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Introduction: toward ecosystem-based management of fisheries

Fisheries have always been important to humanity. In the last century we have, however, witnessed how industrialization of fisheries leads to widespread overexploitation of fish populations. Our general reaction has been to strengthen the call for fisheries management, even if opinions of what this requires differ.

The idea of managing at the ecosystem level has been around for years (McIntosh, 1985), and numerous international agreements make it clear that this is the way forward for management for fisheries as well as for many other resources, such as forestry. Yet, there is considerable uncertainty in the minds of most scientists, environmentalists, managers, and policymakers, of what the term actually implies. Many definitions have been put forward, and we are slowly and gradually getting a clearer picture of what is involved in implementing ecosystem-based management of fisheries.

Pikitch *et al.* (2004) stated that approaches to ecosystem-based management of fisheries should avoid degradation of ecosystems while minimizing the risk of irreversible change therein, consider how to obtain and maintain long-term socioeconomic benefits, and in the process gain an understanding of the likely consequences of human actions. Clearly, area-based management has to be an integral part of ecosystem management, and it must be carried out so as to balance conflicting trade-offs and ensure long-term economic and social sustainability. Implementing ecosystem-based management requires going beyond traditional management and business-as-usual, and this is, in essence, what has dictated the content selection for this book.

We have shaped this book around elements required for ecosystem-based management of fisheries, beginning with how developments in fisheries science over the last three decades have led to the present ecosystem view. Fisheries science has evolved very much in

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synchrony with the research focus of our main subject (Nauen and Hempel, this volume), and we exemplify this in a series of essays describing some essential elements for ecosystem-based management.

The other parallel focus of this book is on how an influential scientist, Daniel Pauly, has shaped the field and helped to kick-start the science and communication of ecosystem-based management of fisheries.

When fisheries science became a quantitative field, it was with a focus on population dynamics (Beverton and Holt, 1957; Pauly, 1998). Populations are units of a single species, which are not a natural locus for ecosystem-based management, where it is more important to study trade-offs for management – we cannot optimize exploitation of all species separately and simultaneously (Walters *et al.*, 2005). Daniel Pauly realized this when, as a young graduate, he was posted by the German Agency for Technical Cooperation (GTZ) to Indonesia. There, the catches in their trawl surveys included hundreds of species. How was a budding young scientist educated in the era of age-based population dynamics going to assess the fisheries for all those species when there was no way to even age them, let alone derive population parameters for the important ones? Ray Hilborn later said of him "the Prophet Daniel ... must toil in infernal heat, deprived of holy catch-at-age data, armed only with a thermometer" (Hilborn, 1992).

Daniel Pauly took on the task to develop simple assessment methods for use by scientists in developing countries, and to conduct training on how to use them properly. Hilborn was not quite right in his prophet statement; population dynamics in the tropics calls for a ruler in addition to a thermometer. The name of the game was length-based assessment and, through the 1980s, Pauly became the dominant figure in this field, introducing and developing suitable methodologies (Munro, this volume). More than anything, the training that was needed for length-based methods to become part of the applied toolbox in developing countries made it clear that the focus had to be on capacity building as well; methods alone were not enough (Nauen and Hempel, this volume).

The 1970s led to another realization: fish eat fish. This was not explicitly considered in classical population dynamics, but is an essential consideration when working at the ecosystem level. Do you want tuna or herring, predator or prey? You cannot expect to have plenty of both; there are trade-offs to be considered and management decisions influence the options.

Andersen and Ursin (1977) and Laevastu and co-workers (e.g., Laevastu and Larkins, 1981) knew this, but were building complex models calling for data way beyond what was conceivably of use in a developing country context. The breakthrough in realizing that methods for "multispecies management" (as it was called then; Pauly, 1979) could be developed for use in the tropics came when Daniel Pauly visited Jeff Polovina in Hawaii in the mid-1980s. Polovina had made a simplified version of Laevastu's gigantic ecosystem model, and used it to predict "missing" parameters for the part of the ecosystem where information was sparse to nonexisting. As an example, Polovina would predict biomasses for a prey based on how much production was required to meet the combined demand of all predators. Importantly, it did not require individual species data, nor age groups within species (as fisheries biologists of the time were indoctrinated to believe). Instead, the unit of analysis could be the "functional group," consisting of a variety of species.

The neatness of the approach led Pauly to tell Polovina: "If you publish this model, I will ensure that it is applied throughout the (tropical) world." They both met these challenges (Polovina, 1984; Pauly *et al*., 2000). The result was that the model, Ecopath, was further developed and supported to the degree that it has become the de facto world standard for ecosystem modeling of marine resources (Christensen and Pauly, 1992; Christensen and Walters, this volume), and to the extent that it was nominated by the US National Oceanic and Atmospheric Administration in 2007 as one of the ten biggest scientific breakthroughs in the organization's 200-year history.

Methodologies for ecosystem-based management, while necessary for successful implementation, do not constitute a sufficient condition. For one, we also need details about the resources to be managed. Daniel Pauly recognized this early on, and became increasingly frustrated when expert after expert, expatriated to develop fisheries in some developing country, invariably would start their project document with the argument "We do not know anything about the key species occurring in the area, so we have to start by studying the biology of . . . " How many times do we need to establish length–weight relationships for *Rastrelliger kanagurta*?

What caused such repetitive research was the lack of an easily accessible repository for basic information from previous research in developing countries. Development projects rarely end up being published in scientific journals. The best source at the time was the library in Rome of the Food and Agricultural Organization of the United Nations (FAO), where project reports and other grey literature by many fisheries experts was stored. The eventual solution to the problem of accessibility was FishBase, a database initiated by Daniel Pauly and Rainer Froese, and designed to supply "everything you ever wanted to know about fish" as Froese phrased it. FishBase has collated a vast amount of published information (Froese and Pauly, 2006; Froese, this volume).

Still, fish are not the only living beings in the sea, and while FishBase has become the model for how to develop class-specific databases, showing the way for later initiatives, such as Species 2000 and OBIS, similar information is needed for the rest of the ecosystem. Recently, this has been facilitated through the comprehensive SeaLifeBase, which parallels FishBase and, when used jointly with it, will supply much of the global biodiversity information required for ecosystem-based management, especially for modeling (Palomares and Bailly, this volume).

Given methods, given biological and ecological information, what else is needed? We certainly need to understand more about the natural processes that control life in the ocean (Pauly *et al.*, 1989; Bakun, this volume), and we need to incorporate such understanding in the models we make of the oceans. What makes this especially important is the speed with which ecosystems are changing due to human impact, be it through fisheries or climate change.

As ecosystems change there is an inherent danger that we and future generations may forget what has been, and importantly, what could be. We have lived off the oceans for millennia, and, in so doing, we have had an ever-increasing impact. Even when we deal with seemingly unexploited systems (Warne, 2008), we have to question if such systems really are pristine; what about the mega-predators? Yet each (human) generation comes to accept an increasingly degraded state as natural. The shifting baselines syndrome, a term coined and described by Daniel Pauly (1995), has had profound implications on how we think about what is natural in the field of ecology (Jackson and Jacquet, this volume). The symptom of this societal illness is the ability of the collective human psyche to create new impressions of what is pristine; how big is a big fish? The treatment of the illness includes incorporation of historical anecdotes as data and an emphasis on historical ecology in environmental education and ecosystem management.

In the oceans, exploitation greatly expanded after the Second World War when industrialization spread, and when fisheries, especially in the developing world were "developed," soon to be devastated (Pauly, 1979). Worldwide, fisheries catches peaked in the 1980s and have since been declining (Watson and Pauly, 2001; Watson and Sumaila, this volume). Such, at least, is the common perception now, based on reported catch statistics. Yet, catch statistics only paint part of the picture; United Nations member states send their official statistics every year to the FAO where they are compiled and disseminated, e.g., to the Sea Around Us project (Pauly, 2007). This project then combines the information with estimates from other sources, seeking ways to improve it notably with regard to taxonomic and spatial resolution. We know from experience that the official statistics focus on traded products, while extraction for local consumption tends to be underestimated or neglected. Accounting for such has, in the more severe cases, resulted in catch estimates that exceed the official figure by a factor of six or more (e.g., Zeller *et al.*, 2007; Watson *et al.*, this volume).

The increase in landings brought about by industrialized fisheries has had a large impact on ocean resources (Pauly and Christensen, 1995; Pauly *et al.*, 1998; Stergiou and Christensen, this volume), in the process marginalizing the small-scale sector (Pauly, 1997; Chuenpagdee, this volume). Combined with the decline in capture fisheries production, this has led to a widespread belief that future fisheries production should come from aquaculture. While aquaculture clearly has a role to play, much of it is focused on high-trophic-level species, which can only be reared on diets that are based on feeds made from other fish. Given the efficiency of this, more fish are used than produced, and aquaculture of this sort ("farming up the food web"; Pullin, this volume) cannot lead to increased, sustainable fish supply (Liu and Sumaila, 2008). Alternatively, low-trophic-level farming is more likely to contribute to the world's food supply. Food supply is indeed a major part of what we seek in the oceans; just like fish, we eat fish and we have to consider how we best obtain and treat our food (Pullin, this volume; Jacquet, this volume).

Given the generally dismal state of the world's fisheries, it is appropriate to ask how the increased demand for fish products as predicted by the International Food Policy Research Institute (Delgado *et al.*, 2003) is going to be met. Our answer may be "it probably is not" (Alder *et al.*, 2007) because we indeed may be reaching a global state of "Malthusian overfishing" (Pauly, 1994; Ruddle, this volume). The only real hope we see for meeting future demand for fisheries products is through better management and utilization of fisheries resources (Jacquet, this volume). We are also convinced that this implies ecosystem-based management because it is impossible to extract maximum sustainable yield from all the resources all the time

(Walters *et al.*, 2005), and considering options calls for evaluating ecosystem-level trade-offs.

One form of trade-off that needs to be considered, and which has created heated debate in scientific and conservation circles, relates to the role of protected areas. Some view them as highly valuable tools to secure healthy breeding populations; others believe that they are doing more harm than good by increasing fishing pressure in smaller areas, endangering local, weak populations. One thing is clear, however, we need large-scale information about how protected areas can contribute to ecosystem-based management, and we may need to protect vast parts of the oceans (Jackson and Jacquet, this volume).

We also need to understand how ecosystem-based management of fisheries may be affected by future climate change. Modeling this calls for thorough analysis of how populations have changed in the past, relating such changes to climatic factors. This calls for expanding ecosystem modeling with information about species vulnerability and productivity patterns, while building on global databases of biology, ecology, and fisheries of marine organisms (Cheung *et al.*, this volume).

Better management calls for thorough analysis of the resources (Christensen and Walters, this volume) and appropriate methods to ensure that the analyses build on all available, relevant data. Further, we need to understand how human behavior in fisheries is influenced by economic and social factors (Sumaila, 2005) and how this leads to trade-offs between alternative uses. To evaluate such trade-offs, policy-makers need to understand the ecological and economic benefits (Sumaila *et al.*, this volume) as well as social issues, such as those related to small-scale versus large-scale fisheries (Chuenpagdee, this volume).

With better management, we may indeed be able to increase the world's fish production sustainably, not by increasing effort, but by fishing less. That should be a win–win situation, one would think. In the long term, it certainly makes sense economically, but reality is different. Increased fishing pressure will be unavoidable as long as there is a race for the fish and no efficient means or willingness to curtail effort. Changing this mindset calls for a way for scientists to influence ocean management policies more directly. This is not an area that traditionally has been frequented by scientists. There is a deeply rooted skepticism concerning the role of advocacy. "Science should stay pure." We question this, as have many of the scientists who were behind the Intergovernmental Panel for Climate Change, and the Millennium Ecosystem Assessment. It is far better that policy decisions are science-based and with due consideration for environmental impact, than driven primarily by commercial and political interests (Safina and Hardt, this volume).

For this to happen, science has to be conducted in a way that will be of use for policymaking (Hirshfield, this volume), though this by no means is a sufficient condition. There also needs to be communication between policymakers and scientists (Reichert, this volume; Nauen and Hempel, this volume), and while this may seem obvious, it rarely occurs. It is not without cause that scientists often are accused of hiding in their ivory towers.

This may be because of a deep mistrust by many scientists with regard to the role of the press when it comes to communicating science. Too many have been burned, having produced their masterpiece and delivered lengthy speeches, only to be surprised by the seemingly odd and irrelevant tidbits chosen by the journalists who interviewed them. Few scientists excel as communicators, Daniel Pauly being one of the rare exceptions (Baron, this volume). We may ask of course, if the reaction of scientists should be to start thinking like journalists. As scientists, we are good at communicating with fellow scientists. How do you deal with people who are not used to communication based on tables and figures? One possibility is to rethink how we communicate science, and make it more targeted for policymakers. There is no better way of ensuring communication than to talk the language of those you are trying to reach.

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Section I Life in the oceans

ANDREW BAKUN

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The oxygen constraint

In trying to understand processes and mechanisms regulating ocean ecosystems, we humans, being terrestrial mammals, naturally rely on intuitions and common sense notions formed by our terrestrial experiences as well as on our inherent terrestrial-mammalian evolved capacities and inclinations. As a result, many aspects of life that may be unique to organisms evolved and operating within marine situations may tend to elude our intellectual grasp and even our notice.

In the early 1980s, I worked with Daniel Pauly and other colleagues on developing an international collaborative "Ocean Science and Living Resources" (OSLR) program (Bakun *et al.*, 1982). This experience presented me with, among other things, an exposure to Pauly's developing theory on the special role of oxygen in the marine situation (Pauly, 1979, 1981, 1984, 2010). The interest was on individual-organism-scale biological issues, such as growth rate and maturation timing. Not being a biologist, but rather an oceanographer habitually focused on regional population-scale issues, I found the notions intriguing while not yet beginning to apprehend their significance to the particular questions that were consuming my own attention.

But, the "seeds" were planted in my mind. Daniel's early insights on the size-related oxygen issues faced by fishes in the ocean led me over the years to the notions outlined here, and are an example of how my own joy in the "ocean quest" has been enriched by his influence.

In the decades that have followed the OSLR program, as I have continued to encounter questions and conundrums in my own views of marine ecosystem operation as well as in the sometimes contrasting views of my community of colleagues, these seeds have occasionally suddenly sprouted forth, rewarding me with delicious flashes of

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