

Mapping Global Fisheries Patterns and Their Consequences

Reg Watson, Jackie Alder, Villy Christensen, and Daniel Pauly

Abstract

Despite increasing reports of fisheries collapses world wide, investigations of the effects of fishing on the global marine environment have been constrained by the paucity of fisheries landings data on suitable spatial scales. Working to overcome this, we have developed new databases and approaches that demonstrate basin-scale reductions in biomass and landings due to intensifying fishing effort, and equally disturbing, reductions in the size and trophic level of species landed. Starting with international, regional, and national datasets acquired from many sources, we have collated global datasets and mapped fisheries landings from 1950 to the present to a system of 30-min spatial cells. To facilitate this, we have also developed databases describing the global distribution of all fished species, as well as the fishing patterns/access rights of all fishing nations. Our methods effectively “reverse engineer” landing records to approximate the original catch patterns. The process includes disaggregation of records bundled as “miscellaneous fishes” and the “de-flagging” of reflagged fishing vessels. Our results have revealed rich evidence of dramatic change, which includes declines in catch, reductions in fish length, and a general reduction in the trophic level of landings. The analyses have also uncovered major problems in ‘official’ datasets, including significant over-reporting that has masked decades of decline. As we proceed, we remain committed to making our data available through our Web pages at www.seararoundus.org.

Introduction

To say that the commercial fisheries of the world require careful management would be contested by few people, largely because we read daily of fisheries collapses, lost livelihoods, and shattered fishing

communities. To continue that managers require information about the impact of past fishing on commercial stocks and on the ecosystems that support them would also rarely be opposed. It would, however, surprise many to learn that the information available to do this is sadly often not up to the task. Some developed countries have comprehensive reporting systems, but many more countries do not. Beyond records of port landings, there is often scant information on where fish are actually caught, even as fisheries are pursued farther offshore following the demise of valuable inshore stocks.

Besides national fisheries statistical systems, there are a number of regional fishery management bodies. These are most highly developed in the North Atlantic, where most catch is reported from relatively small statistical areas. Elsewhere, as in the Central Pacific, reporting areas are enormous (Fig. 2.1: see page 56). Statistical reports from such areas do not allow the kind of analysis that managers often require. Indeed, in many coastal waters it is not possible to closely estimate catches at the small spatial scale often used in ecosystem models. Clearly more spatial precision is required.

The Sea Around Us Project (SAUP; www.seararoundus.org) has a mandate to examine the impacts of fishing on the marine environment. This requires global fisheries data on a scale fine enough to use in ecosystem models. In short, it requires a new approach to working with existing fisheries data, one that uses all possible secondary data sources to help map fisheries landings with a precision not previously possible. Whereas original reporting areas may measure up to 48 million km² (such as FAO's Eastern Central Pacific area), our methods allocate landings to a system of spatial cells measuring only 1/2 degree latitude by 1/2 degree longitude—or averaging under 1,400 km² in area. This means we have more than 180,000 spatial cells for which we estimate fisheries landings—a formidable task, but worth the effort.

Fisheries managers also have limited information about the future of fisheries under varying potential management policies, which can impact on their willingness to change current approaches to management. Ecosystem approaches to fisheries management have been mandated by many agencies in recent years. Current developments in modeling software and improved knowledge of fisheries through the mapping work of the SAUP and others have enabled researchers to quantitatively explore the future fisheries of specified ecosystems. The improved understanding and role of scenarios also provides a qualitative framework for describing what could happen.

Scenarios are plausible, challenging, and relevant stories about how the future might play out. They widen our perspective on what the future can include and highlight key issues that might have been missed or dismissed. Using scenarios allows us to re-think the present and pursue changes so that we can influence the future. Using scenarios such as those being investigated by the Millennium Ecosystem

Assessment process (Millennium Ecosystem Assessment, 2003), in combination with quantitative ecosystem models, we describe the possible futures of fisheries using examples from the Gulf of Thailand, the Central North Pacific and the Benguela Current off the west coast of southern Africa.

Methods

Data Sources – Getting the Best Mix

For many parts of the world we need to rely on data provided by the Food and Agriculture Organization (FAO) of the United Nations (UN) which are supplied voluntarily by UN member states. These “official” data vary considerably in quality. They may be biased (Watson and Pauly, 2001) or just incomplete, and they do not include either illegal or discarded catch—they can more accurately be thought of as “reported landings.” As the reporting areas for the global data are typically very extensive, it is advantageous to use regional datasets, which typically use smaller reporting areas, whenever possible. Such data exist, for example, for the Northeast Atlantic from the International Council for the Exploration of the Sea (ICES), for the Northwest Atlantic from the Northwest Atlantic Fisheries Organization (NAFO), and from regional UN bodies in the Mediterranean, and along the western coast of Africa. In theory there are other regional bodies that use more compact reporting areas than those used in the global FAO dataset, but in practice these are not readily available except from groups such as ours. Most regional bodies have data starting in the early 1970s, whereas FAO’s global landings dataset starts in 1950. By 1950, large-scale fisheries were already well advanced in the North Sea. The FAO data therefore do not provide a glimpse of the unfished past. In addition, there are national datasets. Our project has had strong cooperation from many countries, and we are, as an example, currently using data from Canada for its east coast as these afford even more precise reporting areas than our initial starting point. Future versions will incorporate smaller scale datasets from many areas.

Allocation of Fisheries Landings

Most landings statistics contain clues, e.g., species-specific information, that make it possible to assign the records to a comparatively small portion of the whole nominal area. Species have known geographic distributions, or at the very least, they have preferences and some have very limited ranges. Knowing the range of the species reported is of great help in determining where the catch could have come from. You cannot catch a given species where it does not occur, and it is more likely to have come from the parts of its geographic distribution where it is most abundant or accessible than from the extremes of its range.

Similarly, we usually know the year the landing was reported, and which country reported landing it. Since the declaration of exclusive economic zones (EEZ) or fishing zones by most maritime states in the 1970s and '80s, access to the coastal waters of many countries has been limited. It is common for fishing arrangements to be required before other countries' fleets may access sovereign waters. While these arrangements vary according to the acceptance of maritime claims and the surveillance/enforcement capabilities of the countries involved, the threat of eventually attracting detection, fines, penalties, and seizures leads most fleets to accept some sort of arrangement. Using databases of such fishing arrangements, and observations of fishing activities by foreign fleets, it is often possible to further reduce the possible area from which reported landings were actually taken. As the coastal waters (EEZ) presently account for about 90% of global landings, it is very valuable to know who is fishing, and where, in order to increase the spatial precision of landing reports. If a reporting county may not, or does not, access the coastal waters of another country, then this area can be eliminated as a possible source for the reported catch.

Eliminating from the statistical areas reported in the official datasets both those areas that are outside the distribution of the animals caught and those where the reporting country may or simply does not fish greatly increases spatial precision (Watson et al., 2004). Furthermore, it is possible to create a gradient of likelihood in a system of global spatial cells (30 min longitude and latitude) based on the relative abundance of the reported taxon, which allows reported catch to be prorated amongst a collection of spatial cells. Cells where the fishing nation does not, or—for lack of a fishery access agreement—may not fish can be eliminated as possible locations for the reported catch. Each catch record is processed in turn, with the catch rate of each spatial cell adjusted accordingly. The resulting spatial database allows for queries stratified by year, country fishing, and/or taxon fished. Because cells also belong to collections representing major statistical areas, the exclusive economic zone of coastal states, large marine ecosystems, and other groupings, results can be presented for any of these aggregate categories.

There are several complications in using this method. First, it requires a spatial database showing the geographic distribution of all commercial species. We were able to build such a database by adapting and adding to existing efforts (Froese and Pauly, 2000; FAO, 2001). Second, and more challenging, was the construction of a database of fisheries access arrangements. This task had already been started by the FAO in their *Faris* database (FAO, 1998), but required updating and the creation of a complementary database that records observations of countries fishing in the waters of other nations (many arrangements are not in the public domain for obvious commercial reasons). Such fishing

arrangements are usually limited to certain species or gear types, and there may be quotas imposed on how much may be caught. These qualifications and limitations must also be considered in our process for spatially allocating landings.

Even with the best "cocktail" of data sources, the starting data are still problematic. Considerable uncertainty exists around the question of what the reported catch actually consists of, i.e., its taxonomic or biological composition. For example, if we are to use the geographic distribution of the animal to limit where catches of it originate, we must first identify it, and usually to at least the family level. All too often, considerable portions of landings reported by nations are simply described as "miscellaneous" or the equally unfortunate "nei" (not elsewhere included). Whether for sake of expediency, lack of resources, taxonomic problems, or other reasons, there is no useable biological identification for considerable segments of global fishery landings statistics. Countries like China and North Korea have the largest tonnage of landings provided with these vague labels, while some smaller tropical countries may have their entire national catch reported this way. FAO staff work hard to improve reporting statistics and even attempt to interpret and recover missing information, but unfortunately some datasets remain incomplete. Our approach has been to use the spatial and temporal distribution of landings by species, genus, and families to guide the proportioning of "miscellaneous" taxa into useable taxonomic groups.

Our method is further complicated by determining "who" (which country) is taking the catch. This is the issue of "reflagging" or the use of flags of convenience for fishing vessels. This practice is very prevalent, but fortunately the European Parliament (2001) has tried to identify the frequency and trends in this practice. Our approach entails recognizing which vessels are likely "reflagged," as this influences what coastal waters the vessel can access. For example, if a vessel from Spain has been reflagged to the country of Belize, then the landings reported by Belize may include landings from coastal waters where vessels from Spain have access, even if these same waters are not usually accessible by vessels from Belize.

Last, but not least, is the problem of illegal, unreported and unregulated (IUU) catches. This is a serious problem when catch data is supposed to be used in the analysis of the impacts of fishing on the marine environment. For example, much of the non-target species killed by trawlers is never reported. Aside from the mortality caused by the fishing gear on the bottom, sometimes as much as eight times the weight of animals is discarded as retained. (Alverson et al., 1994). Quotas, trip limits and commercial expediency encourage the discarding of less valuable, under-sized, or over-quota animals. Without unbiased observers, this catch is never documented. Our project is addressing these reporting problems and will be attempting to map various types

of IUU catches on the same spatial scale as is used for those officially reported landings (Pitcher et al., 2002).

The SAUP process for allocating global landings to spatial cells is one of constant refinement. New, more detailed data are obtained to replace more general data. National datasets replace regional datasets that replace global ones. The allocation process itself uncovers errors in the reporting process—some notable examples of such data artifacts include species reported caught in areas where the animal does not occur, obvious reflagging of fishing vessels that mask the true fishing country, or even significant biases in the statistics themselves (Watson and Pauly, 2001). For the last four years, we have refined the method, included more detailed and comprehensive data sources, produced rules to correct misidentifications and reporting biases, and improved the databases used in the process. The results from our allocation process, aggregated by EEZ, large marine ecosystems (LME), and for areas of the high seas, are available on our Web site (www.seaaroundus.org). We have also made the distributions of the target species analyzed in the SAUP available for inspection and comment. Similarly, the contents of our databases that describe fishing access arrangements and observations of foreign fishing are available on-line. We are currently engaged in a process of contacting experts from maritime nations to inspect our results and offer suggestions and comments. This process will lead to further refinement and greater collaboration with the providers and users of fisheries data.

Ecosystem Modeling

Using Ecopath with Ecosim (EwE; Christensen and Pauly, 1992; Walters et al., 1997; Pauly et al., 2000; Walters et al., 2000; Christensen and Walters, 2004), we used the data compiled using the above methods to explore four scenarios developed as part of the international Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2003). EwE is an ecological modeling software suite for personal computers, some components of which have been in development for nearly two decades. The approach is thoroughly documented in the scientific literature with over 100 ecosystems models developed to date (for a literature list, see www.ecopath.org). EwE uses two main components: Ecopath—a static, mass-balanced snapshot of the system, and Ecosim—a time-dynamic simulation module for policy exploration that is based on an Ecopath model.

Ecosim can be used in “gaming” mode, where the user can explore policy options. This is achieved by “sketching” fishing rates over time and examining the results (catches, economic performance indicators, biomass changes) for each sketch. In addition, formal optimization methods can be used to search for fishing policies that would maximize a particular policy goal or “objective function” for management. The objective function represents as a weighted sum of the four objectives:

economic, social, legal, and ecological. Assigning alternative weights to these components is a way to see how they conflict or tradeoff with one another in terms of policy choice.

The goal function for policy optimization is defined by the user in Ecosim, based on an evaluation of four weighted policy objectives:

- maximize fisheries rent;
- maximize social benefits or value of landings;
- maximize mandated rebuilding of species;
- maximize ecosystem structure or "health."

Maximizing profits is based on calculating profits as the value of the catch (catch * price, by species) less the cost of fishing (fixed + variable costs). Meeting this objective often results in phasing out all but the most profitable fleets, and the elimination of ecosystem groups competing with or preying on the more valuable target species. The derived fishing effort is often lower than the current, as profit may be reduced by lowering the effort.

Social benefits are calculated as number of jobs relative to the catch value, and are fleet specific. Therefore, social benefits are largely proportional to fishing effort. Optimizing effort often leads to even more extreme (with regards to overfishing) fishing scenarios than optimizing for profit.

Mandated rebuilding of species (or guilds) explores policies that focus on preserving or rebuilding the population of a given species in a given area. This corresponds to setting a threshold biomass (relative to the biomass in Ecopath) for the species or group, and optimizing towards the fleet effort structure that will most effectively ensure this objective. The outcomes of this policy option are case-specific.

Maximizing ecosystem structure (or "health") uses E.P. Odum's ecosystem "maturity" concept, where large, long-lived organisms dominate (Christensen, 1995). In this case, optimizing a group-specific biomass/production ratio as a measure of longevity often results in a reduction of fishing effort for all fleets, except those targeting species with low weighting factors.

Fisheries Scenarios

Four scenarios were harmonized with three ecosystem models as described in the section that follows, using EwE to investigate the future of fisheries to 2050.

Humanity uses scenarios to think about the future all of the time, much of it through narrative storytelling. In the last 50 years, however, the use of scenarios has expanded to include quantitative approaches. The storylines are developed to be plausible, challenging, and relevant descriptions of future events that may take place, and not necessarily what will take place. Scenarios also offer support for more informed and rational decision making in the present and in the future.

The use of scenarios began in the 1960s, but it was not until the 1970s that they were used to link natural resources sufficiency to population growth and consumption that led to its use today. In the fisheries sector, the use of scenarios began in the late 1980s. Since then, there have been six studies that use scenarios with different foci to describe how fisheries may develop past 2010 (Table 2.1).

The Scenarios Working Group of the Millennium Assessment developed the scenarios used in this study over several months of consultation in 2003. The four scenarios are Global Orchestration, Order from Strength, Adapting Mosaics and Technogarden, and they describe the range of possible future directions policy-makers may take in the management of ecosystems. The scenarios differ by the specific conditions necessary for change, proposed rate of change, and the policies that are needed to facilitate change.

GLOBAL ORCHESTRATION

This scenario is about finding the right balance between ecological structure, economic rent, and social benefits. In this scenario, many regional fishing agreements as well as the Fish Stocks and Compliance agreements are strengthened and implemented, and perverse subsidies are reduced or eliminated. Areas where there is good governance will see improvements in selected fisheries, especially for those of high economic value and not necessarily those species integral to ecosystem stability and structure. Some fisheries with extensive ecosystem impacts are phased out and habitats closed to allow the area and stocks to recover. Depending on the degree of degradation, it may take decades to see improvement using these measures. In areas where climate change has a severe impact (e.g., Caribbean reef fisheries), improvements may not eventuate. Effort will be reduced in some fisheries through economic incentives (e.g., bycatch reduction devices), and marine protected areas (MPAs) will be used to improve fisheries habitats. Areas where high exploitation combined with habitat destruction continues will see local stock collapses.

ORDER FROM STRENGTH

In this scenario, fishing and environmental management agreements break down, and impacts such as climate change continue, and in some areas, intensify. Despite these breakdowns, distant-water fleets from rich nations continue to expand into waters of countries not as severely impacted from overfishing to secure fish food as well as fishmeal for national food production. Domestically, fisheries are sustainably managed. This approach does not necessarily maintain ecosystem functions and services. Since some nations will focus on export-driven, high-value fisheries, which are often low-trophic, short-lived

text continues on page 23

Table 2.1: Summary of harmonizing the storylines and EwE models

Global Orchestration

Gulf of Thailand

2000-2010	Optimize profits from shrimp and jobs (70/30), climate change moderate to high
2010-2030	Optimize profits, jobs and then ecosystems (50/30/20), climate change impact reducing
2030-2050	Optimize profits and ecosystem (biomass) (50/50)

North Benguela

2000-2010	Optimize profits and jobs (50/50) Climate change moderate
2010-2030	Optimize profits and jobs (30/70) climate change moderate to low, increase catch of fish for fish food
2030-2050	Optimize profits, jobs and ecosystems (50/20/30), increase the catch of small pelagics

Central North Pacific

2000-2010	Optimize profits from tuna and jobs (80/20) – climate change low
2010-2030	Optimize profits from tuna and jobs (70/30), climate change stable
2030-2050	Optimize profits and ecosystems (50/50) rebuilding of bigeye

Order from Strength

Gulf of Thailand

2000-2010	Optimize profits of the invertebrate fishery and jobs (50/50)
2010-2030	Optimization mix continues (50/50) but effort increasing since Thailand feels the effects of national EEZs and despite agreements it has no room to expand Distant Water Fleet (DWF) which is now concentrated in Gulf of Thailand.
2030-2050	Climate change has significant impact (high impact) and ecosystem severely destabilized; rebuilding stocks of demersal species continues with objective of optimizing jobs rather than profits.

North Benguela

2000-2010	Optimize profits and jobs (50/50) of high value fisheries; DWF increases effort (moderate to high of current species as EU pushes for food security & Africa's debt mounts.
2010-2030	Climate change starts low with build-up over this decade to medium impact. Rebuilding of biomass starts late in this period but there is still concern with maintaining jobs. (30/50/20)
2030-2050	Mix of profit and job optimization (60/40). Increased fishing effort with switch through time to fishmeal species for domestic and international aquaculture operations and also internal food security

table continues

Central North Pacific

- 2000-2010 Optimize profits from the tuna fishery as well as jobs (75/25); distant-water fishing effort remains stable since countries focused on national issues
- 2010-2030 Optimize profit and jobs (85/15). Japan returns to drift netting. DWF has moderate increase as US secures food and increases presence in Pacific for security.
- 2030-2050 Profit optimization not as important as jobs (60/40). Japan stops drift netting by 2040; DWF effort remains stable

Adapting Mosaics*Gulf of Thailand*

- 2000-2010 Optimize profits of the invertebrate fishery and jobs (70/30)
- 2010-2030 Climate change starts in earnest (moderate to high impact), optimize for profits, shift to rebuilding stocks of demersal species starts
- 2030-2050 Climate change has significant impact (high impact) and ecosystem severely destabilized, rebuilding stocks of demersal species continues with objective of optimizing jobs rather than profits.

North Benguela

- 2000-2010 Optimize profits and jobs (40/60) and maintain food and fishmeal fisheries
- 2010-2030 Climate change starts low with build up over this decade to medium impact. Rebuilding of biomass starts late in this period but there is still concern with maintaining jobs. (30/50/20)
- 2030-2050 Climate change continues to high impact with some destabilization of the system, food security becomes an issue and therefore focus is on maximizing biomass for fish feed since it goes to aquaculture that ensures a stable supply of food. (0/100/0)

Central North Pacific

- 2000-2010 Optimize profits from the tuna fishery; turtle exploitation ceases
- 2010-2030 Climate change minimal if any impact, severe exploitation of bigeye until close to 2030 when stock rebuilding commences, at the same time shift to optimizing for jobs with profit (70/30)
- 2030-2050 Climate change has a low impact, bigeye rebuilding continues, optimize for ecosystem especially for top predators. International MPA to rebuild stocks. (50/50)

Techno Garden*Gulf of Thailand*

- 2000-2010 Optimize profit
- 2010-2030 Optimize pelagic catch (cost of fishing lower) followed by ecosystem optimization (since impacts can be engineered)
- 2030-2050 Optimize pelagic catch – by 2040 ecosystem irrelevant due to technology advances – profits maximized by using Gulf of Thailand to produce quality fishmeal for prawn aquaculture.

North Benguela

- 2000-2010 Optimize profit
- 2010-2030 Optimize profits while increasing pelagics (50/50) for fish food since technology makes aquaculture widespread and demand for fish meal up despite artificial feed improvements
- 2030-2050 Optimize profits from fish used in fishmeal. Basically supplies European demand for aquaculture.

Central North Pacific

- 2000-2010 Optimize profit
- 2010-2030 Optimize profit – but with costs lowered since technology improves. Possible to have more tuna caught younger for ranching (2015-2030)?
- 2030-2050 Optimize profits – but fish changes to species for fishmeal since technology cracks tuna hatchery technology.

invertebrate species, the result may be that large, long-lived species are eliminated from the system overall. These changed systems are vulnerable to severe events and therefore food and fishmeal supplies are highly variable. In areas without appropriate management systems, destructive fishing practices continue and stocks eventually decline along with inshore ecosystems. Towards 2050, developed nations reduce their net outflows of fish products to secure food supplies and social benefits. There is a significant reduction in effort starting with distant-water fleets, which are seen as threats to national food security. Areas are closed to fishing, where appropriate fisheries with low biomass production and destructive impacts, (e.g., long-living species) are phased out.

ADAPTING MOSAICS

This scenario includes a significant culture shift to maintaining the ecological structure of coastal and marine ecosystems that includes the recovery of long-lived, high-trophic-level species. In this scenario, there is considerable variation in the state of fisheries and the ecosystems as different management regimes, including variations on individual transferable quotas, community quotas, adaptive management, and community-based management, are tested. Global fishing agreements are largely ignored and regional fishing agreements decline in

importance, but regional fisheries bodies are maintained for technical support for local and regional initiatives rather than for management advice. Initially, efforts are focused on coastal areas, but once it is realized that oceanic systems need to be included to ensure the recovery of long-lived species, ocean management is also embraced. Correspondingly, regional fisheries agreements and management bodies begin to coordinate information and learning exchanges.

TECHNOGARDEN

In this scenario, technology in the fisheries sector is primarily used to optimize economic returns and therefore the focus is on producing high-value, short-lived species, such as prawns, lobsters, squids, and salmon, through capture fisheries and aquaculture. The capture fisheries will not be purposely phased out because of the need to maintain the genetic resources should major failures take place in the aquaculture sector. Food provisioning by marine and coastal ecosystems is an important service and one which is well served by technology in addressing destructive fishing practices as well as a number of aquaculture development issues. The dominance of large corporations in the fisheries sector implies that ecosystem services other than food provisioning are considered to be secondary, except in a few isolated areas where other services such as tourism, biodiversity, and water regulation are given the same or higher priority.

This scenario also includes the development of ecologically sound aquaculture ventures in the coast and oceans. Given the importance of maintaining ecosystem structures, environmental concerns and uncertainty around genetically modified organisms (GMO), the expansion of aquaculture slows dramatically until these issues are resolved, which takes two to three decades. Technology plays an important role in developing fishmeal and fish oil replacements. Slow expansion only takes place under strict environmental and GMO policies.

Case Studies

GULF OF THAILAND

The Gulf of Thailand is located in the South China Sea. It is a shallow, tropical, coastal shelf system that has been heavily exploited since the 1960s. Prior to the early 1960s, fishing in the area was primarily small scale with minimal impact on the ecosystem. However, a trawl fishery was introduced in 1963, and since then the area has been subjected to intense, steadily increasing fishing pressure (Pauly, 1979; Pauly and Chuenpagdee, 2003). The system has changed from a highly diverse ecosystem with a number of large, long-lived species (e.g., sharks and rays), to one that is now dominated by small, short-lived species that support a highly valued invertebrate fishery. Shrimp and squid caught primarily by trawl gear are economically the dominant fisheries in the

Gulf of Thailand. The bycatch of the trawl fishery is used for animal feed. The Gulf of Thailand model is well established and detailed in an FAO technical report (FAO/FISHCODE, 2001).

CENTRAL NORTH PACIFIC

The modeled area of the Central North Pacific is focused on epipelagic waters from 0°N to 40°N latitude and between 150°W to 130°E longitude (Cox et al., 2002). Tuna fishing is the major economic activity in the area, after tourism in the Hawaiian Islands. The tuna fishery is divided into deepwater, longline fisheries that target large-sized bigeye, yellowfin, and albacore tuna, and surface fleets that target all ages/sizes of skipjack tuna, small-sizes of bigeye, yellowfin, and albacore using a range of gear, including purse-seine, large-mesh gillnet (i.e., driftnet), small-mesh gillnet, handline, pole-and-line, and troll (Cox et al., 2002). Recent assessments of the tuna fisheries indicate that top predators, such as blue marlin (*Makaira* spp.) and swordfish (*Xiphias gladius*), declined since the 1950s, while their prey, small tunas, have increased. The Central North Pacific model is described in detail in Cox et al. (2002).

NORTH BENGUELA

The North Benguela Current is an upwelling system off the west coast of Southern Africa. This upwelling system is highly productive resulting in a rich living marine resource system that supports small, medium and large pelagic fisheries (Heymans et al., 2003). The system undergoes dramatic changes due to climatic and physical changes and therefore the marine life production can be quite variable. Sardine or anchovy used to be the dominant small pelagics; both species however been at very low abundance for years as indicated by surveys in the late 1990s (Boyer and Hampton, 2001). The North Benguela ecosystem model is now used by the Namibian Fisheries Research Institute and is described in detail in Heymans et al. (2004).

Harmonizing of the scenarios and ecosystems models is summarized in Table 2.1. The landings, value of the landings and the diversity of the landings were used to investigate the differences between the various scenarios (Table 2.1) for each ecosystem.

Results and Discussion

Reporting Biases

By mapping landings into a global grid of cells it is possible to compare landings between locations while considering depth, latitude, primary productivity etc. In this way reporting anomalies become readily apparent. Systematic over-reporting from China was documented in this way (Watson and Pauly, 2001) and by estimating the expected landing levels it became apparent that this bias had maintained global

landing totals for many years when actually landings had been declining. Since that time a more complete analysis of global reporting anomalies has been prepared for FAO.

Plans for future work include validation of our “top-down” approach to mapping fisheries catches by comparisons with more localized and intensive “bottom-up” efforts such as spatial models of the groundfish fisheries along the N.W. coast of the U.S (Scholz et al., this volume). Such comparisons are very instructive for those involved. For those working on global mapping it tests whether significant local spatial structures have been reconstructed by the rule-based disaggregation process from large-scale data. This could be very beneficial to modify future versions of the procedures involved. To those working on a smaller scale it helps examine whether there are spatial discontinuities when the boundaries of the mapped domain are reached, in other words, how representative are the local conclusions, and how significant are they in a broader spatial context.

Decades of Decline

Maps of landings for all years since 1950 can establish when spatial cells were first fished (where “first fished” is defined as the point in time when allocated landings first reached 10% of their all-time maximum). Mapping the decades when the maximum is reached over time, we can see a pattern of global expansion and decline (Fig. 2.2; see page 57). The parts of the North Atlantic where large-scale commercial fisheries started (for example the North Sea) were the first to decline, and in some cases they peaked as early as the 1960s (Watson et al., 2003). Generally areas to the south are either currently at their highest historical landings or in the case of areas nearer the Antarctic, there has been so little fishing history as to make this analysis impractical. The collapse of inshore stocks (Christensen et al., 2003) combined with the technical ability to fish deeper (Roberts, 2002) and further from ports have driven fisheries to expand. Our mapping method demonstrates that more and more of the deeper ocean depths are exposed to fishing each year (Pauly et al., 2003). While the largest off-shore expansion has involved the tuna fleets, many other distant-water fleets fish thousands of kilometers from home ports for smaller pelagic fishes, most of which is reduced to meal and oil.

Reduction in the Average Length of Landings

If annual landings are combined with the maximum length of taxa landed it is possible to calculate the average length of the animals landed, and map the change in this revealing statistic. Most people are aware that historical accounts of fisheries cite larger animals as well as more abundant catches than are currently landed. The composition of landings, however, has also changed, often accompanied by a decline in the average length of animals landed. In some areas of the North

Atlantic where fisheries were well developed even before our data series began in the 1950s, there has been a decline of nearly one meter in the average length of animals reported (Fig. 2.3; see page 57). As we move to fishing smaller fishes and concentrate on small invertebrates like shrimp this trend is likely to accelerate.

Reduction in the Trophic Level of Landings

Similarly, it is possible to use biological databases such as FishBase (www.fishbase.org) to estimate the mean trophic level for each reported commercial species. If this information is combined with spatially allocated landings it is possible to produce a map showing the change in mean trophic level in commercial landings (Fig. 2.4; see page 57). In this way, we can see that the oldest commercial fisheries in the North Atlantic are also those where the trophic level of animals landed has been reduced the most (Pauly and Watson, 2003). This process has been shown in bivariate graphs by Pauly et al. (1998), but it was never previously possible to map the changes.

Modeled Futures

Gulf of Thailand

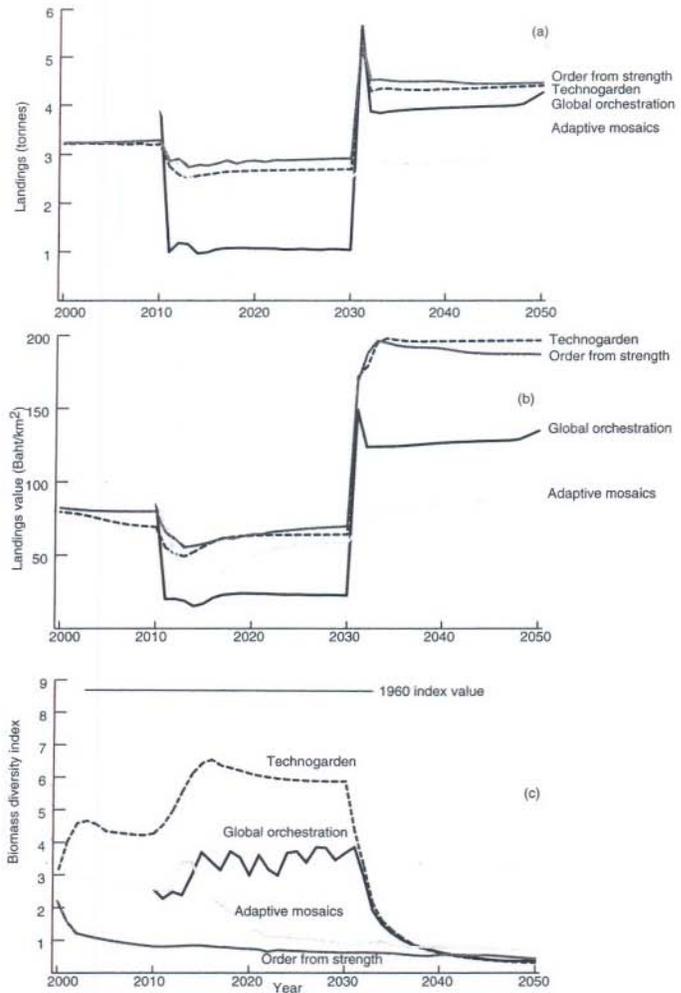
The Gulf of Thailand landings vary between scenarios (Fig. 2.5). Overall landings are low in the Adapting Mosaic, which optimizes the value of the invertebrate fishery and jobs. Landings are maximized in the Order from Strength, which primarily optimizes the overall value of the fisheries and jobs, and Technogarden, which optimizes the value of small pelagic and lower trophic fish to support the aquaculture industry. The Global Orchestration also optimizes a mix of value and jobs initially, but after 2010 it changes to balancing value, jobs, which is reflected in the substantial decline in landings after 2010. In 2040 the focus is changed again to optimizing the ecosystem and the value of the fisheries.

The value of the landings is optimized in the Technogarden scenario due to the focus on supporting fisheries that are used in the fishmeal industry (Fig. 2.5b). The value of the landings in the Order from Strength scenario is similar to the Technogarden even though the management includes a focus on jobs. Some of the lowest landed values are in the Adapting Mosaic scenarios. Landing diversity initially differs substantially between the four scenarios with the Technogarden scenario having the highest diversity (Fig. 2.5c). By 2050, however, landing diversity declines below 2000 levels for all the scenarios as the fisheries are optimized for either invertebrate or small pelagic fisheries.

Central North Pacific

Changes in landing are substantially different initially between the four scenarios initially (Fig. 2.6). Between 2010 and 2030 landings for the Technogarden and Order from Strength scenarios are similar despite

Figure 2.5. Future scenarios results for the Gulf of Thailand showing a) landings, b) value of landings and c) diversity index of landings.



optimizing value in the Technogarden scenario and a mix of value and jobs in the Order from Strength scenario. The two scenarios diverge even further after 2040. Landings in the Adapting Mosaics scenario, which initially focus on optimizing value from the tuna fisheries and later on rebuilding the bigeye stocks and optimizing jobs, remain relatively constant. Landings in the Global Orchestration scenario drop substantially after 2010 which corresponds with a shift from optimizing primarily value followed by jobs to a mix which also optimizes value but an increased emphasis on jobs.

Overall the value of the landings are highest in the Technogarden and Global Orchestration scenarios, which is as expected since the focus is on optimizing higher valued tuna fisheries (Fig. 2.6b). Although the landings in the Adapting Mosaic remained constant, the value of landing increases, while in the Order from Strength scenario the value of landings decrease. The diversity of the landings remains relatively constant for the Techno and Global Orchestration scenarios due to their focus on tuna fisheries (Fig. 2.6c). The Adapting Mosaic scenario yields

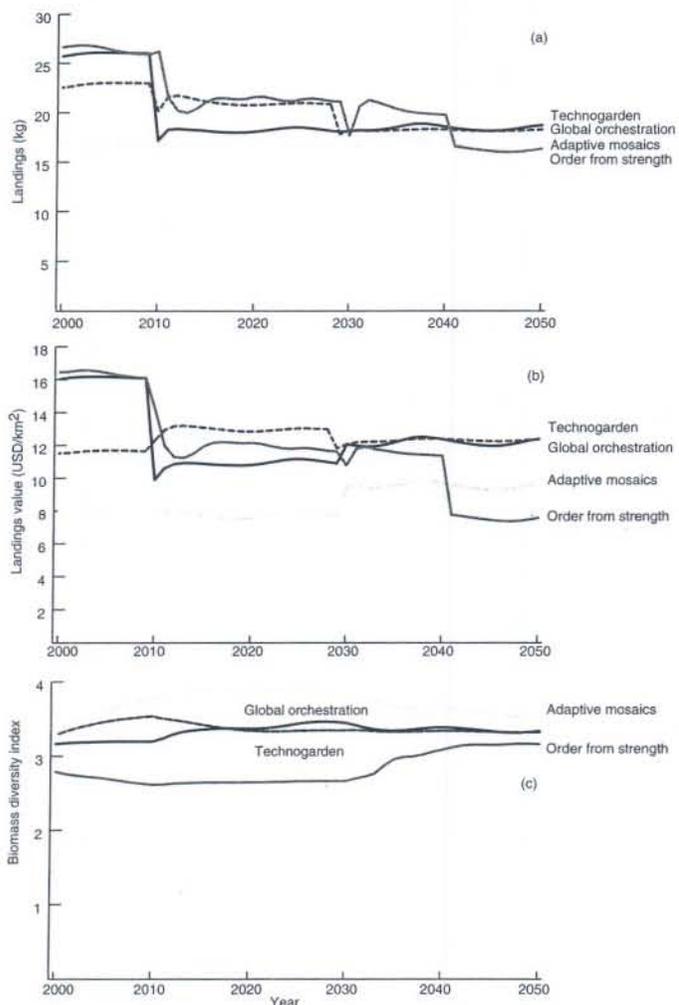


Figure 2.6. Future scenarios results for the Central North Pacific showing a) landings, b) value of landings and c) diversity index of landings.

the highest diversity of the landings. The diversity changes, however, as the focus in the Adapting Mosaic scenario changes from optimizing value to rebuilding bigeye stocks and optimizing the ecosystem. Diversity of the landings is lowest in the Order from Strength scenario, which is focused initially on optimizing value from tuna fisheries.

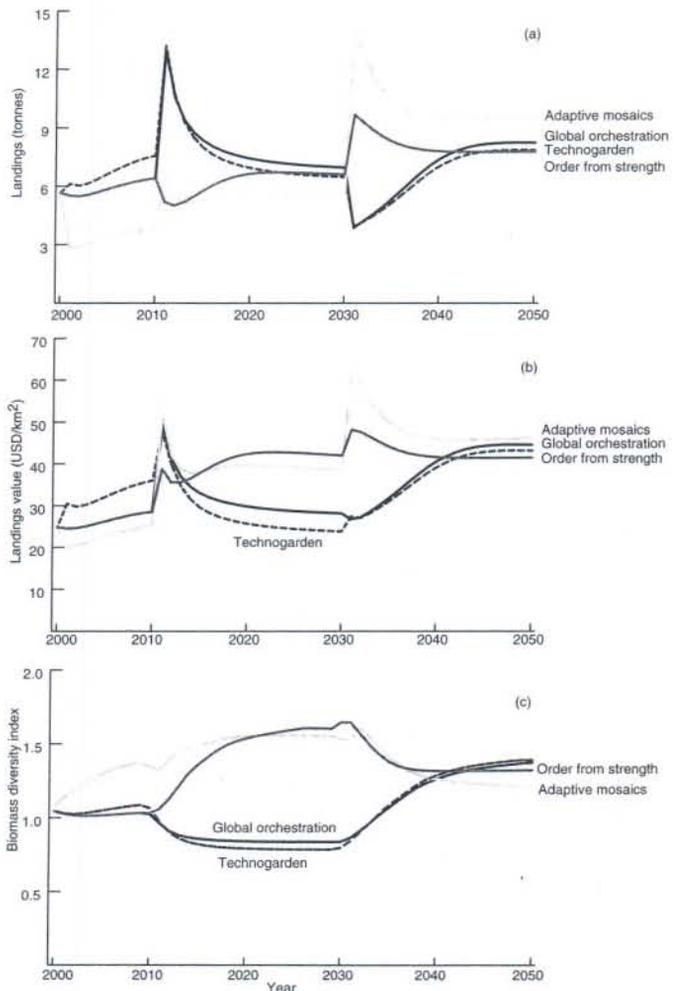
North Benguela

Until 2040, landings for the Technogarden and Global Orchestration scenarios follow the same trend (Fig. 2.7). These scenarios initially focus on optimizing value and then diverge in 2010, where management focus continues on optimizing value in the Technogarden scenario. In the Global Orchestration scenario, however, jobs are optimized as well as value. By 2040, the Technogarden scenario continues to optimize value but the Global Orchestration scenarios tries to balance value, jobs and the ecological values. Over the same time period, landings in the Mosaic scenario, which focuses on optimizing value and jobs initially and then shifts to rebuilding ecosystem, increases very slowly until

2040. After 2040, the focus changes to optimizing biomass and consequently landings increase. By 2050, however, landings in these three scenarios approach similar levels. The Order from Strength scenario landings are significantly less than the other scenarios due to the focus on optimizing value initially from the high value, distant-water fisheries. In 2010, the focus changes to optimizing jobs and later rebuilding the ecosystem, resulting in substantial increases in landing. This increase, however, is short-lived due to management changing to a mix of optimizing value and jobs.

The value of the landings also follows a similar trend to the landings, with differences due to fisheries that are optimized (Fig. 2.7b). If jobs are the focus, then the fisheries that are optimized may not yield as high a value as fisheries that employ fewer people but target high-valued species. Diversity of the landings follows a similar trend to value. By 2050, the diversity of the landings begin to approach the same level with the Technogarden and Global Orchestration scenarios yielding slightly higher levels than the other scenarios (Fig. 2.7c).

Figure 2.7. Future scenarios results for the North Benguela showing a) landings, b) value of landings and c) diversity index of landings.



Conclusions

Conventional fisheries data do not provide spatial information on landings and their trends suitable to support either broad global analysis or fine-scale spatial ecosystem modeling. Using additional data, such as marine distributions, fishing access, and fishing patterns, considerable spatial precision can be achieved. By treating landing data this way, we can demonstrate worrying patterns present since the 1970s and before, notably reductions in landings, and a decrease in the mean size and trophic level of animals landed in some of the major fisheries of the world.

Landings data can be combined with new approaches in ecosystem modeling to examine the impact of future scenarios on marine resources, and on the people and industries that depend on them. Choices made in the management of marine resources will greatly affect the outcomes, but they will have different impacts on different places.

Our preliminary exploration of the future of fisheries indicates that it is not too late to reverse current trends in capture fisheries around the world. The future depends on where policy-makers chose to focus their interests: profits, jobs, or ecosystems.

In all three case studies discussed here, which represent very different ecosystems, testing the four future scenarios yielded varied outcomes. Policies that were totally focused on maximizing profits did not necessarily maintain diversity or support employment. Similarly, a policy that was focused on employment did not necessarily maximize profits or maintain ecosystems.

The diversity of the stocks exploited can be enhanced if the policy favors maximizing the ecosystem or rebuilding stocks. Diversity, however, is lost if the sole objective of management is to maintain or increase profits. Our results demonstrate that society is going to have to take a more active role in exploring the right balance or tradeoffs between profits, jobs, and ecosystems.

Acknowledgments

The authors would like to thank database providers, including Rainer Froese and the "FishBase team," CephBase (particularly Catriona Day), the World Conservation Monitoring Centre (Cambridge), and the Food and Agriculture Organization (Rome). We are grateful for the assistance of Fred Valdez, Wilf Swartz, and the other "Sea Around Us" project (SAUP) staff. We thank the editors and their referees for their valuable suggestions. The SAUP is an activity initiated and supported by the Pew Charitable Trusts of Philadelphia.

References

- Alverson, D. L., Freeberg, M. H., Murawski, S. A., and Pope, J. G., 1994. A global assessment of fisheries by-catch and discards, FAO Fisheries Technical Paper 339, 233 pp.
- Boyer, D. C. and Hampton, I., 2001. An overview of the living marine resources of Namibia, *South African Journal of Marine Science*, 23:5-35
- Christensen, V., 1995. Ecosystem maturity - towards quantification, *Ecological Modelling*, 77:3-32.
- Christensen, V., Guénette, S., Heymans, J. J., Walters, C. J., Watson, R., Zeller, D., and Pauly, D., 2003. Hundred-year decline of North Atlantic predatory fishes, *Fish and Fisheries*, 4: 1-24.
- Christensen, V., and Pauly, D., 1992. Ecopath II - a software for balancing steady-state ecosystem models and calculating network characteristics, *Ecological Modelling*, 61:169-85.
- Christensen, V., and Walters, C.J., 2004. Ecopath with Ecosim: methods, capabilities and limitations, *Ecological Modelling*, 172: 109-39.
- Cox, S. P., Martell, S. J. D., Walters, C. J., Essington, T. E., Kitchell, J. F., Boggs, C., and Kaplan, I., 2002. Reconstructing ecosystem dynamics in the central Pacific Ocean, 1952-1998. 1. Estimating population biomass and recruitment of tunas and billfishes, *Canadian Journal of Fisheries and Aquatic Sciences*, 59:1724-35.
- European Parliament, 2001. Revised Working Document 3 on the Role of Flags of Convenience in the Fisheries Sector, Committee on Fisheries, European Parliament, DT\452747EN.doc PE 309.162/REV, 5 pp.
- Food and Agriculture Organization (FAO) of the United Nations, 1998. FAO's fisheries agreements register (FARISIS), Committee on Fisheries, 23rd Session, Rome, Italy, February 15-19, (COFI/99/Inf.9E), 4 pp.
- FAO, 2001. Fisheries Department, Fishery Information, Data and Statistics Unit. FISHSTAT Plus, Universal software for fishery statistical time series, Version 2.3.
- FAO/FISHCODE, 2001. Report of a Bio-economic Modelling Workshop and a Policy Dialogue Meeting on the Thai Demersal Fisheries in the Gulf of Thailand held at Hua Hin, Thailand, 31 May - 9 June 2000, FI: GCP/INT/648/NOR: Field Report F-16 (En), Rome, FAO, 104 pp.
- Froese, R., and Pauly, D. (eds.), 2000. FishBase 2000: Concepts, Design and Data Sources, Los Baños, Philippines, distributed with 4 CD-ROMs; updates on www.fishbase.org.
- Heymans, J. J., Shannon, L. T., and Jarre, A., 2004. The Northern Benguela Ecosystem: Changes over three decades (1970, 1980 and 1990). *Ecological Modelling* 172(2-4): 175-96.
- Millennium Ecosystem Assessment, 2003. *Ecosystems and Human Well-being: A Framework for Assessment*, Washington, DC, Island Press, 245 pp.
- Pauly, D. 1979. Theory and management of tropical multispecies stocks, ICLARM Studies and Reviews 1, Manila, 35 pp.
- Pauly, D., Alder, J., Bennett, E., Christensen, V., Tyedmers, P., and Watson, R. 2003. World fisheries: the next 50 years, *Science* 302: 1359-61.
- Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., and Francisco T., Jr., 1998. Fishing down marine food webs, *Science* 279: 860-63.
- Pauly, D., Christensen, V., and Walters, C., 2000. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries, *ICES Journal of Marine Science*, 57: 697-706.

- Pauly, D., and Chuenpagdee, R., 2003. Development of fisheries in the Gulf of Thailand large marine ecosystem: Analysis of an unplanned experiment, in Hempel, G., and Sherman, K. (eds.), *Large Marine Ecosystems of the World: Change and Sustainability*, Amsterdam, Elsevier Science.
- Pauly, D., and Watson, R. 2003. Counting the last fish. *Scientific American*, July 2003, 42-47.
- Pitcher, T. J., Watson, R., Forrest, R., Valtasson, H., and Guénette, S., 2002. Estimating illegal and unreported catches from marine ecosystems: a basis for change, *Fish and Fisheries*, 3: 317-39.
- Roberts, C. M., 2002. Deep impact: the rising toll of fishing in the deep sea, *Trends in Ecology and Evolution*, 17(5): 242-45.
- Scholz, A. J., Mertens, M., and Steinback, C., this volume. The OCEAN Framework—Modeling the Linkages between Marine Ecology, Fishing Economy, and Coastal Communities, in Wright, D. J., and Scholz, A. J. (eds.), *Place Matters—Geospatial Tools for Marine Science, Conservation and Management in the Pacific Northwest*, Corvallis, OR, Oregon State University Press.
- Walters, C., Christensen, V., and Pauly, D. 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments, *Reviews in Fish Biology and Fisheries*, 7:139-72.
- Walters, C., Pauly, D., and Christensen, V., 1998. Ecospace: prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas, *Ecosystems* 2: 539-54.
- Walters, C., Pauly, D., Christensen, V., and Kitchell, J. F., 2000. Representing density dependent consequences of life history strategies in aquatic ecosystems: Ecosim II, *Ecosystems*, 3:70-83.
- Watson, R., and Pauly, D., 2001. Systematic distortions in world fisheries catch trends, *Nature*, 414: 534-36.
- Watson, R., Tyedmers, P., Kitchingman, A., and Pauly, D., 2003. What's left: the emerging shape of the global fisheries crisis, *Conservation in Practice*, 4(3): 20-21.
- Watson, R., Kitchingman, A., Gelchu, A. and Pauly, D., 2004. Mapping global fisheries: sharpening our focus, *Fish and Fisheries* 5: 168-77.