specific to the Atlantic as an emerging pattern shows worrying global decline for larger, long-lived species (Myers and Worm, 2005).

Shifting baselines and sustaining present misery

It is clear that if the present catch levels are to be sustained, or perhaps even improved, the avenue will be through improved management of marine resources, not through expansion of fisheries for underexploited resources or the building of bigger fleets (Hilborn *et al.*, 2003; Garcia and Grainger, 2005; Pauly *et al.*, 2005). The management strategies must include consideration of the ecosystem interactions, form and functioning, including the role of the top predators (Christensen, 1996), and it has been suggested that marine ecosystems may yield considerably more than the present catch levels if stocks were rebuilt to their pre-impact levels (Pauly and Christensen, 1996; Christensen and Pauly, 1998). This had led to a series of ecosystem restoration studies aimed at describing historic ecosystems and how best to exploit such systems using the Ecopath with Ecosim (EwE, www.ecopath.org) approach as the enabling tool and based on a variety of information from a wide-ranging set of disciplines (Pitcher *et al.*, 2004; Pitcher, 2005; Ainsworth, 2006). This indeed raises the issue that the goal for fisheries management should be rebuilding of ecosystems, not what is termed 'sustainability' if this merely infers sustaining a severely depleted level (Pauly, 1995; Pitcher and Pauly, 1998).

WHO DID IT? EVALUATING HUMAN AND ENVIRONMENTAL IMPACT

Ecosystems are vulnerable to natural- and human-induced changes and their combined effects are often difficult to disentangle. While humans are not always the sole contributor to environmental degradation, damage inflicted by humans is often of a drastic, perhaps even irreversible, character. Freshwater and marine habitats are being destroyed by pollution, infrastructure development, and human settlements. A compelling adaptation on how humans can change the course of ecosystem evolution was presented through the 2004-film about Lake Victoria, "Darwin's nightmare" by Hubert Sauper. Though heavy predation of cichlids by the introduced Nile tilapia combined with heavy fishing have ended up in depleted stocks and biodiversity loss (Pitcher and Hart, 1995), one cannot say that the ecosystem would have 'survived' longer in the absence of the stress inflicted by the Nile tilapia.

Numerous problems put forward in this paper, concerning the overexploitation of marine biological resources, must be solved. It is apparent that human activities out-run a sense of co-habitation as environments are exploited beyond the sustainable. Placing price tags on aquatic resources have made humans the most cunning and innovative prey hunters. Excessive fishing pressure has resulted not only in a loss in total production, but has also had a significant social and economic impact. This ends up in a world becoming a single enterprise where resources, such as in the fishing industry, are 'free' goods, endlessly exploited for human investment.

There is therefore, growing public concern regarding the declining condition of the world's aquatic environment as a consequence of the impact of human activities. This concern has resulted in increasing pressure on decision makers to establish new and innovative policies that can be deployed in order to reverse those negative trends. Currently, establishment of marine protected area is becoming one of the management tools needed in order to achieve policy goals (Roberts *et al.*, 2005).

Management of marine resources is a complex undertaking, and the scientific knowledge required for a cross-sector approach that integrates environmental, socioeconomic, and developmental requirements is often lacking or unavailable to policy makers. We have, however, seen progress in ecosystem modeling in recent years that seeks to enable such multi-sector approaches. Underlying this is that ecosystem modeling is now reaching a state where it is able to produce plausible simulations of the impact caused by fisheries, ecosystem and environmental impact factors (Christensen and Walters, 2005).

An example of this is an ecosystem modeling study of how threatened Steller sea lions have been impacted by the combined effects of fishing, predation, competition, and ocean productivity in the Aleutian Islands and the eastern Gulf of Alaska (Guénette *et al.*, *Resubmitted after review*). Numerous studies have attempted to find the cause of Steller sea lion decline, but no clear explanation has emerged

in spite of very extensive research activities and expenditures reaching into the hundred million dollar price range. The modeling indicated that it was possible to replicate the changes in sea lion population size as well as of most other ecosystem groupings, but that this was only possible if included the combined effects of the major drivers that impact sea lion abundance. Also, the relative impact of these drivers could be quantified, leading to killer whale predation and ocean productivity patterns being found the most important, followed by fishing, and competition with flatfish.
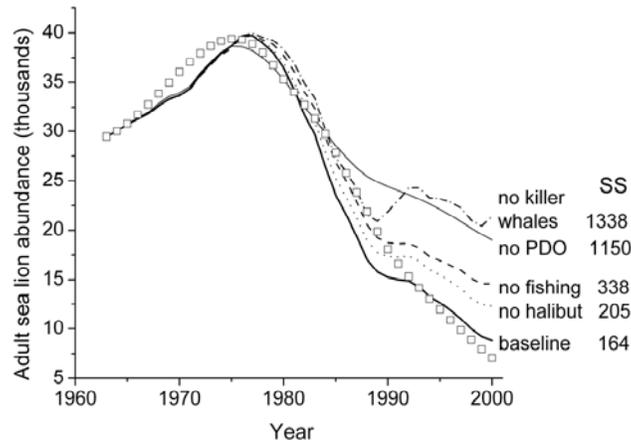
Figure 3. Simulated impact of not considering impact of predation (killer whales), ocean productivity (PDO), fishing and competition from flatfish (halibut). The baseline run includes all these drivers, while the observed time series is indicated by squares (Guénette *et al.*, *Resubmitted after review*)

This study clearly illustrates how ecosystems are impacted by multiple forces, and that it is necessary to consider more than just the 'usual suspects' if we are to improve our understanding and management of marine resources. The study is also a good example of one of the most important achievements that has been reached in ecosystem modeling in recent years, the capability to simulate and reproduce the recent ecosystem history. This has by now been done this for more than two dozen systems (Christensen and Walters, 2005), and we emphasize that the capability of ecosystem models to replicate trends of abundance, productivity and exploitation in ecosystem represents a major step forward for the modeling.

During the years of the International Biological Program (1964-1974) considerable effort was allocated to establishing systems ecology as a discipline, and while this succeeded, a major undertaking of the system ecologists, to construct ecosystem models that could be used to simulate changes in ecosystem as response to anthropogenic and environmental factors never did. This lead to most of the practitioners in the field eventually abandoning ecosystem modeling, and it was only with Carl Walters' formulation of the 'foraging arena' that clear progress was achieved (Walters and Juanes, 1993; Walters and Martell, 2004). Notably, it has made it possible to produce well-behaved models capable of reproducing trends in ecosystems, and subsequently to evaluate how multiple drivers impact ecosystems (as illustrated by the Steller sea lions), and to conduct the modeling in a well-structured data management and parameter estimation system in form of the Ecopath with Ecosim modeling software (Christensen and Walters, 2004a).

The possibly most important finding from the modeling is that in order to understand what is happening in the oceans we need to consider how ecosystems are impacted by environmental as well as by anthropogenic factors. Changes in primary productivity have strong impact at all trophic levels in ecosystems. This in turn, links fisheries to climate change research, and notably underlines the importance of the numerous activities that are now starting up to link marine ecosystem and climate change modeling.

SCENARIO MODELING

The newly-developed capabilities of ecosystem modeling to reproduce historic trends in ecosystems open them to being used to explore scenarios. While there is no guarantee that the fit to historic trends is obtained for the right reason (Essington, 2004), we know that the parameter settings and the model formulation used for such a model is at least done so that its reaction to the major ecosystem drivers (notably fisheries and environmental effects) are plausible. Thus we see that a minimum requirement for a model to be used for scenario modeling is that it should be well-behaved enough to reproduce historic trends. Simulation modeling related to fisheries and based on these premises has mainly been on two fronts; exploring policy options and exploring scenarios for future states of ecosystems. We will discuss each of these.

Optimum policy exploration

A number of studies have explored how to allocate effort among fleets (or 'metiers') so as to maximize a given objective function, see, e.g., Christensen and Walters (2004b). While the modeling aspects of this are fairly simple (Walters *et al.*, 2002), the analysis highlighted the important question of how to best define and agree on an objectivity function for desired development. Ideally, the objectivity function should represent society's interest, but rarely is there an omnipotent ruler to make decisions on such matters. More often diverging interests between stakeholders have to be considered, precluding overall maximization.

In the EwE approach, the policy exploration is done by defining an objectivity function with four components, involving optimization of

- profit from fisheries;
- value of fisheries or number of jobs in the fisheries;
- 'ecosystem structure';
- mandated rebuilding.

Of these the first two are self-explanatory, while the 'ecosystem structure' maximizes for overall longevity of the populations in the given ecosystem, while the mandated rebuilding is used to incorporate legal constraints, (e.g., certain restrictions are in place until a given species has recovered to a defined level) or simply minimum acceptable biomasses (MBAL) for given species.

The policy explorations underline the importance of valuing fisheries and ecosystem services from multiple angles. When taking a narrow approach, placing emphasis of only one of the components of the policy objectivity function the expected result is often of a drastic nature with either the social component or the ecosystem suffering (Christensen and Walters, 2004b). Emphasizing value of the catch only (as has been the case in most systems) leads to drastic changes in the ecosystem structure, with long-lived species being fished out, and the ecosystem shifted toward dominance of low-trophic level, high-value species, notably shrimps. Alternatively, emphasizing ecosystem structure leads to near-complete closure of the fisheries.

The optimizations do, however, typically lead to sensible solutions when a balanced approach is taken, indeed there may be win-win situations where all or at least the majority of the parties involved would benefit (Christensen and Walters, 2004b). The results also highlight that there are trade-offs involved in managing at the ecosystem level. Indeed, we cannot expect that the maximum sustainable yield from an ecosystem perspective corresponds to the sum of maximum sustainable yields that are estimated by optimizing for each of the ecosystem populations using standard single-species MSY methodologies (Walters *et al.*, 2005). Typically, we find that MSY will be higher for low-trophic level species, (which benefit from predation release), and lower for high-trophic level species, (which will have poorer feeding conditions when their forage species are exploited).

An important aspect of the policy explorations is that they emphasize the need for properly evaluating the cost of fisheries. In addition to the more straightforward aspect of evaluating direct cost of fishing we need to consider indirect effects, both socially and for the ecosystem. The social aspect calls for understanding of social interactions and values, while the ecosystem aspect calls for ecological considerations of direct and indirect effects of fishing. Up to now, there has been little work attributed to jointly examining all of these factors, i.e. of the overall cost of fishing in an ecosystem context, and we note that this is an area where the European Community-funded project ECOST has an important contribution to make.

Future modeling

A major, recently completed international initiative, the Millennium Ecosystem Assessment, (MA), , was launched by the UN Secretary General with the aim of providing a scientific assessment of the health of the world's ecosystems (www.millenniumassessment.org). The work involved fourteen hundred scientists from around the globe cooperating over a five-year period, and among other included a component aimed at exploring scenarios for future development, including for fisheries (Pauly *et al.*, 2003).

The MA scenario work, and its follow-up through the UNEP GEO-4 Report Series, uses a standardized set of scenarios for analyzing complex systems in an attempt to predict the possible outcomes. The scenarios for how to manage ecosystem services include,

- Global Orchestration; assuming socially conscious globalization, with emphasis on equity, economic growth, and public goods, reacting to ecological problems when needed;
- Order from Strength; a regionalized approach with emphasis on security and economic growth, responding to ecological problems as required ;
- Adapting Mosaic; also regionalized, but more proactive with regards to ecosystem management, and including local adaptations and flexible governance;
- TechnoGarden; a globalized approach relying on green technology and with a proactive approach to ecosystem-based management.
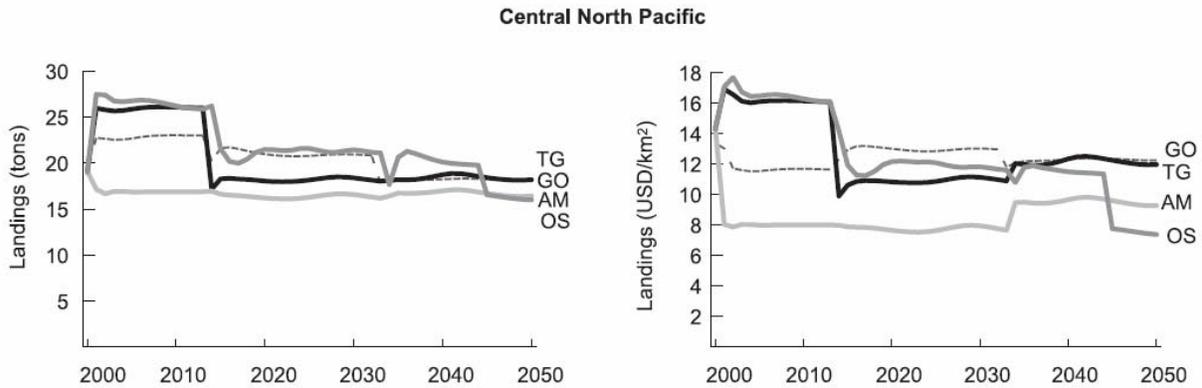
Figure 4. Comparison of fish landings in the central North Pacific for four MA scenarios based on EwE modeling. Scenario names: AM: Adapting Mosaic; GO: Global Orchestration; OS: Order from Strength; TG: TechnoGarden. Source: Millennium Ecosystem Assessment, Volume 2, Chapter 9.

The part of this scenario modeling that deals with marine systems are using EwE models to explore how ecosystems and the fisheries relying on them may react to policy interventions providing external pressure on the resources. This work is currently being expanded through funding from UNEP and the Netherlands

Ministry of the Environment to provide regional examinations of how future fish supply is likely to be impacted by the four scenarios. We expect this work may impact future policy settings in many areas.

OUTLOOK

Marine ecosystems are impacted by a multitude of factors and they have been exploited to the degree that overall productivity has started to decline. This along with concern for biodiversity in the oceans has prompted the development of an integrated approach towards the management of biological resources. Monitoring system productivity requires sufficient knowledge on how species interact, respond and adapt to varying environmental conditions. Single-species modelling has led to various inconsistencies and discouraging results as underlying assumptions have not occurred. 'What is the future of the World's fisheries'? This question can not be treated by a single scientific discipline. The complexity of managing fisheries resources using ecosystem models relies on consideration of several 'uncertainties': spatio-temporal changes in species abundance, parameters considered, varying dynamics of fishing effort and unpredictable future environmental and economic conditions. We consider ecosystem modelling an important and necessary tool to this aim, and note that recent developments in the field has improved its capabilities to the degree that it can now be of direct use for fisheries management and for exploring sustainable scenarios for future development.

Sustainability programs have failed due to limiting efforts on discipline-specific processes and the absence of interactive engagements with other scientific disciplines. Frequently, conventional ecological methods and institutional arrangements fail to recognize the influence of anthropogenic forces or other dimensions such as those concerning biophysical or socio-political issues in ecosystem development and evolution. As ecosystem function reacts as a consequence of environmental changes and human activity, this shows that biological, social and economical incentives can not be readily separated and a continuous education combined with ethical concern are imperative towards ecosystem conservation. Integrating community-based research and ecosystem management based on social learning and transdisciplinary inquiry is significant in the quest to conserve global biological resources (McMichael *et al.*, 2003).

This is quite a difficult task, in a practical point of view, due to several underlying factors such as conflicting interests in different scientific disciplines, process of effective public inclusion and the coherence of these approaches to existing institutional management schemes. It is only adequate to assume that ecosystem modelling needs to define critical values and risk-prone conditions in collaboration with managers and stakeholders. The need for a 'precautionary' approach in ecosystem modelling can mitigate 'shocks' due to unpredictable changes following intensive exploitation. This approach captures the idea that scientific methods should be combined with societal values to protect global commons.

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