Towards increasing fisheries' contribution to food security

Part II: The potentials of 25 fishing countries

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Towards increasing fisheries' contribution to food security

Part 2: The potentials of 25 fishing countries

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Executive summary

This report reviews the status of fisheries in 25 countries: Argentina, Belize, Brazil, Canada, Chile, China, Denmark, Iceland, India, Indonesia, Japan, Malaysia, Mexico, Morocco, Norway, Peru, the Philippines, Russia, South Africa, South Korea, Spain, Turkey, the U.K., the U.S., and Vietnam.

The abundance and coverage of marine protected areas (MPAs) is reviewed, with the conclusion that most countries have not sufficiently protected the biodiversity and fisheries resources occurring in their EEZ waters.

The status of the twelve species, which in each of these countries, contribute most to the catch is assessed using a recently-developed stock-assessment method that has minimum data requirements. The results suggest that some of the countries are experiencing strong exploitation and that reduction in fishing effort would allow key species to increase their biomass, and thus their sustainable levels of yield. Additionally, for 15 of these countries, the stock assessment results are compared with well-documented ecosystem models. For all the countries examined here, both the single-species and the ecosystem-based analyses suggest that overall catches could be increased by approximately 35 % given fishing at single-species F_{MSY}. However, if one considers biodiversity or rebuilding criteria for exploited species, the approximate increase in catch would be lower.

There is general agreement between the two types of analyses performed here, in that both suggest that overall catch could be increased, sometimes considerably, by managing the major species in the catch. Obviously, the results differ by country, given existing management regimes and data quality, but the results are clear regarding the possibility of catch increases. In the majority of countries, the single-species analyses could be validated using the ecosystem models. These models, given their sophistication, provided other relevant information, notably on the biodiversity losses that increased catches would incur. Obviously, such trade-off analyses are tentative, and would have to be refined, were they to provide the basis for policy elaborations in a given country.

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Introduction[1]

The global fisheries crisis has been illustrated by numerous examples: catches are declining worldwide in spite of increasing fishing effort (Anticamara *et al.* 2011; Watson *et al.* 2012); fisheries that would otherwise not be profitable are kept afloat by government subsidies (Sumaila *et al.* 2010a; Sumaila *et al.* 2010b); and the state of stocks – except for a few areas with prudent management – is abysmal (Jackson *et al.* 2001; Coll *et al.* 2008a; Costello *et al.* 2012). This occurs in the face of an increasing world population, more than ever in need of the protein that seafood can provide (Garcia and Rosenberg 2010; Srinivasan *et al.* 2010; LeManach *et al.* 2012; Sumaila *et al.* 2012). There are now over one billion people that rely on marine resources for livelihoods (Teh and Sumaila 2013).

Fisheries overexploitation also manifests itself in the form of a marine biodiversity crisis, with an increasing number of species of large fishes, seabirds and marine mammals registered on the IUCN Red List of Endangered Species (IUCN 2011). Additionally, research has illustrated that the rate of marine biodiversity decline has not been reduced in the last decade (Butchart *et al.* 2010; Veitch *et al.* 2012).

It is common, in the world of marine fisheries and biodiversity, to frame approaches that attempt to mitigate and overcome this fisheries crisis in the form of a zero-sum game, where increased fisheries yields are seen as incompatible with maintaining marine biodiversity. This view is best exemplified by the notion, spread by Japanese officials, that 'whales eat our fish' (Tamura and Ohsumi 1999, 2000), and that, hence, large-scale culling (i.e., eradication) of whales and other marine mammals would make immense quantities of fish available for commercial fisheries. However, this zero-sum view is not only wrong as an approach to increasing fisheries yields (see e.g., Kaschner and Pauly 2005; Gerber *et al.* 2009; Morissette *et al.* 2012), but reflects a deeper problem: an erroneous framing of the issues at hand.

We can look at this framing issue by comparing the situation in the ocean to the situation on land. For example, in countries such as Brazil, which is known for both its productivity and biodiversity, we may find either a productive soya field *or* a diverse tropical forest – we can't have both. On the contrary, in the aquatic realm, if the mostly depleted stocks were allowed to rebuild, they would produce more in terms of fisheries yield *and* contribute to increased biodiversity in the marine ecosystems in question (see e.g., Tremblay-Boyer *et al.* 2011). That we have the potential, in the sea, for a win-win situation was stressed, e.g., in the keynote address of the 4th World Fisheries Congress held in 2004 (Pauly 2008). Unfortunately, this is counterintuitive to those with a mindset shaped by the conservation debates on land, and also to fisheries managers who still believe that increasing fishing effort in order to 'out-fish' the other guys is the way to go. But, the win-win situation is a fact that logically follows from the basic principles of both fisheries science and marine conservation science (Hilborn and Walters 1992; Odum and Barrett 2005): in situations where stocks have been (or are being) overfished, allowing stocks to rebuild will, after a transition period, lead to potentially higher marine productivity and, and if managed well, sustainable catches. Additionally, the rebuilt biomass will also accommodate a wider array of top predators, among them many species that are now considered threatened (Worm and Myers 2003; Sibert *et al.* 2006; Ainley and Blight 2008), which at the same time contribute to maintaining the productivity of the ocean (e.g., Nicol *et al.* 2010; Pershing *et al.* 2010).

In this report, we will document the potential for catch increases in 25 key fishing countries. The level of management in these countries varies, with some currently lacking strong fisheries management systems, and the control and surveillance that is required for enforcement of quotas and regulations (Pitcher *et al.* 2006; Mora *et al.* 2009). We will estimate this potential using a variety of methods, including an assessment-type approach that relies on a time series of landings to estimate a reference point, *Maximum Sustainable Yield* (*MSY*), and biomass time series.

[1] This Introduction and some parts of the Material and Methods sections are modified from Part I of the report, i.e., Pauly *et al.* (2012b).

Also, as indicated in Part I of this report (Pauly *et al.* 2012b), here we use ecosystem-modeling techniques to quantify the potential sustainable catch increases while explicitly taking into account the ecosystem context in which fisheries are embedded. Well-documented and previously published and available *Ecopath with Ecosim* models (Pauly *et al.* 2000; Christensen and Walters 2004), representing the country examined here separately or jointly will be used for this purpose.

Finally, we also present indicators that describe the level of protection currently and potentially afforded to the marine species of each of the countries covered here.

Materials and Methods

Fisheries catch data

Currently, global reported landings data represent the basic data available for assessing a fishery. Landings data from 1950 to 2006, as reported to the Food and Agriculture Organization of the United Nations (FAO) and other sources by country, are spatialized by the *Sea Around Us* Project (Watson *et al.* 2004). The process of spatialization relies on information on the mapped distributions of all commercially exploited species reported in fisheries statistics and information on fishing access agreements, which determine which countries are permitted to operate in other countries' EEZ waters.

Landings refer to fish caught and kept, and differ from 'catch' data, which include both the fish which are kept and those that are discarded, and may include landings that are unreported. Therefore, the basic input to the analysis presented here are catch data, recently criticized as inadequate to deal with issues of fisheries status and stock assessments (Branch *et al.* 2011; Daan *et al.* 2011), but which are indeed the key to any fisheries research (Froese *et al.* 2012; Kleisner *et al.* 2012).

There are three kinds of catch data:

a) Locally precise catch data, often collected by researchers, and used to answer questions pertaining to local fisheries (such data are not considered here);
b) Official national data, assembled and published by national governments, and also submitted to the FAO, where they are combined with the data from other countries to become the only available set of international 'FAO statistics'; and
c) 'Reconstructed' catch statistics, which include the *total* catch and discards from *all* fisheries, including those that are usually ignored in official statistics.

Presently (November, 2012), the *Sea Around Us* Project and its global collaborators, are engaged in completing catch reconstructions for all maritime countries and territories of the world, including those countries presented here. These catch reconstructions have highlighted that in many cases there is severe underreporting, or more rarely, over-reporting of catches (Watson and Pauly 2001). Unfortunately, at the present time, these reconstructions are not available for the majority of the countries presented here and therefore we urge caution when interpreting present results as catches may in reality be higher than those used in these analyses.

The rationale for reconstructions stems from a need to have a better quantification of what is removed from marine systems and thus get better estimates of fishing mortality (Pauly 1998; Zeller and Pauly 2007). Currently, the catch data that are available on a global basis are the 'FAO statistics' referred to in (b) above. However, there are typically three components of catch data: (i) nominal landings, (ii) discarded by-catch, and (iii) unreported catch, which is typically catch from small-scale fisheries and illegal catches (Pauly and Zeller 2003). Catches of type (i), i.e., nominal landings, are typically all that is reported to FAO, although there may be temporal and taxonomic gaps in these data. Additionally, landings from small-scale artisanal and subsistence fisheries are generally underreported to FAO by member countries, particularly among developing countries. The catch reconstruction approach (detailed in Zeller *et al.* 2007) attempts to complement the FAO landings data that have been spatialized by the *Sea Around Us* Project (Watson *et al.* 2004) with more inclusive catch statistics. These data can provide a more complete picture of the total fish biomass that is extracted from marine systems.

Biomass and MSY estimates

The majority of commercially exploited species have never been formally assessed and there are no traditional estimates of *Maximum Sustainable Yield* (*MSY*) for these species. Determining *MSY* typically requires, at minimum, time series information on historical removals (e.g., catch and discard), information on trends in abundance (e.g., catch per unit of effort or CPUE), and a model that describes the underlying production function (e.g., a surplus-production model; Schaefer 1954). Parameters for the model, the carrying capacity of the stock (k), and the maximum rate of population increase (r), are normally estimated by fitting the model to the relative abundance data. While landings data are available for most species (but with several problems as mentioned above), abundance estimates are more difficult to obtain. However, a recent method developed by Martell and Froese (2012) enables preliminary stock assessments to be performed without a time series of fishing effort being available. While the method is new, it rests on a sound foundation of population dynamics principles, explained in the following paragraphs.

The method of Martell and Froese (2012) requires a time series of annual catches, extracted from a population (B). This population has an initial abundance (B_0), which can be treated as a proxy for carrying capacity k. If B_0 was reduced by successive catches, this would logically result in a decline in abundance, (partly) offset by population growth. If the initial value of B_0 was small and/or its growth rate r was low[2], the population would have crashed early, and we would not have the time series of catches that we do have. Conversely, if the initial value of B_0 was very large and/or its growth rate was very high, the catches would not have been able to noticeably reduce the population, and, with time, the population would approach its carrying capacity[3]. Thus, the novelty of this method rests on the finding that, if one has a relatively long time series of annual catches and is willing to assume that the population has not collapsed or exceeded carrying capacity, it is possible to identify a relatively narrow range of carrying capacity k (and consequently initial population size, B_0) and population growth rate r compatible with the available catch time series. From these 'viable' r-k pairs, *MSY* can then be calculated for each species of interest and an associated biomass time series developed based on an assumed level of depletion.

For each country presented here, we compute the *MSY* and we use the geometric mean r and k values from the distribution of viable r-k pairs to compute biomass time series for all of the taxa available in the catch data at the species or genus level for which there are 20 or more years of catch data at depletion levels of 10, 15, 20, 25, 30, 35, 40, 45, and 50%. We use the biomass trajectories at each depletion level that do not crash and determine whether each of these biomass trajectories are decreasing or are stable or increasing. We assume that biomass trajectories that are stable or increasing are indicative of years when the biomass was in equilibrium. Years of stable or increasing biomass were selected by calculating the derivative of the biomass trajectory and selecting the years from the end of this time series that had a derivative > -0.1*mean. The consecutive years from the end of the time series that met this condition were selected as the years over which the average catch was calculated. Therefore, the number of years of catch that were averaged differed for each country and species. When the biomass trajectories for a given country-species combination was decreasing, we used the average catch over the most recent seven years. We present the ratio of this average to the *MSY* for the top 12 species that represent the bulk of the reported landings data. Tables are presented for each country (or region within a country, e.g., Pacific Canada), which provide the catch, *MSY*, and catch:*MSY* ratios for the top 12 taxa, the averages for the top 12 taxa and all taxa evaluated (straight average and average weighted by the total catch), with an indication of the number of taxa evaluated for each region. These averages are used to obtain an idea of the potential for increased yields for the fisheries given optimal management and conservation. While we present both weighted and un-weighted averages for the catch-MSY ratios, we discuss only the weighted average results as we consider

[2] The growth rate, i.e., the rate of instantaneous population growth, is defined as the rate at which a population increases in size if there are no density-dependent forces regulating the population.

[3] In Part I of this report, the word 'exceed' was erroneously used instead of the correct 'approach'.

them more robust. This approach was inspired by the fisheries Food Provision model recently designed for the 'Ocean Health Index' (Halpern *et al.* 2012), which compares estimates of *multispecies MSY* (*mMSY*) derived for all fished stocks in a country or region to the current level of total landings in 2006 (the latest year for which the *Sea Around Us* Project has spatialized the FAO reported landings).

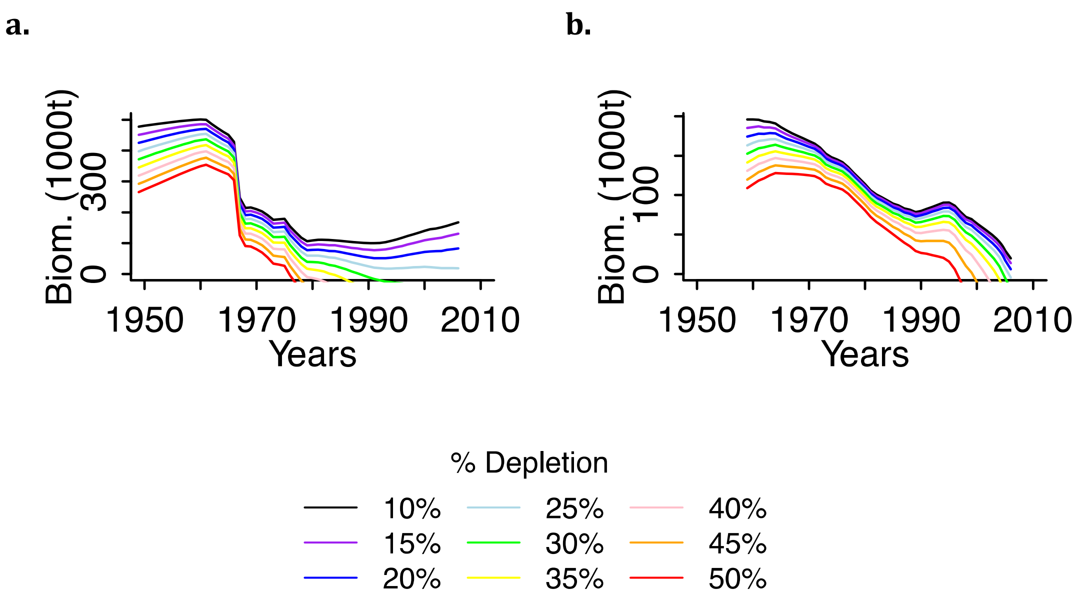


Figure 1. An example of the biomass trajectories for two different species: (a) one with stable/increasing biomass from the late 1960s and (b) one with decreasing biomass from the early 1990s. For (b), and for all taxa with decreasing biomass in the later years, 2000-2006 is the time period over which the catch is averaged for the catch:MSY ratios, whereas for (a), the entire period of stability/increase is used. In both instances, the years of stability/increase or decline are estimated from the end of the time series, and depletion trajectories that collapse, in this case depletion levels from 30-50% are not used to determine the averaging period.

Ecopath with Ecosim models

Since target and non-target species in marine ecosystems interact by establishing complex, but mainly trophic relationships, fishing and human activities have direct and indirect impacts whose analysis is notoriously challenging. Marine ecosystems are also influenced by environmental fluctuations and variability (Cury *et al.* 2008; Link *et al.* 2010). Thus, the ability to understand how human activities, environmental factors and ecological components interact, and eventually how the services and products provided to humans are affected, including the potential sustainable catch that can be extracted from marine ecosystems, is an issue that is of growing importance. The need to consider natural changes and human activities when analyzing and managing marine resources requires the adaptation of an integrated view of these systems, which should make it possible to consider not only the dynamics of target species, but also non-target organisms, trophic relationships and flows, and environmental factors. New methodological tools have been developed to take these complexities into account, in particular ecological modeling tools (Walters *et al.* 1997; Christensen and Walters 2004; Plagányi 2007; Fulton 2010).

Currently, the *Ecopath with Ecosim* approach (EwE; Polovina 1984; Pauly *et al.* 2000; Christensen and Walters 2004; www.ecopath.org) is applied worldwide for building ecological models of aquatic ecosystems. Some scientists have questioned the potential of EwE models

(Longhurst 2006). However, despite this, they are widely used (e.g., Palomares *et al.* 2009). In addition, the Institute for European Environmental Policy concluded that, among the available models of marine ecosystems, EwE is the most suitable for the development of scenarios for exploring future trends of marine biodiversity and changes in ecosystem services (Sukhdev 2008).

The software package EwE (Christensen *et al.* 2005) can be used to build food-web models by describing the ecosystem by means of functional groups, each representing a species, a sub-group of a species (e.g., juveniles) or a group of species that have functional and ecological similarities (Christian and Luczkovich 1999). The functional groups can be set to represent consumers, primary producers as well as non-living groups (e.g., detritus).

In this study, we used the *Ecopath* model routine of EwE, which is the mass-balance routine that allows the creation of 'snapshot' models of food webs (Christensen and Pauly 1992; Christensen and Pauly 1993), and the *Ecosim* time dynamic modeling routine (Walters *et al.* 1997; Walters *et al.* 2000). When available, we used previously well-documented and published EwE models that had been fitted to time series of data to quantify the potential sustainable catch by country or regional country groupings. The fitted models were chosen because they had been shown to be able to hind-cast historical ecosystem trajectories reasonably well. We estimated potential sustainable catch while simulating fishing at sustainable levels, taking into account the ecosystem context where fisheries operate (such as the productivity regime and ecosystem structure). In fact, the models available for Denmark, Indonesia, Peru, South Africa, Spain and the U.K. explicitly incorporated environmental time series. We then compared these sustainable catch estimates to historical catch trajectories.

For several countries, one model partially or fully covering the EEZ was available, while for others we had several models available, so we chose the most suitable one. References to the original model chosen for our analysis are indicated in the results section, by country. No modeling results are presented for countries that do not have published models which partially or fully overlap with their EEZ.

Modeling simulations were developed using the following three modeling approaches:

(1) First, the historical exploitation trajectory was analyzed using each fitted EwE model with historical time series and default configuration of parameters (Walters *et al.* 2005). These runs provided the baseline results to which the other two simulations were compared. We refer to this simulation as the '*baseline*' simulation;

(2) Then, the 'MSY Equilibrium' routine in EwE was run to find single-species *Fmsy* (Walters *et al.* 2005). We used the 'full compensation assessment', which enables a full ecosystem-scale dynamic response effect in all species including ecosystem interactions. Thus, while calculating the *Fmsy* values, we also took ecosystem dynamics into account. After we estimated single-species *Fmsy*, we ran a long-term simulation with the *F* value for each exploited species set to the *Fmsy* values. Results at the end of this simulation represent predicted equilibrium values under the all-species *Fmsy* policy (which should not be confused with a maximization of multispecies MSY, Walters *et al.* 2005). We refer to this simulation as the '*allFmsy*' simulation;

(3) As a final step, the 'Fisheries Policy Search' routine in EwE was used to formally optimize the search in each model to find the fishing policy that would maximize a particular objective function for management (Christensen and Walters 2004). In our case, we optimized our search to achieve maximum total catch, but under two major sustainability constraints: (i) the maintenance of biodiversity, and (ii) the avoidance of species being depleted. Therefore, while searching for the fishing fleet configuration that would maximize total catch, we constrained our search to *F* values that would avoid the loss of biodiversity and the depletion of individual groups. This enabled us to prevent, for example, scenarios where the optimization resulted in the depletion of large predatory organisms in return for increased catches of smaller and more productive organisms.

To constrain the search while maintaining biodiversity, we used the 'biomass biodiversity' option in the 'Fisheries Policy Search' routine, and to avoid depletion of species, we used the 'mandated rebuilding' option (Christensen and Walters 2004). For the mandated rebuilding option, we additionally set up a threshold of 25% of baseline biomass (thus: 75% depletion) as our maximum limit reference point under which we did not allow any of the species or groups in the models to fall. This level of depletion was chosen to as compromise between the 'rare species' definition, which was set to be at 10% of baseline biomass, and the 'depleted species', which was set at 50% of baseline biomass in previous studies (Pandolfi *et al.* 2003; Lotze *et al.* 2006). Furthermore, to avoid the optimization search from obtaining the highest catch from intensely exploiting species that are typically lightly exploited due to the fact that they are of low value (such as benthopelagic fish or benthic invertebrates with marginal value), we constrained the *F* values to be a maximum of twice the *Fmsy* values obtained under strategy (2), under the *allFmsy* simulations. In our results, we refer to this simulation as the '*optimization*' simulation.

We analyzed the results from the 3 modeling simulations comparing the catch resulting from the historical exploitation regime with that from the *allFmsy* and *optimization* simulations. We also compared the relative average mean fishing mortality of all exploited species in the ecosystem as the sum of all the catch over the sum of all the biomass for the historical exploitation period where the ecosystem model had been fitted.

Marine Protected Areas

To better understand the level of marine protection within the EEZs of the 25 countries analyzed, information regarding the Marine Protected Areas (MPAs) established by each of these countries was analyzed.

The *Sea Around Us* Project maintains a global database of MPAs (see individual country pages at www.seaaroundus.org) from which data for this report were gathered. This database includes information describing MPA size, location, year of establishment, as well as governance and management. To ensure that this information is current and accurate for each country, this database is continually updated using data compiled from peer-reviewed and grey literature, including government documents and websites. For certain countries assessed here, the information is not current to 2012, but represents the data as collated and analyzed by Wood *et al.* (2008), or a partially updated version. The two exceptions are China and Japan. For China, aggregated MPA data were taken from Qiu *et al.* (2009). The number of MPAs in Japan was drawn from Yagi *et al.* (2010), who generated a comprehensive dataset of Japanese MPAs, including difficult-to-obtain information on local, self-imposed MPA agreements among members of fishery cooperative associations. Yagi *et al.* (2010) report that an estimate of coverage was not possible given the lack of information available on the area of individual sites and their overlap.

In most countries, MPAs are predominately located adjacent to the coast. Therefore, it was necessary to include MPAs designated within the territorial waters extending up to 12 nm from the shoreline, in addition to MPAs situated offshore within the EEZ waters, which are generally defined as extending from the outer limit of territorial waters of a country out to a maximum distance of 200 nm from shore. For simplicity, we treat territorial waters as part of a country's EEZ in the present context.

Recently, countries have begun establishing MPAs in the waters surrounding islands separated from the mainland, thus meeting protection targets while avoiding potential conflicts with local stakeholders. While this is indeed a positive conservation action, we excluded these MPAs from this analysis because they do not offer protection to the marine resources within the main EEZs. However, we make reference, in some cases, to MPAs created within the EEZs of offshore territories to provide context for the current and potential future state of MPA development in each country. This serves, in some cases, to illustrate the difference between MPA coverage in the main EEZ versus the EEZs of island territories.

For each country, the total area encompassed by all MPAs was computed. However, not every 'MPA' is entirely 'marine', as the boundaries of some MPAs may encompass both land and sea. To determine the proportion of the EEZ that is protected, it was necessary to estimate the marine portion of each MPA. When available documentation for an MPA only indicates total area, we estimate the marine area using the median fraction of marine area relative to total area for those MPAs for which this quantity was known in that country. Sites designated under the UNESCO (United Nations Educational, Scientific and Cultural Organization) World Heritage Convention and Ramsar Convention were excluded from this report because of the high level of overlap of such sites with nationally designated protected areas (Wood *et al.* 2008). Additionally, MPAs for which there was no information on areal extent were excluded.

MPAs are established for a variety of reasons and provide differing levels of protection for the species and habitats that occur within their boundaries. Not all MPAs are created for the purpose of improving the sustainability of fisheries (Cullis-Suzuki and Pauly 2008, 2010); in fact, relatively few restrict or prohibit fishing activities. In addition to estimating the total area and marine area covered by MPAs in each country's EEZ, this study lists the area in which fishing is prohibited within MPA boundaries, i.e., the 'no-take' area. An assessment of coverage alone cannot provide a complete picture of protection; one needs to also consider effectiveness (Spalding *et al.* 2008). It is well acknowledged that many MPAs represent 'paper parks' – existing only on paper, but without any in-the-water implementation (Jameson *et al.* 2002; Alcala *et al.* 2008). As it is likely that many of the MPAs currently designated in the present countries' EEZs (and the rest of the world) are no more than paper parks, we also provide a brief discussion of the current level of MPA effectiveness.

Results

Argentina[4]

The Argentinean continental shelf extends for 769,400 km^2 within the total EEZ of 1,164,500 km^2 (Figure 2) It is the largest shelf in South America (Bisbal 1995). Estimates of net primary productivity are high (over 500 mgC·m^{-2}·day^{-1}) around the mouth of the Rio de la Plata and the South-eastern Brazilian Bight, from Cape Frio to Cape Santa Marta Grande (Bisbal 1995). These biochemical conditions provide a favourable reproductive habitat for important fisheries in Argentina, which has some of the most productive marine ecosystems in the world (Bezzi *et al.* 2000).

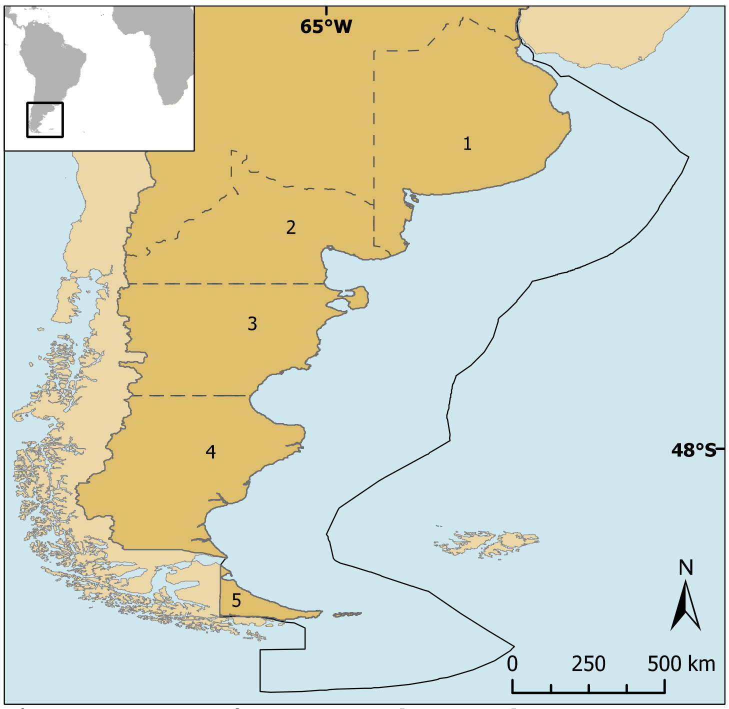


Figure 2. Map of Argentina showing the 200 nm EEZ adjacent to the mainland. The Argentine EEZ is part of the Patagonian Shelf LME. Numbers correspond to maritime states: Cuidad de Buenos Aires, Río Negro, Chubut, Santa Cruz, and Tierra del Fuego, 1-5 respectively.

The exploitation of fishing resources for commercial purposes is estimated to have begun in 1978 when Argentinean, Japanese and Polish fleets started fishing activities mainly of squid and other previously unexploited demersal resources. Fishbase (www.fishbase.org) reports 334 species of marine finfishes, 119 deep-water species, 16 species of cephalopods, 4 species of crustaceans and 50 marine mammals from the ecosystem, but only 37 of them are commercially important and support the multispecies, multi-sector fisheries. In particular, four commercially important fisheries have been identified in the country: the Argentine hake (*Merluccius hubbsi*), mainly exploited off the coast of Uruguay and near the basin of the Rio de la Plata, Argentine shortfin squid (*Illex argentinus*), Southern blue whiting (*Micromesistius australis*) and Patagonian squid (*Logilo gahi*). Total landings in the EEZ increased from 170,153 t in 1970 to 1,373,000 t in 2006, with a significant increase in the landings of distant water fishing fleets (mainly from South Korea, Taiwan, Japan and China but also from Germany, Italy, Portugal and Spain; Villasante *et al.* in prep).

Geopolitically, two fisheries areas can be identified: the EEZ and the Argentine-Uruguayan Common Fisheries Zone. The management of shared fish stocks is also a critical problem for the country, namely because of the distant-water fleet's activity in the area beyond the 200-mile limit of the EEZ and the Malvinas/Falkland Islands (Villasante *et al.* in prep). The legal basis for the Argentinean Fishery System is provided by the Federal Fishery Regime, established by Law N°

[4] This introduction was provided by Dr. S. Villasante (University of Santiago de Compostela, Galicia), who is the lead author of the catch reconstruction for Argentina that will be completed in 2013.

24922, enacted in late 1997, that is aimed to satisfy a maximum development of fishing activities at sea with a rational use of living resources.

Since 1999, the Federal Fisheries Council sets an annual Total Allowable Catch (*TAC*), which takes into account the *MSY* determined by scientists from the National Institute for Fisheries Research and Development (INIDEP; Villasante 2012). However, the increase of illegal, unreported and unregulated (IUU) catches, the lack of transparency of fisheries management, and the insufficient implementation of conservation strategies to protect fish stocks have had negative biological and socio-economic effects. For the region, Agnew *et al.* (2009) estimated that the economic loss from IUU fishing in 2003 was between $205-606 million.

As result, the underreporting of total removals in Argentina is extremely high. Indeed, reconstructed catches are, on average, 1.9 times higher than official statistics for the 1950-2010 period because of the still high level of discards and IUU catches (Villasante *et al.* in prep). At present, several marine resources of Argentina are fully exploited or overexploited, including the Argentinean hake, which supports one of the most important demersal fisheries in Latin America and is the most important species for the fisheries sector in the country (Österblom and Villasante in press). Other factors affecting key species such as the Argentinean hake are ineffective control and enforcement, the liberalization and opening of the fishing grounds to foreign fleets through joint ventures and the Argentina-European Union fisheries agreement (1993-1997), which resulted in the continued overexploitation of the fishery (Irusta *et al.* 2001). The recorded landings for this species exceeded the allocated TAC by 87% in 1999 and 93% in 2000. Consequently, the biomass of the Argentinean hake is at critical levels, resulting in high socio-economic losses for the national industry (Fundación Vida Silvestre 2008). There has also been an increase in discards of juveniles, which represented between 11% and 24% of total landings during the period 1990-1997 (Dato *et al.* 2006). In economic terms, this represents annual losses of $11-77 million (Villasante 2012).

Catch-MSY method for Argentine stocks

For Argentina, the single-species analyses suggest that the overall catch could be increased by 10 % when considering the top 12 landed species, or 6 % when considering all 44 taxa, given fishing at single species F_{MSY} (Table 1). However, the absence of an ecosystem model precludes evaluation of ecosystem effects, such as trophic interactions, on this evaluation.

Table 1. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Argentine catch. Catch:MSY ratios are presented for each of these species, along with overall straight and weighted averages by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Argentine hake	345,785	308,693	1.12
Argentine shortfin squid	146,928	168,151	0.87
Southern blue whiting	42105.73	75,147	0.56
Patagonian grenadier	106,116	70,349	1.51
Argentine anchoita	30,176	25,826	1.17
Argentine red shrimp	36,656	30,339	1.21
Patagonean scallop	52,442	40,318	1.30
Chub mackerel	5,830	19,734	0.30
Narrownose smooth-hound	8,542	6,529	1.31
Pink cusk-eel	15,776	14,634	1.08
Sea bass	4,534	8,203	0.55
South American striped weakfish	11,811	15,062	0.78
Average of top 12 taxa (weighted)			**0.98 (0.90)**
Average of 44 taxa (weighted)			**0.63 (0.94)**

Belize[5]

Belize is located on the east coast of Central America between 18˚and 15˚N and 88˚and 89˚W, with a land area of around 22,600 km^2 and an EEZ of 35,000 km^2 (Figure 3). Adjacent to Belize are Mexico to the north, Guatemala to the west and south and the Caribbean Sea to the east. The coastline is flanked by the second longest barrier reef in the world (Heyman and Kjerfve 2001), beyond which offshore areas drop off to between 300 and 600 fathoms depth. There are several reef areas located offshore, outside of the barrier reef.

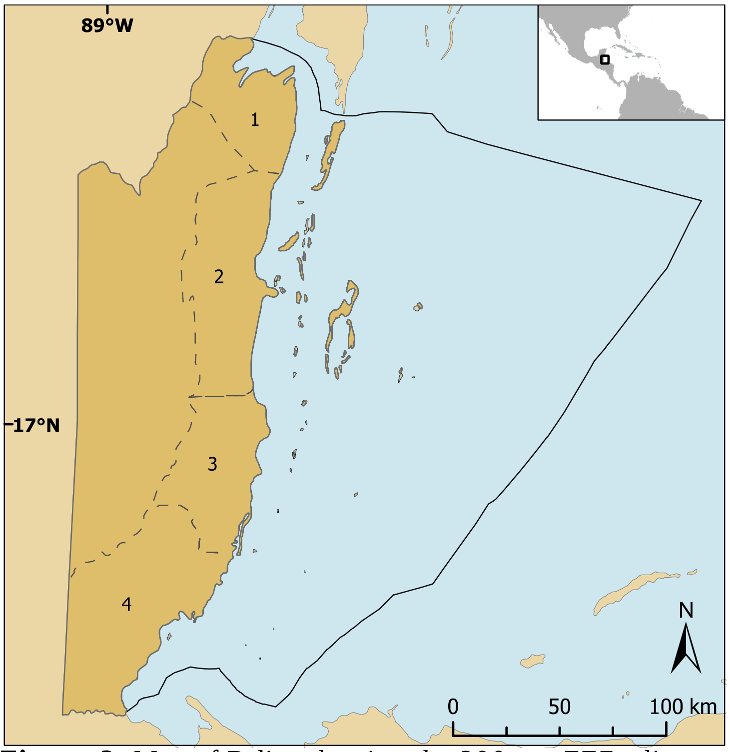


Figure 3. Map of Belize showing the 200 nm EEZ adjacent to the mainland and all maritime states. The Belizian EEZ is part of the Gulf of Mexico LME. Numbers correspond to maritime states: Corozal, Belize, Stann Creek, and Toledo, 1-4 respectively.

Belize was a British colony from 1862 until gaining partial independence in 1964 and full independence in 1981, and is now part of the British Commonwealth of Nations and a member of the United Nations (Shusterich 1984). The ethnic composition of the Belizean population consists mainly of Mestizo and Creole, representing approximately 75 % of the population, with the remaining 25 % consisting of Maya, Garifuna and other ethnicities. A recent census indicated that just under half of the population lives in urban centers, which is a decrease from earlier decades (Tietze *et al.* 2006). Belize has the lowest population density of the Central American countries and one of the lowest population densities in the world, with approximately 9 inhabitants·km^{-2}, whereas Guatemala has 95 inhabitants·km^{-2} and Honduras has 49 inhabitants·km^{-2} (Heyman and Kjerfve 2001).

The commercial fishing industry of Belize has traditionally focused on lobster (*Panulurus argus*) and conch (*Strombus gigas*), with the commercial lobster fishery starting in the 1920s (Harborne *et al.* 2000). The establishment of fishing cooperatives in the 1960s greatly improved the sale and marketing of these products for export. Prior to the establishment of the cooperatives, fishing was mainly conducted for subsistence purposes (Craig 1966; Shusterich 1984). The cooperatives, however, quickly gained favor and became the major channel for moving fisheries products, mostly to foreign markets. Finfish fisheries have predominantly supplied the local market, although in recent years, export of snapper (Lutjanidae) and grouper (Serranidae) have become more prevalent. A small shrimp trawl fishery also existed, starting in the mid-1960s, with only a few artisanal trawlers and minimal expansion in the subsequent decades (Shusterich 1984). All trawl fishing was banned in Belize in late 2010, bringing this fishery to an end. Sharks, although not consumed locally, are caught for export using mainly gillnets, and supply meat and fins to Guatemala, Honduras, Mexico and Asia (Graham 2007). It is likely that Belize will enact legislation banning the use of gillnets in the near future, thus substantially limiting shark catches.

[5] This introduction is adapted from the Belize catch reconstruction (Zeller *et al.* 2011b)

The establishment of fishing cooperatives in the 1960s brought about some significant changes to the fishing industry. Most importantly, it allowed fishers to establish a lucrative export market and command a high price for items such as lobster, conch and finfish (Price 1987). The cooperatives started in the north and expanded throughout the country. More recently, there are five main cooperatives (National, Northern, Placencia, San Pedro and Rio Grande), the National and Northern cooperatives being the largest both in numbers of fishers and catch. However, only 50 % of licensed fishers belong to one of the five main cooperatives and there are many unlicensed fishers operating in Southern Belize (Anon. 2008).

In recent decades, Belize has become a popular tourist destination with over 250,000 tourists visiting the country annually (Anon. 2010a). The development of the tourism industry was, in part, linked with overfishing, which caused fishers to seek alternate economic activities. Another reason for this shift is the struggle of fishers to make a living due to high fuel costs and lack of capital to maintain equipment and vessels (Anon. 2008). In the popular tourist areas some of the hotels are actually owned by lobster fishers who used their capital from fishing to start tourism businesses (Price 1987). Tourism began in the 1980s, and by the 1990s, the industry was well established. Tourists come to partake in a variety of marine related activities such as diving and sport fishing. During their stay in Belize, tourists commonly enjoy the local cuisine, with a particular taste for Caribbean lobster. This has put further pressure on the marine ecosystem in recent decades (Gillett 2003).

A survey conducted in the early 1940s by British scientist Ernest Thompson, estimated artisanal and subsistence catches to be approximately three million pounds (1360 t) and one million pounds (454 t), respectively (Thompson 1944). He further stated that marine fisheries exports were minimal at that time. Prior to improvements in transportation and processing infrastructure that allowed for the expansion of commercial production (i.e., lobster and conch fisheries expansion in 1960s), fishing was mainly for subsistence and domestic purposes (Craig 1966).

Due to a combination of low population density and high reef productivity, it is not surprising that neighboring countries enter Belizean waters to fish. Some of these fishers have special permits to fish in Belize (A. Matura-Shepherd, pers. comm.), while others fish illegally (Heyman 1996). Depleted fish resources in Honduras and Guatemala have driven fishers to illegally exploit the waters of Belize, which has historically had less pressure on its marine resources (Heyman and Kjerfve 2001). The demand for fish products in Guatemala and Honduras increases every year during the Lenten Season, during which Catholics abstain from eating meat (Heyman 1996). During this time, salted fish (e.g., shark, mackerel, jack and snook) are illegally transported from Belize to Guatemala and Honduras. Other forms of illegal catch from both foreign and local fishers are the harvest of undersized and out of season lobster and conch (Price 1987; Arce *et al.* 1997; Perez 2009).

Catch-MSY method for Belizean stocks

For Belize, the single-species analyses suggest that the overall catch could be increased by 5 % when considering the top 12 landed species given optimal management of all exploited species, but the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation (Table 2).

Table 2. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Belize catch. Catch:MSY ratios are presented for each of these species, along with overall straight and weighted averages by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Round sardinella	7,693	6,799	1.13
Caribbean spiny lobster	506	703	0.72
Blue crab	703	576	1.22
Common snook	635	666	0.95
King mackerel	824	578	1.42
Red grouper	693	304	2.28
Flathead mullet	759	689	1.10
Atlantic thread herring	437	386	1.13
Common octopus	606	499	1.22
American cupped oyster	235	204	1.15
Northern red snapper	279	186	1.50
Yellowfin tuna	14	123	0.11
Average of top 12 (weighted)			**1.16 (0.95)**
Average of 40 taxa (weighted)			**1.07 (1.01)**

Brazil[6]

The Brazilian EEZ spans the northeast and central eastern coast of South America from approximately 5° N, at the border with French Guyana, to about 33° S, at the border with Uruguay (Figure 4). There are 17 maritime states in Brazil. In northern Brazil, the states are Amapá and Pará (Figure 4, 1-2). There are nine states in northeast Brazil: Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, and Bahia (Figure 4, 3-11). In southeast Brazil, the maritime states include Espirito Santo, Rio de Janeiro, and São Paulo (Figure 4, 12-14). Finally, in the south, we find the states of Paraná, Santa Catarina, and Rio Grande do Sul (Figure 4, 15-17). The Brazilian EEZ encompasses three LMEs, the North Brazil Shelf (in part), the East Brazil Shelf, and the South Brazil Shelf. Also, the EEZ of Brazil includes a few oceanic islands, Trinidade and Martin Vaz Islands, which are located 1,200 km off the coast, but we refer only to the mainland component Brazilian fisheries for the analyses presented here.

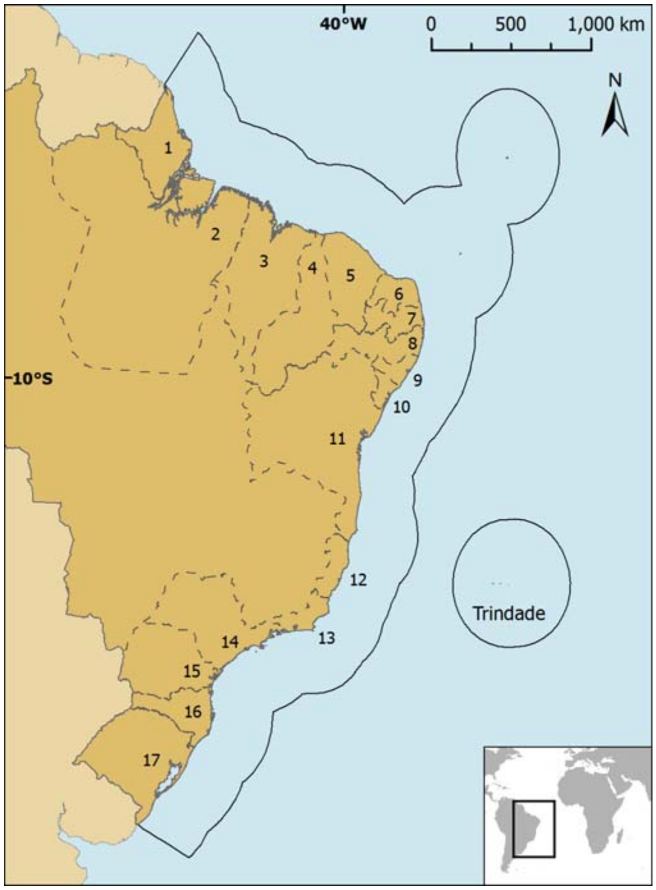


Figure 4. Map of Brazil, the EEZ adjacent to the mainland, maritime states, and the EEZ of Trinidade and Martin Vaz Islands. The Brazilian EEZ is part of three LMEs: the North Brazil Shelf, the East Brazil Shelf, and the South Brazil Shelf. Numbers correspond to maritime states: Amapá, Pará, Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia, Espirito Santo, Rio de Janeiro, São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul, 1-17 respectively.

Within the Brazilian EEZ, there is a wide range of ecosystem types resulting in differences between the fisheries exploiting the diverse array of marine resources. In the southern states of Brazil, these fisheries tend to concentrate on fewer temperate species, notably the much diminished, but once very abundant Brazilian sardine (*Sardinella brasiliensis*)[7]. Conversely, in the tropical northern states of Brazil, the fisheries exploit a diverse array of tropical species, most of which have not been assessed as to their status (Freire *et al.* 2007).

One of the key issues plaguing Brazilian fisheries is the fact that there are many national and state fisheries agencies, which may collaborate in varying degrees, but have not settled on a standardized list of common names for the fish whose catches they report. This results in national catch statistics that are even more unreliable than catch statistics in biodiverse tropical/subtropical countries usually are (Freire and Pauly 2003, 2005).

[6] This introduction is adapted from Pauly *et al.* (2012b).

[7] The scientific name of this species has changed a few times in the last decades. We stick here to the original name, which seems to be the 'right' one anyway.

To address this issue of taxonomic inaccuracy and the other problems associated with reported landings data mentioned above (e.g., missing data, erroneous reporting, estimation of discarding, etc.), a reconstruction of Brazilian catches is underway. Currently, however, the best available data remain the FAO reported landings that have been spatialized by the *Sea Around Us* Project. Therefore, the analyses and indicators presented here must be viewed with caution and be used only tentatively to estimate the status of Brazilian fisheries.

Moreover, while there are numerous publications on Brazilian marine biodiversity, there is, in Brazil a scarcity of fish stock assessment. The only exception to this may be the Brazilian sardine (*Sardinella brasiliensis*), which has received a lot of attention because of the strong fluctuations of its biomass and catches (Cergole *et al.* 2002), and also because this stock occurs in the south of the country, off the coast of São Paulo state, where living standards are higher than along the more northern shores of Brazil, with consequent effects for fisheries research.

Because of this socio-economic gradient, the fisheries of north and northeastern Brazil are understudied, which is aggravated by the large number of exploited species, as occur in other tropical regions of the world. In recent years, however, this situation is slowly being resolved through an improvement of catch statistics (Freire 2003), including the nomenclatural problems associated with these statistics (Freire and Pauly 2003, 2005). This has enabled detecting the occurrence of the 'fishing down' phenomenon in northeastern Brazil (Freire and Pauly 2010), and constructing ecosystem models (Freire *et al.* 2008), on whose basis it became possible to identify elements of what could become an ecosystem-based management plan for the fisheries of northeastern Brazil (Freire *et al.* 2007).

Catch-MSY method for Brazilian stocks

For Brazil, the single-species analyses suggest that the overall catch could be increased by 60 % when considering the top 12 landed species, or 49 % when considering all 41 taxa, given fishing at single species F_{MSY} (Table 3). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 3. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Brazil catch. Catch:MSY ratios are presented for each of these species, along with overall straight and weighted averages by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Brazilian sardinella	41,436	192,539	0.22
Whitemouth croaker	39,376	42,384	0.93
Argentine hake	3,315	11,776	0.28
Atlantic seabob	13,017	12,189	1.07
Chola guitarfish	1,029	9,875	0.10
Chub mackerel	4,448	13,688	0.32
Argentine croaker	11,409	11,594	0.98
Brazilian menhaden	13,929	15,594	0.89
Caribbean spiny lobster	6,745	7,321	0.92
Southern red snapper	6,671	5,225	1.28
Bluefish	1,563	3,968	0.39
Dana's swimming crab	1,737	3,018	0.58
Average of top 12 (weighted)			**0.66 (0.40)**
Average of 41 taxa (weighted)			**0.80 (0.51)**

Canada[8]

Constituting 41 % of the North American continental area, Canada spans a diverse territory from the north Pacific and Alaska to the west to the North Atlantic in the east and from the Arctic Ocean in the north to the northern border of the U.S. The country extends from 141°W in the west to 52°37′ W in the east, and from 41°41′ N in the south to the North Pole in the north, and covers a total of 9,984,670 km², including a marine EEZ of 2,755,564 km² and a continental shelf area of 2,363,381 km², and covering six LMES (Figure 5). Commercial fisheries occur in the Pacific and Atlantic, while fishing activities in the Arctic are limited to subsistence fishing.

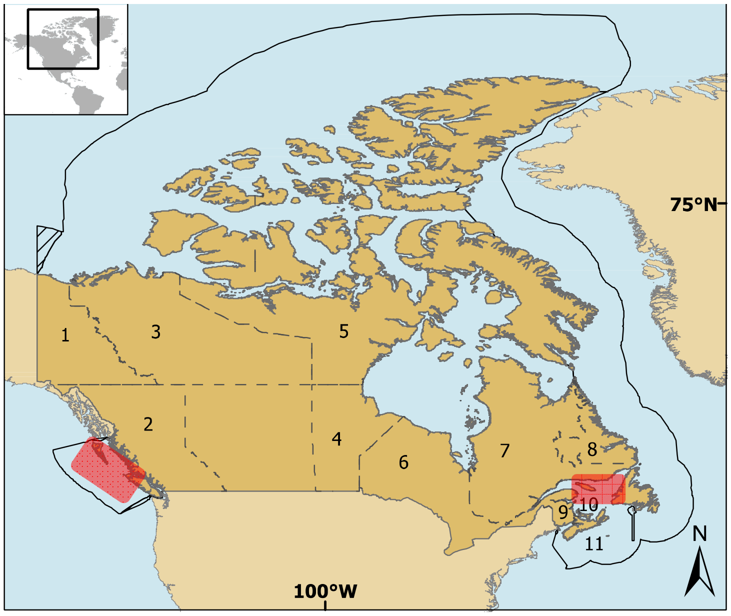


Figure 5. Map of Canada showing the 200 nm EEZ and all maritime states. The Canadian EEZ is part of six LMEs: clockwise from the west, the west coast of Canada falls within the Gulf of Alaska LME; Arctic Canada is within the Beaufort Sea LME, the Arctic Ocean LME, and the Hudson Bay LME; and eastern Canada falls within the Newfoundland-Labrador Shelf LME and the Scotian Shelf LME. Numbers correspond to maritime states: Yukon, British Columbia, Northwest Territories, Manitoba, Nunavut, Ontario, Quebec, Newfoundland and Labrador, New Brunswick, Prince Edward Island, and Nova Scotia, 1-11 respectively. The areas covered by ecological models are highlighted in red.

The Pacific coast of Canada is part of the Gulf of Alaska system. With significant upwelling associated with the Alaska Current generating zones with cold, nutrient-rich waters, the region supports a number of commercially important fisheries for crab (*Cancer magister*), shrimp (*Pandalus borealis, P. jordani, P. danae, P. hypsinotus, P. goniurus, P. platyceros*, and *Pandalalopsis dispar*), scallops (*Chlamys hastata, C. rubida*), walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), rockfishes (*Sebastes* spp.), sockeye salmon (*Oncorhynchus nerka*), pink salmon (*Oncorhynchus gorbuscha*) and halibut (*Hippoglossus stenolepis*). In addition, the Pacific herring (*Clupea pallasii*) fishery is an important pelagic fishery in the Pacific, including the herring roe fishery targeting export markets in Asia.

Some stocks, such as Pacific halibut and petrale sole (*Eopsetta jordani*) have been showing signs of increased abundance, and rockfish stocks depleted during the 1980s and 1990s are now managed under recovery plans. However, offshore Pacific hake (*Merluccius productus*), Pacific cod (*Gadus macrocephalus*) and sablefish (*Anoplopoma fimbria*) stocks are in decline. Pacific herring stocks are down all along the coast. Shellfish stocks are generally in good condition except for abalone. Pacific salmon returns in recent years have been quite depressed, with historically low returns in 2009. Many possible causes have been suggested, including reduced survival and deteriorating conditions of the freshwater environment due to climate change.

On the Atlantic coast, The Newfoundland–Labrador shelf extends from Labrador to the Grand Banks in the south. The ocean environment is influenced by several factors, including the Labrador Current, cross-shelf exchange with warmer continental slope water and bottom

[8] This introduction was provided by Dr. L. Morissette (St. Lawrence Global Observatory, Rimouski), who is the lead author of one of the catch reconstructions for Canada that will be completed in 2013.

topography and large seasonal and inter-annual variations, particularly in ice cover. The Gulf of St. Lawrence forms one of the most important estuarine shelves in the world. It is a stratified semi-enclosed sea connected to the North Atlantic Ocean through the Cabot Strait to the southeast and the Strait of Belle-Isle to the northeast. The bathymetry of the Gulf is dominated by the Laurentian Channel, which divides the Gulf into two very distinct systems: the deep northern Gulf, characterized by a number of deep channels with depths greater than 200 m, and the southern Gulf represented by a shallow shelf, the Magdalen Shallows, with depths mostly less than 100 m. The eastern Scotian Shelf is a broad continental shelf made up of a number of shallow offshore banks and deeper inner basins. It extends from the Laurentian Channel in the northeast to a line from Halifax south to the shelf break in the southwest. The physical environment of the eastern Scotian Shelf is governed by two primary factors: its location, near the meeting place of major currents of the Northwest Atlantic, the Labrador Current and the shelf current which brings cool fresh water from the Gulf of St. Lawrence; and its complex topography.

The eastern Canadian waters, and principally the Newfoundland-Labrador Shelf, were home to the one of the most important fisheries in the world, the Atlantic cod (*Gadus morhua*) fishery. The Grand Banks, the continental shelf east of Newfoundland, has been fished since the 1400s by fleets from many fishing nations of Europe, and by the 1600s from North America. The Atlantic cod fishery was the basis of economic activities in Newfoundland before the stock underwent a well-documented collapse in the late 1980s to early 1990s, ending with the moratorium on commercial fishing in 1992, imposed on a number of stock management areas by the Canadian government in order to promote recovery of the depleted populations. The Scotian Shelf ecosystem supported rich and diverse bottom fish communities including cod, haddock (*Melanogrammus aeglefinus*), pollock (*Pollachius virens*), silver hake (*Merluccius bilinearis*), halibut (*Hippoglossus hippoglossus*), white hake (*Urophycis tenuis*) and turbot (*Scophthalmus maximus*). The system, however, experienced a major shift in environmental conditions, particular a major cooling of the bottom waters in the mid-1980s. The system has since undergone major structural changes in the fish community, with a decline in groundfish populations, while small pelagic species and invertebrate species have increased. The Gulf of St. Lawrence also has a history of high disturbances due to heavy exploitation by the commercial fishing industry, the most recent being a steep decline in Atlantic cod abundance in the late 1980s and early 1990s.

During the period that the moratorium was in place, a modest improvement in mature cod abundance was observed in Canadian Atlantic waters. Since the re-opening of directed cod fisheries in the two ecosystems, mature cod biomass has remained roughly constant. Since the collapse of the Atlantic cod fishery, the composition of the marine fisheries landings in Canada are composed of shrimp (*Pandalus* spp.) and crabs (30 %), small pelagic species (27 %), bottomfishes (25 %) and shellfishes and other invertebrates (13 %). Salmon, though small in terms of the share of the total catch, constitutes an important fishery in the Pacific. The Atlantic fisheries account for over 80 % of the total catch, with the Pacific accounting for the remaining 20 %. Fisheries in the Arctic are conducted strictly on a subsistence basis and no catches are reported (Booth and Watts 2007; Zeller *et al.* 2011a).

Scientific and management advice is mainly implemented by the Department of Fisheries and Oceans of Canada (DFO), but also by provincial entities such as the Ministry of Agriculture (Provincial aquaculture and commercial fisheries program) in the Pacific area, the Departments of Fisheries and Aquaculture in Newfoundland, Nova Scotia, the Department of Agriculture, Aquaculture and Fisheries of New Brunswick, and the *Ministère Agriculture Pêcheries et Alimentation* of Québec. In addition, Canada collaborates in several international organizations, such as the United Nations Food and Agriculture Organization (FAO), the North Atlantic Fisheries Organization (NAFO), the Inter-American Tropical Tuna Commission (IATTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), the North Atlantic Salmon Conservation Organization (NASCO), the North Pacific Salmon Conservation Organization (NPAFC), and the Western and Central Pacific Fisheries Commission (WCPFC).

Catch-MSY method for Canadian (Arctic) stocks

For the Canadian Arctic, the single-species analyses suggest that the overall catch could be increased by 54 % when considering the top 10 landed species, given fishing at single species F_{MSY} (Table 4). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 4. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Canadian Arctic catch. Catch:MSY ratios are presented for each of these species, along with overall straight and weighted averages by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Charr	842.98	1,667.17	0.51
Atlantic salmon	34.00	160.82	0.21
Fourhorn sculpin	2.45	8.80	0.28
Greenland halibut	3.55	11.06	0.32
Dolly varden	0.83	2.95	0.28
Northern prawn	10.02	8.24	1.22
Arctic cisco	0.07	0.21	0.33
Saffron cod	0.03	0.16	0.19
Polar cod	0.12	0.10	1.16
Sardine cisco	0.01	0.01	0.92
Average of top 12 (weighted)			**--**
Average of 10 taxa (weighted)			**0.54 (0.46)**

Catch-MSY method for Canadian (Atlantic) stocks

For the Canadian Atlantic, the single-species analyses suggest that the overall catch could be increased by 57 % when considering the top 12 landed species, or 51 % when considering all 70 taxa, given fishing at single species F_{MSY} (Table 5).

Table 5. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Canadian Atlantic catch. Catch:MSY ratios are presented for each of these species, along with overall straight and weighted averages by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Atlantic cod	258,785	725,419	0.36
Atlantic herring	199,855	246,070	0.81
Silver hake	18,251	76,689	0.24
American sea scallop	77,806	80,299	0.97
Capelin	21,978	76,310	0.29
Haddock	16,048	94,206	0.17
American lobster	50,749	46,056	1.10
American plaice	4,454	30,917	0.14
Northern prawn	121,027	94,235	1.28
Queen crab	92,934	76,749	1.21
Saithe	9,560	30,705	0.31
Atlantic mackerel	50,309	42,340	1.19
Average of top 12 (weighted)			**0.67 (0.43)**
Average of 70 taxa (weighted)			**0.81 (0.49)**

Model results for Canadian (Atlantic) ecosystems

We used the Gulf of Saint Lawrence model (Morissette *et al.* 2006) as a representation of Canadian Atlantic ecosystems. The original model covers 103,812 km^2 of the Canadian EEZ. The study area was the northern Gulf of St. Lawrence (Northwest Atlantic Fisheries Organization divisions 4RS) between 50˚and 46˚N and 68˚W and 56˚ W (Figure 5). The model had been fitted to historic time series of data from 1985 to 2009.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy*, both in terms of most targeted species and in terms of all catch (Table 6, Figure 6a). Under the *optimization* simulations, the overall catch is also slightly higher. The average fishing mortality from 1985 to 2009 is higher in the *allFmsy* simulations with respect to the historical trajectory and similar between the historical exploitation period and the *optimization* simulation (Figure 6b).

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 41-54 % given fishing at single species F_{MSY}. However, the catch could only be increased by 3 % when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass.

Table 6. Catch rate from the historical exploitation period from the Canadian Atlantic ecosystem (1: *baseline*) and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species/groups	Catch (t·km^{-2}·year^{-1})			Catch:MSY	
	1. Baseline	2. AllFmsy	3. Optimization	1/2	1/3
Large cod	0.0200	0.8700	0.680	0.020	0.030
Small cod	0.0040	0.0050	0.001	0.80	3.410
Large Greenland halibut	0.0001	0.0300	0.030	0.002	0.002
American plaice	0.0900	0.0500	0.020	1.800	3.660
Flounders	0.0400	0.0400	0.010	1.200	4.190
Redfish	1.0100	0.4400	0.330	2.300	3.010
Large demersals	0.0600	0.0002	0.020	>100.000	3.500
Capelin	0.0600	0.1600	0.030	0.400	2.170
Large pelagics	0.0050	0.0010	0.002	3.700	2.810
Planktiv. small pelagics	0.2700	0.2300	0.240	1.200	1.120
Shrimp	0.1200	0.3400	0.090	0.300	1.370
Large crustaceans	0.0800	0.1000	0.050	0.800	1.690
Molluscs	0.0800	0.1700	0.040	0.500	2.080
Total catch (sp table)	**1.8300**	**2.4300**	**1.550**	**0.750**	**1.180**
Total catch*	**1.5200**	**2.5700**	**1.570**	**0.590**	**0.970**

* Number of commercial taxa/groups in the model = 19

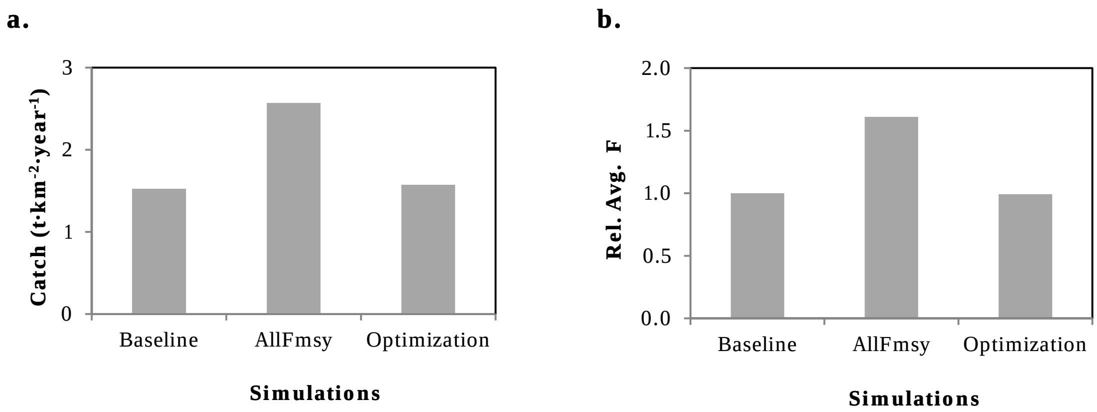


Figure 6. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) average relative fishing mortality (sum of catch/sum of biomass of exploited species for the historical period years for the Canadian Atlantic ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Catch-MSY method for Canadian (Pacific) stocks

For the Canadian Pacific, the single-species analyses suggest that the overall catch could be increased by 62 % when considering the top 12 landed species, or 56% when considering all 36 taxa, given fishing at single species F_{MSY} (Table 7).

Table 7. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Canadian Pacific catch. Catch:MSY ratios are presented for each of these species, along with overall straight and weighted averages by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Alaska Pollack	27,621	104,229	0.26
Pacific herring	16,784	50,077	0.34
North Pacific hake	65,354	56,451	1.16
Pacific cod	8,322	18,068	0.46
Pink salmon	9,037	21,334	0.42
Pacific ocean perch	5,686	9,016	0.63
Yellowfin sole	2,750	18,286	0.15
Chum salmon	3,757	13,781	0.27
Sablefish	4,350	6,403	0.68
Sockeye salmon	1,667	13,934	0.12
Arrowtooth flounder	5,643	5,533	1.02
Coho salmon	235	7,038	0.03
Average of top 12 (weighted)			**0.46 (0.38)**
Average of 36 taxa (weighted)			**0.53 (0.44)**

Model results for Canadian (Pacific) ecosystems

We used the British Columbia Shelf model (Preikshot 2007) as a representation of Canadian Pacific ecosystems. It covers 150,000 km^2 and is located between 54˚and 48˚N and 134˚W and 122˚ W (Figure 5). The model had been fitted to historic time series of data from 1950 to 2002.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under both *allFmsy* and *optimization* simulations, both in terms of most targeted species and in terms of all catch (Table 8, Figure 7a). The average fishing mortality from 1950 to 2002 is similar in the *optimization* simulations with respect to the historical trajectory and larger for the *allFmsy* simulation (Figure 7b).

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 49-56 % given fishing at single species F_{MSY}. However, the catch could only be increased by 11 % when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass.

Table 8. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period from the Canadian Pacific ecosystem (1: *baseline*) and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species/groups	Catch (t·km^{-2}·year^{-1}) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Pacific cod juveniles	0.001	0.004	0.001	0.3	1.6
Pacific cod adults	0.010	0.080	0.030	0.1	0.4
Sablefish juveniles	0.003	0.001	0.010	1.9	0.5
Sablefish adults	0.020	0.005	0.020	5.4	1.6
Pollock juveniles	0.001	0.010	0.002	0.2	0.9
Pollock adults	0.060	0.030	0.010	2.0	8.3
Herring adults	0.620	1.010	0.920	0.6	0.7
Chum	0.200	0.230	0.160	0.9	1.3
Sockeye	0.090	0.110	0.090	0.8	1.0
Coho	0.060	0.100	0.060	0.6	1.1
Pacific ocean perch	0.010	0.030	0.020	0.5	0.6
Pacific hake	2.73E-14	0.240	0.210	0.0	0.0
Rock sole	0.003	0.010	0.003	0.4	1.1
Flatfish other	0.040	0.140	0.020	0.3	2.0
Total catch (sp table)	**1.130**	**1.990**	**1.530**	**0.57**	**0.74**
Total catch*	**1.940**	**3.770**	**2.170**	**0.51**	**0.89**

* Number of commercial taxa/groups in the model = 33

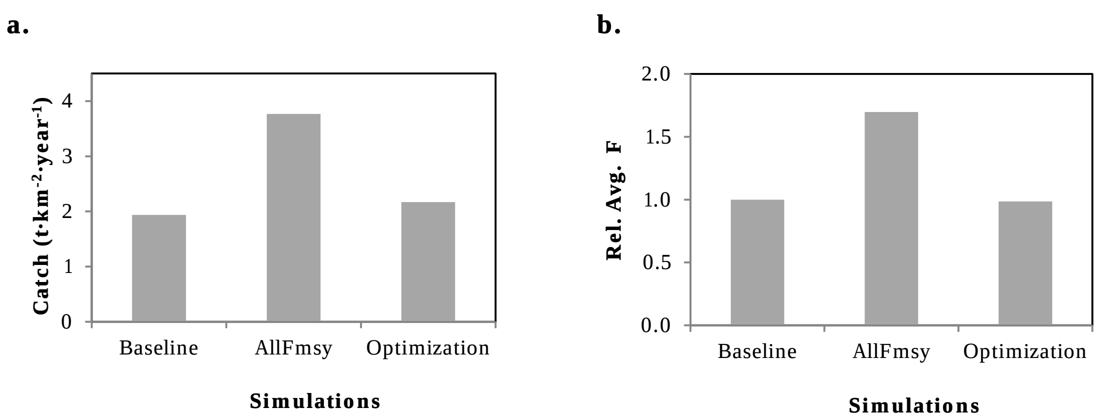


Figure 7. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years for the Canadian Pacific ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Chile[9]

The Republic of Chile is located in South America. The narrow, elongated shape of Chilehas resulted in a population with strong ties to the sea (Figure 8). Indeed, although nationally, fishing accounts for only 0.4 % of the GDP, dwarfed by mining, Chile's overall landings in 2010 were the seventh largest in the world (OEDC 2012). In addition to the mainland EEZ, which encompasses approximately 2,009,000 km², Chile holds several oceanic islands: the Desventuradas Islands (EEZ area: 449,800 km²) 850 km from the Chilean coast, the Juan Fernandez, Felix and Ambrosio Islands (EEZ area: 502,500 km²) 890 km west of Chile, and Easter Island (EEZ area: 720,400 km²), which is known as the most remote inhabited island, and is located over 3,500 km from Chile in the central south Pacific. For this report, the Chile's oceanic islands are not considered, except with reference to their MPAs.

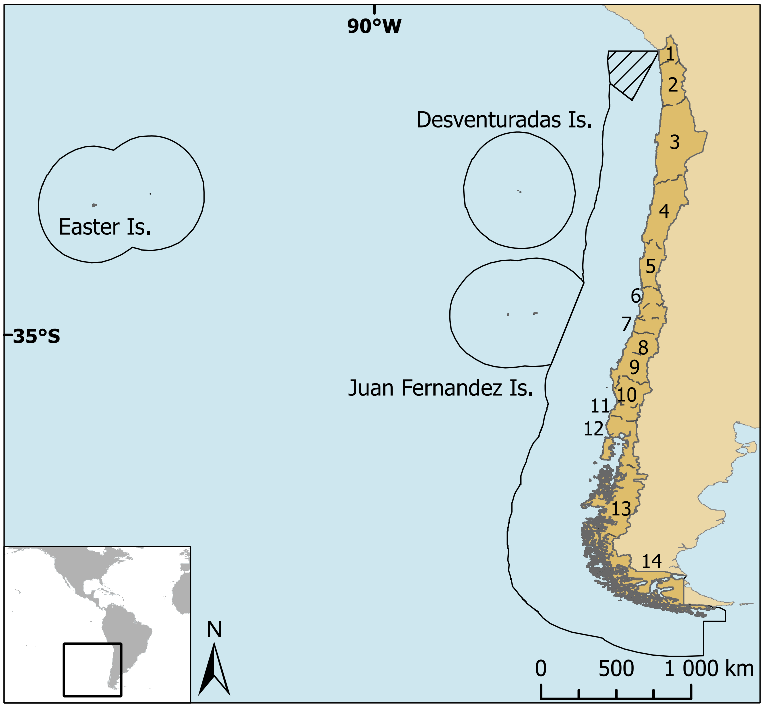


Figure 8. Map of Chile showing the 200 nm EEZ adjacent to the mainland, all maritime regions, and the EEZs of the Desventuradas, Juan Fernandez and Ambrosia, and Easter Islands. (The shaded area indicates an area also claimed by Peru). Numbers correspond to maritime regions: Arica, Tarapaca, Antofagasta, Atacama, Coquimbo, Valaparaiso, Libertador, Maule, Biobio, Araucania, Los Rios, Los Lagos, Aisen, and Magallanes, respectively, 1-14 respectively.

Mainland Chile is divided into 15 administrative 'regions', all but one of which border the coast, and each with its own governor. The northern regions include Arica, Tarapaca, Antofagasta, Atacama, Coquimbo, and Valaparaiso (Figure 8, 1-6), while the southern states include Libertador, Maule, Biobio, Araucania, Los Rios, Los Lagos, Aisen, and Magallanes (Figure 8, 7-14). In terms of biology and biodiversity, marine scientists consider Chile's EEZ as consisting of four main regions: the north, central, southern and austral zones, each characterized by specific environmental and biological conditions (Peña-Torres 1997).

The mainland EEZ component largely overlaps with the southern half of the Humboldt Current LME. The Eastern Boundary Humboldt Current (EBHC) is recognized as one of the largest and most productive marine ecosystems in the world (Mann and Lazier 1991), and is highly variable due to El Niño events. The EBHC is a classical eastern boundary zone (Parrish *et al.* 1983; Werner *et al.* 2008), where strong coastal winds drive water northward and off the coast, which results in upwelling of deeper nutrient-rich waters and allows for an extraordinarily strong primary production (Carr and Kearns 2003). The large amount of plankton in this region allows, in turn,

[9] This introduction is adapted from Pauly *et al.* (2012b).

for a high abundance of zooplankton, which eventually translates to fish and other vertebrates, i.e., seabirds and marine mammals.

Thus Chile, similar to Peru, which occupies the northern part of the Humboldt Current LME, is one of the richest countries in the world in terms of marine fisheries resources. The high fish catches that this allows, however, are concentrated on a few species, notably forage fish, sardine and anchovy, as well as chub and horse mackerel – most of which are fed to reduction plants, i.e., turned into fishmeal and related products[10]. Pelagic species represent 85 % of the total catch, with anchovies and South American pilchards comprising 65 % of the total catch. Demersal species account for only 3.6 % of the total catch and include species such as Pacific hake and Patagonian grenadier. These species are of higher value and are exported as frozen or chilled seafood products (Hugo Arancibia, Universidad de Concepcion, Chile, pers. comm.). Overall, an average of 4.76 million $t \cdot year^{-1}$ were landed in the last decade. While artisanal fisheries have increased their catch, the catch of the industrial fisheries have declined, such that overall landings have decreased by an estimated 17 % in the last decade (SONAPESCA 2008; CENDEC 2010).

Fisheries in Chile consist of large-scale industrial fisheries and small-scale artisanal fisheries. Industrial fisheries operate vessels greater than 18 m in length, and correspondingly, small-scale (or artisanal) fisheries refer to landings from vessels under 18 meters in length and with a hold capacity not exceeding 80 m^3. Both industrial and artisanal fishers must be registered with the National Registry of Industrial Fisheries (NRIF) and National Registry of Artisanal Fisheries (NRAF), respectively.

In terms of volume, the main Chilean industrial fishing activities are related to pelagic resources, both in the north and central part of the country. In the northern regions, anchovy account for most of the landings, followed by jack mackerel and American mackerel (OEDC 2009). The largest quantities of mackerel and sardine are caught in central and southern Chile. Up to 80 % percent of the industrial landings are used by the local fishmeal industry to produce premium fishmeal and fish oil directed to salmon aquaculture, while the rest is exported chilled or frozen. In 1994, landings reached a historic record of 7.5 million tonnes and declined since, particularly since 2004, and reaching 3.55 million tonnes in 2010.

A relatively recent development is that Inca scad (*Trachurus murphyi*) and chub mackerel (*Scomber japonicus*) are also caught in increasing quantities outside of the Chilean EEZ, which has required the deployment of large vessels with adequate autonomy and refrigeration capacities. The rest of the industrial fleet is composed of several factory vessels, which are allowed to fish only in the Austral zone and in international waters, and which target South Pacific hake, conger eels and 'Chilean seabass' (=Patagonian toothfish, *Dissostichus eleginoides*) for local consumption and export (OEDC 2012; Hugo Arancibia, pers. comm.).

Artisanal fisheries are widely practiced along the Chilean coastline, with participation having substantially increased in the past 10 years. Today these fisheries contribute to almost half (46 %) of the fish and crustacean landings in the country. Artisanal fisheries land their products in coastal villages ('*caletas*') or at wharfs, most of the latter located in rural areas where most livelihoods depend directly on fishing (CENDEC 2010). Historically, artisanal fisheries have targeted shell-fish such as 'Chilean abalone' or '*loco*' (*Concholepas concholepas*, a snail species), mussels, and demersal fish (Gelcich *et al.* 2005). Most of the artisanal landings are used for local consumption since most of the *caletas* lack freezing capacity. The remaining portion of the artisanal landings are directly sold to seafood exporters.

Artisanal fishers are required to register with the NRAF in the particular area where they reside and can only operate in that area. They are allocated exclusive rights to 5 nm from the coastline. The most southern regions are also allowed to fish in 'interior marine waters', i.e., as waters out to 12 nm, but industrial fisheries are not. Artisanal fishers are typically allocated free access to these zones, but once the stock is considered 'fully exploited', access can be limited (OEDC 2009).

[10] As required by a large (and problem-ridden) salmon-farming industry, not covered here.

As a result of the overexploitation of benthic resource such as Chilean abalone or *loco*, an area-based cooperative system was introduced after the fishery was officially closed in 1989. This new form of management was established in 1997 and established the Management Areas for the Exploitation of Benthic Resources (MAERB). Through this policy, the Undersecretary of Fisheries (SUBPESCA) gives formal property rights to certain natural resources in defined geographical areas of the seabed to registered syndicates. This includes the right to exclude non-members from exploiting that area of the seabed (Gelcich *et al.* 2005). After this measure was established, the stocks recovered, and now provide steady income for some 50,000 artisanal fishers (Anon. 2012). This policy model is now a global example of successful property rights management in fisheries.

However, the current fishery and aquaculture legislation ('*Ley General de acuicultura y pesca*') expires at the end of 2012 and the government has yet to decide on a more permanent solution. Moreover, as artisanal fisheries have grown in importance, the government is realizing the need to regulate the artisanal fleet. As an initial step, an official distinction is being made between medium-sized boats (those between 12 and 18 meters in length) and boats that are less than 12 meters long. The medium-sized boats represent only 10 % of the artisanal fleet, but account for 90 % of its catch. Other measures include the mandatory installation of satellite transponders in the vessels at the owner's expense (http://www.businesschile.cl/en/news/cover-story/fishing-chile-race-against-time).

The new laws will create scientific committees which will intervene in the decision making process of quota allocations of the marine resources. The inclusion of scientific committees in the decision making process of quota allocation was part of a proposal given by *Oceana* to the Ministry of Economy in 2010. *Oceana* also proposed a new mechanism for quota allocation: (1) scientific recommendations must be respected when quotas are allocated; (2) the setting of global quotas must not be influenced by any fishing actors; (3) there must be transparency in the decision making process, and (4) scientific committees must include participants such as universities, NGOs and any competent organization that could enhance the knowledge about the stocks and the overall biology of the resource being assessed[11]. This proposal represents a major step forward for Chilean fisheries.

There have been several other successful policy and environmental campaigns in Chile over the past decade in which *Oceana* played a key role. In July 2001, a national ban on shark-finning was implemented. A multi-year campaign to raise the awareness about the overfishing of jack mackerel resulted in a considerable quota reduction in October 2010. Also, several marine reserves were established, including the world's fourth largest marine reserve around Salas y Gomez Islands in the Pacific and a reserve in Northern Chile to protect endangered Humboldt penguins, which was established in an area where a power plant was to be built.

[11] www.pescaaldia.cl/entrevistas/?doc=458.

Catch-MSY method for Chilean stocks

For Chile, the single-species analyses suggest that the overall catch could be increased by 32 % when considering the top 12 landed species, or 30% when considering all 48 taxa, given fishing at single-species F_{MSY} (Table 9). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 9. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Chilean catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Anchoveta	1,350,734	1,430,434	0.94
South American pilchard	67,995	1,176,783	0.06
Inca scad	484,698	455,661	1.06
Araucanian herring	347,430	363,157	0.96
Patagonian grenadier	88,314	97,444	0.91
Chub mackerel	257,976	197,302	1.31
South Pacific hake	27,616	44,806	0.62
Chilean sea urchin	36,196	40,522	0.89
Taca clam	15,809	23,260	0.68
Southern hake	27,102	3,2417	0.84
Cholga mussel	6,400	10,806	0.59
Southern blue whiting	26,780	25,017	1.07
Average of top 12 (weighted)			**0.83 (0.68)**
Average of 48 taxa (weighted)			**0.71 (0.70)**

China[12]

The Chinese EEZ, which is the 15th largest in the world at 2,285,872.49 km², spans across three LMEs, the Yellow Sea and the East China Sea, both highly productive ecosystems, and the South China Sea, a moderately productive ecosystem (Figure 9). China has areas of disputed claims in the East China Sea over the Senkaku/Diaoyu Islands (with Japan and Taiwan) and the Socotra Rock (with the Republic of Korea) and in the South China Sea over the Spratly Islands (with Taiwan, Vietnam, Malaysia, Brunei and the Philippines), the Paracel Islands (with Taiwan and Vietnam), the Pratas Islands (with Taiwan), the Macclesfield Bank (with Taiwan and the Philippines), and the Scarborough Shoals (with Taiwan and the Philippines). A large section of the South China Sea is thus disputed, making management of the fisheries in the area politically charged and difficult.

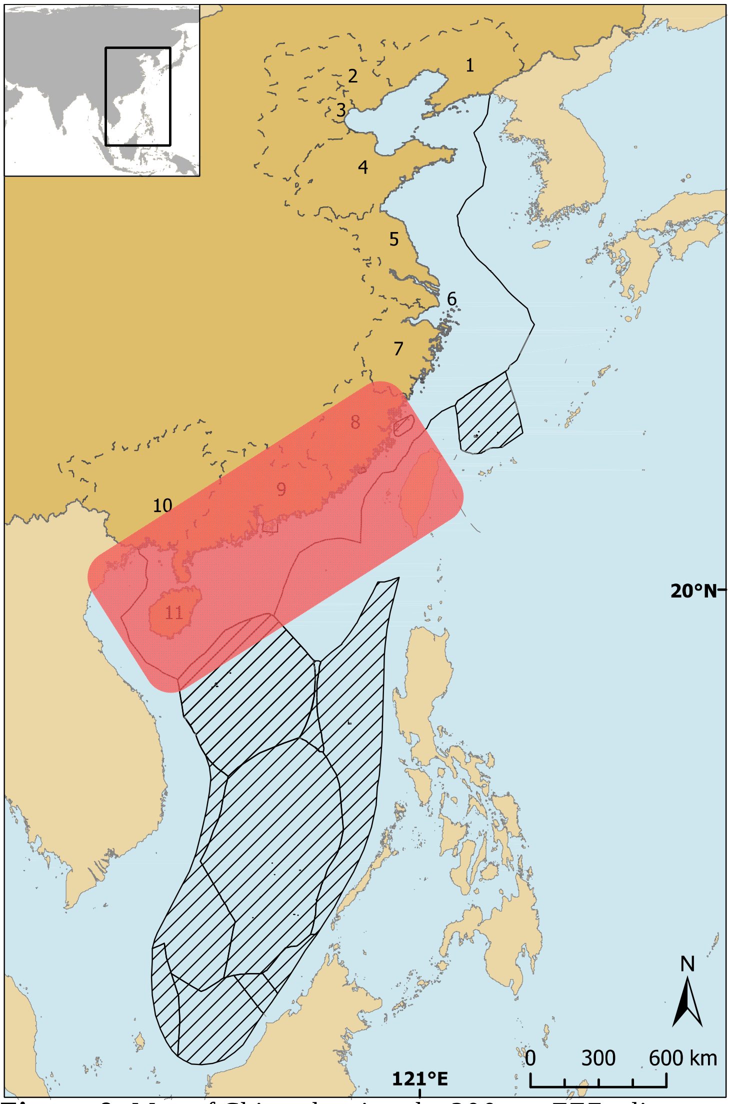


Figure 9. Map of China showing the 200 nm EEZ adjacent to the mainland, all maritime states, and disputed regions (cross-hatch). The Chinese EEZ is part of three LMEs: the Yellow Sea LME, the East China Sea LME, and the South China Sea LME, from north to south. Numbers correspond to maritime states: Liaoning, Hebel, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, and Hainan, 1-11 respectively. The area covered by ecological models is highlighted in red.

The Yellow Sea contains 10 major estuaries, including the Yangtze and Huanghe Rivers, which provide nutrient-rich waters to the ecosystem. The region is the largest shallow continental shelf in the world with an average depth of less than 50 m, supporting well-developed multi-species fisheries with about 100 species of fish, squid and crustaceans that are commercially fished. The ecosystem has been exploited by fishing vessels from China, Korea and Japan for centuries, targeting stocks such as Pacific saury (*Cololabis saira*), chub mackerel (*Scomber japonicus*), largehead hairtail (*Trichiurus lepturus*), Japanese anchovy (*Engraulis japonicus*), yellow croaker (*Larimichthys polyactis*) and Japanese flying squid (*Todarodes pacificus*).

Further south, the East China Sea is a vast, semi-enclosed ecosystem, bordered by the Ryukyu Islands and the Taiwan Strait. It is a highly productive region with shallow coastal waters providing spawning and nursery grounds for many

[12] This introduction was assembled from material in Pang and Pauly (2001) and Pauly *et al.* (2012a).

species of pelagic fish, including some stocks of tunas and swordfishes. About 200 species of finfishes and invertebrates are commercially exploited in the region.

The South China Sea has relatively shallow coastal waters (less than 200 m) with the South China Sea Basin and Palawan Through running through the middle at depth over 1,000 m. Over 100 rivers drain into the region and primary productivity is governed by river run-off and seasonal monsoons. Productivity of the South China Sea is also sensitive to the El Niño-Southern Oscillation (ENSO), which drives rainfall patterns in the region. Main target species include large pelagics such as tuna, billfish and sharks, and a large array of demersal fish and invertebrates, especially penaeid shrimp. The landings are dominated by small coastal pelagic fishes such as herring, sardine and anchovy.

The Chinese marine capture fisheries experienced considerable growth since the founding of the People's Republic of China, in 1949 (here referred to as 'China', and excluding Taiwan, Hong Kong and Macau). However, this growth was irregular, due to a series of political crises, and the ensuing recoveries. The major steps in this uneven development are: (a) Postwar Recovery (1949-1952); (b) First 5-Year Plan (1953-1957); (c) Second 5-Year Plan/Great Leap Forward (1958-1962); (d) Three-Year Re-Adjustment Period (1963-1966); (e) Cultural Revolution and Aftermath (1966-1978); and (f) Return to normalcy and growth (1978-present). However, the official Chinese fisheries statistics, as submitted to FAO, reflect the changes and upheavals that went along with these events only imperfectly, if at all.

Few records are available from the Postwar Recovery Period. Overall landings for this period appeared to have increased rapidly, starting from a base of about 0.6 million t in 1950 and reaching one million t in 1952, most of it caught by non-motorized coastal vessels (Sarhage and Lundbeck 1992). The growth momentum established during the postwar recovery period continued through the First 5-Year Plan, nominal landings increasing to about 1.7 million t in 1955. However, Sarhage and Lundbeck (1992, p. 214) note that, "early statistics were rather inaccurate," suggesting, "it is possible that the catches before 1958 were higher than indicated." Be it as it may, the established trends of increases in fishing effort and landings did not continue in the following period: what was to be the Second 5-Year Plan turned into the Great Leap Forward, itself ending in a catastrophic decline of production in literally all sectors of the Chinese economy, leading to widespread famines accentuated by a series of droughts and other calamities (Hunter and Sexton 1999). Official statistics from this period reflect this as stagnating landings, continuing during the subsequent Three-Year Re-adjustment Period (see e.g., Fig. 113 in Sarhage and Lundbeck 1992). Throughout the 1960s, nominal landings remained around 2 million t and Chinese fishers targeted relatively large and valuable demersal and benthopelagic species, such as large and small yellow croakers, flounder and other flatfish, pollock and cuttlefish. Nominal fisheries catches did increase during the Cultural Revolution and its aftermath, but rather slowly. This is not a surprise, given the turmoil prevailing during the Cultural Revolution (Hunter and Sexton 1999; Lippit 2000), also known as "ten years of disasters." Indeed, various fisheries were closed during this period, to prevent victims of the Cultural Revolution, and/or even disillusioned fish workers, to use fishing vessels to leave the country.

By the late 1970s, the economically important species targeted during the previous period had been largely depleted (see below for the example of large yellow croaker), and species such as filefishes, and herring, which had been spurned earlier, became the target of directed fisheries, and contributing increasingly to total landings.

However, overall economic growth started to pick up as successive reforms were launched, the first of these, promulgated in 1978, being devoted to the agricultural and fisheries sectors (Blecher 2000). In its first stage (1978-1984), this reform abolished the People's Commune system that had been in place since 1958, and replaced it with a 'household contract responsibility' system that linked remuneration to output. However, nominal landings grew only 1.2 %, from 3.5 million t in 1976 to 3.9 million t in 1985.

Indeed, this period bracketed a net decline in nominal catches, from about 1978 to the early

1980s. A government report of 1979 on the state of the country's fisheries pointed out that the expansion of bottom trawling and stake nets had depleted the resources, and induced the collapse of several species. That same report called for a stabilization of overall fishing effort at current levels, the replacement of trawling by gillnetting and other fixed gear, etc. Given the manifest decline of China's own coastal resources, this report also suggested distant water fishing as outlet for its excess fishing capacity, and as source of fish. The conservation measures proposed in that report were not implemented, but the expansion into distant water fishing was (Mathew 1999).

By the end of the 20th century, China had become a major distant-water fishing nation. However, at first, China was lacking the specialized vessels required for distant-water fishing, and the infrastructure required for supplying such vessels. Thus, initially, China simply 'exported' its coastal fleet, mainly consisting of bottom trawlers, to the waters of foreign countries it could operate in (Pang and Pauly 2001)

At the onset of the 21st century, however, Chinese distant-water fisheries had changed, with specialized 'catcher' vessels (bottom trawlers still, but also purse seiners, squid jiggers, longliners, etc.) linked to motherships delivering their catch to strategically located freezer facilities, and supplying local, international and domestic markets. These are all remarkable achievements in technology, logistics, and business, mirroring other sectors of the Chinese economic expansion into the rest of Asia (Gaulier *et al.* 2007), Africa (Zafar 2007; Beuret *et al.* 2008), Latin America (Ferchen 2012) and Oceania (Wesley-Smith 2007).

Unfortunately, what did not improve in the transition to the 21st century – occasionally seen as the start of an age of transparency (Sifry 2011) – is the tendency toward secrecy in fisheries data, and the near complete disregard for public accountability of the use of public fisheries resources. Thus, there are no publically accessible databases of access agreements between China (or Chinese companies) and the countries in the Exclusive Economic Zone (EEZ) where Chinese fishing vessels operate, unlike the European Union (EU), which provides in its law database[13] all texts related to fishing access agreements with other countries, even if the agreements themselves are often questionable (Kaczynski and Fluharty 2002; Kalaidjian 2010). Therefore, the activities and catches of the Chinese distant-water fleets are almost completely undocumented and unreported, often spanning the entire gamut of activities implied by the 'IUU' acronym (Bray 2000).

A related problem is posed by the Chinese fisheries statistics. The factors which cause China to massively over-report the catch of its domestic marine fisheries (Watson and Pauly 2001) were discussed in Pang and Pauly (2001), and essentially are a perverse result of a planned centralized economy that rewards individuals for appearing to fulfill the plan (thus providing a powerful incentive for over-reporting production), combined with the absence of an independent statistical system.

[13] http://eur-lex.europa.eu

Catch-MSY method for Chinese stocks

For China, the single-species analyses suggest that the overall catch could be increased by 24 % when considering the top 12 landed species, or 17 % when considering all 91 taxa, given fishing at single species F_{MSY} (Table 10).

Table 10. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Chinese catch. Catch:MSY ratios are presented for each of these species, along with straight and weighted averages by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Largehead hairtail	939,776	1,006,021	0.93
Akiami paste shrimp	675,109	569,968	1.18
Japanese anchovy	656,347	804,683	0.82
Chub mackerel	174,563	207,103	0.84
Large yellow croaker	65,790	155,966	0.42
Gazami crab	300,363	254,501	1.18
South American pilchard	74,789	171,853	0.44
Southern rough shrimp	320,440	250,980	1.28
Alaska Pollack	2,867	58,672	0.05
Daggertooth pike conger	284,238	178,454	1.59
Yellow croaker	191,270	173,943	1.10
Flathead mullet	59,923	70,663	0.85
Average of top 12 (weighted)			**0.89 (0.76)**
Average of 91 taxa (weighted)			**0.57 (0.83)**

Model results for Chinese ecosystems

We used the northern shelf of the South China Sea model (Cheung 2007a) as a representation of Chinese marine ecosystems. The original model covers 150,000 km^2 of the EEZ, including the continental shelf (i.e., areas less than 200 m depth) between 106°53'-119°48' E to 17°10'-25°52' N (Figure 9), and it had been fitted to historic time series of data from 1973 to 1988.

The *baseline* simulation results show higher catch in the area under the historical exploitation regime than under *allFmsy* simulation, both in terms of most targeted species and in terms of all catch (Table 11., Figure 10a). The average fishing mortality from 1973 to 1988 is higher in the historical exploitation regime than in both *allFmsy* and *optimization* simulations (Figure 10b).

For China, we note a divergence between the single-species and the ecosystem-based analyses, as the catch could not be increased when we account for fishing at F_{MSY} or optimal management, which includes fishing at F_{MSY}, biodiversity and criteria for rebuilding biomass. Several explanations for this divergence exist, including the extremely low taxonomic resolution of Chinese fisheries statistics and the fact that the time periods of analysis for the catch-based and the ecosystem model are quite different. Also, the domestic catch of China is known to be grossly over-reported (Watson and Pauly 2001).

Table 11. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the Chinese ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

	Catch (t·km^{-2}·year^{-1})			Catch:MSY	
Exploited species / groups	**1. Baseline**	**2. AllFmsy**	**3. Optimization**	**1/2**	**1/3**
Shrimps	0.470	0.17	0.07	2.7	6.7
Crabs	1.680	0.05	0.02	31.9	82.4
Threadfin bream (nemipterids)	0.100	0.22	0.10	0.5	1.0
Lizard fish (synodontids)	0.020	0.23	0.15	0.1	0.1
Juvenile hairtail (trichiurids)	0.010	0.01	0.01	0.3	0.7
Adult hairtail (trichiurids)	0.001	0.04	0.03	0.0	0.0
Croakers (< 30cm)	0.040	0.07	0.03	0.7	1.4
Juvenile large croakers	0.010	0.02	0.02	0.5	0.6
Croakers (> 30 cm)	1.96E-06	0.05	0.07	0.0	0.0
Demersal fish (< 30 cm)	0.520	0.39	0.18	1.3	2.9
Juvenile demersal fish (> 30 cm)	0.040	0.05	0.03	0.9	1.3
Adult demersal fish (> 30 cm)	6.26E-06	0.09	0.10	0.0	0.0
Benthopelagic fish	0.270	0.14	0.06	1.9	4.4
Pelagic fish (< 30cm)	0.180	0.99	0.33	0.2	0.5
Juvenile large pelagic fish	0.050	0.02	0.02	1.9	3.1
Pelagic fish (>30 cm)	0.010	0.06	0.05	0.1	0.1
Total catch (sp table)	**3.390**	**2.60**	**1.26**	**1.30**	**2.69**
Total catch*	**4.250**	**3.08**	**1.50**	**1.38**	**2.83**

* Number of commercial taxa/groups in the model = 34

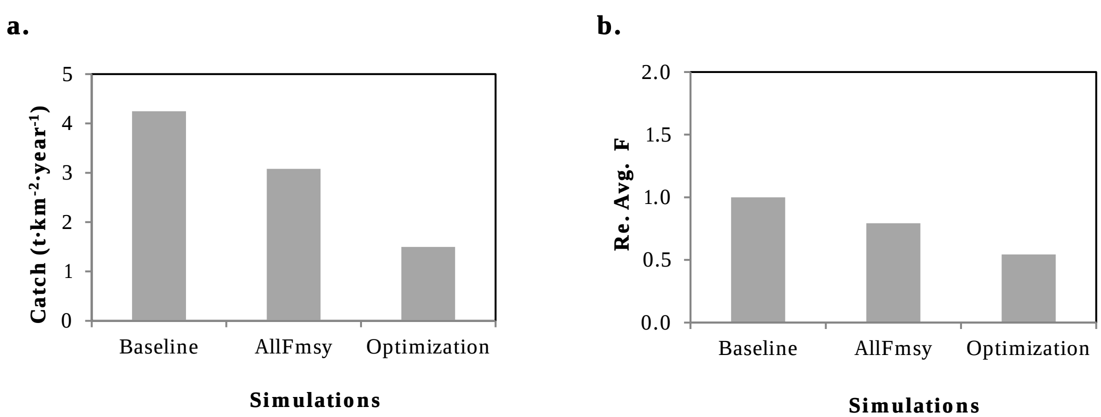


Figure 10. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years for the Chinese ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Denmark[14]

Denmark is located on the boundary of the Baltic and North Seas (Figure 11). Jutland, the main peninsula of Denmark, extends northward dividing the Skagerrak from the Kattegat, which connects to the Baltic Sea through the Danish Sound and Belts. The Danish archipelago is comprised of many islands, with the most easterly being Bornholm, some 180 km southeast of Copenhagen. Denmark has a total land area of approximately 43,000 km² and a population of about 5.4 million. Historically, Denmark controlled Greenland, Iceland, and the Faroe Islands, but ties between Iceland and Denmark were severed during WWII, and both the Faroe Islands and Greenland have since gained home rule. Denmark joined the European Union (EU) in 1973 and has a strong market economy.

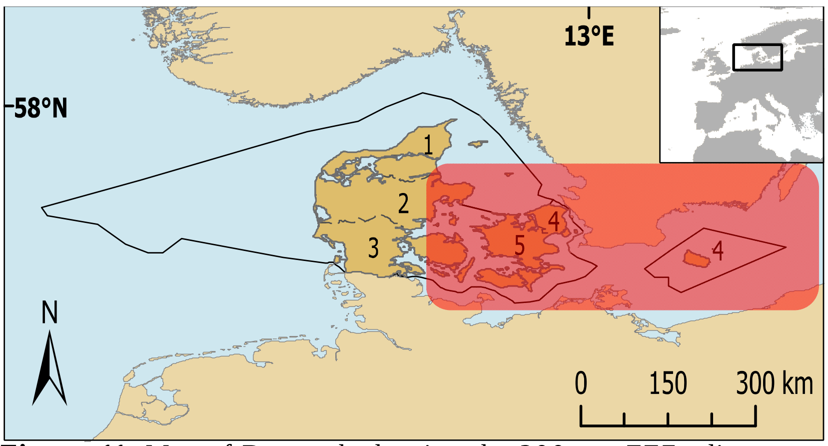


Figure 11. Map of Denmark showing the 200 nm EEZ adjacent to the mainland and all maritime states. The Danish EEZ is part of the North Sea LME to the west and the Baltic Sea LME to the east. Numbers correspond to maritime states: Nordjylland, Midtjylland, Syddanmark, Hovedstaden, and Sjaaelland, 1-5 respectively. The area covered by ecological models is highlighted in red.

Though fisheries contribute only 0.5 % of the GDP, they have been integral to the livelihoods of communities in north and west Jutland, and the island of Bornholm (Anon. 2007b). Detailed records of cod (*Gadus morhua*), salmon (*Salmo salar*), and herring (*Clupea harengus*) landings in Bornholm date as far back as the late 1800s (Bager *et al.* 2007). The Baltic Sea is the third most important fishing area for Denmark after the North Sea and the Skagerrak (Anon. 2007b). In 2006, Denmark's catches in the Baltic Sea amounted to approximately 12 % of the country's catches (Anon. 2007a).

Denmark's fisheries in the Baltic Sea can be divided into four categories: 1) the industrial sector for fishmeal and fish oil; 2) the commercial pelagic fishery for human consumption; 3) the commercial demersal fishery for human consumption; and 4) the marine recreational fishery (Anon. 2007b). Since the 1950s, the three main species targeted by Denmark in the Baltic Sea, according to the International Council for the Exploration of the Sea (ICES), have been sprat (*Sprattus sprattus*), cod, and herring.

Denmark has become the predominant industrial reduction fishing nation in the EU, producing the most fishmeal from both domestically caught and imported fish (Anon. 2007b). Nearly all that is produced is exported, and in the last decade Denmark's allocated quotas (of the Baltic's Total Allowable Catches [TACs]) have been reduced, further increasing reliance on imported fish for industrial reduction purposes. In the Baltic, the Danish fleet consists mostly of gillnetters, trawlers, and multi-purpose vessels. In 2006, the number of fishing vessels with homeports in the Baltic numbered approximately 1,400 (Anon. 2007a). Vessels operating in the industrial reduction fisheries for fishmeal/oil (targeting herring and sprat) as well as pelagics for human consumption (targeting herring and mackerel), are based mostly out of ports in North and West Jutland. Vessels targeting demersal species have traditionally operated out of ports in Bornholm

[14] This introduction is adapted from the Danish catch reconstruction (Bale *et al.* 2010; Zeller *et al.* 2011c).

and currently target cod, whiting (*Merlangius merlangius*), haddock (*Melanogrammus aeglefinus*), hake (*Meluccius merluccius*), saithe (*Pollachius virens*), sole (*Solea solea*), plaice (*Pleuronectes platessus*), and flounder (*Platichthys flesus*), as well as lobster (*Homarus gammarus*) and prawns (Palaemon serratus; Anon. 2004). Prior to the 1970s, the majority of bycatch in the cod fishery was plaice; however in the 1980s, plaice stocks collapsed and other flatfish species including dab (*Limanda limanda*), flounder, turbot and brill (*Scopthalmus rhombus*) became the predominant bycatch from both trawl and gillnet fisheries targeting cod (ICES 1986, 1992).

Catch-MSY method for Danish stocks

For Denmark, the single-species analyses suggest that the overall catch could be increased by 43 % when considering the top 12 landed species, or 38 % when considering all 65 taxa, given fishing at single species F_{MSY} (Table 12).

Table 12. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Danish catch. Catch:MSY ratios are presented for each of these species. along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Atlantic herring	92,517	138,583	0.67
European sprat	200,915	162,702	1.23
Atlantic cod	48,407	89,894	0.54
Blue mussel	76,819	63,105	1.22
European plaice	30,044	45,394	0.66
Norway pout	6,905	48,461	0.14
Atlantic mackerel	3,307	91,901	0.04
Whiting	2,056	38,178	0.05
Blue whiting	5,986	27,490	0.22
Haddock	5,700	24,832	0.23
Atlantic horse mackerel	2,342	16,012	0.15
Saithe	3,212	13,459	0.24
Average of top 12 (weighted)			**0.45 (0.57)**
Average of 65 taxa (weighted)			**0.75 (0.62)**

Model results for Danish ecosystems

We used the Baltic Sea model (Harvey *et al.* 2003) as a representation of Danish marine ecosystems. The Baltic Sea covers an area of 377,000 km² between 53° N and 66°N and 20° E and 26° E (Figure 7). The model had been fitted to historic time series of data from 1974 to 2000.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and optimization simulations (Table 13, Figure 12a). On the contrary, the average fishing mortality from 1974 to 2000 is higher in the historical exploitation regime than in both *allFmsy* and *optimization* simulations (Figure 12b).

Table 13. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the Danish ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	**Catch (t·km^{-2}·year^{-1})** 1. Baseline	2. AllFmsy	3. Optimization	**Catch:MSY** 1 / 2	1 / 3
Juvenile sprat	3.57E-05	1.21E-16	3.42E-08	>100.0	>100.0
Juvenile herring	0.4300	0.25	0.200	1.7	2.1
Juvenile cod	0.0100	7.03E-13	0.003	>100.0	3.8
Adult sprat	0.0001	4.12E-11	1.49E-05	>100.0	9.4
Adult herring	5.11E-11	0.06	1.36E-05	7.92E-10	3.77E-06
Adult cod	0.3300	1.26	0.790	0.3	0.4
Salmon	1.30E-20	9.13E-21	1.11E-20	1.4	1.2
Total catch (sp table)	**0.7700**	**1.57**	**0.990**	**0.5**	**0.8**
Total catch*	**0.7700**	**1.57**	**0.990**	**0.5**	**0.8**

* Number of commercial taxa/groups in the model = 7

a. **b.**

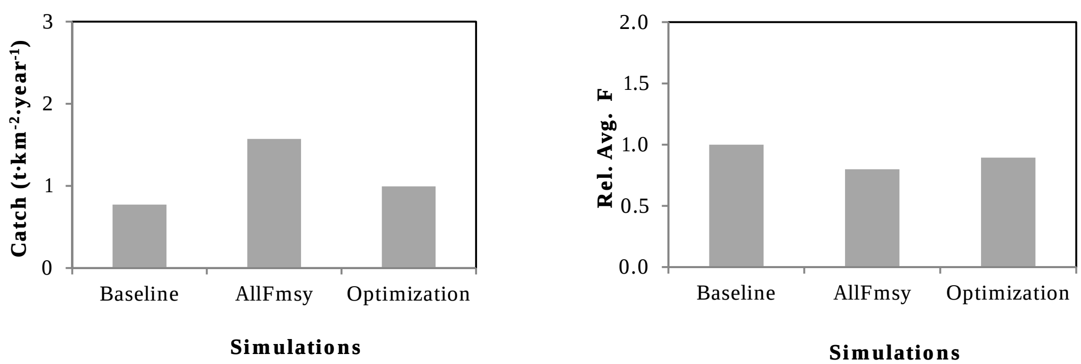


Figure 12. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the Danish ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 38-51 % given fishing at single species F_{MSY}. However, the catch could only be increased by 22 % when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass.

Iceland[15]

Iceland is the second largest island in Europe (103,000 km^2), located just under the Arctic Circle, stretching from the uninhabited volcanic island of Surtsey at 63°17N to the equally uninhabited island of Kolbeinsey at 67°08N (Figure 13). The closest neighbor is Greenland, 287 km away. The Icelandic EEZ borders Greenland in the west, Jan Mayen (Norway) in the north and the Faroe Islands (Denmark) in the east. Iceland is at the crossroad of two main oceanic ridges, which heavily influence the waters around Iceland by diverting ocean currents. The most important is the Scotland-Greenland ridge that separates cold deep Arctic waters from the warmer Atlantic waters. The total size of the EEZ is 758,000 km^2 and the continental shelf less than 500 m deep is 212,000 km^2.

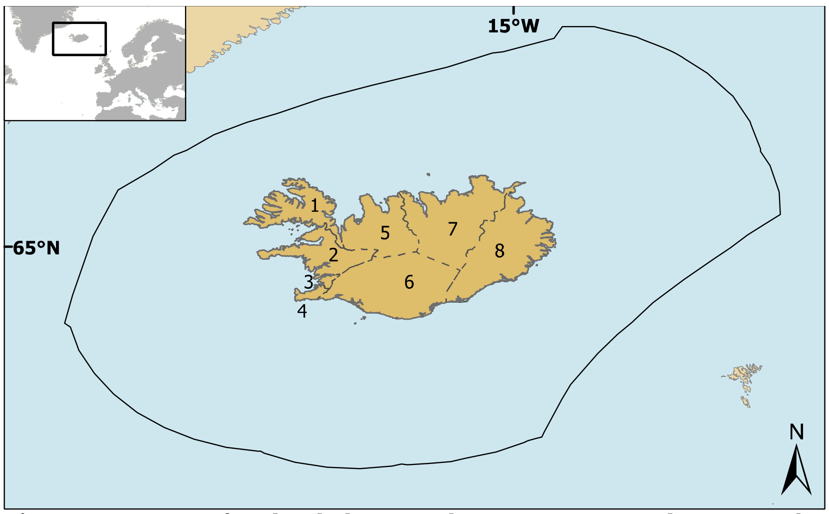


Figure 13. Map of Iceland showing the 200 nm EEZ adjacent to the mainland and all maritime states. The Icelandic EEZ is solely contained within the Iceland Shelf LME. Numbers correspond to maritime states: Vestfirðir, Vesturland, Höfuðborgarsvæði utan Reykjavíkur, Suðurnes, Norðurland vestra, Suðurland, Norðurland eystra, and Austurland, 1-8 respectively.

The productivity of Icelandic waters is moderately high, influenced both by temperature driven merging of sunlit surface waters with nutrient rich deep waters and the mixing of the cold and warm ocean currents. The major spawning grounds for most demersal stocks are in the warmer waters off the southern and western coasts. Most of them spawn in early spring, when the larvae are able to utilize the spring phyto- and zooplankton bloom, while they drift to nursery areas. Although many species live around Iceland, the ecosystem is dominated by rather few, but very abundant species. About 25 species are of commercial importance, but again only a handful dominate the catches. Atlantic cod (*Gadus morhua*) has, until lately, provided more than half of the export earnings for Icelandic marine products.

The main groundfish fishing season was formally in the spring when large schools of cod and other gadoids migrated during the spawning season to shallower waters along the southwest coast. A large part of the catch was therefore fished during a very short period with gillnets. This has changed lately as the fisheries are now spread much more evenly over the year. Although the gillnet fishery has declined, longline fisheries have increased. Other important fishing areas are the northwest and southeast, where sharp boundaries between cool and warm currents create a great productivity. These are the most important feeding grounds for several large commercial stocks, most notably cod, saithe (*Pollachius virens*) and redfish (*Sebastes* spp.). The presence of commercially important species declines as one moves north. However, northern prawn (*Pandalus borealis*), capelin (*Mallotus villosus*) and Greenland halibut (*Reinhardtius hippoglossoides*) are fished in the far northern waters.

[15] This introduction is adapted from the Icelandic catch reconstruction (Valtýsson 2001).

The highest catches come from a few pelagic species, which are characterized by strong fluctuations in stock size and migration routes. Herring (*Clupea harengus*) was caught in the highest volume until the 1960s when the stock collapsed. After the collapse, capelin was targeted, having been previously unfished. This fishery rapidly grew to around 1 million t annually, in some years surpassing the catch of all other species combined. Oceanic redfish (*Sebastes mentella*), blue whiting (*Micromesistius poutassou*), and Atlantic mackerel (*Scomber scombrus*) are newly developed pelagic fisheries.

The current distant water fleets fishing in Icelandic waters are based on reciprocal fishing rights (groundfish, redfish), shared stocks (capelin, herring, blue whiting and redfish) or lack of fishing knowledge, e.g., in the case of tuna. Except for the groundfish fisheries, these all occur at the fringes of the Icelandic EEZ; redfish in the southwest, tuna in the south, herring in the east and capelin in the north (Valtýsson 1998).

Catch-MSY method for Icelandic stocks

For Iceland, the single-species analyses suggest that the overall catch could be increased by 29 % when considering the top 12 landed species, or 26 % when considering all 44 taxa, given fishing at single species F_{MSY} (Table 14). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 14. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Icelandic catch. Catch:MSY ratios are presented for each of these species along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	**Catch**	**MSY**	**Catch:MSY**
Capelin	594,517	695,282	0.86
Atlantic cod	261,824	407,623	0.64
Atlantic herring	188,996	491,154	0.38
Blue whiting	356,468	225,823	1.58
Saithe	65,340	81,282	0.80
Haddock	78,360	85,075	0.92
Ocean perch	44,748	44,175	1.01
Deepwater redfish	24,979	12,706	1.97
Greenland halibut	12,789	16,491	0.78
Northern prawn	3,780	28,802	0.13
Wolf-fish	15,190	13,632	1.11
Ling	5,895	9,023	0.65
Average of top 12 (weighted)			**0.90 (0.71)**
Average of 44 taxa (weighted)			**0.71 (0.74)**

India[16]

The Republic of India is located in South Asia and shares land borders with Pakistan on the west, China, Nepal, and Bhutan to the northeast, and Burma and Bangladesh to the east (Figure 14). India is the second most populous country in the world, with approximately 1.2 billion people (2011 census), representing 17.5 % of the total world population[17]. India covers a total land area of about 3.3 million km², with 28 States and 7 Union Territories, the latter under the direct authority of the central government (Arora and Grover 1996; Bhathal 2005). The west coast of India has 5 maritime States: Gujarat, Maharashtra, Goa, Karnataka, Kerala (Figure 14, 1-5) and two Union Territories, Daman and Diu, and Lakshadweep. The east coast of India has 4 maritime States: Tamil Nadu, Andhra Pradesh, Orissa, and West Bengal (Figure 14, 6-9). The Union Territories include Pondicherry and Andaman and Nicobar Islands. The marine waters of India encompass two LMEs, the Arabian Sea along the west coast and the Bay of Bengal along the east coast. India's EEZ covers a total area of 1.63 million km² (including the Lakshadweep Islands on the west coast). Off the east coast, the EEZ of the Andaman and Nicobar Islands, covers a total area of 660,000 km² (www.seaaroundus.org) and represents about 30 % of the total Indian EEZ. For the purposes of this study, we concentrate only on the fisheries of the mainland EZZ and do not evaluate the fisheries of Andaman and Nicobar Islands (but see Bhathal and Pauly 2008). As with most developing countries with vast coastlines, the rich resources of the surrounding ocean play an important role in the economy, diet, and culture of the Indian people.

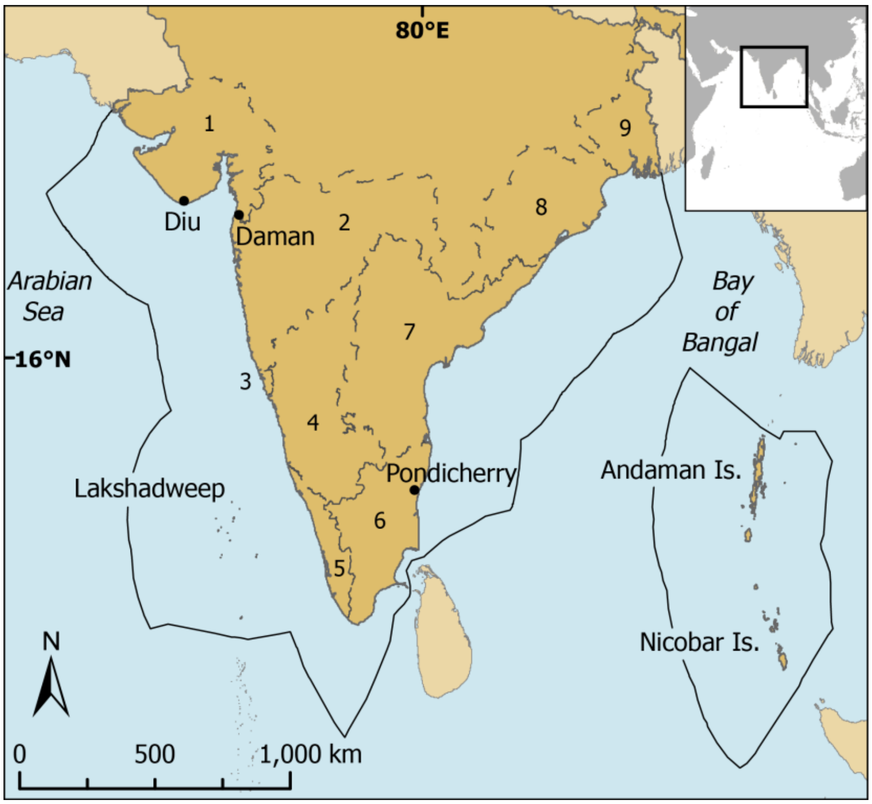


Figure 14. Map of India showing the 200 nm EEZ adjacent to the mainland, all maritime States and Union Territories, and the territorial EEZ of the islands of Andaman and Nicobar. The Indian EEZ is part of two LMEs: the Arabian Sea LME to the west and the Bay of Bengal LME to the east. Numbers correspond to maritime States: Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Orissa, and West Bengal, 1-9 respectively.

The Indian Ocean is the warmest ocean in the world, resulting, via a strong, semi-permanent stratification, in low primary productivity in most regions. Despite this low productivity, the marine fishing sector in India has shown steady growth since India's independence in 1947. India

[16] This introduction was adapted from Pauly *et al.* (2012b).
[17] http://www.censusindia.gov.in/2011-prov-results/data_files/india/Final_PPT_2011_chapter3.pdf

declared its EEZ in 1976, and divided the EEZ into three regions: territorial waters, which extends out to 12 nm, the contiguous zone, which extends out to 24 nm, and the continental shelf, which extends out to 200 nm (Bhathal 2005). The west coast of India, also known as the 'Malabar coast', has a broader continental shelf and a relatively high primary production, and supports over 75 % of India's total fish landings (Bhathal 2005). The east coast of India, also known as 'Coromandel coast', has a much narrower shelf and primary and secondary production in the Bay of Bengal is much lower than the Arabian Sea. Still, there are nearly 4,000 fishing villages and 2,000 traditional landing centers along this coast (FAO 2004).

The waters off India host a wide diversity of marine resources targeted by artisanal fishers, some operating with century-old methods, and by large-scale industrial fishing operations which are disrupting coastal communities and their way of life, notably through intense competition for the same resources. In general, marine resources in India are targeted by four groups, operating various types of fishing vessels and gears: (1) artisanal fishers operating non-mechanized vessels, (2) artisanal fishers operating vessels with outboard motors (less than 50 hp) in inshore waters, (3) industrial fishers using vessels with inboard motors, and (4) industrial deep-sea vessels. Overall, there are approximately 1.45 million fishers in India and the bulk of marine fish landed (68 %) is taken by artisanal mechanized vessels (Funge-Smith *et al.* 2005). Trawling has emerged as the dominant gear for demersal resources and accounts for 50 % of the total Indian catch.

Valuable species such as Indian oil sardine (*Sardinella longiceps*), penaeid and non-penaeid shrimp, Indian mackerel (*Rastrelliger kanagurta*), Bombay duck (*Harpadon nehereus*), and croakers (*Micropogonias* spp.) are the preferred targets, although various types of commercial finfish are often caught as bycatch (Gordon 1991). Among the multitude of species contributing to the catch, one species, the Indian oil sardine (*Sardinella longiceps*) contributes the majority of the yields, although they fluctuate strongly (Longhurst and Pauly 1987).

The marine fisheries in India are regulated both by the Central and State Governments. Offshore fishing within the EEZ by domestic and foreign fleets is managed by the Central Government; however, there is no comprehensive fisheries legislation for fisheries within the EEZ (Bhathal 2005; Rajagopalan 2011). Fisheries within the 12 nm territorial waters fall under the jurisdiction of the States, which are responsible for managing and collecting official fisheries statistics under the *Marine Fishing Regulation Act* (MFRA; Bhathal 2005; Rajagopalan 2011). Along with the State governments, the Central Marine Fisheries Research Institute (CMFRI) estimates the annual fish landings by State and compiles the data for the entire country[18]. National catch statistics prior to 1994 were obtained through a rigorous stratified sampling procedure; however, since the mid-1990s, changes to the sampling program have caused the deterioration of India's marine production statistics (Bhathal and Pauly 2008).

India regularly reports commercial landings from the artisanal sector. However, industrial landings have historically been unreported. Bhathal (2005) estimated total catch by industrial vessels from 1972-2000, since the first commercial trawlers arrived in Indian waters and began operation in 1972 (Devaraj 1996). Industrial and mechanized vessel discards were also estimated, as they are rarely reported (Bhathal and Pauly 2008). However, these estimates were considered to be conservative compared to previous reports on bycatch and discards in India (Gordon 1991; Davies *et al.* 2009; Dineshbabu *et al.* 2010). Furthermore, it is likely that all bycatch was retained prior to 1970, as even low-value species had a market, resulting in negligible discarding during that time (Bhathal 2005).

An estimate of fishery extractions, including illegal and unreported catches from India can be found in Ganapathiraju (2012). Estimates of illegal fishing by Indian and foreign vessels, discards by industrial trawlers, subsistence fishing, and underreporting by the artisanal sector, such as bait fish, dry fish landings and harvest of molluscs, were sampled during a 2008 field study. Ganapathiraju (2012) conducted interviews with fishers from the small-scale and mechanized sector in 9 out of 10 coastal states, including the Andaman and Nicobar Islands. In addition to the

[18] http://www.cmfri.org.in/

reported catch of about 3.1 million tonnes, Ganapathiraju's findings suggested that at least 1.5 million tonnes went unreported in 2008. The highest unreported catch (~1.2 million tonnes) was contributed by industrial discards. Subsistence fishing, which are generally missing from the catch statistics (Zeller *et al.* 2007), was estimated at 149,000 t·year^{-1} and underreported catch within the artisanal sector was estimated at 105,000 t·year^{-1} (details in Ganapathiraju 2012).

Through the 1970s, the non-mechanized sector fished primarily with hooks and lines, gillnets, seines, bag nets and traps, from catamarans, canoes and plank built boats. These vessels were gradually modified through the 1980s to hold outboard engines of 5-9 hp, in order to travel farther. Major endeavours were made to increase mechanization during the 1970s and 1980s, prompting the development of an industrial motorized fleets consisted of small trawlers, pair trawlers, purse seiners and gillnetters that could accommodate small inboard engines and fish down to 50 m. Additionally, chartered and joint venture deep-sea trawlers, tuna long-liners, and multi-purpose vessels that have the capacity to target both prawns and fish, were introduced in 1972 and now make up the bulk of the industrial fleet (Devaraj 1996).

This push for modernization of the vessels in India stemmed from a desire to promote the evolution of fishery into a more industrial activity (Rao and Murty 1993; Bhathal 2005). The resulting geographic expansion into deeper waters was the main reason for the growth and maintenance of Indian fisheries catches (Figure 8). However, this expansion must be accounted for when evaluating the health and productivity of Indian fisheries, as true trends in the status of fisheries (e.g., changes in mean trophic level and changes in mean size of fishes) may be masked when catch data is not disaggregated spatially. Overall, the push to expand has been fuelled mainly by the perception by Indian policy makers that the demersal fisheries could be expanded greatly by operating in deeper waters. However, the low oxygen levels in deeper water layers, especially on the West Coast (Banse 1959), constrain the expansion into deeper waters. Therefore, the new subsidized trawlers added to the Indian fleets since the 1980s tend to compete with small-scale fishers operating inshore. This, indeed, is one of the reasons why the conflict between small- and large-scale fisheries is most pronounced in India.

Catch-MSY method for Indian stocks

For India, the single-species analyses suggest that the overall catch could be increased by 20 % when considering the top 12 landed species, or 16 % when considering all 40 taxa, given fishing at single species F_{MSY} (Table 15). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 15. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Indian catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Indian oil sardine	321,734	316,160	1.02
Bombay duck	193,642	206,042	0.94
Indian mackerel	68,707	169,749	0.40
Silver pomfret	63,589	55,862	1.14
Giant tiger prawn	215,116	152,021	1.42
Narrow-barred Spanish mackerel	39,223	36,195	1.08
Torpedo scad	59,746	50,966	1.17
Black pomfret	30,133	29,887	1.01
Dorab wolf-herring	26,305	22,831	1.15
False trevally	10,618	27,252	0.39
Indo-Pacific king mackerel	15,220	16,249	0.94
Kawakawa	29,204	30,279	0.96
Average of top 12 (weighted)			**0.97 (0.80)**
Average of 40 taxa (weighted)			**1.00 (0.84)**

Indonesia[19]

Indonesia is a large archipelagic country straddling the equator in southeast Asia, ranging from 95^0 to 141^0 E (Figure 15), and largely encompasses the Indonesian Sea LME (www.searoundus.org/lme/38.aspx). Indonesia can be conveniently divided into two different parts, i.e., Western and Eastern Indonesia, with the former comprising most of its shelf (1,155,000 km^2 vs. 655,000 km^2) and the overwhelming bulk of its population and markets (Pauly 1989). Western Indonesia has a smaller EEZ (2,464,000 km^2) than Eastern Indonesia (3,617,000 km^2), but given its larger shelf, it has more demersal fisheries, whose early development is reviewed in Pauly and Martosubroto (1996) and Butcher (2004).

According to the FAO, there were approximately 750,000 fishing boats in 2004, a major increase since the mid-1990s. The majority of boats are fishing around North Java, followed by Maluku-Papua, South Sulawesi, North Sulawesi, Bali-Nusatenggara, and East Sumatra. Most of the motorized boats fish around North Java, while non-powered boats dominate around the Maluku-Papua area.

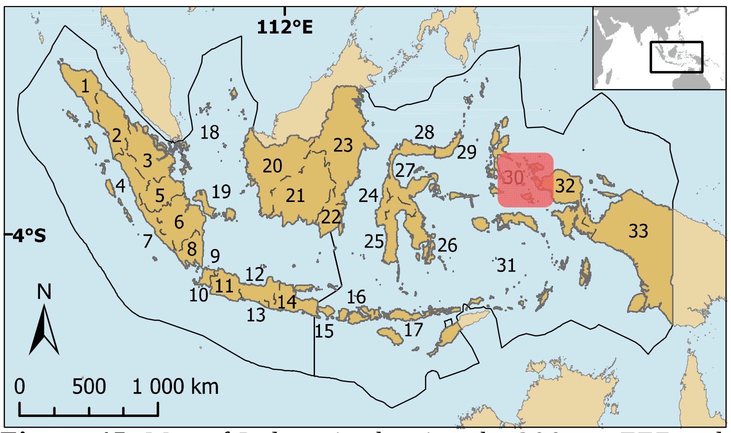


Figure 15. Map of Indonesia showing the 200 nm EEZ and all maritime states. The Indonesian EEZ is part of two LMEs: the Bay of Bengal LME and the Indonesian Sea LME. Numbers correspond to maritime states: Aceh, Sumatra Utara, Riau, Sumatra Barat, Jambi, Sumatera Selatan, Bengkulu, Lampung, Jakarta Raya, Banten, Jawa Barat, Jawa Tengah, Yogyakarta, Jawa Timur, Bali, Nusa Tenggara Barat, Nusa Tengarra Timur, Kepulauan Riau, Bangka- Belitung, Kalimantan Barat, Kalimantan Tengah, Kalimantan Selatan, Kalimantan Timur, Sulawesi Barat, Sulawesi Selatan, Sulawesi Tenggara, Sulawesi Tehgah, Gorontalo, Sulawesi Utara, Maluku Utara, Maluku, Irian Jaya Barat, and Papua, 1-33 respectively. The area covered by ecological models is highlighted in red.

In western Indonesia, the majority of marine resources, including large pelagics, mackerels, sardinellas, groupers, and crustaceans, have been heavily exploited. Conversely, many of the resources in the east are still being 'developed'. Generally, marine resources are supposed to be managed through fishing quotas based on the total allowable catch (TAC), themselves based on estimates of 'potential yield'.

One important feature of Western Indonesian fisheries development is the 1980 trawling ban, whose impact was studied by Buchary (1999) and which, while being partly circumvented, led to the development of a large industrial fishery for small pelagic fishes, especially in the Java Sea.

Eastern Indonesia is part of the Coral Triangle, and indeed, may be viewed as its very core. Much of the waters of Eastern Indonesia are in deep, relatively unproductive basins (Dalzell and Pauly 1989). The main fisheries are for tuna, which, together with shrimp trawling in the easternmost province of Papua, represent the bulk of Indonesian industrial fishing. There is a significant amount of illegal fishing, mainly for tuna, by distant water fleets from Thailand, Taiwan, China and the Philippines.

The catch of Indonesia is presently under reconstruction by the *Sea Around Us* Project and will be available in early 2013.

[19] This introduction was provided by Ms. V. Budimartono and Dr. D. Pauly (both: Fisheries Centre, University of British Columbia), the lead researchers for the Indonesian catch reconstruction.

Catch-MSY method for eastern Indonesian stocks

For eastern Indonesia, the single-species analyses suggest that the overall catch could be increased by 19 % when considering the top 12 landed species, or 8% when considering all 46 taxa, given fishing at single species F_{MSY} (Table 16).

Table 16. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Indonesian catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Short mackerel	156,473	167,234	0.94
Goldstripe sardinella	86,542	93,942	0.92
Skipjack tuna	104,653	88,853	1.18
Yellowstripe scad	79,059	80,434	0.98
Bali sardinella	42,873	50,164	0.85
Narrow-barred Spanish mackerel	64,654	55,038	1.17
Banana prawn	28,712	29,762	0.96
Yellowfin tuna	42,851	29,606	1.45
Longtail tuna	31,604	34,948	0.90
Indian scad	27,423	25,807	1.06
Kawakawa	34,100	28,035	1.22
Barramundi	17,155	16,021	1.07
Average of top 12 (weighted)			**1.06 (0.81)**
Average of 46 taxa (weighted)			**1.01 (0.92)**

Model results for eastern Indonesian ecosystems

We used the Raja Ampat archipelago model (Ainsworth *et al.* 2008; Bailey and Pitcher 2008) as a representation of Indonesian marine ecosystems. The model covers an area of 450,000 km^2 and describes the region from 129^0 12’ E and 0^0 12’ N to 131^0 30’ E and 2^0 42’ S off the west coast of New Guinea in the Indonesian province of Papua (Figure 15). The model had been fitted to historic time series of data from 1990 to 2005.

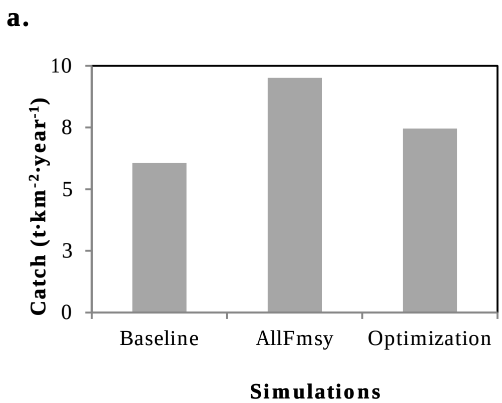
The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and *optimization* simulations (Table 17., Figure 16a). The average fishing mortality is also higher in both *allFmsy* and *optimization* simulations than in the historical exploitation regime (Figure 16b).

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 8-36 % given fishing at single species F_{MSY}. However, the catch could only be increased by 19 % when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass. We note that, in this case, the results from the ecological model provide more optimistic results than the catch-based method, which we attribute to the fact that the ecosystem model was applied to a small, protected area where fishing is light.

Table 17. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the eastern Indonesian ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

	Catch (t·km^{-2}·year^{-1})			Catch:MSY	
Exploited species / groups	**1. Baseline**	**2. AllFmsy**	**3. Optimization**	**1/2**	**1/3**
Adult groupers	0.080	0.19	0.0600	0.4	1.4
Adult snappers	0.110	0.08	0.0400	1.3	2.9
Adult Napoleon wrasse	0.030	0.03	0.0020	0.7	11.2
Skipjack tuna	0.780	1.03	0.8700	0.8	0.9
Other tuna	0.130	0.15	0.1000	0.8	1.3
Mackerel	0.160	0.13	0.0900	1.3	1.9
Billfish	0.020	0.01	0.0100	1.3	1.8
Adult coral trout	0.003	0.01	0.0100	0.3	0.3
Adult large sharks	0.060	0.10	0.0020	0.6	26.8
Adult small sharks	0.010	0.01	0.0001	1.0	60.8
Adult rays	0.010	0.04	0.0300	0.3	0.5
Adult large pelagic	0.060	0.03	0.0300	1.7	1.8
Adult medium pelagic	0.020	0.01	0.0100	1.9	2.0
Adult small pelagic	0.140	0.05	0.0600	2.6	2.5
Adult large reef associated	0.240	0.72	0.5000	0.3	0.5
Adult med. reef associated	0.220	0.62	0.5700	0.3	0.4
Adult large demersal	0.080	0.04	0.0300	2.2	3.1
Adult large planktivores	0.080	0.50	0.4800	0.2	0.2
Adult anchovy	0.850	1.69	1.5600	0.5	0.5
Adult deepwater fish	0.100	0.06	0.0500	1.6	2.0
Penaeid shrimps	1.090	1.88E-17	2.97E-21	>100	>100
Total catch (sp table)	**4.280**	**5.52**	**4.5100**	**0.78**	**0.95**
Total catch*	**6.070**	**9.51**	**7.4600**	**0.64**	**0.81**

* Number of commercial taxa/groups in the model = 75



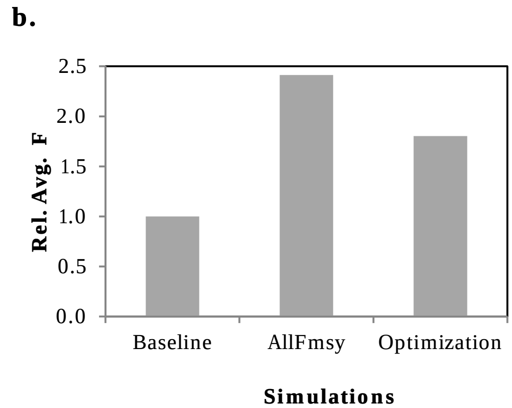


Figure 16 a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years for the eastern Indonesian ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Catch-MSY method for western Indonesian stocks

For western Indonesia, the single-species analyses suggest that the overall catch could be increased by 34 % when considering the top 12 landed species, or 13 % when considering all 45 taxa, given fishing at single species F_{MSY} (Table 18). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 18. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the western Indonesian catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	**Catch**	**MSY**	**Catch:MSY**
Banana prawn	73,747	74,177	0.99
Goldstripe sardinella	81,045	88,158	0.92
Bali sardinella	56,729	64,163	0.88
Short mackerel	48,445	52,298	0.93
Yellowstripe scad	64,746	64,342	1.01
Barramundi	47,891	44,524	1.08
Blood cockle	50,382	39,747	1.27
Narrow-barred Spanish mackerel	53,710	46,045	1.17
Skipjack tuna	41,914	36,267	1.16
Giant tiger prawn	22,653	22,147	1.02
Silver pomfret	30,742	26,764	1.15
Black pomfret	32,251	31,864	1.01
Average of top 12 (weighted)			**1.05 (0.66)**
Average of 45 taxa (weighted)			**1.00 (0.87)**

Japan[20]

Japan's EEZ covers over 4.4 million km² and is the 7th largest in the world. It extends north-south along the main islands and the Ryukyu Archipelago, and into the Pacific around the Ogasawara (Bonin) and Daito Island groups (Figure 17). The EEZ occupies five Large Marine Ecosystems (LMEs), with the Oyashio and Kuroshio systems to the east, Sea of Okhotsk to the north, Sea of Japan to the northwest and the East China Sea to the west. Japan has disputed EEZ claims in the East China Sea over Senkaku/Diaoyu Islands (with China and Taiwan), in the Sea of Japan over Takeshima/Dokdo (with the Republic of Korea) and in the Sea of Okhotsk over the Kuril Islands (with Russia).

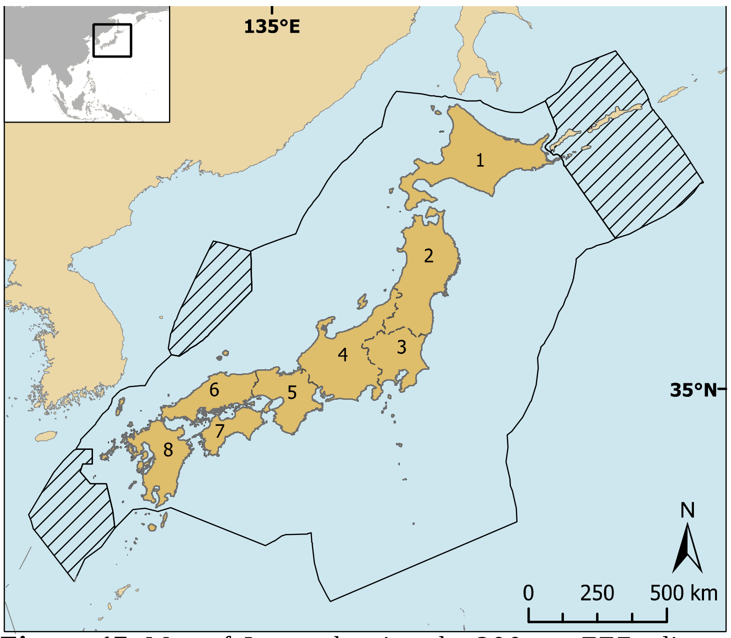


Figure 17. Map of Japan showing the 200 nm EEZ adjacent to the mainland and disputed regions (cross-hatch). The more remote Japanese Pacific islands and their EEZs are not shown. The Japanese EEZ is part of five LMEs: the Oyashio Current LME and the Sea of Okhotsk in the north, the Sea of Japan/East Sea in the central west, the Kuroshio Current LME in the central east, and the East China Sea LME in the south. Numbers correspond to maritime states: Hokkaidō, Tōhoku, Kantō, Chūbu, Kansai, Chūgoku, Shikoku, and Kyūshū, 1-8 respectively.

The confluent zone between the warm Kuroshio Current flowing northeast along the southern coast of the main islands and the cold Oyashio Current flowing southward along the east coast of the main islands is one of the most productive fishing grounds in the world. The region serves as an important spawning and nursery ground for many important pelagic fishes such as herring, horse mackerel, mackerel and saury, as well as many species of tunas. Commercially important stocks include salmon, Alaska pollock (*Theragra chalcogramma*), invertebrates such as crab, shrimp and sea urchins in northern Japan, and small pelagics (e.g. Pacific sardine, *Sardinops sagax*) and coastal demersal species (e.g. yellowtail) in the south.

Until recently, Japan had been the largest fishing nation in the world. However, marine fisheries landings in Japan have been decreasing since 1986, most notably due to the collapse of the Pacific sardine stock (*Sardinops sagax*; likely due to the combination of an environmental regime shift and overfishing) and a reduction in the catches of Alaska pollock following the phasing out of foreign access to U.S. East Bering Sea fishing grounds. By the early 1990s, China replaced Japan as the largest fishing nation in the world. The high cost of fishing and an aging population of fishers also contributed to the decline of the Japanese fisheries. Distant-water and high seas fisheries, for example, have been reduced to primarily tuna fisheries.

In 2008, Japan's fishing fleet consisted of 185,000 vessels, although almost half of these vessels were un-motorized and used primary for coastal aquaculture operations, and over 90 % of the motorized fleet consisted of vessels less than 50 GRT in size. The total number of fishing vessels

[20] This introduction was provided by Dr. Wilf Swartz (Fisheries Centre, University of British Columbia), the lead author of catch reconstruction for Japan, currently being completed.

has been declining from 410,000 in 1980, 325,000 in 2002 to the current level, less than half of the fleet in 1980. Like the number of fishing vessels, the number of fishers has also been declining, from 478,000 in 1978 to 222,000 in 2008. Nearly 50 % of Japanese fishers are 60 years old and older, and with the lack of new entrants into fisheries, the decline and aging of the Japanese fisher population is likely to continue (JFA 2008).

Japan has reciprocal fishing access agreements with China (since 1975, with new agreements since 1997), the Republic of Korea (since 1965, with a new agreement in 1998) and the USSR/Russia (since 1984). The agreements with China and the Republic of Korea are designed to address the issues of reaffirmation of maritime rights; establishment of reciprocal fishing access (arrangements had also existed prior to the EEZ regimes); and creation of cooperative management regimes for their shared fisheries stocks. The agreement with Russia is primarily to secure Japanese fishing access to the Sea of Okhotsk, with Japan providing financial compensation to acquire quotas considerably larger than those allocated to Russian vessels. All three agreements established Joint Fishery Committees (JFCs), and although each JFC has somewhat different scope and authority, they all have several common functions, such as research on the status of the fisheries, consultation with fishing industry interests, and recommendations to fisheries management authorities on access to fishing zones. The major work of each JFC is to determine, each year, how many fishing vessels from each country to permit in these joint resource management areas, based on the TAC established for target species. Operations by other foreign vessels in the Japanese EEZ are prohibited (JFA 2012).

The agreements between governments permitting Japan's fishing vessels access to fishing in foreign waters are as follows (as of 2008): Australia (since 1979), Canada (since 1978), France (since 1979), Kiribati (since 1978), Marshall Islands (since 1981), Morocco (since 1985), Solomon Islands (since 1978), Senegal (since 1992), and Tuvalu (since 1986). No quota is currently allocated to Japanese vessels under the Australian and Canadian agreements and the French agreement is in reference to fishing access in the French territories in the Pacific. In addition, there are private sector-based agreements permitting Japan's fishing vessels to fish in foreign waters, which include Cape Verde, Côte d'Ivoire, Equatorial Guinea, Fiji, Gabon, Gambia, Guinea, Guinea Bissau, Madagascar, Mauritania, Mauritius, Micronesia, Mozambique, Nauru, Palau, Papua New Guinea, Sao Tome and Principe, Seychelles, Sierra Leone, St Helena and Tanzania. Most of the above agreements are related to tuna fisheries. Terms and conditions of the access agreements vary from country to country.

Japan manages its fisheries through fishing effort regulation such as limitations on the number of licenses issued and restrictions on fishing methods as well as output controls, i.e., the TAC system. Seven species of fish and invertebrates are currently subject to the TAC system, covering 1.2 million t (or about a third of the total catch) in 2011[21]

[21] http://www.jafic.or.jp/tac/

Catch-MSY method for Japanese stocks

For Japan, the single-species analyses suggest that the overall catch could be increased by 60 % when considering the top 12 landed species, or 56 % when considering all 80 taxa, given fishing at single species F_{MSY} (Table 19). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 19. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Japanese catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Chub mackerel	214,834	333,362	0.64
Japanese flying squid	141,540	200,354	0.71
Alaska Pollack	113,499	165,798	0.68
Japanese anchovy	192,726	234,633	0.82
Pacific saury	70,469	154,433	0.46
Japanese jack mackerel	70,166	101,061	0.69
Pacific herring	29,426	103,148	0.29
Round herring	34,096	57,318	0.59
Pink salmon	26,721	23,168	1.15
Skipjack tuna	36,214	42,598	0.85
Yesso scallop	68,707	68,025	1.01
Okhostk atka mackerel	21,508	17,158	1.25
Average of top 12 (weighted)			**0.76 (0.40)**
Average of 80 taxa (weighted)			**0.62 (0.44)**

Malaysia[22]

Malaysia is divided into two geographical regions: Peninsular Malaysia and East Malaysia. East Malaysia is separated from the Malaysian Peninsula by several hundred kilometers of the South China Sea, and includes the states of Sabah and Sarawak, situated on the island of Borneo (Figure 18). The east and west coasts of Peninsular Malaysia are very different (Figure 19). The east coast faces the South China Sea, and has a sandy bottom due to the presence of patchy coral reefs that occur along the coast. The coast consists of long sandy beaches, which are broken up intermittently by estuaries and mangroves. This coast is subject to severe weather during the northeast monsoon (November to March), during which no fishing, or a very limited amount, takes place. In contrast, the west coast, which is bordered by the Strait of Malacca, is less exposed. There are few sandy beaches; instead, the coast is characterized by extensive mangrove lined areas with shallow muddy waters less than 100 m deep (Kesteven 1949; Abu Talib *et al.* 2003b). Eight of Malaysia's thirteen states are located on the west coast.

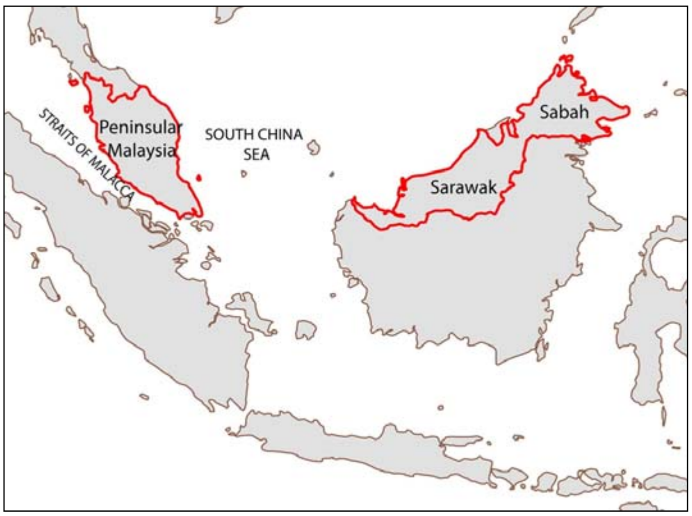


Figure 18. Map of Peninsular Malaysia and East Malaysia. East Malaysia is separated from the Peninsular by several hundred kilometers of the South China Sea, and includes the states of Sabah and Sarawak, situated on the island of Borneo.

Sarawak's EEZ covers an area of about 160,000 km^2 in the South China Sea. Its continental shelf covers 125,000 km^2 and slopes to 200 m in depth (Garces *et al.* 2003). In the north, a 2,000-2,500 m deepwater trench stretches towards Sabah waters (Gambang *et al.* 2003). Mangrove swamps and mudflats, with stretches of sandy and exposed shoreline, characterize the inshore area. Fishing effort in Sarawak is concentrated in near shore muddy areas. The fishing season in Sarawak is determined by the northeast monsoon from November to February, during which conditions are usually too rough for most small-scale fishers to go fishing.

Sabah is a state of Malaysia, situated on the northeast corner of Borneo. The state polices the territorial waters extending up to 12 nm, while the federal government has jurisdiction over the EEZ, measured as either 200 nm from shore or the midline between neighboring countries' landmasses. Sabah is bordered by the South China Sea in the west, the Sulu Sea to the northeast, and the Sulawesi Sea to the southeast. Mangroves and mudflats fringe the coastal zone, and many outlying islands are scattered offshore. Coral reefs are present in shallow waters throughout the state's coast, and are heavily exploited by Sabah's substantial population of subsistence and artisanal fishers.

Fisheries are an integral part of Malaysian society. They provide an affordable source of protein for up to two-thirds of Malaysia's population (Saharuddin 1995), and are crucial sources of income and employment in rural coastal fishing villages throughout the country, both historically and in present time (Firth 1966; Raduan *et al.* 2007). Uncontrolled expansion of commercial fishing from the mid-1960s through to the 1970s resulted in the overexploitation of Malaysia's inshore fisheries by the late 1970s (Omar *et al.* 1992; Saharuddin 1995; Abu Talib *et al.* 2003a). This was driven in part by the national government's production-oriented policies following

[22] This introduction was provided by Dr. L. Teh (Fisheries Centre, University of British Columbia), the lead author of the catch reconstruction for Malaysia presently being conducted.

national independence. Efforts to manage Malaysia's fisheries have been hampered by a lack of data on biological stocks, conflicting goals of government agencies involved in different aspects of fisheries, and lack of political support (Abdul Majid 1985; Yahaya 1988; Omar *et al.* 1992). Overcapacity in the fishing fleet is a key factor underlying the current degraded state of Malaysia's fisheries resources (Abdul Majid 1985; Mohd Taupek 2003). It is likely that this arose from historical and present levels of fishing that were, and still are, higher than accounted for by fisheries regulatory agencies.

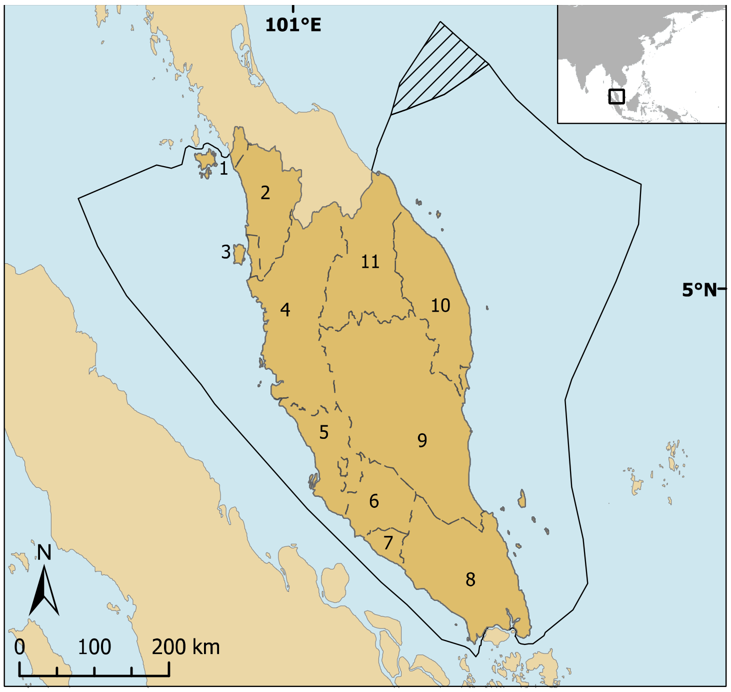


Figure 19. Map of Peninsular Malaysia showing the 200 nm EEZ adjacent to the mainland, all maritime states, and disputed regions (cross-hatch). The Malaysian mainland EEZ is part of the Gulf of Thailand LME and the South China Sea LME. Numbers correspond to maritime states: Perlis, Kedah, Pulau Pinang, Perak, Selagor, Negeri Sembilan, Melaka, Johor, Pahang, Trengganu, and Kelantan, 1-11 respectively. The area covered by the ecological model is not show due to the fact that it covers the Gulf of Thailand (north of the eastern Malaysian EEZ).

Malaysia's marine fisheries are primarily inshore (<30 nm from shore), and can be split into two sectors – 'traditional' (i.e., small-scale) and 'commercial'. The Malaysian Department of Fisheries (DoF) classifies trawl and purse seine as commercial gears, while traditional gears include drift/gill nets, hook and line, traps, fishing stakes, bag nets, lift nets, and barrier nets. Marine capture fisheries in Malaysia are multi-species, with over 100 species reported from the catch. Both pelagic and demersal species are targeted. Pelagics formed the mainstay of fisheries on both coasts of Peninsular Malaysia in the early period (Pathansali 1961; Firth 1966; Pong 1992), and continue to contribute substantial portions of marine landings (up to 40 % in 2010).

In Sarawak, demersal fishes make up the largest part of marine catches; pelagic fisheries are relatively small compared to those in Peninsular Malaysia due to the low numbers of purse seiners in operation (Gambang *et al.* 2003). Overall, shrimp is the most important demersal species group because of their high economic value (Nuruddin and Urn 1994), and the majority of shrimp is caught off the west coast of Peninsular Malaysia. Until the introduction of trawlers, prawns and shrimps were caught with traditional gears such as trammel nets, push nets, and bag nets. Sabah's marine capture fisheries are exploited by the commercial and small-scale sectors, which accounted for approximately 65 % and 35 % of annual total fisheries landings in 2004, respectively.

Sabah's total catches were previously reconstructed (Teh *et al.* 2009). This work suggested that Sabah's marine catches were 2.5 times higher than national reported landings, likely due to a poor knowledge about existing sources of fishing pressure. From the mid 1990s until 2006, the number of small-scale fishers in Sabah may have been up to 3 times higher than the number of officially reported fishers. In addition, the presence of unlicensed trawl vessels also led to reported commercial landings being underestimated.

Catch-MSY method for eastern Malaysian stocks

For eastern Malaysia, the single-species analyses suggest that the overall catch could be increased by 19 % when considering the top 12 landed species, or 11 % when considering all 34 taxa, given fishing at single species F_{MSY} (Table 20).

Table 20. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the eastern Malaysian catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Indian scad	43,074	39,159	1.10
Yellowstripe scad	5,229	8,289	0.63
Torpedo scad	6,494	8,036	0.81
Kawakawa	2,996	4,687	0.64
Largehead hairtail	7,281	7,101	1.03
Blue swimming crab	5,661	4,821	1.17
Brown mussel	2,224	3,692	0.60
Indian mackerel	4,549	4,774	0.95
Longtail tuna	14,185	11,251	1.26
Mangrove red snapper	4,551	4,880	0.93
Daggertooth pike conger	3,683	2,401	1.53
Banana prawn	2,297	1,764	1.30
Average of top 12 (weighted)			**1.00 (0.81)**
Average of 34 taxa (weighted)			**0.92 (0.89)**

Model results for eastern Malaysian ecosystems

We used the Gulf of Thailand model (Vibunpant *et al.* 2003) as a proxy representation of Malaysian marine ecosystems, although the model covers an area that is located north to the EEZ of Malaysia (Figure 19). The study area is located between 6° to 13° 30' N latitudes and 99° to 104° E longitudes, covering an area of 304,000 km^2. The Gulf of Thailand is relatively shallow with a mean depth of about 58 m. The model had been fitted to historic time series of data from 1973 to 1993.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and optimization simulations when the main target species are taken into account (Table 21, Figure 20a). Total catch is also higher under the *allFmsy* simulation and slightly lower under the *optimization* simulation. The average fishing mortality from 1973 to 1993 is similar in the historical exploitation regime and *optimization* simulation and higher in the *allFmsy* results (Figure 20b).

Table 21. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the eastern Malaysian ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch (t·km^{-2}·year^{-1}) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Rastrelliger species	0.220	0.230	0.110	0.9	1.9
Scomberomorus	0.003	3.96E-10	3.57E-11	>100	>100
Carangidae	0.040	0.030	0.020	1.6	2.9
Pomfret	0.010	3.98E-04	1.53E-05	13.0	>100
Small pelagics	0.200	0.380	0.120	0.5	1.6
False trevally	0.003	0.001	3.38E-04	4.7	9.3
Large piscivores	8.61E-07	0.010	0.020	0.0	0.0
Scianidae	0.003	0.050	0.040	0.1	0.1
Saurida species	0.040	0.030	0.030	1.1	1.1
Lutianidae	4.55E-07	0.010	0.010	0.0	0.0
Plectorhynchidae	0.001	0.002	0.002	0.4	0.5
Priacanthus species	0.030	0.050	0.030	0.6	1.0
Shrimps	0.310	0.250	0.230	1.3	1.4
Crab, Lobsters	0.190	0.490	0.150	0.4	1.3
Demersal piscivores	0.050	0.030	0.030	2.0	2.0
Shellfish	0.110	0.510	0.500	0.2	0.2
Coastal tuna	0.010	0.010	0.005	1.4	2.0
Sergestid shrimp	0.080	0.130	0.050	0.6	1.6
Total catch (sp table)	**1.280**	**2.210**	**1.320**	**0.58**	**0.97**
Total catch*	**2.840**	**4.010**	**2.570**	**0.71**	**1.10**

* Number of commercial taxa/groups in the model = 31

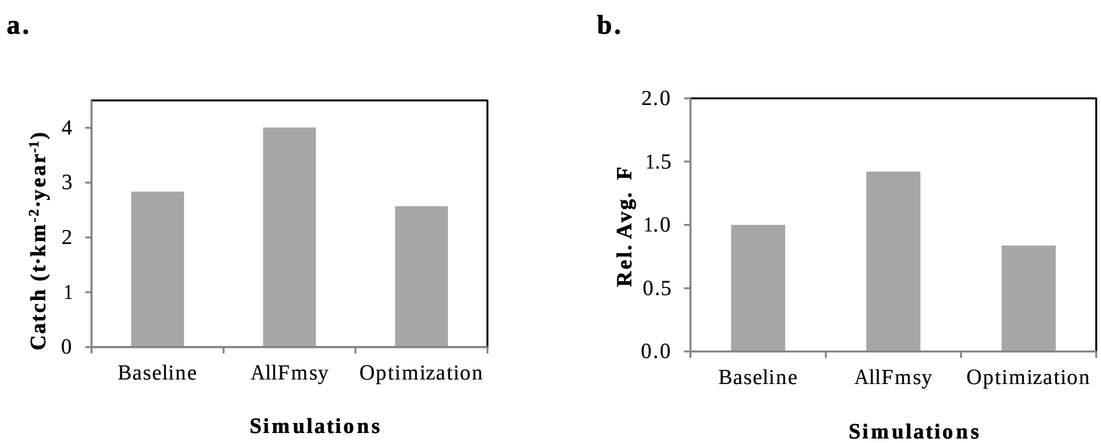


Figure 20. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the eastern Malaysian ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 11-29 % given fishing at single species F_{MSY}. However, the catch could not be increased when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass.

Catch-MSY method for western Malaysian stocks

For western Malaysia, the single-species analyses suggest that the overall catch could be increased by 18 % when considering the top 12 landed species, or 9 % when considering all 40 taxa, given fishing at single species F_{MSY} (Table 22). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 22. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the western Malaysian catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Indian scad	34,060	28,181	1.21
Torpedo scad	11,081	10,850	1.02
Yellowstripe scad	2,926	6,383	0.46
Indian pellona	8,527	9,643	0.88
Largehead hairtail	6,739	5,627	1.20
Blue swimming crab	5,152	4,031	1.28
Chacunda gizzard shad	2,999	3,039	0.99
Daggertooth pike conger	2,412	2,283	1.06
Mangrove red snapper	985	1,750	0.56
Banana prawn	4,193	2,940	1.43
Black pomfret	1,896	2,708	0.70
Brown mussel	1,231	2,281	0.54
Average of top 12 (weighted)			**0.94 (0.82)**
Average of 40 taxa (weighted)			**0.86 (0.91)**

Mexico[23]

Mexico is a federal republic in North America bordered in the north by the U.S., in the south by Guatamala and Belize, in the east by the Gulf of Mexico and in the west by the Pacific Ocean (Figure 21). The land area of Mexico is nearly 2 million km² and its population is almost 115 million. The majority of the population lives along the extensive coastline. This has resulted in strong ties to the fisheries and marine resources.

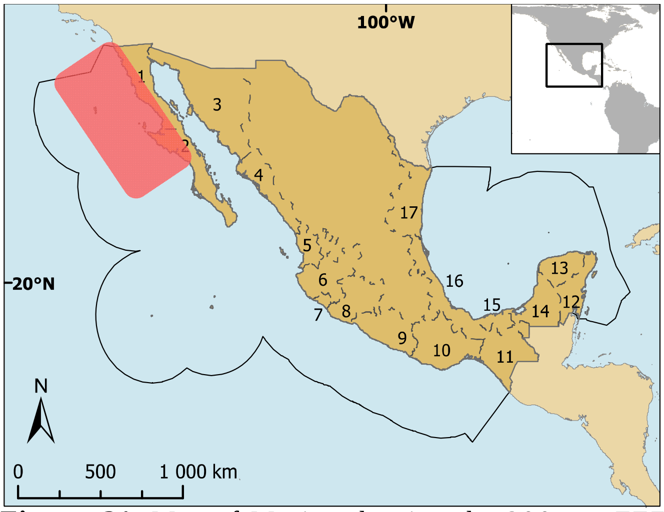


Figure 21. Map of Mexico showing the 200 nm EEZ adjacent to the mainland and all maritime states. The Mexican EEZ is part of three LMEs: the Gulf of California LME and the Pacific Central-American Coastal EEZ in the west and the Gulf of Mexico EEZ in the east. Numbers correspond to maritime states: Baja California, Baja California Sur, Sonora, Sinaloa, Nayarit, Jalisco, Colima, Michoácan, Guerrero, Oaxaca, Chiapas, Quintana Roo, Yucátan, Campeche, Tabasco, Veracruz, and Tamaulipas, 1-17, respectively. The area covered by ecological models is highlighted in red.

Fisheries in Mexico, reflecting the political system, have historically been characterized by constant shifts in objectives and management schemes (OECD 2006). They have thus evolved from an overlooked sector, to a primary source of food and job creation, to a casualty of economic reform and now to a tug-of-war between *laissez-faire* management on the one hand and ecological conservation priorities on the other (Espinoza-Tenorio *et al.* 2011). The participation and influence of scientists, academics and conservation organizations has also evolved towards a broader understanding of the socio-political and ecological context of Mexican fisheries, with increased training in and application of quantitative methods to assess fisheries' status (Hernández and Kempton 2003). Unfortunately, a lack of effective fisheries governance has resulted in highly uncertain fishery statistics, which often lack the quality that is required for their use within quantitative frameworks.

In general, the Mexican fishing industry is comprised of a very large artisanal sector (>100,000 registered vessels plus an unknown number of non-registered vessels) and a smaller (<5,000) industrial fleet of (mostly aging) trawlers, seiners and longliners. The most important fisheries by volume are small pelagics, particularly Pacific sardine (*Sardinops sagax*), though environmental changes have made for substantial fluctuations in landings (from ~ 100,000 t·year^{-1} in the 1990s to over 500,000 t·year^{-1} currently). The most valuable fishery continues to be for shrimp, with a current landed value of ~450 million USD (excluding aquaculture). Although these fisheries are usually at the forefront of management discussions, along with other valuable or large-volume fisheries such as tuna, lobster, squid and abalone, sub-tropical ecosystems along most of the Mexican coastline result in catch of many species in smaller amounts. It would be interesting to compare the social and economic value of these multi-species fisheries with that of the more prominent ones, which are usually destined for fishmeal and/or export.

In Mexico, the large fishing sector (>300,000 fishers), versatile boats and gear, a large coastline, corruption and a limited capacity for monitoring and enforcement result in significant illegal,

[23] This introduction was provided by A. Cisneros-Montemayor (Fisheries Centre, University of British Columbia), the lead author of the catch reconstruction for Mexico.

unreported and unregulated catch (Rodríguez-Valencia and Cisneros-Mata 2006). Official statistics rely on the compulsory, but unenforced submission to the local fisheries office of catch logs by (legal) fishers or buyers. There is little validation of catch, and logs are often filled in on the spot by fishery officers based on the fishers' accounts from memory (Espinosa-Romero *et al.* 2012). A survey of Mexican fishery experts including scientists, officials, fishers and others, found that in some fisheries, 'irregular' fishing (unreported and illegal) currently represents 40-60 % of reported catch (Cisneros-Mata 2012). This estimate does not account for discards in shrimp trawls, which historically have had a 1:10 shrimp to bycatch ratio and are widely regarded as the single most important source of unreported bycatch (Vázquez et al. 2004).

Overall, the historic management of fisheries in Mexico has led to both ecological and economic waste of potentially valuable resources. On the other hand, fisheries have become an important source of direct and indirect employment along all coasts, making enforcement of regulations difficult both operationally and politically. Addressing sustainability issues will require full knowledge of the context in which fisheries and management have evolved in the country. Though developing, and particularly enforcing, new regulations will be difficult, there is an increasing number of people in Mexico, including within the fishing industry, who recognize the need for management reform, and will hopefully act to support it.

Catch-MSY method for Mexican (Gulf of Mexico) stocks

For the Gulf of Mexico, the single-species analyses suggest that the overall catch could be increased by 65 % when considering the top 12 landed species, or 64 % when considering all 31 taxa, given fishing at single species F_{MSY} (Table 23). However, the absence of an ecosystem model precludes evaluation of ecosystem effects, such as trophic interactions, on this evaluation.

Table 23. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Mexican Gulf of Mexico catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
American cupped oyster	45,121	40,760	1.11
Blue crab	3,481	7,153	0.49
Common octopus	15,223	12,092	1.26
Common snook	5,640	4,595	1.23
Flathead mullet	1,478	4,581	0.32
King mackerel	7,035	4,517	1.56
Northern red snapper	927	2,452	0.38
Red grouper	38	3,732	0.01
Spanish mackerel	3,213	3,533	0.91
Spotted weakfish	1,600	3,121	0.51
Round sardinella	351	1,776	0.20
Yellowtail snapper	844	832	1.01
Average of top 12 (weighted)			**0.75 (0.35)**
Average of 31 taxa (weighted)			**0.65 (0.36)**

Catch-MSY method for Mexican (Pacific) stocks

For the Mexican Pacific, the single-species analyses suggest that the overall catch could be increased by 13 % when considering the top 12 landed species, or 12 % when considering all 20 taxa, given fishing at single species F_{MSY} (Table 24).

Table 24. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Mexican Pacific catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	**Catch**	**MSY**	**Catch:MSY**
Pacific sardine	551,165	493,872	1.12
Californian anchovy	4,635	92,316	0.05
Jumbo flying squid	40,281	23,225	1.73
Yellowfin tuna	15,222	13,974	1.09
Chub mackerel	6,109	10,678	0.57
Pacific calico scallop	3,998	6,638	0.60
Pacific sierra	7,562	7,181	1.05
Pacific bonito	157	8,020	0.02
Skipjack tuna	1,605	3,935	0.41
Yellow snapper	1,111	2,595	0.43
Totoaba	366	1,343	0.27
Bigeye tuna	31	1,606	0.02
Average of top 12 (weighted)			**0.61 (0.87)**
Average of 20 taxa (weighted)			**0.64 (0.88)**

Model results for Mexican (Pacific) ecosystems

We used the Baja California Sur model (Cisneros-Montemayor 2007) as a representation of Mexican marine ecosystems (Figure 21). The study area is located between 33° N to 28° 30’ N latitudes and 119° E to 111° E longitudes with an area of 286,740 km^2. The model had been fitted to historic time series of data from 1972 to 2007.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and *optimization* simulations (Table 25, Figure 22a). The average fishing mortality from 1972 to 2007 is lower in the historical exploitation regime than in the *allFmsy* and *optimization* simulations (Figure 22b).

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 12-20 % given fishing at single species F_{MSY}. Indeed, the ecosystem model suggests that the catch could actually be increased by 48 % under optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass. However, the fact that the ecosystem model produces these optimistic results may be attributed in part to the small area it covers.

Table 25. Catch rate ($t \cdot km^{-2} \cdot year^{-1}$) from the historical exploitation period (1: *baseline*) from the Mexican Pacific ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	**Catch ($t \cdot km^{-2} \cdot year^{-1}$)** 1. Baseline	2. AllFmsy	3. Optimization	**Catch:MSY** 1/2	1/3
Large_sharks	0.010	0.010	0.010	0.7	1.2
Small_sharks	0.010	0.020	0.020	0.8	0.8
Marlin	0.030	0.050	0.040	0.6	0.8
Yellowfin_tuna	0.030	0.070	0.060	0.4	0.4
Dorado	0.010	0.010	0.004	0.8	2.7
Skipjack_tuna	0.020	0.020	0.010	0.9	2.9
Sailfish	0.020	0.050	0.030	0.4	0.7
Other_billfish	0.005	0.005	0.001	1.1	3.9
Small_scombrids	0.040	0.020	0.020	1.6	2.4
Misc_piscivores	0.010	0.010	0.005	1.6	2.5
Squids	0.840	0.520	0.350	1.6	2.4
Small_pelagics	0.770	1.460	2.910	0.5	0.3
Total catch (sp table)	**1.800**	**2.250**	**3.440**	**0.80**	**0.52**
Total catch*	**1.800**	**2.250**	**3.440**	**0.80**	**0.52**

* Number of commercial taxa/groups in the model = 12

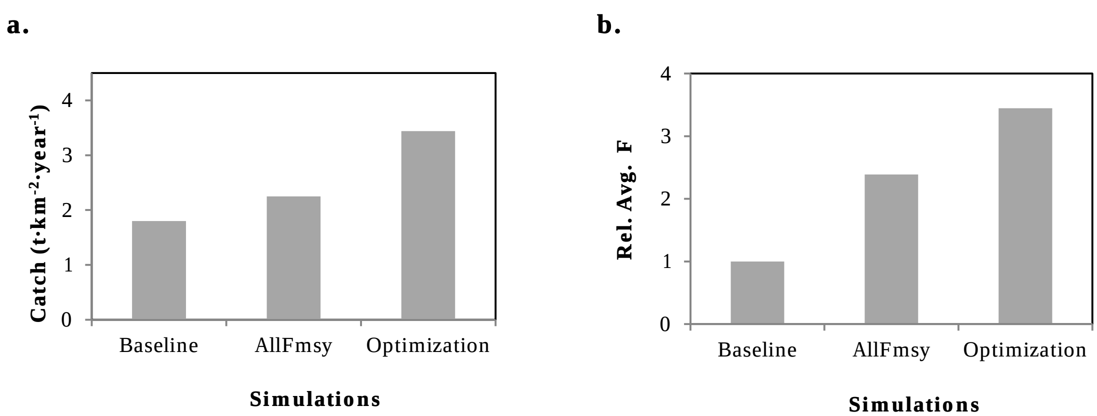


Figure 22. a) Predicted total catches ($t \cdot km^{-2} \cdot year^{-1}$), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the Mexican Pacific ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Morocco[24]

Morocco is located to the west of Algeria in northwest Africa, and it shares the Alboran Sea with Spain in the North (Figure 23). On the West African coast, Morocco (including the Western Sahara) range from Tangier (36° N) to Lagouira (20° N) on Cape Blanc, which is one of the richest fishing areas in the world, due to the sustained East central Atlantic upwelling (Porter 1997). Morocco proclaimed its EEZ in 1981. Morocco maintains Western Sahara under its administration since invading it in 1976, after Western Sahara became independent from Spain (Rojo-Diaz and Pitcher 2005). Morocco is located on the boundary between the Mediterranean Sea and the Atlantic Ocean, and experiences high productivity due to the flow of the Atlantic current into the Mediterranean Sea. Western Sahara is located south of Morocco, and is also bordered by Mauritania and Algeria. The Moroccan and Western Saharan EEZs are respectively 254,000 km^2 and 300,600 km^2, and together encompass the Canary Current Large Marine Ecosystem, within which high marine productivity supports some of the most valuable fishing operations in the world (Cruzado 1979; Pauly *et al.* 2008). The narrow shelf of Morocco offers good opportunities for pelagic fishing fleets, while a larger continental shelf along the Western Sahara, along with coastal upwelling, result in significant demersal and cephalopod resources for foreign fleets to exploit (Cruzado 1979; Pauly *et al.* 2008).

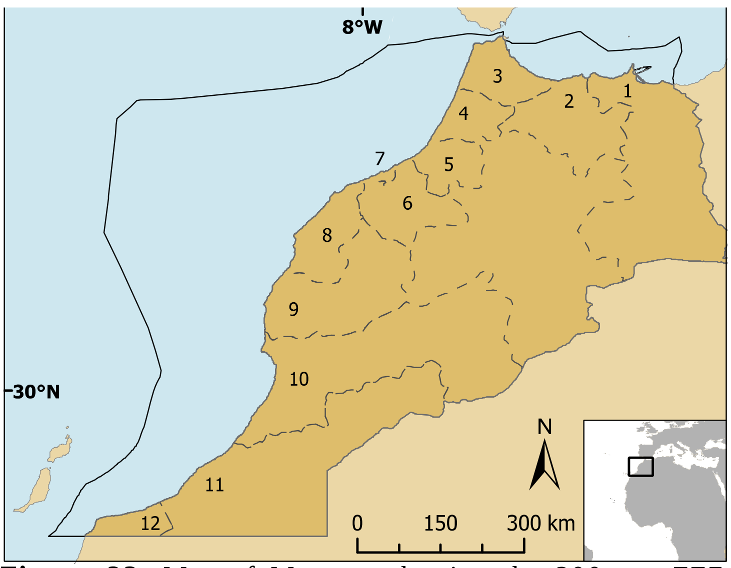


Figure 23. Map of Morocco showing the 200 nm EEZ adjacent to the mainland and all maritime states. The Moroccan EEZ is part of the Mediterranean Sea LME and the Canary Current LME. Numbers correspond to maritime states: Oriental, Taza, Tanger, Gharb, Rabat, Chaouia, Grand Casablanca, Doukkala, Marrakech, Souss, Guelmim, and Laâyoune, 1-12 respectively. The area covered by ecological models includes the entire EEZ of Morocco.

The artisanal fishery is an informal sector in Morocco, and there are no data collection systems (Malouli Idrissi *et al.* 2001; ArtFiMed 2009). The domestic fisheries consist mostly of small wooden dories called *pateras* targeting mainly small fish and other valuable species. This category also includes hand collection of algae and mussels and shore-based fishing using lines (Baddyr and Guénette 2001). The large-scale fisheries include two types of activities: inshore or coastal fisheries initiated by Spanish and Portuguese fishers with 16 to 24 m wooden boats manufactured locally without catch preservation system, targeting pelagic species using purse seines, demersal species using long liners, bottom trawls and driftnets, and the off-shore industrial fishery which started in 1972. It consists almost exclusively of large freezer trawlers fishing for several weeks at a time (Tudela 2000; Baddyr and Guénette 2001; Franquesa *et al.* 2001; Rojo-Diaz and Pitcher 2005; FAO 2011b). Fishing off Morocco and the Western Sahara has been a major activity since the 1930s, and the industry experienced tremendous growth during the 1980s (Rojo-Diaz and Pitcher 2005). However, heavy exploitation by both national and foreign vessels (Ariz 1985; Baddyr and Guénette 2001)**,** a lack of monitoring and enforcement, and an interest in short-term profits from resource exploitation rather than long-term benefits (Kaczynski 1989) resulted in over-exploitation of important demersal stocks,

[24] This introduction was provided by Ms. D. Belhabib (Fisheries Centre, University of British Columbia), the lead author for the Moroccan catch reconstruction presently being completed.

shifting stocks (Balguerías *et al.* 2000; Baddyr and Guénette 2001; Pitcher *et al.* 2002; Anon. 2005a) and increasing illegal unreported and unregulated fisheries (Anon. 2005b). Importantly, fisheries contribute to the livelihood of around 400,000 people in poor, rural areas, and represent 15 % of the total Moroccan exports (including from Western Saharan waters). Moreover, 20% of the Moroccan population suffers from protein deficit and live under the poverty line (Anon. 2005a).

Catch-MSY method for Moroccan stocks

For Morocco, the single-species analyses suggest that the overall catch could not be increased when considering the top 12 landed species, or when considering all 67 taxa, given fishing at single species F_{MSY} (Table 26). However, a straight average of the catch:MSY ratios for all 67 taxa does indicate that a catch increase of approximately 40 % could be achieved.

Table 26. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Moroccan catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	**Catch**	**MSY**	**Catch:MSY**
European pilchard	573,982	512,669	1.12
Chub mackerel	44,785	34,143	1.31
European anchovy	7,322	15,556	0.47
European hake	7,951	5,115	1.55
Largehead hairtail	4,190	4,871	0.86
Bogue	4,676	4,130	1.13
Yellowfin tuna	406	1,626	0.25
Pouting	1,800	1,748	1.03
Skipjack tuna	1,084	1,659	0.65
Meagre	3,126	1,984	1.58
Atlantic bluefin tuna	1,088	1,191	0.91
European conger	1,824	931	1.96
Average of top 12 (weighted)			**1.07 (1.06)**
Average of 67 taxa (weighted)			**0.59 (1.08)**

Model results for Moroccan ecosystems

We used the North West Africa model (Morissette *et al.* 2010) as a representation of Moroccan marine ecosystems (Figure 23). The model includes latitudes from 8.5° to 35.97° N, and longitudes from 30° to 6.5° W, for a total area of 3.6 million km^2. The model had been fitted to historic time series of data from 1986 to 2007.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and *optimization* simulations (Table 27, Figure 24a). The average fishing mortality from 1986 to 2007 is lower under the historical exploitation than the other two simulations (Figure 24b).

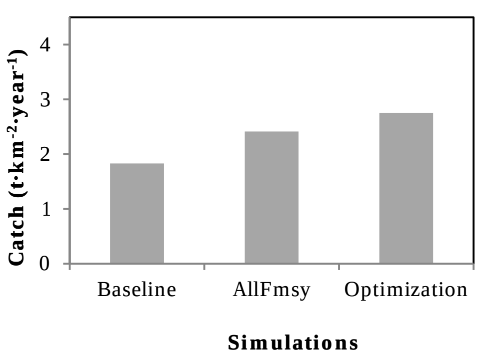
We note a divergence between the single-species and the ecosystem-based analyses, as the catch could be increased by 24 % when we account for fishing at F_{MSY} or 34 % with optimal management, which includes fishing at F_{MSY}, biodiversity, and criteria for rebuilding biomass. However, no increase would be possible under the catch-based evaluation. The more optimistic results from the ecosystem model may be due to the fact that it encompasses a large fraction of the North African shelf.

Table 27. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the Moroccan ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch (t·km^{-2}·year^{-1}) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Large pelagics	0.0500	0.060	0.070	0.90	0.70
Mesopelagic predators	0.0001	0.003	0.005	0.03	0.02
Bathydemersal predators	0.0300	0.030	0.050	1.00	0.70
Sharks	0.0200	0.010	0.010	2.30	1.40
Rays	0.0100	0.005	0.005	2.50	2.40
Coastal tunas	0.0100	0.030	0.030	0.20	0.20
Coastal demersals	0.1700	0.220	0.310	0.80	0.50
Clupeids	0.8800	1.110	1.350	0.80	0.70
Other coastal pelagics	0.4300	0.720	0.620	0.60	0.70
Cephalopods	0.2100	0.170	0.230	1.30	0.90
Crustaceans	0.0100	0.040	0.060	0.30	0.20
Benthos	0.0100	0.010	0.020	0.60	0.30
Total catch (sp table)	**1.8300**	**2.410**	**2.750**	**0.760**	**0.660**
Total catch*	**1.8300**	**2.410**	**2.750**	**0.760**	**0.660**

* Number of commercial taxa/groups in the model = 12

a.



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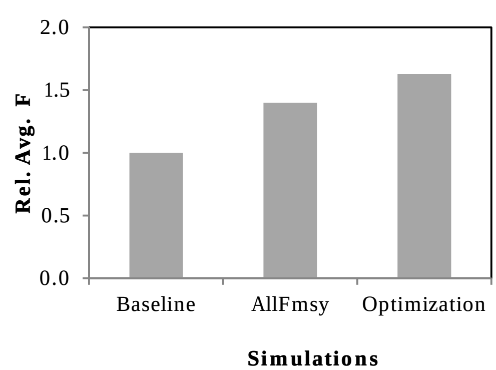


Figure 24. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the Moroccan ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Norway[25]

The mainland of Norway is located in the north of the European continent between 58˚and 71˚N and between about 5˚and 31˚E, with a land area of around 323,800 km² and an EEZ of 819,600 km² (Figure 25). Additionally, the Svalbard Archipelago (with a land and sea area of 61,000 km² and 715,000 km², respectively) and the island of Jan Mayen (with a land and sea area of 377 km² and 288,800 km², respectively) belong to Norway. In the southern hemisphere, Norway also holds the Queen Maud Land in the Antarctic, Peter I Island, and Bouvet Island.

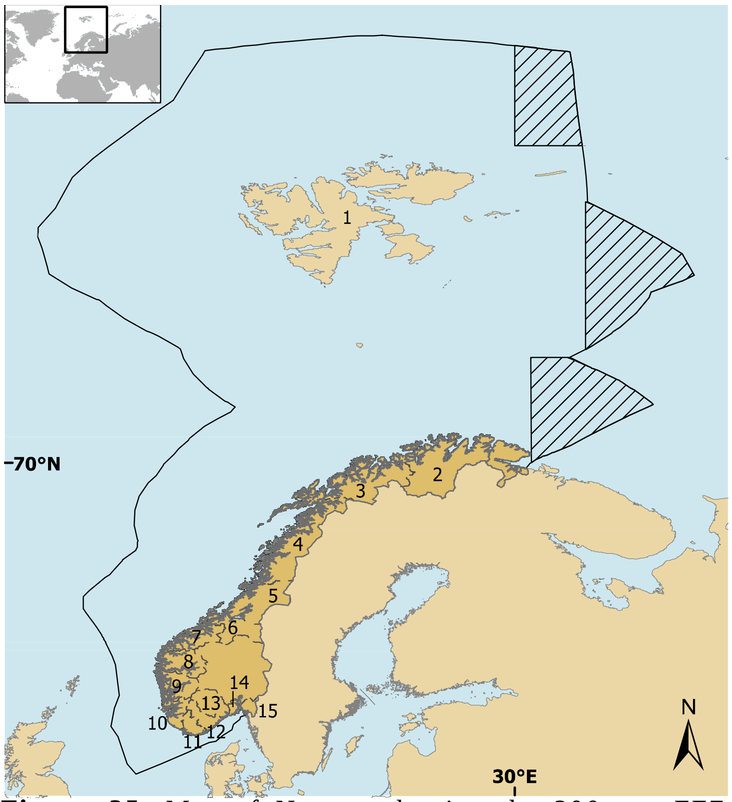


Figure 25. Map of Norway showing the 200 nm EEZ adjacent to the mainland, including the EEZ of the Svalbard Islands (1), all maritime states, and regions (cross-hatch) that were disputed with Russia until 2011. The Norwegian EEZ is part of the Barents Sea LME, Norwegian Sea LME, and the North Sea LME. Numbers correspond to maritime states: Svalbard, Finnmark, Troms, Nordland, Nord-Trøndelag, Sør-Trøndelag, Møre og Romsdal, Sogn og Fjordane, Hordaland, Rogaland, Vest-Agder, Aust-Agder, Telemark, Vestfold, and Ãstfold, 1-12 respectively. The area covered by ecological models includes the entire EEZ of Norway.

The Norwegian sea occupies three shelf ecosystems: the Barents Sea (mean depth 230 m), the North Sea (94 m) and the Norwegian coast, and one deep ocean ecosystem: the Norwegian Sea (1,600 m). There are 431 municipalities, 280 of which are coastal. Norway hosts more than 5 million people. Fossil fuel and renewable marine resources are fundamental to the national economy, with seafood representing the third most important commodity.

Given the generally high human population along its shores and the long history and diversity of human impacts, the Norwegian EEZ has been altered throughout history, mainly due to the extensive oil and gas industry since the 1970s. At present, fishing impacts, as well as habitat loss and degradation, and pollution are the most important threats to diversity. However, no eradication of marine species has been seen in recent history (Kålås *et al.* 2010). In Norwegian waters in the northern hemisphere, 268 marine fish species are registered, of which 168 reproduce in these waters. Since 2006, Norway has produced and published a Red List for marine fish species in Norwegian waters using the IUCN criteria and categories, with the intent of updating it regularly every 5 years. The 2010 Red List contains 17 marine fish species, representing 6 % of all marine fish species, in different Red List categories. Since 2006, 16 species have been removed from the Red List, mainly due to more knowledge and focus on conservation and protection of species and habitat.

[25] This introduction was provided by Dr. Kjell Nedreaas (Institute of Marine Research, Bergen), the lead author of the Norwegian catch reconstruction being conducted at present.

The total Norwegian landings of wild commercial fish, shellfish and seaweed was 2.4 million t in 2011, with a value of US$ 2.7 million. The recreational fishery is estimated to be about 57,000 t, of which about 48,000 t is estimated to be caught by the domestic fleet and 7,000-9,000 t by a growing foreign tourist fishing industry (Moksness *et al.* 2011).

The number of active Norwegian fishing vessels of all sizes reached a peak of more than 40,000 vessels around 1960. Since the turn of the century, the total number of vessels has been reduced from 13,017 in 2000 to 6,248 in 2011. This implies a reduction of 52 % of fleet capacity. The main reason for the reduction in the number of vessels is the removal of inactive coastal vessels from the register and a vessel scrapping scheme. In 2011, the Norwegian commercial fishing fleet consisted of 5,635 vessels (90 %) less than 15 m in length, and 613 vessels (10 %) larger than 15 m. Also, the total number of fishers was reduced by about 36 % or 7,284 persons from 2000 to 2011.

There are four main types of gear used by groundfish vessels in the Norwegian commercial fisheries: trawl (37 %), gillnet (23 %), longline (17 %), and Danish seine (11 %). There is also an important seasonal, coastal purse seine fishery for young saithe (*Pollachius virens*; 8 %) and a jigging fishery (4 %) composed of smaller vessels that always deliver their catches to shoreside processing plants. In the pelagic fishery, purse seiners and pelagic trawlers catch about 89 % and 10 % of the total landings, respectively.

Discarding fish is illegal for most of the marine fish species. The main elements of the Norwegian discard policy are the defined minimum mesh size and minimum catch size of fish, the requirement to change fishing grounds if catching too many undersized fish, the temporary closure of fishing grounds (since 1984), bans on discard of commercial important species (since 1987; since 2008 extended to account for nearly all fish species), and the development of selective gear technology in the fishery, for deep-water shrimp since 1992 and in the fishery for demersal fish species since 1997. Despite the ban on discards, there is still some discarding that occurs. Unfortunately, information on discards is fragmented and incomplete. Norway is currently running a pilot project to better quantify the discards in several fisheries and establish cost-effective routines under a management regime where discarding is forbidden.

From 1985-2011, the spawning stocks of the main pelagic species have increased by a factor of 3 from about 6 million t to about 18 million t. Likewise, the spawning stocks of the main commercial demersal species have increased from less than 1 million t to 2.6 million t. Norwegian official landings increased from the 1950s to the mid-1960s then decreased. Since 1985, landings have steadily increased from about 1.7 million t to about 2.4 million t.

Important elements in the Norwegian management framework to prevent overfishing and to secure long-term sustainability have been developed during the last decades. These consist of limiting the access to the fisheries, ending subsidies, reducing overcapacity, distributing annual fishing opportunities within the industry including stakeholder participation, increasing international cooperation and agreements, improving exploitation pattern and discard policy, implementing harvest control rules (e.g., the *MSY* approach), enhancing monitoring, control and surveillance, and adopting an ecosystem approach, including an integrated Ocean Management Plan and a new (2008) Marine Living Resources Act (Gullestad *et al.* 2012).

Catch-MSY method for Norwegian stocks

For Norway, the single-species analyses suggest that the overall catch could be increased by 31 % when considering the top 12 landed species, or 26% when considering all 74 taxa, given fishing at single species F_{MSY} (Table 28).

Table 28. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Norwegian catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	**Catch**	**MSY**	**Catch:MSY**
Atlantic herring	852,920	925,004	0.92
Atlantic cod	252,231	331,397	0.76
Saithe	206,035	222,333	0.93
Capelin	4,670	225,251	0.02
Norway pout	34,907	139,118	0.25
Atlantic mackerel	134,369	130,102	1.03
Haddock	61,953	92,127	0.67
Blue whiting	240,643	143,603	1.68
Whiting	5,801	23,844	0.24
European sprat	7,212	23,900	0.30
Tusk	9,482	14,075	0.67
Ling	9,960	12,815	0.78
Average of top 12 (weighted)			**0.69 (0.69)**
Average of 74 taxa (weighted)			**0.71 (0.74)**

Model results for Norwegian ecosystems

We used the Norwegian Sea and Barents Sea model (Dommasnes *et al.* 2001) as a representation of Norwegian marine ecosystems (Figure 25). The model covers ICES areas I, IIa and IIb north to approximately 81° N, which includes the Barents Sea and the Norwegian Sea, to 11° W and to 63°-64 ° N. The total surface area is 3,116,000 km^2. The model had been fitted to historic time series of data from 1950 to 2007.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy*, and similar results to the *optimization* simulations (Figure 26a, Table 29). The average fishing mortality from 1950 to 2007 is lower under the historical exploitation than the other two simulations (Figure 26b).

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 26-30 % given fishing at single species F_{MSY}. However, the catch could not be increased when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass.

Table 29. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the Norwegian ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch (t·km^{-2}·year^{-1}) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Cod 4+	0.2300	0.2600	0.2600	0.9	0.9
Haddock	0.0600	0.0600	0.0500	1.0	1.2
Saithe	0.0500	0.0600	0.0400	0.9	1.2
Blue whiting	0.0200	0.0700	0.0100	0.2	1.6
Mackerel	0.0300	0.0700	0.0300	0.5	1.3
Other pelagic fish	0.0100	0.0300	0.0100	0.3	1.2
Herring 4+	0.4600	0.5000	0.4800	0.9	1.0
Polar cod	0.0020	0.0100	0.0020	0.2	1.6
Capelin	0.0200	0.0300	0.0040	0.6	4.1
Redfish	0.0100	0.0200	0.0100	0.4	1.6
Squid	0.0001	0.0003	<0.0001	0.2	1.7
Prawns	0.0100	0.0500	0.0100	0.2	1.5
Krill	0.0010	0.0030	0.0004	0.2	1.6
Total catch (sp table)	**0.9000**	**1.1700**	**0.8900**	**0.76**	**1.01**
Total catch*	**0.9300**	**1.3200**	**0.9100**	**0.70**	**1.02**

* Number of commercial taxa/groups in the model = 17

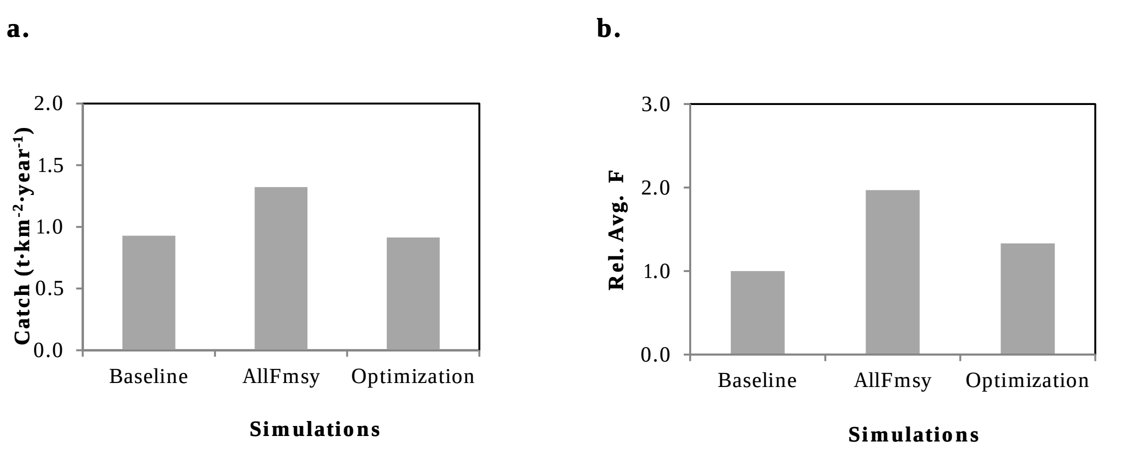


Figure 26. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the Norwegian ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Peru[26]

Peru claims an exclusive economic zone of more than 906,000 km², some of it contested by Chile, its southern neighbor (Figure 27). Peru also shares the Humboldt Current with Chile, a large marine ecosystem characterized by intense upwelling and high productivity (see www.seaaroundus.org/lme/13.aspx, and contributions in Pauly *et al.* 1987; Werner *et al.* 2008).

Much of this productivity is, off Peru, shunted through immense schools of Peruvian anchoveta (*Engraulis ringens*), which, since the early 1950s, has been subjected to intense exploitation by the purse seine fishery. This peaked in the early 1970s with an annual (nominal) catch of 12 million t, but which was most probably higher, in the vicinity of 16-18 million t (Castillo and Mendo 1987).

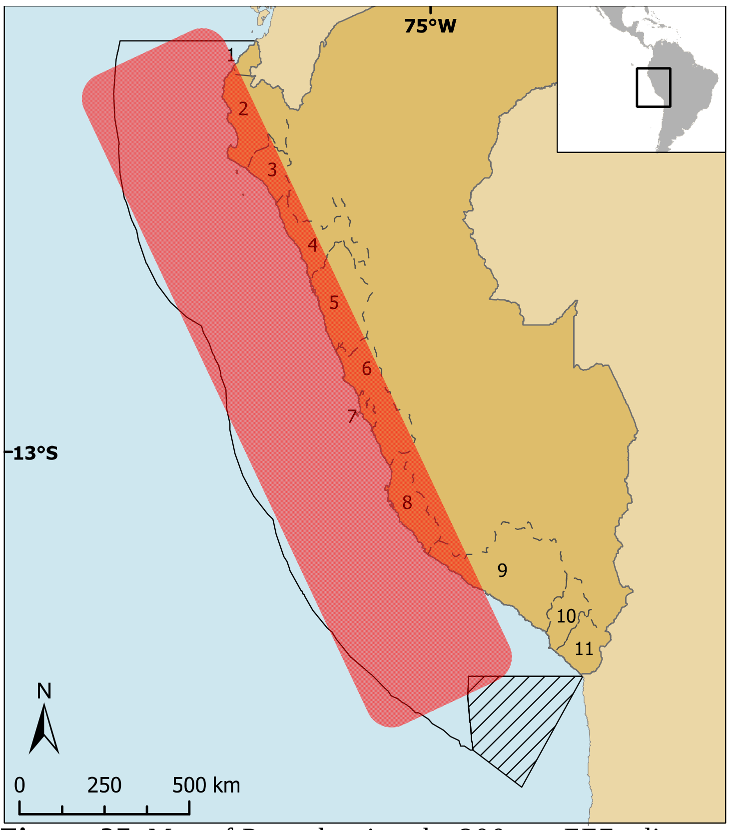


Figure 27. Map of Peru showing the 200 nm EEZ adjacent to the mainland, all maritime states, and disputed region (cross-hatch). The Peruvian EEZ is part of the Humboldt Current LME. Numbers correspond to maritime provinces: Tumbes, Piura, Lambayeque, La Libertad, Ancash, Lima Province, Lima, Ica, Arequipa, Moquegua, and Tacna, 1-11 respectively. The area covered by ecological models is highlighted in red.

By present standards (Pikitch *et al.* 2012), this fishery, which overwhelmingly fed fishmeal plants, was not well-managed. This, combined with successive El Niño events, led to spectacular crashes of the anchoveta population, with subsequent collapse of the anchoveta-dependent seabird and marine mammal populations.

The anchoveta fishery is now subjected to quota management, which foresees that it ought to be closed when the anchoveta biomass reaches 4-5 million t. However, frenetic fishing for juvenile anchoveta, and their subsequent dumping to avoid fines is now affecting recruitment to the adult stock.

The other components of the Peruvian upwelling ecosystem, e.g., the pelagic bonito (*Sarda chiliensis*) and various coastal fishes, notably croakers (Family Sciaenidae), caught by the coastal artisanal fishery are not well studied, let alone managed, while the trawl fishery for hake (*Merlucius gayi peruanus*) has essentially collapsed.

Overall, it can be expected that the biomass of demersal nearshore fish would be enhanced by sound management, while re-establishing the abundance of anchoveta and associated pelagic resources (e.g., bonito) will require restraints on the fishery and favorable oceanographic conditions.

[26] This introduction was provided by Dr. D. Pauly (Fisheries Centre, University of British Columbia).

Catch-MSY method for Peruvian stocks

For Peru, the single-species analyses suggest that the overall catch could be increased by 27 %, both when considering the top 12 landed species or all 21 taxa, given fishing at single species F_{MSY} (Table 30).

Table 30. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Peruvian catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Anchoveta	7,370,235	8,721,099	0.85
Pacific sardine	61,570	1424,826	0.04
Inca scad	145,229	129,435	1.12
Chub mackerel	66,846	119,610	0.56
Peruvian hake	30,522	83,533	0.37
Eastern Pacific bonito	4,218	106,935	0.04
Jumbo flying squid	214,491	157,731	1.36
Pacific menhaden	7,163	25,635	0.28
Cholga mussel	9,989	8,580	1.16
Peruvian calico scallop	14,362	8,405	1.71
Peruvian banded croaker	1,523	6,284	0.24
Skipjack tuna	670	12,509	0.05
Average of top 12 (weighted)			**0.65 (0.73)**
Average of 21 taxa (weighted)			**0.66 (0.73)**

Model results for Peruvian ecosystems

We used a combined version of previously available Peru models (Guénette *et al.* 2008) as a representation of Peruvian marine ecosystems (Figure 27). This model of the Peruvian ecosystem encompasses the coast of Peru between latitudes 4° and 14° S, out to an average of 40 nm offshore (Jarre *et al.* 1991) for a total area of 82,000 km^2, and corresponding to the main distribution area of the north-central stock of Peruvian anchovy. The model had been fitted to historic time series of data from 1950 to 2011.

The *baseline* simulation results show higher catch in the area under the *allFmsy* and the *optimization* simulations with respect to the historical exploitation regime (Table 31, Figure 28a). The average fishing mortality from 1950 to 2011 is similar under the historical exploitation and the *allFmsy* simulation, and lower under the optimization simulation (Figure 28b).

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 12-20 % given fishing at single species F_{MSY}. However, the catch could be increased by 48 % when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass. The more optimistic results may be attributed to the fact that the ecosystem model accounts for past climate variability in addition to trophic interactions.

Table 31. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the Peruvian ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

	Catch (t·km^{-2}·year^{-1})			**Catch:MSY**	
Exploited species / groups	**1. Baseline**	**2. AllFmsy**	**3. Optimization**	**1/2**	**1/3**
Tuna	0.020	0.050	0.0100	0.300	1.100
Bonito	1.72E-05	1.31E-20	0.0200	>100	0.001
Pacific mackerel	0.050	0.120	0.0100	0.400	3.600
Jack mackerel	0.150	0.100	0.0001	1.500	>100
Anchoveta	2.020	3.110	5.6900	0.600	>100
Anchoveta, south	0.660	1.820	0.8000	0.400	0.800
Pelagic S	0.220	0.003	3.86E-05	82.400	>100
Pelagic ML	0.110	0.180	0.0100	0.600	10.500
Demersal M	0.040	0.100	0.0020	0.400	23.100
Flatfishes	0.002	0.010	0.0001	0.200	36.500
Megabenthos	0.001	0.220	0.0010	0.005	0.900
Scallops	3.02E-05	0.003	3.03E-05	0.011	1.000
Total catch (sp table)	**3.260**	**5.700**	**6.5500**	**0.570**	**0.500**
Total catch*	**3.340**	**5.770**	**6.5700**	**0.580**	**0.510**

* Number of commercial taxa/groups in the model = 17

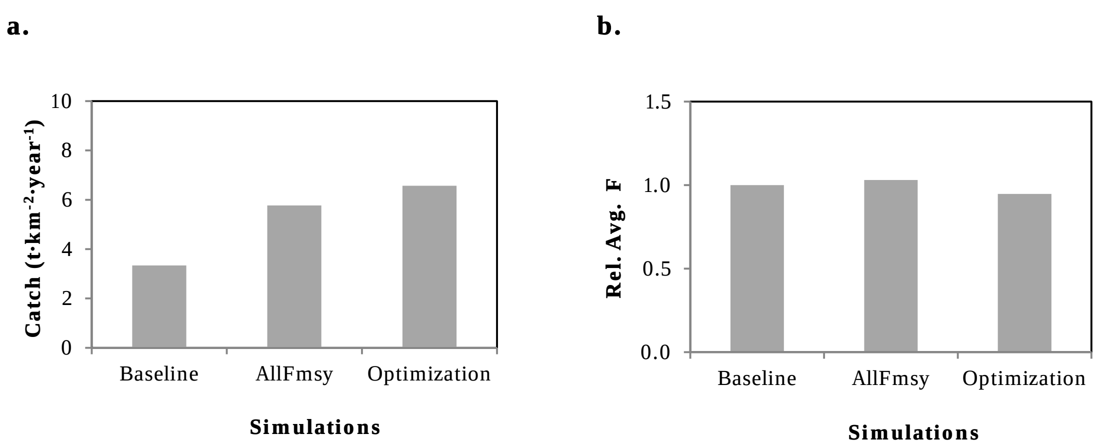


Figure 28. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the Peruvian ecosystem, relative to the historical period value), under the baseline, the *allFmsy* and *optimization* simulations, respectively.

Philippines[27]

The Philippines, consisting of over 7,000 islands of various sizes (Figure 29), encompasses most of the Sulu-Celebes Sea LME, a world hotspot of marine biodiversity (Randall 1998; Carpenter and Springer 2005; Hoeksema 2007; Carpenter *et al.* 2011). These islands cover a land area of 300,000 km², while the EEZ that might be claimed by the Philippines covers an area of 2.3 million km² (ADB 1993), including parts of the hotly contested Spratly Islands group, Scarborough Shoal, and Miangas Island (Bautista 2008)[28]. About 12 % of this sea area consists of continental shelf (to 200 m depth), hosting coral reefs, mangrove and algal ecosystems, i.e., the habitats of a large number of valuable species supporting coastal fisheries. The Philippine islands are organized into 14 administrative regions covering 81 provinces (80 % coastal) and 1,514 municipalities (65 % coastal; see ADB 1993). Fisheries are administered locally, i.e., by the municipal governments, a form of micro-management which renders implementation of fisheries rules and regulations rather difficult, and produces very variable results (see e.g., Fabinyi and Dalabajan 2011), although it allows flexibility, a theme to which we shall return.

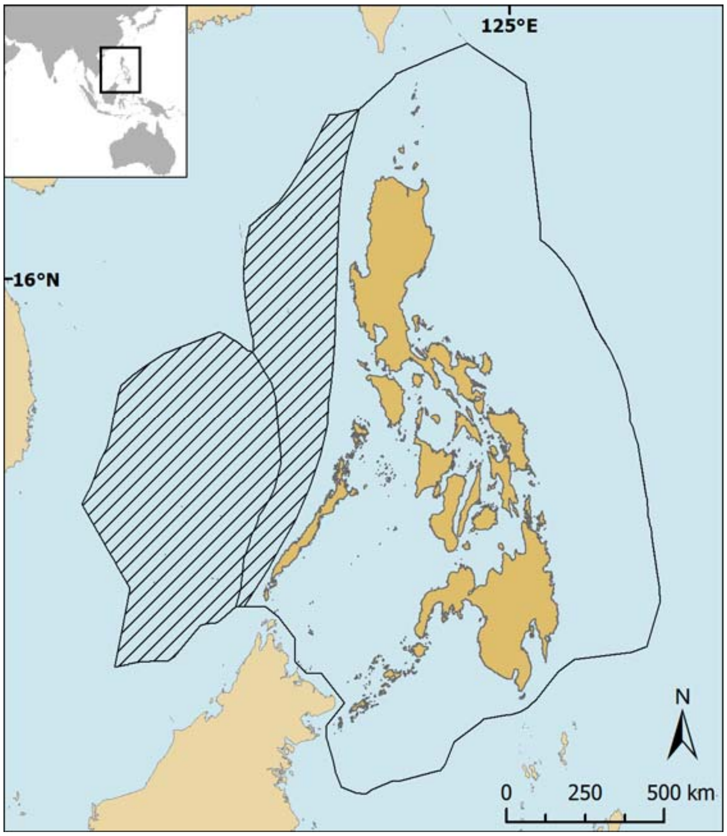


Figure 29. Map of the Philippines showing the 200 nm EEZ. The Philippine EEZ is part of the Sulu-Celebes Sea LME. Shaded area indicates part of the EEZ disputed by other countries.

In addition, due to the archipelagic nature of the Philippines, with monsoon seasons affecting its huge biodiversity, no single (or small group of) species dominates its fisheries catches. In fact, even abundant taxa, such as 'galunggong' (i.e., 'round scads', of the genus *Decapterus*) consist of different species and populations, caught in different parts of bays, gulfs and seas, depending on the season (Alix 1976). None of these, if optimized in terms of biomass and effort, would noticeably affects the total catch (Ronquillo 1975; Calvelo and Dalzell 1987).

Moreover, in the Philippines, which produces, publishes, and distributes annually immense amounts of extremely precise fisheries statistics (see BFAR 2012b) that are readily cited by various national and international NGOs, the *real* catch of the marine fisheries is essentially unknown. Commercial landing statistics were collected since 1954 by the Bureau of Fisheries and Aquatic Resources (BFAR) for ten fishery districts (Simpson 1979), based on monthly catch reports (by the operators of vessels >3 gross tonnes). It was determined that these landings were

[27] This introduction is adapted from Pauly *et al.* (2012b).

[28] This tortuous wording is based on the fact that the Philippines claim is not based on UNCLOS, as might be expected, but on the 1898 Treaty of Paris, which formalized the transfer of colonial territories from Spain to the United States (Bautista 2008).

'inadequate', and they were summarily 'corrected' by an expansion factor derived from monthly landings collected by enumerators from randomly sampled survey areas to estimate regional and national production values (PDNR 1976). Already then, underreporting of the catch and/or undervaluing of species caught by the few registered (and/or reporting) fishing vessels was a rampant form of tax evasion and as such, these statistics accounted for less than half of what was really caught (Simpson 1979). In some areas, underreporting may have been as much as 80 % of the actual catch (Storer 1967).

In addition, small-scale fisheries catches were estimated from only six municipal reports since 1951, which was later discontinued (FIDC 1979). The small-scale fisheries, called 'municipal fisheries' in the Philippines, are defined as using fixed gear or craft of less than 3 gross tonnes (Philippines 1933; Pauly 1982). Since the 1960s, the catch of municipal fisheries has been estimated from the *same* fixed ratio for the relationship between small-scale and industrial catches (FIDC 1979; see below). This ratio most likely originated from the projected increase of fisheries production to respond to domestic demand, i.e., 6-7 %, needed for self-sufficiency in fish by 1976, and thus, for surplus production by 1977 (PDNR 1976). Thus, it appears that even before the conjugal dictatorship of Ferdinand and Imelda Marcos, fisheries statistics were generated which showed politically convenient regular catch increases, a problem which has not been addressed since democracy was restored.

Lack of funds and repeated reorganizations of the government divisions handling fisheries prevented the establishment of a comprehensive fisheries data collection system that included the catch of small-scale and subsistence fishers (PDNR 1976; FIDC 1979). It took more than seven decades since the creation of the Division of Fisheries created by the Philippine Commission under the Department of the Interior in 1901 (BFAR 2012a) before a fisheries statistics data collection system could be put in place (Chakraborty 1976). This was implemented after several training workshops for enumerators organized by the South China Sea Fisheries Development and Coordinating Programme in the mid-1970s (Chakraborty and Wheeland 1976). The first of a series of annual fisheries statistics accounting for all sectors in the same detail as the commercial fisheries sector was published by BFAR only in 1977 (BFAR 2012b). Further changes in the governing institutions in the late 1980s transferred the responsibility of fisheries data collection from BFAR to the Bureau of Agricultural Statistics in 1988 (see BFAR 2012a). The continuous problems of funding data collection, which has beset this sector for decades, prevented regular/consistent data collection into the 2000s (see Itano and WIlliams 2009).

Municipal fishing operators, however, remained a problem, notably because of the 1935 Fish and Game Administrative Order (No. 2-2) limiting vessels more than 3 GT to operate outside municipal waters (see Philippines 1933). This led to the development of scaled-down industrial operations ('baby trawlers') which can be operated in the inshore waters, i.e., within 7 km of the coastline (amended to 15 km of the coastline in 1998 by the Philippine Fisheries Code; Philippines 1998), and in waters less than 12.8 m deep, which was traditionally reserved for artisanal fisheries (Tapiador 1978; Pauly and Smith 1983; Cruz-Trinidad 1997). Thus, the highly heterogeneous municipal sector, which is clearly suffering from dwindling resources, as indicated by a very small and declining daily catch rate of individual fishers (see Simpson 1979; Dalzell *et al.* 1987; Dickson 1987; Muñoz 1991; Sunderlin 1994; Shannon 2002; Stobutzki *et al.* 2006; Muallil *et al.* 2012), and an ever increasing number of fishers, i.e., the 'Malthusian overfishing' of Pauly (2006) is linked to the ever-increasing industrial fleet, which obtains an increasing share of their ill-assessed catches from (mostly illegal) fishing in the waters of their neighbours, especially in Malaysia (Sabah) and Eastern Indonesia (see Lewis 2004).

Catch-MSY method for Philippine stocks

For the Philippines, the single-species analyses suggest that the overall catch could be increased by 25 % when considering the top 12 landed species, or 21% when considering all 39 taxa, given fishing at single species F_{MSY} (Table 32). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 32. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Philippine catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Indian mackerel	79,998	79,170	1.01
Short mackerel	37,096	37,674	0.98
Skipjack tuna	34,522	35,131	0.98
Bigeye scad	41,557	41,964	0.99
Kawakawa	19,949	31,651	0.63
Rainbow sardine	10,704	50,992	0.21
Blue swimming crab	33,148	29,501	1.12
Yellowfin tuna	20,971	19,799	1.06
Moonfish	14,145	14,390	0.98
Narrow-barred Spanish mackerel	5,360	12,534	0.43
Torpedo scad	19,353	16,952	1.14
Japanese anchovy	19,460	19,617	0.99
Average of top 12 (weighted)			**0.88 (0.75)**
Average of 39 taxa (weighted)			**0.84 (0.79)**

Russia[29]

Barents Sea

The Barents Sea was among the first areas of the world to be subjected to large-scale, industrial fishing. On average, commercial fishing in the Barents Sea corresponds to around 5 % of global reported catches, and Russian fisheries catch in the Barents Sea fishery accounts for approximately 39 % of the total Barents Sea reported landings (Spiridonov and Nikolaeva 2005). For our purposes, the Barents Sea region consists of the Barents Sea and the White Sea, and is bordered by the Norwegian Sea in the west, the Svalbard archipelago and Bear Island in the northwest, Franz-Josef Land in the northeast, and Novaya Zemlya and the Kara Sea in the east (Figure 30). It extends between the latitudes 82°-59° N and 15°-68° E longitude (Matishov et al. 2011). It covers approximately 1.5 million km^2 of surface area and has an average depth of 200 m (Spiridonov and Nikolaeva 2005; Matishov et al. 2011). The fish fauna is composed of around 182 species and subspecies, belonging to 59 families, of which 21 species and subspecies are commercially targeted by Russian fisheries (Karamushko 2008). A detailed description of the marine environment of the Barents Sea can be found in Hempel *et al.* (2012). Russian commercial fishing activities in the Barents Sea existed since the 15th century, but were primarily artisanal in nature. Two main fleets exist and operate in the Barents region, the Arkhangels'sk fleet and the Murmansk fleet. The first steam trawler in the Arkhangels'sk region was introduced in 1906 (Helin 1964). In 1916, the city of Murmansk was intentionally build by the Soviet Union to serve as an industrial and fisheries center (Helin 1964). In 1927, the Russian Barents region fishing fleet consisted of 17 fishing vessels, in 1931 the first diesel-fuelled trawler was introduced, and by 1933 the fleet counted 60 fishing vessels (Matishov et al. 2004). The year 1950 is noted as the start of the trawling era in Russian fishing history, with the first large stern trawlers enabling fishing in more distant areas. From then on, the fishery was largely dominated by demersal trawl gear, with only very limited use of long lines, gill nets, purse seines, and Danish seine. In 1955, the number of trawlers in the Murmansk fleet alone reached 562 (Grekov and Pavlenko 2011). In 2005, the total Russian Federation fishing fleet (including fleets outside of the Barents region) had 2,977 vessels, of which 2,522 are capture vessels, 39 factory vessels, 369 freezer vessels, and 47 scientific and educational vessels (EUROFISH 2005). In 2007, the Russian Barents Sea

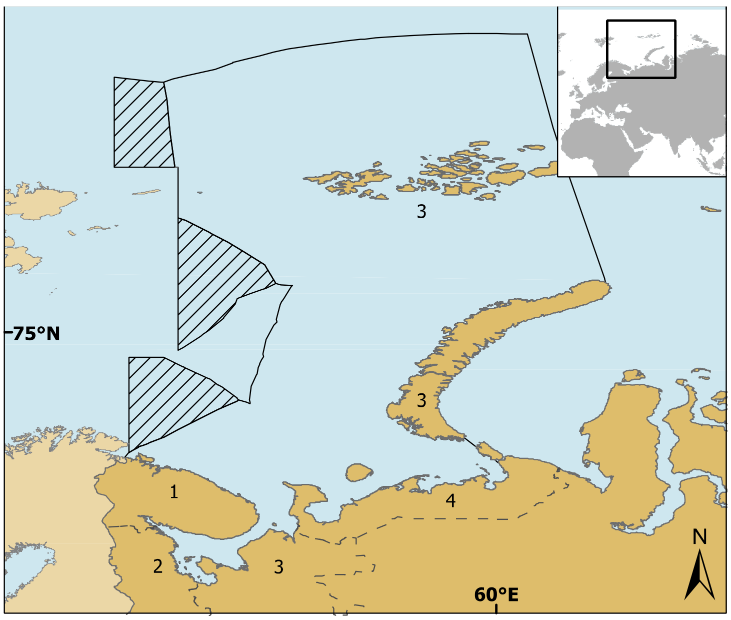


Figure 30. Map of the Russian Barents Sea EEZ showing the 200 nm EEZ adjacent to the mainland, all maritime states, and regions disputed prior to 2011 (cross-hatch). The EEZ dispute has been resolved between Russia and Norway in 2011. The Brazilian EEZ falls completely within the Barents Sea LME. Numbers correspond to maritime states: Murmansk, Karelia, Arkhangel'sk, and Nenets, 1-4 respectively. The area covered by ecological models includes the entire EEZ of Russia in the Barents Sea.

[29] This introduction was provided by Dr. B. Jovanovic (University of Munich), the lead for the Russian catch reconstruction, and by Dr. D. Pauly (Fisheries Centre, University of British Columbia).

groundfish fishery is still mainly operated by demersal trawl (93 % of total catch), followed by longline (7 %), and hand line (0.07 %), while the pelagic fishery consist mainly of pelagic trawl (85 %) and purse seine (15 %).

Black Sea

The Black Sea is the largest landlocked basin in the world, bounded by Europe, Anatolia and the Caucasus (Figure 31). It is connected by the Bosphorus Strait to the Sea of Marmara, which further connects to the Aegean Sea and the Mediterranean by the Strait of the Dardanelles. The Black Sea is also connected to the Sea of Azov by the Strait of Kerch. The Black Sea has an approximate area of 420,000 km^2 and a maximum depth of 2,212 m (Ozsoy and Unluata 1997). Due to its low salinity (18-18.5 ‰) and the anoxic regime bellow 200 m, the Black Sea region is unique, with many otherwise ubiquitous marine taxa being absent (such as cephalopods) while other freshwater/brackish species tolerant of such conditions are endemic to the region (Lleonart 2008; Yankova 2011). A total of 184 fish species inhabit the Black Sea, of which dozens appear on the IUCN list as endangered species (Yankova 2011); the number of commercially targeted fish species is less than 10.

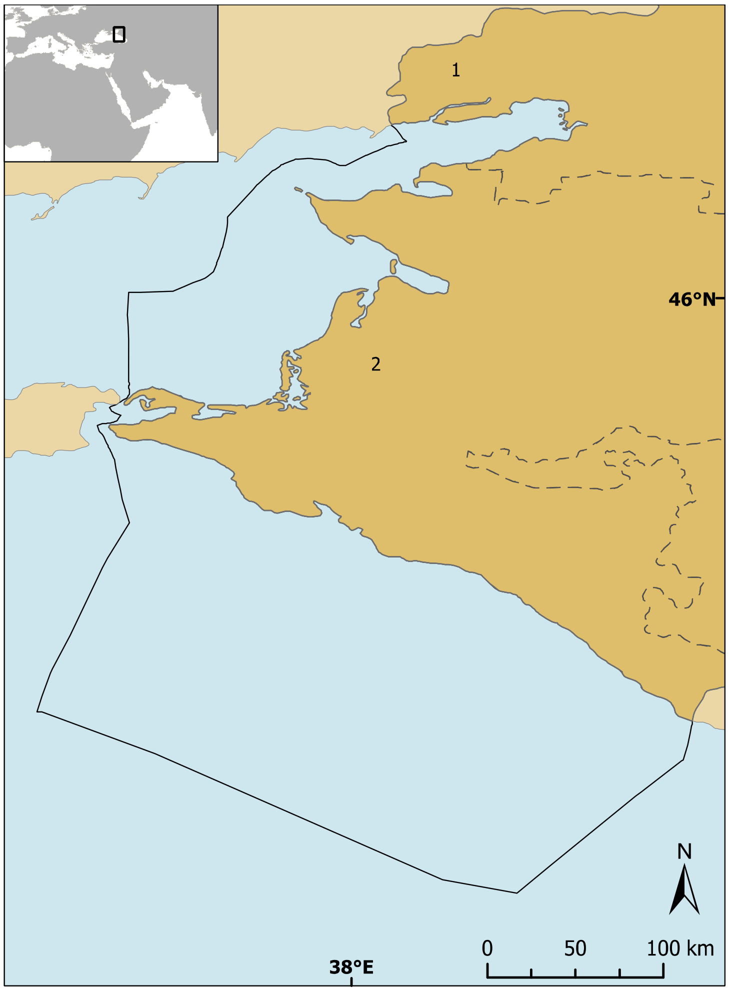


Figure 31. Map of the Russian Black Sea EEZ showing the 200 nm EEZ adjacent to the mainland and all maritime states. The Russian Black Sea EEZ falls completely within the Black Sea LME. Numbers correspond to maritime states: Rostov and Krasnodar, 1-2 respectively.

The Black Sea, together with the Azov Sea, has been a traditionally important fishing ground for the Russian Federation and former Soviet Union (Knudsen and Toje 2008), as its fishery supported thousands of families along its coast since the end of the Crimean War in 1856, when the defeated Ottoman empire signed the treaty in Paris agreeing to Russian commerce and activities in the Black Sea. Prior to 1931, Russian fisheries in the Black Sea were poorly organized and managed, predominately being based on traditional fishing techniques. In 1931, the first seiner was introduced, and in 1950 the first trawler was added to the fleet, with the fishery by then already organized as a state corporation (Knudsen and Toje 2008). The fishing fleet included at least 65 medium size vessels (25-30 m) in 1980, at the peak of the Russian Black Sea fisheries (Knudsen and Toje 2008). During the period 1970-1990, the fish stocks in the Black Sea were adversely influenced by overfishing, eutrophication, and the bloom of the introduced ctenophore *Mnemiopsis leidi*. As a result, the once highly productive ecosystem with species at all trophic levels first shifted towards an ecosystem dominated by small pelagic fish species (with elimination of top predator species) in 1980, and later in 1989 to an ecosystem dominated by gelatinous zooplankton, signaling fisheries collapse (Shiganova 1998; Shiganova and Bulgakova 2000). The final blow to the Russian fishery in the Black Sea was delivered by the collapse of the Soviet Union, manifested by the immediate disruption of state subsidies for the maintenance and operation of vessels. These factors resulted in most of the vessels from the fleet disbanding; the fishery has not recovered since (Knudsen and Toje 2008).

Pacific

The Russian Pacific waters (Figure 32) are also known as the Russian Far East (RFE) and host the largest percentage of the Russian fleet (Johnson 2004). This fleet generates the largest catch of all the entities that emerged from the dismemberment of the USSR (Zeller and Rizzo 2007). The RFE comprises the large Okhotsk Sea, whose biology is summarized (in English) in Chaikina (2004), the waters north of Vladivostok (which include Sakhalin Island), the Kamchatka Peninsula and to its northeast, the Bering Sea (Newell 2004).

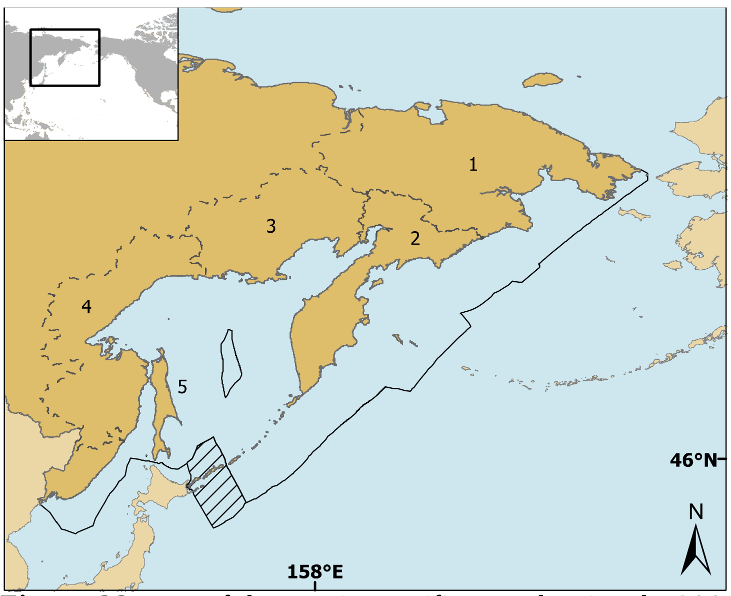


Figure 32. Map of the Russian Pacific EEZ showing the 200 nm EEZ adjacent to the mainland, all maritime states, and disputed region (cross-hatch). The Russian Pacific EEZ is part of four LMEs: the West Bering Sea LME, the Sea of Okhotsk LME, the Oyashio Current LME, and the Sea of Japan/East Sea LME. Numbers correspond to maritime states: Chukchi Autonomous Okrug, Kamchatka, Maga Buryatdan, Khabarovsk, and Sakhalin, 1-5 respectively.

The waters of the RFE may also be seen as encompassing North Siberia, especially the Chukchi and Laptev Seas, but their fisheries yields are negligible (Pauly and Swartz 2007; Zeller *et al.* 2011a) and they can be ignored here. In the 1980s, landings from the RFE peaked at 4.6 million t (of which much was Alaska pollock), but declined to about 2.3 million t in the mid-1990s (Johnson 2004). Since that time, the RFE has experienced a modest catch increase but the management of the fisheries is marred by weak enforcement and strong illegal fishing (see e.g., Johnson 2004; Dronova and Spiridonov 2009; Miranovsky 2012).

Catch-MSY method for Russian (Barents Sea) stocks

For the Russian Barents Sea, the single-species analyses suggest that the overall catch could be increased by 73 % when considering either the top 12 landed species or all 29 taxa, given fishing at single species F_{MSY} (Table 33).

Table 33. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Russia Barents Sea catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Capelin	33,124	632,897	0.05
Atlantic cod	143,155	28,7163	0.50
Haddock	43,019	69,337	0.62
Atlantic herring	2,003	107,640	0.02
Polar cod	14,037	50,419	0.28
Northern prawn	16,593	16,227	1.02
Saithe	6,332	8,055	0.79
European plaice	1,578	10,199	0.15
Wolf-fish	5,875	3,515	1.67
Navaga	742	2,850	0.26
Atlantic halibut	92	533	0.17
American plaice	1,305	972	1.34
Average of top 12 (weighted)			**0.57 (0.27)**
Average of 29 taxa (weighted)			**0.57 (0.27)**

Model results for Russian (Barents Sea) ecosystems

We used the Norwegian Sea and Barents Sea model (Dommasnes *et al.* 2001) as a representation of Russian marine ecosystems in the Barents Sea (Figure 30). The model covers ICES areas I, IIa and IIb north to approximately 81° N, which includes the Barents Sea and the Norwegian Sea, to 11° W and to 63° -64° N. The total surface area is 3,116,000 km^2. The model had been fitted to historic time series of data from 1950 to 2007.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy*, and similar results to the *optimization* simulations (Table 34, Figure 33a). The average fishing mortality from 1950 to 2007 is lower under the historical exploitation than the other two simulations (Figure 33b).

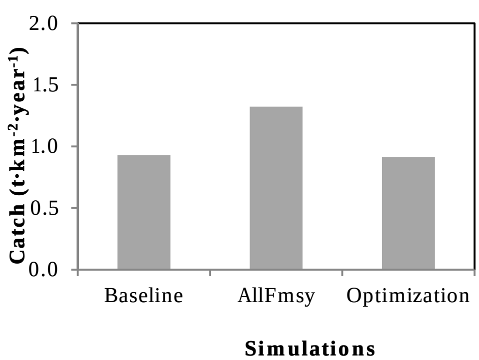
Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 30-73 % given fishing at single species F_{MSY}. However, the catch could not be increased when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass.

Table 34. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the Russian Barents Sea ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch (t·km^{-2}·year^{-1}) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Cod 4+	0.2300	0.2600	0.260	0.9	0.9
Haddock	0.0600	0.0600	0.050	1.0	1.2
Saithe	0.0500	0.0600	0.040	0.9	1.2
Blue whiting	0.0200	0.0700	0.010	0.2	1.6
Mackerel	0.0300	0.0700	0.030	0.5	1.3
Oth pelag fish	0.0100	0.0300	0.010	0.3	1.2
Herring 4+	0.4600	0.5000	0.480	0.9	1.0
Polar cod	0.0020	0.0100	0.002	0.2	1.6
Capelin	0.0200	0.0300	0.004	0.6	4.1
Redfish	0.0100	0.0200	0.010	0.4	1.6
Squid	0.0001	0.0003	<0.001	0.2	1.7
Prawns	0.0100	0.0500	0.010	0.2	1.5
Krill	0.0010	0.0030	<0.001	0.2	1.6
Total catch (sp table)	**0.9000**	**1.1700**	**0.890**	**0.76**	**1.01**
Total catch*	**0.9300**	**1.3200**	**0.910**	**0.70**	**1.02**

* Number of commercial taxa/groups in the model = 17

a.



b.

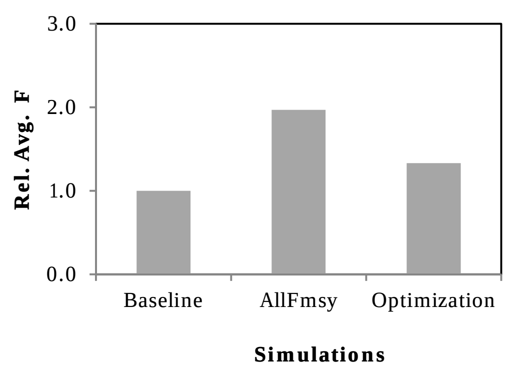


Figure 33. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the Russian Barents Sea ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Catch-MSY method for Russian (Black Sea) stocks

For the Russian Black Sea, the single-species analyses suggest that the overall catch could be increased by 77 % when considering either the top 12 landed species or when considering all 25 taxa, given fishing at single species F_{MSY} (Table 35). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 35. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Russia Black Sea catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Black Sea sprat	4,328.2	22,938	0.19
European anchovy	1,931.6	25,985	0.07
European sprat	5,389.1	4,971	1.08
Atlantic bluefin tuna	1,348.4	1,093	1.23
Big-scale sand smelt	15.7	906	0.02
European pilchard	767.4	806	0.95
Pontic shad	8.1	571	0.01
Atlantic mackerel	910.8	582	1.56
Mediterranean mussel	0.3	270	0.00
Atlantic bonito	5.4	493	0.01
Whiting	13.3	75	0.18
Blue whiting	60.4	63	0.96
Average of top 12 (weighted)			**0.52 (0.23)**
Average of 25 taxa (weighted)			**0.74 (0.23)**

Catch-MSY method for Russian (Pacific) stocks

For the Russian Pacific, the single-species analyses suggest that the overall catch could be increased by 39 % when considering the top 12 landed species, or 37 % when considering all 55 taxa, given fishing at single species F_{MSY} (Table 36). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 36. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Russia Pacific catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Alaska pollack	1,189,150	2,031,096	0.59
Japanese flying squid	274,650	231,669	1.19
Pacific herring	173,896	202,678	0.86
Pacific saury	195,884	221,938	0.88
Pacific cod	116,966	96,732	1.21
Chub mackerel	143,129	154,236	0.93
Pink salmon	125,087	123,056	1.02
Chum salmon	130,921	112,877	1.16
Red king crab	5,433	25,428	0.21
Okhostk atka mackerel	47,533	43,925	1.08
Sockeye salmon	20,408	26,661	0.77
Sailfin sandfish	6,915	32,589	0.21
Average of top 12 (weighted)			**0.84 (0.61)**
Average of 55 taxa (weighted)			**0.76 (0.63)**

South Africa[30]

South Africa has a long coastline, spanning two large marine ecosystems, the Benguela Current LME and the Agulhas Current LME (Figure 34). The Benguela Current ecosystem in particular is one of the most productive ocean ecosystems in the world in terms of biomass production and fishery resources due to the upwelling of cold, nutrient rich water (Cochrane *et al.* 2009). A unique group of fishes exist in the waters off South Africa due to distinct oceanographic conditions and the variety of habitats (Van der Elst *et al.* 2005). Today, the fishing industry in South Africa provides employment and income for at least 27,000 people, contributing less than 1 % of the country's GDP (FAO 2011a). South Africa has the highest reported catches in Africa, but only ranked 30th on a global scale in the 1990s (Hersoug and Holm 2000). The fisheries overall GDP value for 2008 was estimated at approximately 322 million USD and the overall value of the recreational and commercial fishery is estimated at 400-500 million USD annually. The fisheries can be separated into three sectors: commercial/industrial, recreational, and subsistence/artisanal sectors, all targeting over 250 marine species (FAO 2011a).

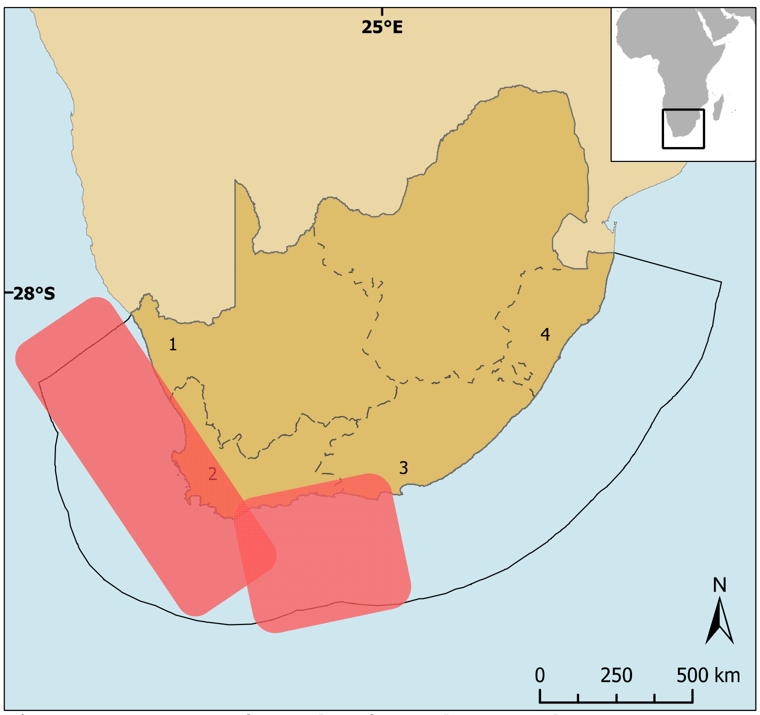


Figure 34. Map of South Africa showing the 200 nm EEZ adjacent to the mainland and all maritime states. The South African EEZ is part of the Benguela Current LME in the west and the Agulhas Current LME in the east. Numbers correspond to maritime states: Northern Cape, Western Cape, Eastern Cape, and KwaZulu-Natal, 1-4 respectively. The area covered by ecological models is highlighted in red.

Apartheid left South Africa with a horrible legacy of unemployment and an extremely unequal distribution of resources. Marine resources were also unequally distributed between small-scale and well-established large-scale operators. Furthermore, there was a regional imbalance in the fishing industry with most industry confined to the Western Cape (Hersoug and Holm 2000).

The commercial fishing industry consists of several different fisheries. The most important fishery is the deep-sea trawl fishery and the smaller inshore trawl fishery mainly targeting hake stocks (*Merluccius paradoxus* and *M. capensis*), contributing approximately 50% of the overall value of the fishery. There are also small fisheries for hake using demersal longlines and handlines (FAO 2011a). There is also a pelagic purse seine fishery targeting sardine (*Sardinops ocellatus*), anchovy (*Engraulis capensis*) and round herring (*Etrumeus whiteheadi*); producing fishmeal, oil and canned fish, which contributes 25 % of the value of all fisheries (Hersoug and Holm 2000; FAO 2011a). A midwater trawl fishery is targeting horse mackerel (*Trachurus capensis*) on the Agulhas Bank.

There are two important rock lobster fisheries in South Africa. On the West Coast, an inshore fishery is targeting West Coast rock lobster (*Jasus lalandii*), and on the South Coast, a deep-water fishery is targeting *Palinurus gilchristi*. Rock lobster contributes less than 1 % by mass to the total

[30] This introduction was provided by Dr. S. Baust (Oxford University).

fishery, but the contribution by value is approximately 9-10 %. There is a very valuable, but politically highly disputed, abalone fishery (*Haliotis midae*). 'Poaching' (a politically fraught term) and resulting overexploitation led to the temporal closure of the industry in the late 2000s (Hauck and Sweijd 1999; Raemaekers and Britz 2009).

Other smaller fishing sectors include trawl fleets targeting shrimp off the coast of Kwa-Zulu Natal; a pelagic longline fishery targeting various tuna species, sharks and billfishes; and a tuna bait and pole fishery. Additionally, there is a small squid jig fishery (targeting chokka squid *Loligo vulgaris reynaudi*) and a large linefish sector in terms of area fished and people employed, targeting a great diversity of fish species (FAO 2012).

In general, catch data for the South African industrial fisheries appear to be well documented and catch statistics are readily available. However, there are no official catch statistics for the marginalized subsistence sector, as well as no comprehensive estimates for the recreational sector.

Catch-MSY method for South African stocks

For South Africa, the single-species analyses suggest that the overall catch could be increased by 21 % when considering the top 12 landed species, or 19 % when considering all 48 taxa, given fishing at single species F_{MSY} (Table 37).

Table 37. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the South African catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Cape anchovy	215,899	405,043	0.53
South American pilchard	277,728	230,123	1.21
Whiteheads round herring	43,224	51,996	0.83
Cape horse mackerel	19,334	23,174	0.83
Chub mackerel	4,335	20,536	0.21
Snoek	11,126	12,350	0.90
Cape rock lobster	3,855	9,928	0.39
Kingklip	4,272	3,327	1.28
Cape monk	7,554	5,900	1.28
Cape Hope squid	7,893	6,536	1.21
Silver scabbardfish	6,502	6,698	0.97
Panga seabream	1,255	2,083	0.60
Average of top 12 (weighted)			**0.85 (0.79)**
Average of 48 taxa (weighted)			**0.59 (0.81)**

Model results for South African ecosystems

We used the Southern Benguela upwelling model (Shannon *et al.* 2004; Shannon *et al.* 2008) as a representation of South African marine ecosystems (Figure 34). The model covers the Southern Benguela upwelling current, encompassing the shallow Agulhas Bank in the south in addition to the upwelling area off the West Coast, and it is located between 29° to 36° S and 14° to 27° E. The model had been fitted to historic time series of data from 1978 to 2003.

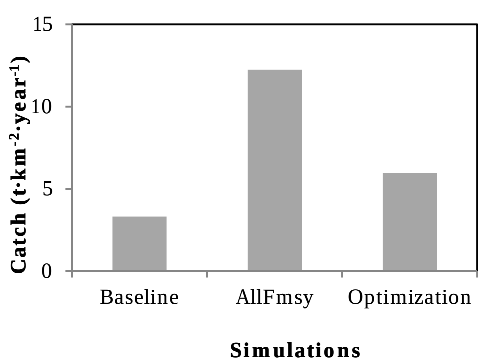
The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and *optimization* simulations (Table 38, Figure 35a). The average fishing mortality from 1950 to 2007 is lower under the historical exploitation in comparison with the one from the *allFmsy* simulation and similar to the *optimization* simulation (Figure 35b).

Table 38. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the South African ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch (t·km^{-2}·year^{-1}) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Anchovy	0.2600	1.51	0.6000	0.2	0.4
Sardine	1.8100	4.90	4.1800	0.4	0.4
Redeye	0.2400	1.68	0.1300	0.1	1.8
Other small pelagics	0.0003	0.02	0.0003	0.02	0.9
Chub mackerel	0.0500	0.08	0.0200	0.6	2.1
Horse mackerel	0.1200	0.66	0.1000	0.2	1.2
Snoek	0.0600	0.09	0.0800	0.7	0.8
Other large pelagics	0.1300	0.29	0.1000	0.4	1.2
Large Merlucius capensis	0.0600	0.14	0.1300	0.4	0.4
Large Merlucius paradoxus	0.2700	0.22	0.1600	1.2	1.7
Benthic demersals	0.0900	0.77	0.2600	0.1	0.3
Total catch (sp table)	**3.0900**	**10.34**	**5.7800**	**0.30**	**0.54**
Total catch*	**3.3100**	**12.25**	**5.9700**	**0.27**	**0.55**

* Number of commercial taxa/groups in the model = 20

a.



b.

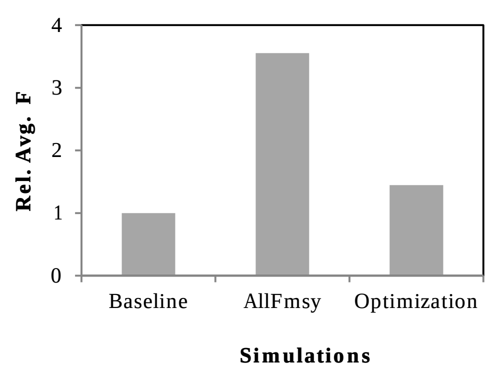


Figure 35. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the South African ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 21-73 % given fishing at single species F_{MSY}. However, when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass, the catch could only be increased by 45 %.

South Korea[31]

The Republic of Korea is located between 33°-38° N and 125°-131° E on the southern portion of the Korean Peninsula, and is generally known as South Korea. Its mainland and 3,400 islands have a land area of over 100,000 km², with an EEZ of over 475,000 km² (Figure 36). Neighboring countries are the Democratic People's Republic of Korea (North Korea), China and Japan.

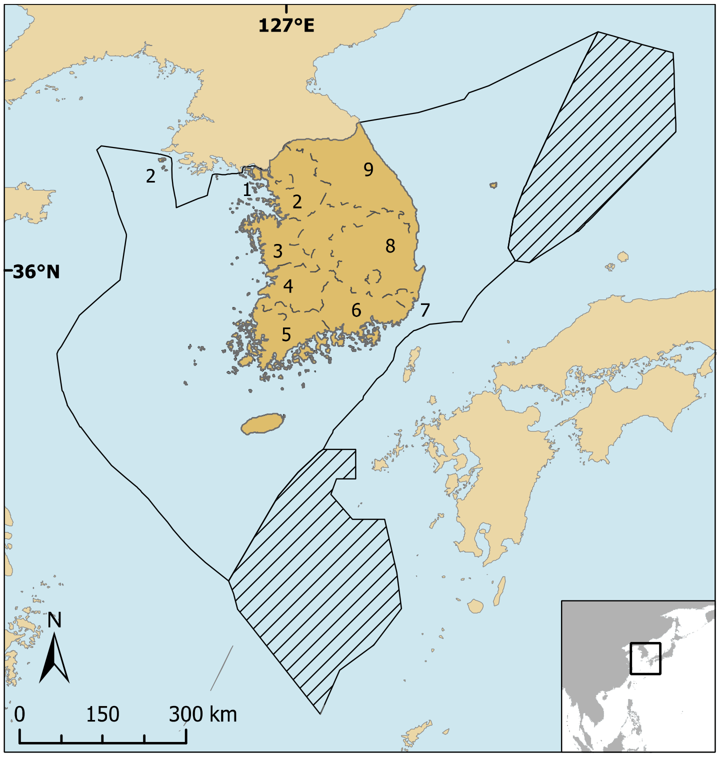


Figure 36. Map of South Korea showing the 200 nm EEZ adjacent to the mainland, all maritime states, and disputed regions. The South Korean EEZ is part of the Yellow Sea LME and the Sea of Japan/East Sea LME. Numbers correspond to maritime states: Inch'on-gwangyoksi, Gyeonggi-do, Chungcheongnam-do, Jeollabuk-do, Gwangju, Gyeongsangnam-do, Ulsan, Daegu, and Gangwon-do, 1-9 respectively.

While fishing contributes less than 1 % to the overall economy of South Korea, this figure is not representative of the importance of fishing and seafood to the South Koreans (Bowden and Prosser 2006). In 2005, Korea ranked as the world's 15th largest marine fishing country. Over 200,000 people are employed in the fisheries sector (Bowden and Prosser 2006). Since the early 1980s, the government has been trying to improve the sustainability of fisheries, introducing catch limits and attempting to curtail effort, a reflection of the importance of this important source of food and income to the country.

During the first half of the 20th century, Japan occupied South Korea, and the fisheries were extremely limited and small-scale. After South Korea's founding in 1948, there was still little industrial infrastructure, and much of the fishing fleet was destroyed during WWII and the Korean War (1950-1953). Typhoon Sarah in 1959 following the Korean War caused a further decline in the number of fishing boats from 49,000 vessels in 1946 to 29,000 in 1959. These events are reflected in the low South Korean reported fisheries landings from the 1940s to the 1960s (Jeong 1991). The South Korean government revised its fishery policy 13 times between 1953 and 1990 in order to develop appropriate policies for managing a growing fishing industry (Ryu 1991).

Despite these revisions, the 1990s witnessed an increase in fishing effort. The number of fishing boats increased to 75,000 in 1996 and 81,000 in 1997, with nearly 70 % operating within the Korean EEZ (Park 1999). The excess effort resulted in the overfishing of many commercially important species, especially coastal resources, and a reduction in the reported landings since 1986 (Kang 2011; Korea Fisheries Association 2011). In response, in 1994, the government

[31] This introduction was provided by Ms. S. Shon (Fisheries Centre, University of British Columbia), the lead for the South Korean catch reconstruction currently being completed.

initiated a boat reduction project to allow exhausted fishery resources to recover, and by 2008, successfully decommissioned 16,800 boats, of which 10,400 were coastal boats(Kang 2011).

In the 1950s, the commercial fishing industry operated solely within EEZ-equivalent waters. Reported landings from these waters were 216,000 t, or approximately 98 % of the overall South Korean fisheries catches at that time. As the distant-water fisheries and aquaculture production increased, the domestic fishery (within EEZ equivalent waters) saw its catches decline to only 36 % in 2010 (Korea Fisheries Association 2011).

The major targeted species have progressively changed over time. In the 1950s and 1960s, the most frequently caught species were largehead hairtail (*Trichiurus lepturus*) and squid (Jang and Lee 2002). This was replaced by large catches of chub mackerel (*Scomber japonicus*) and thread-sail filefish (*Stephanolepis cirrhifer*) catches in the 1970s, and thread-sail filefish and Pacific sardine (*Sardinops sagax*) in the 1980s. In the 1990s, Japanese anchovy (*Engraulis japonicus*) was the most frequently caught species. Overall, the trophic level of major targeted species has decreased from 3.45 in the 1950s to 3.17 by 2000 (Jang and Lee 2002).

The switch from domestic to distant water fisheries really began in 1962 with the establishment of the first five-year Economic Development Plan, which was focused on fisheries development, especially distant-water fisheries[32]. Although the distant-water fishery began with the tuna long-line test fishery in the Indian Ocean in 1957, the government officially added the distant-water fishery as a distinct sector in 1963 (Ryu 1991). The distant-water fishery expanded to all oceans of the world in a relatively short period of time[33]. However, catches were not substantial until the broad utilization of flash-freezers in 1968. Thereafter, the increase of distant-water catches contributed to the large increase of the reported marine landings seen from the late 1950s onward (Korea Fisheries Association 2010). The distant-water fisheries reported 656 t in 1962 and increased their reported landings to 1 million t by 1992. The establishment of 200 nm EEZs by coastal nations starting from the late 1970s, and the establishment of Regional Fisheries Management Organizations (RFMOs) reducing uncontrolled access to fishing grounds may have contributed to the decline in reported landings beginning in the 1990s.

Catch-MSY method for South Korean stocks

For South Korea, the single-species analyses suggest that the overall catch could be increased by 57 % when considering the top 12 landed species, or 45 % when considering all 90 taxa, given fishing at single species F_{MSY} (Table 39). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

[32]www.doopedia.co.kr/doopedia/master/master.do?_method=view&MAS_IDX=101013000848587#MGROUP_101015000148852 [Accessed: March 17, 2010]
[33] www.kosfa.org/english/e_fish/e_fish1.asp [Accessed: January 17 2011]

Table 39. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the South Korean catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Pacific sardine	7,291	129,028	0.06
Chub mackerel	50,429	73,078	0.69
Japanese anchovy	87,889	108,473	0.81
Largehead hairtail	31,462	69,627	0.45
Alaska Pollack	17,200	36,305	0.47
Japanese flying squid	54,217	57,258	0.95
Japanese carpet shell	17,257	21,132	0.82
Japanese jack mackerel	18,957	19,880	0.95
Yellow croaker	11,787	18,265	0.65
Okhostk atka mackerel	26,793	29,180	0.92
Akiami paste shrimp	4,748	8,684	0.55
Chum salmon	6,674	9,998	0.67
Average of top 12 (weighted)			**0.66 (0.43)**
Average of 90 taxa (weighted)			**0.52 (0.55)**

Spain[34]

Spain is located on the southern part of the European continent, between 44^0 and 36^0 N and 9^0 W and 3^0 E, with a land area of around 506,000 km² and an EEZ of 552,000 km² (Figure 37). Adjacent to Spain are France to the north, the Mediterranean Sea to the east, Portugal to the west and the Strait of Gibraltar and Morocco to the south. The shelf area is narrow with 68,000 km² and the bulk of the EEZ consists of deep waters. Spain hosts more than 40 million people and is one of the primary tourist destinations in the world.

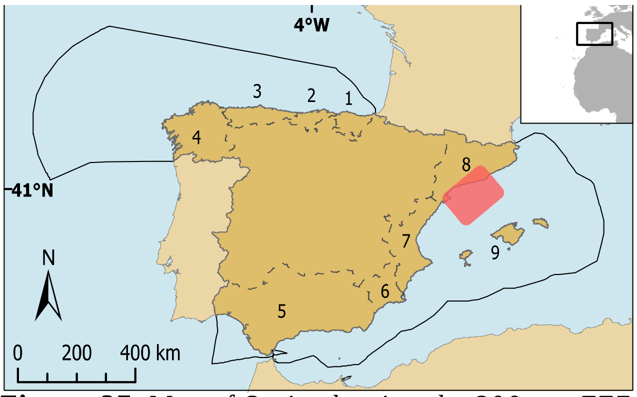


Figure 37. Map of Spain showing the 200 nm EEZ adjacent to the mainland and all maritime states. The Spanish EEZ is part of the Iberian Coastal LME and the Mediterranean Sea LME. Numbers correspond to maritime states: País Vasco, Cantabria, Principado de Asturias, Galicia, Andalucía, Región de Murcia, Comunidad Valenciana, Cataluña, and Islas Baleares, 1-8 respectively. The area covered by ecological models is highlighted in red.

Part of the Spanish EEZ covers the Mediterranean Sea, and the other part covers the Atlantic Ocean. Given the generally high human population along its shores, the long history and diversity of human impacts, the Spanish EEZ has been altered extensively throughout history. At present, fishing impacts, as well as habitat loss and degradation, pollution, eutrophication, and the introduction of alien species are the most important threats to diversity (Costello *et al.* 2010).

The continental shelf in Spain is generally narrow and 50 m depth is usually found approximately 3 nm from shore. Fishing activities are mainly coastal or littoral, although Spain has an important distant water fleet fishing overseas (such as in Morocco and Mauritania). The main fishing fleets operating in the area are bottom and mid-water trawlers, purse seine, bottom and surface long lines, and a diverse artisanal fleet. Spain contains many fishing harbours, first-source fishing markets (or 'Lonjas', where catches that are unloaded in the harbour are commercialized), and fishers labour organizations ('Cofradias de pescadores').

Spanish official landings steadily increased from the 1950s to the 1960s, and have since decreased. Major species in the reported data include European sardine (*Sardina pilchardus*), European anchovy (*Engraulis encrasicolus*), and other small and medium-sized pelagic fish such as round sardinelle (*Sardinella aurita*), horse mackerel (*Trachurus* spp.) and mackerel (*Scomber* spp.), and demersal species, such as common hake (*Merluccius merluccius*), red mullets (*Mullus* spp.), anglerfish (*Lophius* spp.) and blue whiting (*Micromesistius poutassou*). Invertebrate catches are also economically important, such as those of red shrimp (*Aristeus antennatus*), European spiny lobster (*Palinurus elephas*), rose shrimp (*Parapenaeus longirostris*), Norway lobster (*Nephrops norvegicus*) and cephalopod and bivalve species. Spain also lands important catches of tunas and associated species, especially of Atlantic Bluefin tuna (*Thunnus thynnus*).

Scientific and management advice is implemented by national, regional and international entities such as the International Council for the Exploration of the Sea (ICES) and the General Fisheries Commission for the Mediterranean (GFCM) in cooperation with the Fisheries Department of the United Nations Food and Agriculture Organisation (FAO), and the European Community (EC), the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the United Nations Environmental Program (UNEP). Moreover, the Scientific, Technical and Economic

[34] This introduction was provided by Dr. M. Coll (Institut de Ciencies del Mar, Barcelona), the lead for the catch reconstruction for southern and Mediterranean Spain.

Committee for Fisheries (STECF) of the EU provide scientific recommendations about fisheries of EU Member states.

Despite many stockholders being involved in fisheries monitoring and management, considerable evidence of substantial unreported landings and failures of the control system exists for many European countries, including Spain. Unreported landings in Spain, and the ecological and socio-economic problems associated with this, have made the news on several occasions. In 2007, a special report by the European Court of Auditors highlighted many deficiencies and failures of control, inspection and sanction systems of 6 European countries, including Spain (Court of Auditors 2007). The Court stated that overfishing generated by over-capacity and the considerable weaknesses of the European fisheries control system are threatening European fish stocks. The Court concluded that (i) fishing data collected in Member States of the European Union are unreliable and incomplete, and are inadequate as a basis for setting Total Allowable Catches (TACs) and quotas; (ii) national inspection procedures to detect and prevent infringements are ineffective; and (iii) the penalties imposed by national authorities when infringements are detected are not sufficiently onerous to act as a deterrent. Spain was singled out in several occasions as a frequent offender due to, for example, extensive underreporting of catch of large pelagic fish.

Under-reporting is an important proportion of the catch (Coll *et al.* 2013); thus under-reporting it can reach more than 40 % of official catch, and may be increasing due to the recent economic crisis. At present, several marine resources of Spain are fully exploited or overexploited and several fish species are listed as species at risk by the IUCN, e.g., common hake and Atlantic bluefin tuna (Abdul Malak *et al.* 2011).

Catch-MSY method for Spanish (Atlantic) stocks

For the Spanish Atlantic, the single-species analyses suggest that the overall catch could be increased by 99 % when considering the top 12 landed species, or 98 % when considering all 60 taxa, given fishing at single species F_{MSY} (Table 40). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 40. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Spanish Atlantic catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	**Catch**	**MSY**	**Catch:MSY**
Blue mussel	534	32,293	0.02
Common edible cockle	2,532	5,392	0.47
Striped venus	2,140	5,279	0.41
Common shrimp	177	3,438	0.05
Ling	165	1,435	0.11
Grooved carpet shell	301	1,239	0.24
Garpike	151	2,030	0.07
Pullet carpet shell	667	1,191	0.56
European flying squid	189	1,312	0.14
Atlantic cod	64	1,646	0.04
Piked dogfish	37	557	0.07
Northern shortfin squid	481	1,130	0.43
Average of top 12 (weighted)			**0.22 (0.01)**
Average of 60 taxa (weighted)			**0.45 (0.02)**

Catch-MSY method for Spanish (Mediterranean) stocks

For the Spanish Mediterranean, the single-species analyses suggest that the overall catch could be increased by 44 % when considering the top 12 landed species, or 38 % when considering all 68 taxa, given fishing at single species F_{MSY} (Table 41).

Table 41. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Spanish Mediterranean catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
European pilchard	26,085	42,667	0.61
European anchovy	11,997	21,880	0.55
Blue whiting	3,657	6,323	0.58
European hake	4,791	4,704	1.02
Atlantic mackerel	6,140	5,411	1.13
Bogue	1,483	4,344	0.34
Deepwater rose shrimp	979	1,645	0.60
Northern bluefin tuna	3,209	2,626	1.22
Swordfish	1,990	1,978	1.01
Angler	1,447	1,130	1.28
Norway lobster	639	708	0.90
Striped venus	765	944	0.81
Average of top 12 (weighted)			**0.84 (0.56)**
Average of 68 taxa (weighted)			**0.81 (0.62)**

Model results for Spanish (Mediterranean) ecosystems

We used the Southern Catalan Sea model (Coll *et al.* 2008b; Coll *et al.* in press) to represent the Spanish Mediterranean Sea ecosystem. The original model covers 4,500 km^2 of the Spanish EEZ including depths of 30 to 400 m between 41^0 and 39^0 N and 0^0 E and 2^0 E (Figure 24). The model had been fitted to historic time series of data from 1978 to 2010.

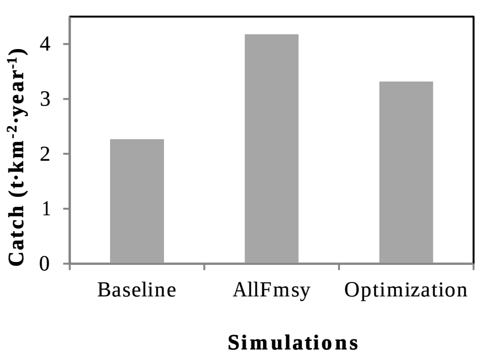
The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and *optimization* simulations, both in terms of most targeted species and in terms of all catch (Table 42, Figure 38a). The average fishing mortality from 1978 to 2010 is lower in both the *allFmsy* and *optimization* simulations than in the historical exploitation regime (Figure 38b).

Table 42. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1; *baseline*) from the Spanish Mediterranean ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

	Catch (t·km^{-2}·year^{-1})			Catch:MSY	
Exploited species / groups	**1. Baseline**	**2. AllFmsy**	**3. Optimization**	**1/2**	**1/3**
European pilchard	0.5300	1.80	1.9900	0.3	0.3
European anchovy	1.0000	0.55	0.6900	1.8	1.5
Blue whiting	0.0900	1.42E-20	0.0500	>100	1.7
European hake	0.1900	0.10	0.0800	1.8	2.3
Atlantic mackerel	0.0030	0.21	0.0030	0.0	1.1
Other small pelagic fish	0.0004	5.78E-07	0.0400	>100	0.0
Shrimps	0.0100	0.02	0.0010	0.4	5.2
Large pelagic fish	0.0200	3.39E-03	0.0004	4.6	36.6
Angler fish	0.0100	0.01	0.0200	0.8	0.3
Norway lobster	0.0100	0.03	0.0100	0.2	1.0
Total catch (sp table)	**1.8400**	**2.72**	**2.8800**	**0.68**	**0.64**
Total catch*	**2.2700**	**4.18**	**3.3200**	**0.54**	**0.68**

* Number of commercial taxa/groups in the model = 26

a. **b.**



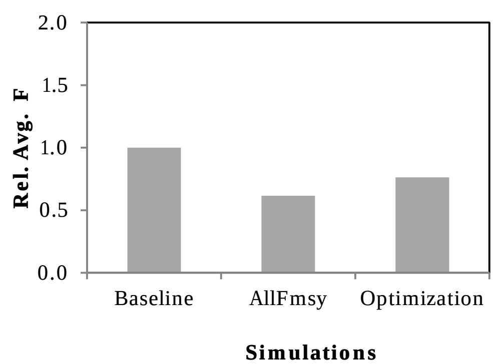


Figure 38. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the Spanish Mediterranean ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 38-46 % given fishing at single species F_{MSY}. However, when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass, the catch could only be increased by 32 %.

Turkey[35]

Turkey's shoreline touches three major seas: the Black Sea, the Aegean Sea and the Levant Sea in the eastern Mediterranean Sea, and one territorial sea, the Sea of Marmara (Figure 39). The significance of Turkish fisheries grew immensely during the 20th century due to a rapid growth in catch capacity from industrial fishing, coupled with state investment in the industry. For example, in the 1930s, total reported catches were between 25,000 and 30,000 t (Üstündağ 2010), and by 2010, Turkey reported over 445,000 t of marine catches (TÜİK 2010).

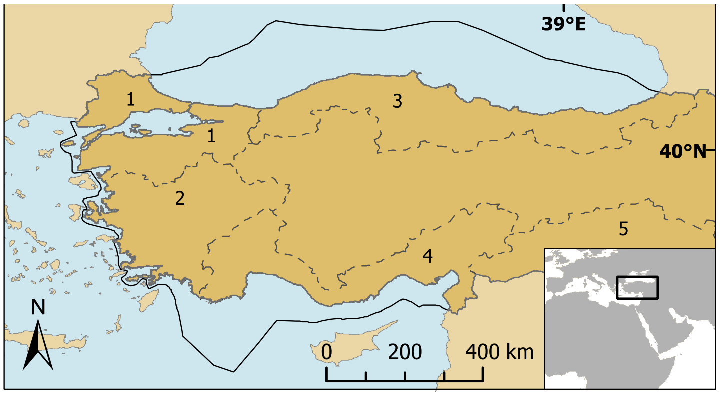


Figure 39. Map of Turkey showing the 200 nm EEZ adjacent to the mainland and all maritime state. The Turkish EEZ is part of the Black Sea LME and the Mediterranean LME. Numbers correspond to maritime regions: Marmara, Aegean, Black Sea, Mediterranean, and Southeastern Anatolia, 1-5 respectively.

The majority of catches from the Turkish Black Sea have been historically dominated by anchovy (*Engraulis encrasicolus*), while more recently, sprat (*Sprattus sprattus*), cockle (*Chamelea gallina*) and sea snail (*Rapana venosa*) catches have gained importance (TÜİK 1967-2009). Dolphin (*Delphinus delphis*) hunts were intensive in the Black Sea from the 1870s for a century, which removed some of the largest predators from this ecosystem (Zengin 2011). Industrial operations dominate the commercial fisheries of this sea, estimated to account for over 93 % of commercial landings (Ulman *et al.*, unpubl. data). Black Sea fishing is mainly conducted by purse seiners and pelagic trawlers. Purse seining began in the Turkish Black Sea in the 1930s and has dominated these fisheries since the 1960s (Gücü 2001). The late 1980s saw a collapse of stocks in the Black Sea, resulting in a 'national fisheries crisis', stemming from overfishing, pollution and an alien jellyfish invasion. Industrial operations shifted from small pelagics to demersal fish post-crisis (Knudsen 1997). Bottom trawlers switched their target fisheries to small pelagics such as sprat after a resulting decline in demersal fish catches in the 1990s. Turkey, by far, dominates total fishery catches in the Black Sea.Although the destructive fishing technique of bottom trawling is technically banned in both the eastern Black Sea and Sea of Marmara, the practice openly continues and the number of bottom trawlers and their catches in these waters are reported to the government.

Industrial fishing operations in the Sea of Marmara contribute about 70 % of total commercial catches, the remainder being caught by the artisanal sector (Ulman *et al.*, unpubl. data). The major taxa commercially landed during the 1950-2010 period were bluefish (*Pomatomus saltatrix*), Mediterranean horse mackerel (*Trachurus mediterraneus*) and bonito (*Sarda sarda*). The corridor extending from the Dardanelles, extending through the Sea of Marmara to the Bosphorus Strait in Istanbul hosts a massive recreational fishery which surpasses catches of some commercially-targeted species (Ünal *et al.* 2010; Zengin 2011).

The commercial fisheries of the Aegean Sea are dominated by the inshore artisanal sector, while the commercial fisheries of the Levant Sea are dominated by the industrial sector. Both areas landed mostly sardine and mullet for the 1950-2010 period (Ulman *et al.*, unpubl. data). Artisanal and recreational catches in these two seas are much lower than the Black Sea and Marmara Sea due to lower ecosystem productivity.

[35] This introduction was provided by Ms. A. Ulman (Fisheries Centre, University of British Columbia), the lead of the Turkish catch reconstruction.

The taxonomic composition of catches has considerably shifted in the last 50 years. In the 1950s and 1960s, larger valuable species such as Atlantic mackerel (*Scomber scombrus*), bonito and bluefish, mullets and turbot contributed about 65 % of catches (Hinrichson 1998), while small pelagics contributed the remaining 35 %. By 2010, small pelagic such as anchovy, sprat and sardine (*Sardina pilchardus*) accounted for 78 % of reported catches in Turkey (TÜİK 2010).

Catch-MSY method for Turkish (Black Sea) stocks

For the Turkish Black Sea, the single-species analyses suggest that the overall catch could be increased by 47 % when considering the top 12 landed species, or 45 % when considering all 47 taxa, given fishing at single species F_{MSY} (Table 43). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 43. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Turkish Black Sea catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
European anchovy	110,093	221,371	0.50
Mediterranean horse mackerel	8,132	41,795	0.19
European sprat	22,021	16,370	1.35
Atlantic bonito	10,787	8,490	1.27
Whiting	7,378	13,755	0.54
Atlantic horse mackerel	4,338	6,803	0.64
Bluefish	10,771	7,347	1.47
Atlantic bluefin tuna	4,195.	3,051	1.38
Black Sea sprat	1,523	10,751	0.14
Striped venus	15,928	12,557	1.27
Chub mackerel	267	4,382	0.06
European pilchard	2,228	3,680	0.61
Average of top 12 (weighted)			**0.78 (0.53)**
Average of 47 taxa (weighted)			**0.91 (0.55)**

Catch-MSY method for Turkish (Mediterranean) stocks

For the Turkish Mediterranean, the single-species analyses suggest that the overall catch could be increased by 23 % when considering the top 12 landed species, or 10 % when considering all 67 taxa, given fishing at single species F_{MSY} (Table 44). However, the absence of an ecosystem model precludes evaluation of the ecosystem effect, such as trophic interactions, on this evaluation.

Table 44. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Turkish Mediterranean catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
European anchovy	62,294	60,971	1.02
Atlantic bonito	13,444	10,611	1.27
European pilchard	13,837	17,542	0.79
Chub mackerel	1,939	8,801	0.22
Atlantic horse mackerel	6,494	5,380	1.21
Blue whiting	3,230	9,668	0.33
Mediterranean horse mackerel	6,510	7,583	0.86
Bluefish	8,090	4,646	1.74
Atlantic mackerel	571	6,573	0.09
Bogue	2,868	3,280	0.87
Striped venus	5,446	7,147	0.76
Mediterranean mussel	3,843	2,129	1.81
Average of top 12 (weighted)			**0.91 (0.77)**
Average of 67 taxa (weighted)			**0.99 (0.90)**

United Kingdom[36]

The United Kingdom of Great Britain and Northern Ireland consists of a group of islands located to the north-west of the European continent between 50˚and 60˚ N and 1˚and 6˚ W, with a land area of around 243,600 km² and an EEZ of 774,000 km² (Figure 40). Northern Ireland shares a land border with Ireland, and the U.K. sahres EEZ boundaries with Ireland in the Irish and Celtic Seas, The Faroe Islands, Iceland and Norway in the North Atlantic and Norwegian Sea, Norway, Denmark, Germany, The Netherlands, Belgium, and France in the North Sea, and France in the English Channel. To the northwest and southwest, the U.K.'s EEZ extends a full 200 nm into the North Atlantic, with the northwest much extended by the uninhabited westerly isles of St. Kilda and Rockall. The U.K. has an extensive continental shelf area that is home to rich fishery resources. The U.K. has a population of over 62 million people.

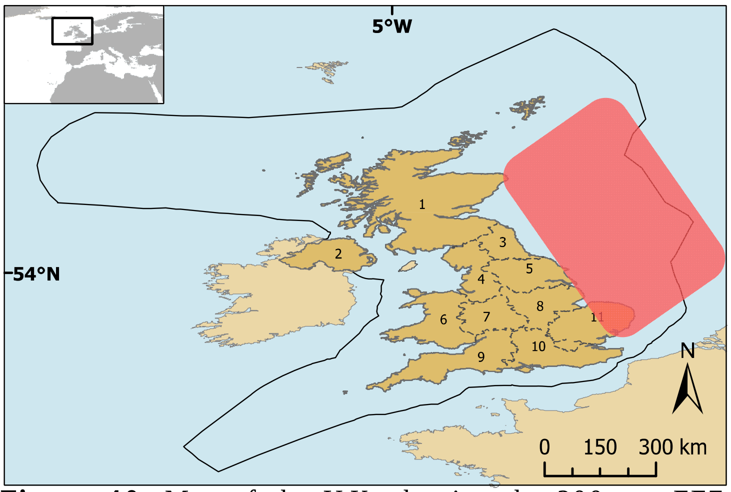


Figure 40. Map of the U.K. showing the 200 nm EEZ adjacent to the mainland and all maritime states. The U.K. EEZ is part of the North Sea LME and the Celtic-Biscay Shelf LME. Numbers correspond to maritime regions: Scotland, Northern Ireland, Northeast, Northwest, Yorkshire and Humberside, Wales, West Midlands, East Midlands, Southwest, Southeast, and Eastern, 1-11 respectively. The area covered by ecological models is highlighted in red.

The seas around the U.K. are host to some of the most productive fisheries in the world (Fishery Agencies 2005). Over 330 species of fish have been recorded in the shallow waters of the U.K. coastal shelf, with more in the deep-water habitats to the northwest of Scotland and Northern Ireland. There is some geographical distinction in fish populations in U.K. waters between north and south. Species diversity is greater in west and southwest U.K. waters, with the least diversity found in the central and south North Sea (Fishery Agencies 2005). The majority of U.K. fishers operate in a diversely mixed fishery, which can lead to high levels of discarding.

As of 2011, there were 6,444 fishing vessels operating in the U.K., 5,056 of which are under ten metres long (MMO 2012). The U.K. has the second largest fishing fleet by capacity in the E.U., at around half the size of the Spanish fleet (MMO 2012). Both the number of vessels and the overall capacity of the U.K. fleet have fallen drastically in recent years, with about a quarter of the vessels and the fishing capacity in the U.K. leaving the fleet since 1996. The main fishing methods are bottom trawling for demersal species, midwater trawling for pelagics and pots for shellfish, with diverse gears used across the small-scale fleet. Much management of the large-scale fleet is devolved to regional producer organisations, which take on a variety of responsibilities from quota management to processing/marketing (Hatcher and Cunningham 1994)

In 2011, U.K. vessels landed 600,000 t of fish (including shellfish) into the U.K. and abroad. This figure covers fish caught both in and out of the U.K. EEZ. The vast majority of U.K. catches are made in the northern North Sea and west of Scotland. These landings have decreased dramatically since the 1960s and 1970s, with official landings figures for U.K. boats landing into the U.K. at around 990,000 t in 1950, 975,000 t in 1970 and 759,000 t in 1980. A large proportion of this decline was in landings of demersal species, landings of which almost halved

[36] This introduction was provided by Ms. E. Cardwell (Oxford University Centre for the Environment, Oxford), the lead for the U.K. catch reconstruction currently being completed.

between 1970 and 1980 as the U.K. distant water fishery was curtailed by the introduction of territorial waters, particularly in Iceland and Norway.

The U.K. is part of the E.U. Common Fisheries Policy, so the EEZ boundaries do not apply to management regimes or fishing fleets, as all European fishers have access to a 'common pool' of the waters of E.U. member states. U.K. government laboratories that research the status of marine fisheries are CEFAS (in England and Wales), the Scottish Fisheries Research Services Marine Laboratory, and the Department for Agriculture and Rural Development for Northern Ireland. All these are involved in the wider European stock assessments undertaken by the International Council for the Exploration of the Sea. These are then used to inform the total allowable catches for given species in certain areas that are set by the European Commission. The U.K. manages its total allowable catch by allocating fixed quota allocations to fishing vessels over ten metres long. These are managed by producer organisations as that organisation sees fit: either as a pool that is fished against by its members, individual quotas or a mixture of both (Hatcher *et al.* 2002). The fleet quota for vessels <10 m is managed separately by the government. Shellfish (except for nephrops) are not managed by a quota system, instead coming under the jurisdiction of regional Inshore Fisheries and Conservation Authorities. Certain species (such as cod) are also subject to days at sea limitations. U.K. fisheries also have a range of rules on gear, closed areas and seasons (including marine conservation zones) and minimum landing sizes.

Unreported landings were considered to be widespread in the U.K. until 2005, when the government introduced the registration of fish at first sale in the U.K., making the sale of illegal fish difficult. Prior to this, fishers generally agree that unreported landings were significant. In early 2012 a high profile court case found seventeen pelagic vessel skippers guilty of landing over £62 million pounds worth of illegal over-quota fish between 2002 and 2005. Skippers in the northeast of Scotland reported that the high level of illegal landings in both the pelagic and demersal sectors depressed the price to such a degree that it was difficult to be economically successful if fishing legally. During the period between the introduction of E.U. quotas and the 2005 registration of buyers and seller's legislation, small scale fishing vessels were largely unregulated by the U.K. government. Government statistics included a nominal estimation of catches by the small-scale fleet, which the data availability afforded by the 2005 regulation proved to be a significant underestimation (Cardwell 2012). As such, official data on U.K. landings before 2005 are underestimations of actual catches.

Catch-MSY method for U.K. stocks

For the U.K., the single-species analyses suggest that the overall catch could be increased by 55 % when considering the top 12 landed species, or 44% when considering all 106 taxa, given fishing at single species F_{MSY} (Table 45).

Table 45. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the U.K. catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Atlantic herring	298,722	930,176	0.32
Atlantic mackerel	279,673	296,089	0.94
Norway pout	43,561	173,032	0.25
Atlantic cod	59,014	122,137	0.48
Blue whiting	349,805	307,654	1.14
Haddock	52,920	112,637	0.47
Saithe	65,643	88,,828	0.74
Whiting	38,271	73,480	0.52
Atlantic horse mackerel	71,243	108,825	0.65
European plaice	22,699	36,020	0.63
European sprat	30,846	60,714	0.51
Blue mussel	10,853	26,629	0.41
Average of top 12 (weighted)			**0.59 (0.45)**
Average of 106 taxa (weighted)			**0.88 (0.56)**

Model results for U.K. ecosystems

We used the North Sea ecosystem model (Mackinson and Daskalov 2007) to represent the U.K. marine ecosystems. The North Sea covers 570,000 km² and has an average depth of 90 m. It is located between 62˚and 50˚ N and 4˚ and 8˚ E (Figure 40) and bounded by the coasts of Norway, Denmark, Germany, the Netherlands, Belgium, France and Great Britain, and it is recognized as a Large Marine Ecosystem. The model had been fitted from 1991 to 2007.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and *optimization* simulations, both in terms of most targeted species and in terms of all catch (Table 46., Figure 41a). The average fishing mortality for the historical period is similar in both the historical exploitation region and *optimization* simulations with respect to the *allFmsy* simulation (Figure 41b).

Table 46. Catch rate ($t \cdot km^{-2} \cdot year^{-1}$) from the historical exploitation period (1: *baseline*) from the U.K. ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch ($t \cdot km^{-2} \cdot year^{-1}$) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Cod (adult)	0.260	0.20	0.13	1.3	2.0
Whiting (adult)	0.050	0.08	0.27	0.6	0.2
Haddock (adult)	0.080	0.15	0.03	0.5	2.3
Saithe (adult)	0.130	0.06	0.08	2.1	1.7
Hake	0.004	0.01	0.01	0.4	0.5
Blue whiting	0.010	0.06	0.09	0.2	0.2
Norway pout	0.710	1.60	0.38	0.4	1.9
Herring (adult)	0.610	0.02	1.19	38.2	0.5
Sprat	0.080	0.28	0.26	0.3	0.3
Mackerel	0.210	0.50	0.66	0.4	0.3
Horse mackerel	0.110	0.30	0.20	0.4	0.6
Plaice	0.550	2.32E-20	0.52	>100	1.1
Total catch (sp table)	**2.140**	**2.95**	**3.09**	**0.73**	**0.69**
Total catch*	**4.580**	**9.72**	**7.07**	**0.47**	**0.65**

* Number of commercial taxa/groups in the model = 49

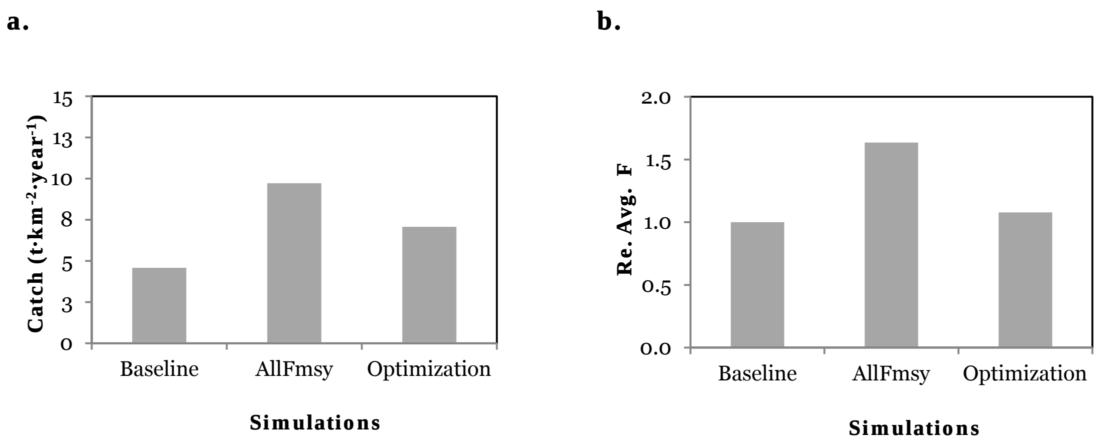


Figure 41. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the U.K. ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 44-53 % given fishing at single species F_{MSY}. However, when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass, the catch could only be increased by 35 %.

United States[37]

The EEZ of the U.S. is the largest in the world, encompassing over 12 million km², covers at least one million km² of continental shelf and includes a variety of physical features and habitats that have resulted in highly productive fisheries.

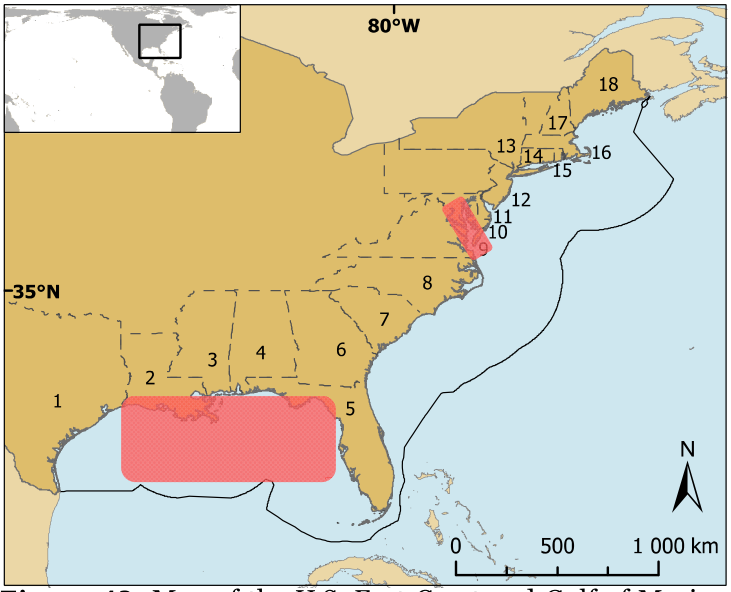


Figure 42. Map of the U.S. East Coast and Gulf of Mexico showing the 200 nm EEZ adjacent to the mainland and all maritime states. The U.S. East Coast is part of the Northeast U.S. Continental Shelf LME and the Southeast U.S. Continental Shelf LME. The U.S. Gulf of Mexico falls within the Gulf of Mexico LME. Numbers correspond to maritime states: Texas, Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, North Carolina, Virginia, Maryland, Delaware, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine, 1-18 respectively. The area covered by the ecological model is highlighted in red.

Prior to the mid-1970s, state authorities were responsible for the management of domestic marine fisheries within the 3 nm-wide territorial sea, while extensive foreign fishing outside of this zone was federally regulated according to international fishing agreements. As foreign catch began to exceed domestic catch during the 1950s and 1960s, the primary focus of the U.S. was to remain competitive via the modernization and expansion of its commercial fishing fleet as well as the extension of domestic fishing rights farther offshore (Hanna *et al.* 2000). In 1966, U.S. jurisdiction over its coastal waters increased to 12 nm from the coastline with the establishment of a fisheries zone contiguous to the territorial sea. During the 1970s, efforts to 'Americanize' fisheries, i.e., remove competing foreign fishing vessels, and develop a 'new frontier' of resources further from shore were evident (Hanna *et al.* 2000). In 1970, President Nixon created the National Oceanic and Atmospheric Association (NOAA), which would oversee the new federal agency, the National Marine Fisheries Service (NMFS). The Fisheries Conservation and Management Act (FCMA) was passed in 1976, establishing a Fishery Conservation Zone (later proclaimed an Exclusive Economic Zone in 1983), which extended U.S. authority over its fisheries resources from 12 to 200 nm. It also legislated the creation of eight regional fishery management councils (New England, Mid-Atlantic, South Atlantic, Gulf of Mexico, Western Pacific, Pacific, and North Pacific, which includes Alaska), charged with coordinating state, regional, tribal and federal interests and developing fishery management plans. It was not until 1989, following decades of expansion and intense fishing pressure which culminated in declining yields from many important stocks, that NMFS acknowledged the need for overfishing definitions to be included in the fishery management plan for each stock. Since 1996, conservation-oriented amendments to the FCMA, renamed the Magnuson-Stevens Fisheries Conservation and Management Act, have resulted in efforts to protect essential fish habitat, rebuild overfished fisheries, reduce bycatch, and assess and minimize impacts on coastal communities (Hanna *et al.* 2000).

[37] This introduction was provided by Dr. A. McCrea Strub (Fisheries Centre, University of British Columbia), the lead for the U.S. catch reconstruction presently being completed.

East Coast and Gulf of Mexico

The portions of the U.S. EEZ located in the Atlantic and Gulf of Mexico collectively account for approximately 13 % of the total area of the U.S. EEZ (Figure 42). Fishing grounds off the East Coast, extending from the coral reefs of the Florida Keys to Georges Bank and the Gulf of Maine, are influenced by the warm, northward flowing Gulf Stream Current, and the cold, southward flowing Slope Current, as well as outflow from numerous rivers. U.S. waters in the Gulf of Mexico are dominated by freshwater input from the Mississippi River, as well as periodic upwelling along the edge of the Loop Current (Sherman and Hempel 2008). Both regions are characterized by an extensive continental shelf.

Important commercial fisheries along the East Coast include the Atlantic menhaden (*Brevoortia tyrannus*) purse seining fleet; trawlers targeting Northeast groundfish, including Atlantic cod (*Gadus morhua*) and silver hake (*Merluccius bilinearis*); and numerous shellfish fisheries, including the American cupped oyster (*Crassostrea virginica*), Altlantic surf clam (*Spisula solidissima*), American sea scallop (*Placopecten magellanicus*), ocean quahog (*Arctica islandica*) and northern quahog (*Mercenaria mercenaria*). Large quantities of blue crab (*Callinectes sapidus*), Atlantic herring (*Clupea harengus*) and Atlantic mackerel (*Scomber scombrus*) are also landed on the East Coast. Commercial fisheries in the Gulf of Mexico have been dominated by the Gulf menhaden (*Brevoortia patronus*) and invertebrate fisheries targeting shrimp, including Northern brown (*Farfantepenaeus aztecus*), white (*Litopenaeus setiferus*), and pink shrimps (*Farfantepenaeus duorarum*) and shellfish, including American cupped oyster (*Crassostrea virginicus*) and Calico scallop (*Argopecten gibbus*) and blue crab (*Callinectes sapidus*).

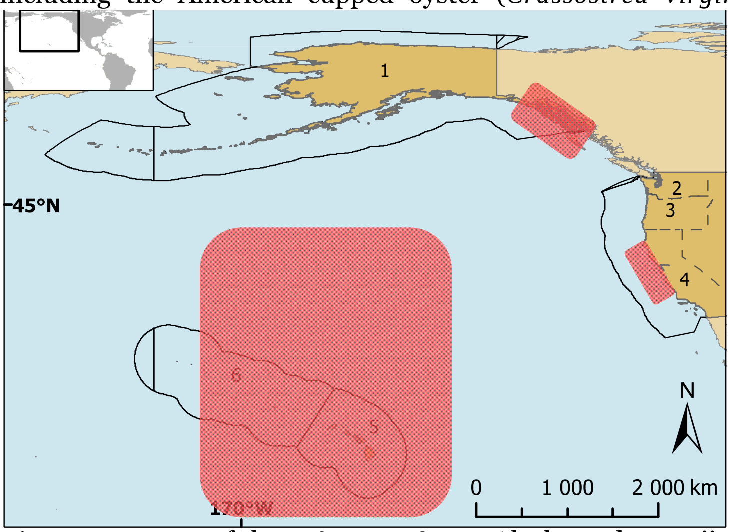


Figure 43. Map of the U.S. West Coast, Alaska and Hawaii, showing the 200 nm EEZ adjacent to the mainland and all maritime states. The U.S. West Coast falls within the California Current LME. Alaska is part of four LMEs: the East Bering Sea LME, the Chukchi Sea LME, the Beaufort Sea LME, and the Gulf of Alaska LME. Numbers correspond to maritime states (or geographic entities for Hawaii): Alaska, Washington, Oregon, California, Hawaii Main Islands, and Hawaii Northwest Islands, 1-6 respectively. The area covered by ecological models is highlighted in red.

West Coast

Pacific waters off of California, Oregon, and Washington comprise approximately 7 % of the U.S. EEZ (Figure 43). This region is dominated by seasonal upwelling of cold, nutrient-rich water along the southward-flowing California Current. While the continental shelf is rather narrow along this coastline, there are numerous bays and estuaries, notably Puget Sound, San Francisco Bay and the Columbia River estuary. Commercial fisheries along the West Coast have primarily targeted groundfish, including Pacific hake (*Merluccius productus*), Pacific cod (*Gadus macrocephalus*), Alaska pollock (*Theragra chalcogramma*), sablefish (*Anoplopoma fimbria*) and Pacific ocean perch (*Sebastes alutus*), salmon, primarily pink (*Oncorhynchus gorbuscha*), transboundary pelagic species, including the anchovy (*Engraulis mordax*), Pacific sardine (*Sardinops sagax*), and Pacific jack mackerel (*Trachurus symmetricus*), dungeness crab (*Metacarcinus magister*), and California market squid (*Loligo opalescens*).

Alaska

The largest proportion of the U.S. EEZ surrounds the state of Alaska, accounting for approximately 30 % by area (Figure 43). This includes the portions of the Arctic Ocean and the Bering Sea, the waters surrounding the Aleutian Islands, and the Gulf of Alaska. Several groundfish species, including Alaska pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), Pacific ocean perch (*Sebastes alutus*), yellowfin sole (*Limanda aspera*) and other flatfishes account for the majority of commercial catches. Also important are several species of salmon, including pink, sockeye (*Oncorhynchus nerka*), and chum (*Oncorhynchus keta*), Pacific herring (*Clupea pallasii pallasii*), Pacific saury (*Cololabis saira*) and snow crab (*Chionoecetes opilio*).

Hawaii

Approximately 7 % of the U.S. EEZ encompasses the Hawaiian Islands (Figure 43). The coral reefs and warm pelagic waters surrounding this tropical, volcanic island chain are influenced by equatorial currents and northeasterly trade winds. Commercial fisheries have primarily targeted pelagic species, including yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis*), bigeye tuna (*Thunnus obesus*), albacore (*Thunnus alalunga*) and chub mackerel (*Scomber japonicus*). Important non-pelagic species are also fished, including shrimps, sea urchins, and a variety of deep-water 'bottomfish' (Zeller *et al.* 2008).

Catch-MSY method for U.S. (Alaskan) stocks

For Alaska, the single-species analyses suggest that the overall catch could be increased by 6 % when considering the top 12 landed species, or 2 % when considering all 52 taxa, given fishing at single species F_{MSY} (Table 47).

Table 47. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the Argentine catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Alaska pollock	1,461,116	1,278,885	1.14
Pacific cod	207,664	165,117	1.26
Pink salmon	133,619	113,528	1.18
Sockeye salmon	95,650	112,958	0.85
Pacific herring	54,316	83,887	0.65
Chum salmon	51,938	59,273	0.88
Pacific ocean perch	11,642	24,928	0.47
Pacific saury	10,613	85,425	0.12
Yellowfin sole	65,780	54,794	1.20
Atka mackerel	48,788	52,712	0.93
Coho salmon	15,125	20,659	0.73
Pacific halibut	33,749	27,235	1.24
Average of top 12 (weighted)			**0.89 (0.94)**
Average of 52 taxa (weighted)			**0.85 (0.98)**

Model results for U.S. (Alaskan) ecosystems

We used the South East Alaska model (Guénette *et al.* 2006) to represent the Alaska marine ecosystems. The South East Alaska model covers the continental shelf to 1,000 m depth and extends from 140°–137° W and the southern limit is the border between British Columbia and Alaska (Figure 43). The model had been fitted from 1963 to 2002.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and *optimization* simulations, both in terms of most targeted species and in terms of all catch (Table 48., Figure 44a). The average fishing mortality from 1963 to 2002 is similar in both the *baseline* and *optimization* simulations, and it is larger under the *allFmsy* simulation (Figure 44b).

Table 48. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the U.S. Alaskan ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch (t·km^{-2}·year^{-1}) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Salmon	0.3400	0.610	0.5200	0.60	0.7
Herring	0.1100	0.320	0.3600	0.40	0.3
Pollock adult	0.0003	0.010	0.0002	0.05	1.3
Rockfish slope	0.0001	0.002	0.0001	0.05	1.2
Rockfish shelf	0.0015	0.020	0.0010	0.10	1.4
Sablefish	0.0400	0.060	0.0100	0.60	4.2
Pacific cod	0.0003	0.003	0.0001	0.10	2.6
Halibut	0.0900	0.090	0.0800	0.90	1.1
Arrowtooth	0.0010	0.010	0.0003	0.10	2.6
Flatfish	0.0004	0.010	0.0003	0.05	1.3
Total catch (sp table)	**0.5800**	**1.120**	**0.9700**	**0.52**	**0.6**
otal catch*	**0.6300**	**1.950**	**1.0000**	**0.32**	**0.6**

* Number of commercial taxa/groups in the model = 21

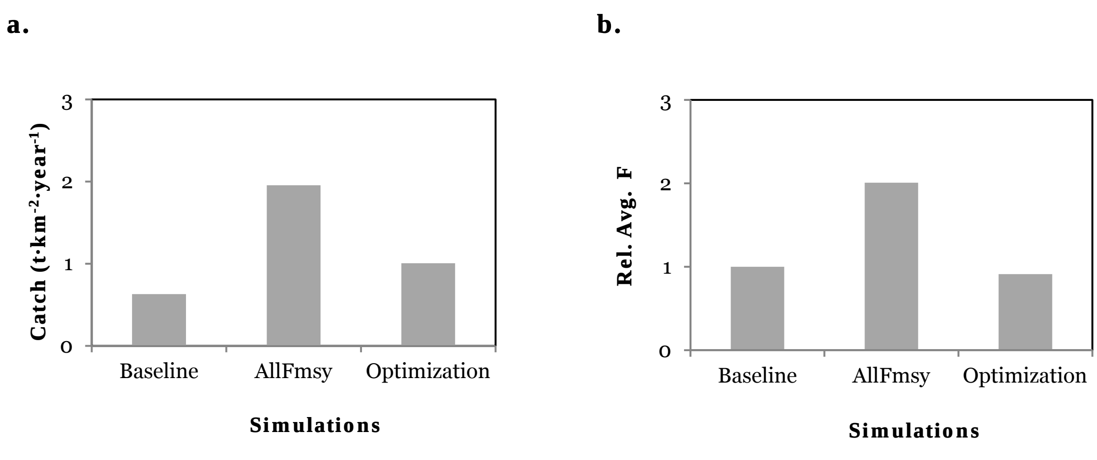


Figure 44. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the U.S. Alaskan, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 2-68 % given fishing at single species F_{MSY}. However, when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass, the catch could only be increased by 37 %.

Catch-MSY method for U.S. (East Coast) stocks

For the U.S. East Coast, the single-species analyses suggest that the overall catch could be increased by 50 % when considering the top 12 landed species, or 41 % when considering all 106 taxa, given fishing at single species F_{MSY} (Table 49).

Table 49. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the U.S. East Coast catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	**Catch**	**MSY**	**Catch:MSY**
Atlantic menhaden	244,556	341,825	0.72
American cupped oyster	59,126	148,764	0.40
Atlantic surf clam	131,845	149,251	0.88
American sea scallop	176,284	137,623	1.28
Atlantic herring	37,997	125,850	0.30
Ocean quahog	90,534	96,100	0.94
Atlantic mackerel	36,229	238,118	0.15
Blue crab	41,469	49,533	0.84
Silver hake	22,856	165,904	0.14
Atlantic cod	3,506	32,275	0.11
Northern quahog	27,007	38,625	0.70
Alewife	739	46,699	0.02
Average of top 12 (weighted)			**0.54 (0.50)**
Average of 106 taxa (weighted)			**0.56 (0.59)**

Model results for U.S. (East Coast) ecosystems

We used the Chesapeake model (Christensen *et al.* 2009a) to represent the U.S. East Coast marine ecosystems. The Chesapeake Bay, Maryland, is the largest estuary in the continental U.S., located midway along the Atlantic coast. The surface area of the tidal portion of the Chesapeake Bay system is approximately 10,000 km^2, while the area including tributaries is estimated to be 18,580 km^2. The model covers 37 °-39° N and 77°-75° W (Figure 42), and it had been fitted from 1950 to 2002.

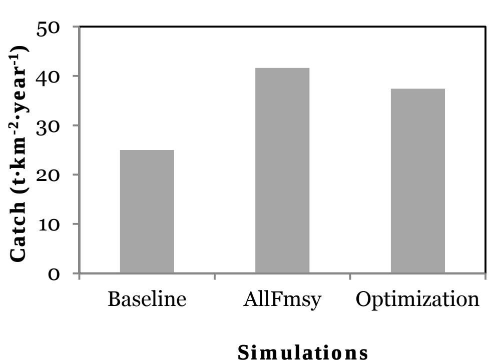
The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and *optimization* simulations, both in terms of most targeted species and in terms of all catch (Table 50, Figure 45a). The average fishing mortality from 1950 to 2002 is lower in the historical exploitation than under the other two simulations (Figure 45b).

Table 50. Catch rate (t·km⁻²·year⁻¹) from the historical exploitation period (1: *baseline*) from the U.S. East Coast ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch ($t \cdot km^{-2} \cdot year^{-1}$) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Striped bass resident	0.13	0.22	0.38	0.6	0.3
Striped bass migratory	0.11	0.09	0.26	1.1	0.4
Bluefish adult	0.20	0.20	0.14	1.0	1.5
Weakfish Adult	0.20	0.30	0.26	0.7	0.7
Atlantic croaker	0.68	0.92	0.60	0.7	1.1
Menhaden 0-1	1.79	1.17	0.40	1.5	4.5
Menhaden adult	10.06	23.20	21.61	0.4	0.5
Alewife and herring	2.08	2.71	1.77	0.8	1.2
Blue crab adult	6.21	6.42	5.26	1.0	1.2
Oyster 1+	2.28	3.58	3.56	0.6	0.6
Soft clam	0.09	0.48	0.86	0.2	0.1
Hard clam	0.10	0.51	0.97	0.2	0.1
Total catch (sp table)	**23.92**	**39.80**	**36.06**	**0.6**	**0.7**
Total catch*	**25.00**	**41.63**	**37.40**	**0.6**	**0.7**

* Number of commercial taxa/groups in the model = 20

a.



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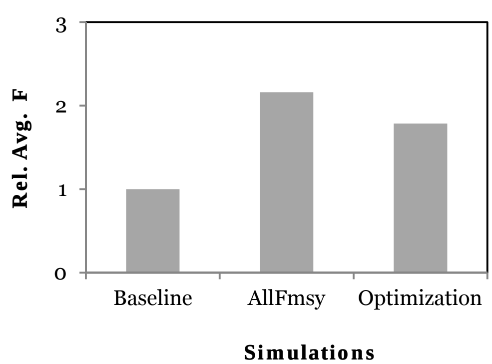


Figure 45. a) Predicted total catches ($t \cdot km^{-2} \cdot year^{-1}$), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the U.S. East coast, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 40-41 % given fishing at single species F_{MSY}. However, when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass, the catch could only be increased by 33 %.

Catch-MSY method for U.S. (Gulf of Mexico) stocks

For the U.S. Gulf of Mexico, the single-species analyses suggest that the overall catch could be increased by 50 % when considering the top 12 landed species, or 49 % when considering all 54 taxa, given fishing at single species F_{MSY} (Table 51).

Table 51. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the U.S. Gulf of Mexico catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Gulf menhaden	388,838	981,678	0.40
Northern brown shrimp	42,704	46,357	0.92
American cupped oyster	59,536	45,124	1.32
Northern white shrimp	39,824	35,653	1.12
Atlantic menhaden	10,964	27,676	0.40
Blue crab	25,761	29,368	0.88
Calico scallop	28,167	40,067	0.70
Northern pink shrimp	4,977	8,754	0.57
Spanish mackerel	928	2,359	0.39
Atlantic croaker	491	6,266	0.08
Spot croaker	318	2,684	0.12
Spotted weakfish	557	1,963	0.28
Average of top 12 (weighted)			**0.60 (0.50)**
Average of 54 taxa (weighted)			**0.58 (0.51)**

Model results for U.S. (Gulf of Mexico) ecosystems

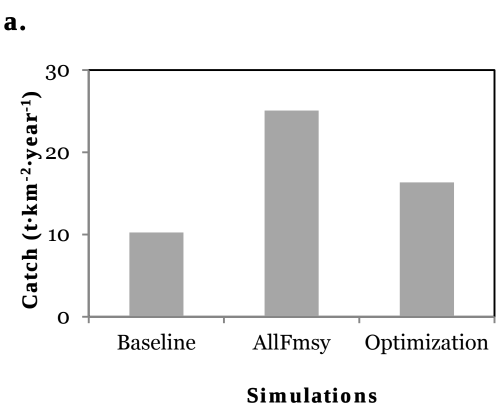
We used the Northern Gulf of Mexico model (Walters *et al.* 2010) to represent the U.S. Gulf of Mexico marine ecosystems. The model in located in the northern part of the Gulf of Mexico Large Marine Ecosystem, from 31°-24° N and 98°-81° W (Figure 42). The model had been fitted from 1951 to 2004.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and *optimization* simulations, both in terms of most targeted species and in terms of all catch (Table 52, Figure 46a). The average fishing mortality from 1951 to 204 is also smaller under the historical exploitation reconstruction (Figure 46b).

Table 52. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the U.S. Gulf of Mexico ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch (t·km^{-2}·year^{-1}) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
18+ Mullet	0.42	1.75E-20	1.04	>100	0.4
Mackerel 3+	0.07	0.030	0.06	2.9	1.3
Grouper 3+	0.08	0.040	0.06	2.2	1.4
Jacks	0.02	0.002	0.01	10.0	2.0
Bay anchovy	0.06	0.100	0.04	0.6	1.5
Silver perch	1.48	1.72E-20	1.32	>100	1.1
Scaled sardine	1.51	13.880	6.60	0.1	0.2
Menhaden	3.10	2.680	2.16	1.2	1.4
Shrimp	1.32	1.300	1.66	1.0	0.8
Red snapper 6-24	0.06	0.010	0.03	8.6	2.0
Red snapper older	0.06	0.010	0.01	4.7	8.3
Atlantic croaker	0.29	0.350	0.29	0.8	1.0
Total catch (sp table)	**8.48**	**18.390**	**13.28**	**0.5**	**0.6**
Total catch*	**10.26**	**25.070**	**16.34**	**0.4**	**0.6**

* Number of commercial taxa/groups in the model = 28



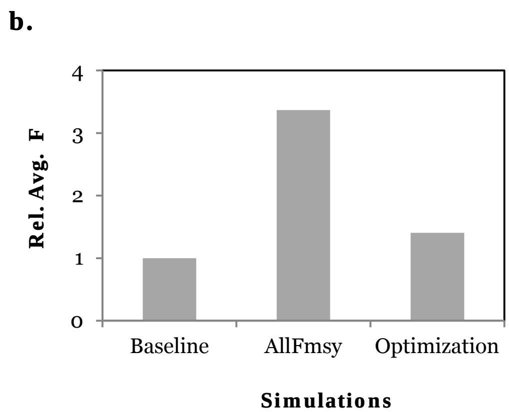


Figure 46. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the U.S. Gulf of Mexico coastal ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 49-59 % given fishing at single species F_{MSY}. However, when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass, the catch could only be increased by 37 %.

Catch-MSY method for U.S. (Hawaiian) stocks

For Hawaii, the single-species analyses suggest that the overall catch could be increased by 88 % when considering the top 12 landed species or when considering all 20 taxa, given fishing at single species F_{MSY} (Table 53).

Table 53. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the U.S. Hawaiian catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
Yellowfin tuna	450.9	9,585	0.05
Skipjack tuna	938.1	7,425	0.13
Chub mackerel	579.0	2,731	0.21
Bigeye tuna	194.2	2,298	0.08
Albacore	200.6	2,539	0.08
Pacific cupped oyster	177.5	241	0.74
Pacific bluefin tuna	53.5	229	0.23
Pacific sierra	2.8	449	0.01
Striped marlin	16.9	274	0.06
Swordfish	66.2	101	0.66
Indo-Pacific blue marlin	15.6	162	0.10
Indo-Pacific sailfish	16.8	155	0.11
Average of top 12 (weighted)			**0.20 (0.12)**
Average of 20 taxa (weighted)			**0.25 (0.12)**

Model results for U.S. (Hawaiian) ecosystems

We used the Central North Pacific ecosystem and Hawaii-based pelagic longline fishery model (Howell *et al.* in press) to represent the U.S. Hawaiian pelagic marine ecosystems. The model is located in the Central North Pacific Subtropical Gyre and Transition Zone, from 170° E to 150° W and 10°-40° N (Figure 43), and covers a surface area of 13,275,700 km^2 encompassing the region where more than 95 % of Hawaii longline sets occur. The model had been fitted from 1991 to 2010.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and *optimization* simulations, both in terms of most targeted species and in terms of all catch (Table 54, Figure 47a). The average fishing mortality from 1991 to 2010 is similar in the three simulations (Figure 47b).

Table 54. Catch rate (t·km⁻²·year⁻¹) from the historical exploitation period (1: *baseline*) from the U.S. Hawaiian ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch ($t \cdot km^{-2} \cdot year^{-1}$) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Swordfish	4.8E-05	4.8E-09	1.7E-04	>100	0.3
Blue marlin	4.9E-05	7.9E-05	2.4E-05	0.60	2.0
Other billfish	4.0E-05	5.6E-05	1.3E-05	0.70	3.0
Yellowfin	5.5E-05	0.003	2.7E-04	0.02	0.2
Juv. yellowfin	7.4E-06	3.2E-04	3.8E-05	0.02	0.2
Albacore	0.002	0.009	0.012	0.20	0.2
Bigeye	2.3E-04	2.8E-04	1.5E-04	0.90	1.6
Juv bigeye	3.4E-04	2.7E-04	7.4E-04	1.20	0.5
Skipjack	0.005	0.002	0.005	2.40	1.1
Mahi mahi	5.6E-05	3.7E-04	2.4E-05	0.20	2.3
Total catch (sp table)	**0.008**	**0.015**	**0.018**	**0.54**	**0.5**
Total catch*	**0.012**	**0.018**	**0.021**	**0.67**	**0.6**

* Number of commercial taxa/groups in the model = 17

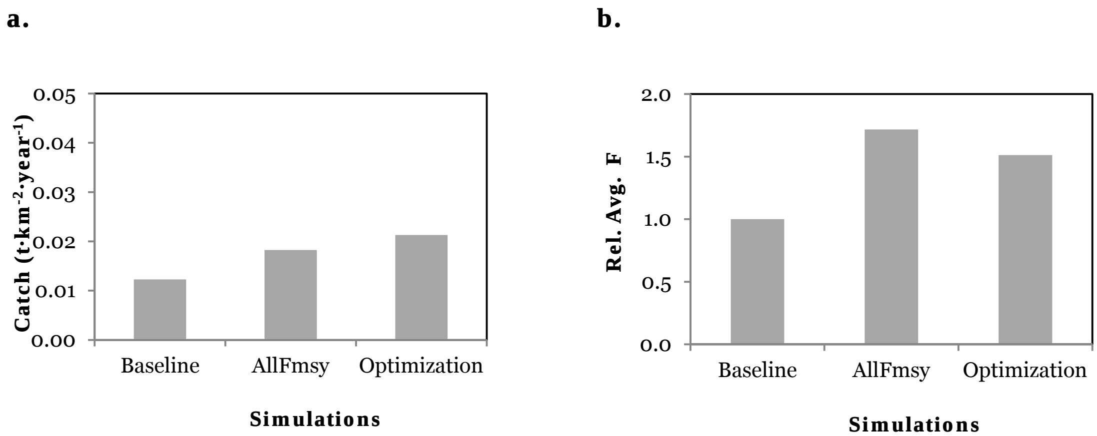


Figure 47. a) Predicted total catches ($t \cdot km^{-2} \cdot year^{-1}$), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the U.S. Hawaiian ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 33-88 % given fishing at single species F_{MSY}. However, when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass, the catch could only be increased by 48 %.

Catch-MSY method for U.S. (West Coast) stocks

For the U.S. West Coast, the single-species analyses suggest that the overall catch could be increased by 21 % when considering the top 12 landed species, or 16 % when considering all 55 taxa, given fishing at single species F_{MSY} (Table 55).

Table 55. Catch and MSY (in tonnes) for the 12 taxa that contribute most to the U.S. west coast catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	Catch	MSY	Catch:MSY
North Pacific hake	199,789	164,236	1.22
Alaska pollock	73,729	66,226	1.11
Californian anchovy	7,622	121,132	0.06
Pacific sardine	57,907	110,369	0.52
Pacific cod	34,093	27,774	1.23
Dungeness crab	23,830	18,387	1.30
Sablefish	10,781	10,296	1.05
Pacific herring	4,116	7,277	0.57
Pacific jack mackerel	2,195	9,008	0.24
Pacific ocean perch	2,902	7,351	0.39
Pink salmon	12,586	10,044	1.25
Arrowtooth flounder	2,111	3,713	0.57
Average of top 12 (weighted)			**0.79 (0.79)**
Average of 55 taxa (weighted)			**0.55 (0.84)**

Model results for U.S. (West Coast) ecosystems

We used the Central California coast model (Walters *et al.* 2010) to represent the U.S. West Coast marine ecosystem. The model is located in the central part of California, from 39º-37º N and 122º-123 º W (Figure 43). The model had been fitted from 1960 to 2005.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and *optimization* simulations, both in terms of most targeted species and in terms of all catch (Table 56, Figure 48a). The average fishing mortality from 1960 to 2005 is also smaller under the historical exploitation reconstruction (Figure 48b).

Table 56. Catch rate (t·km^{-2}·year^{-1}) from the historical exploitation period (1: *baseline*) from the U.S. West coast ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch (t·km^{-2}·year^{-1}) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Lingcod adult	0.02	0.04	0.040	0.6	0.5
Cabezon adult	0.04	0.02	0.004	1.8	8.3
Shortbelly rockfish adult	0.02	0.02	0.030	0.9	0.8
Nearshore rockfish adult	0.11	0.14	0.120	0.8	0.9
Widow rockfish adult	0.23	0.27	0.270	0.8	0.8
Flatfish	0.77	1.13	0.980	0.7	0.8
Hake	2.56	3.12	2.800	0.8	0.9
Salmon	0.21	0.22	0.220	0.9	0.9
Cephalopods	0.20	0.71	0.330	0.3	0.6
Crabs	0.56	0.58	0.200	1.0	2.8
Shrimps	1.94	2.85	4.380	0.7	0.4
Abalone adult	0.06	0.10	0.070	0.6	1.0
Total catch (sp table)	**6.71**	**9.21**	**9.440**	**0.7**	**0.7**
Total catch*	**6.71**	**9.21**	**9.440**	**0.7**	**0.7**

* Number of commercial taxa/groups in the model = 12

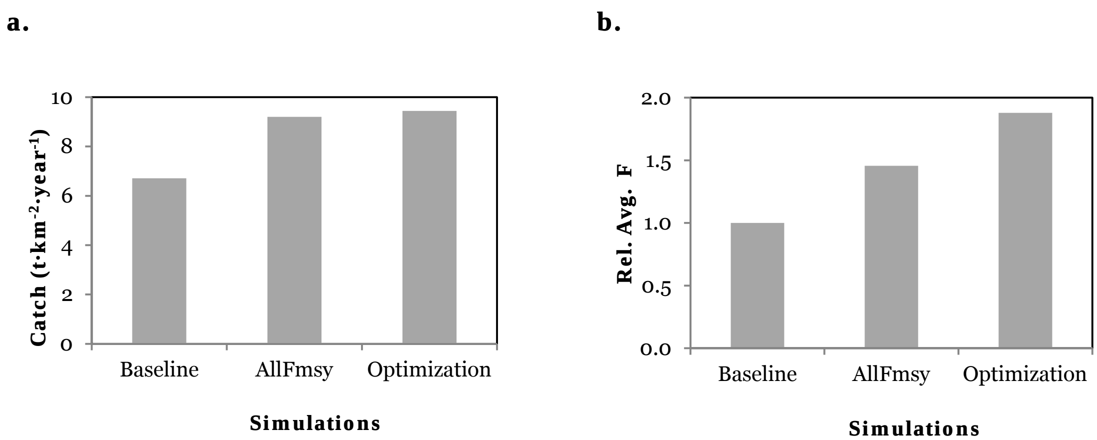


Figure 48. a) Predicted total catches (t·km^{-2}·year^{-1}), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the U.S. West coast ecosystem, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 16-27 % given fishing at single species F_{MSY}. However, catches could be increased by 29 % when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass.

Vietnam[38]

The Socialist Republic of Vietnam is located on the eastern coast of the Indochina peninsula and is bordered in the north by China and in the west by Laos and Cambodia (Figure 49). Fishing in Vietnam occurs in four main areas: the Gulf of Tonkin, shared with China, in the north, the South China Sea in the center and the southeast, and the Gulf of Thailand in the southwest. The total EEZ area of Vietnam is 1,396,000 km² and extends to 200 nautical miles off the coast.

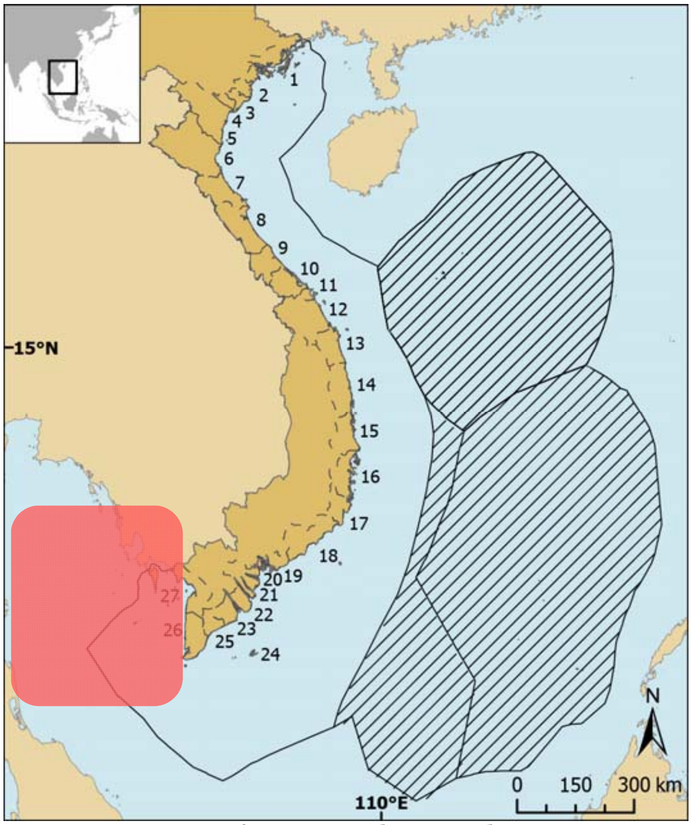


Figure 49. Map of Vietnam showing the 200 nm EEZ adjacent to the mainland, all maritime states, and disputed regions (cross-hatch). The Vietnamese EEZ is part of the South China Sea LME. Numbers correspond to maritime states: Quang Ninh, Thái Bìhn, Nam Dinh, Ninh Bình, Thanh Hóa, Nghe An, Ha Tinh, Quang Binh, Quang Tri, Thua Thien-Hue, à Nang City, Dà Nang, Quang Ngãi, Bình Dihn, Phú Yên, Khánh Hòa, Ninh Thuan, Bình Thuan, Bà Ria, Ho Chí Minh City, Ben Tre, Trà Vinh, Sóc Trang, Bac Liêu, Cà Mau, Kiên Giang, 1-26 respectively. The area covered by th ecological model is highlighted in red.

The majority of marine fishing in Vietnam is small-scale and occurs in shallow near-shore areas, which comprise roughly 11 % of the EEZ (Han 2007). Inshore fishing, which comprises 84 % of the fishing fleet is mandated by the government to be of vessels of less than 90 hp. In 2006, the fishery sector contributed 6 % of the GDP (Nguyen and Tran 2007). According to a recent report by the World Bank, at least 20 million people depend on inshore fisheries for a portion if not all of their subsistence and income (MOFI 2005).

Women have a relatively small role in marine fisheries, with reports of only 1.4 % of fish workers being women (MOFI 2005). However, due to fewer cultural constraints, women have a larger role in aquaculture. Efforts by the Ministry of Fisheries are currently underway to strengthen the role of women in fisheries (Lem *et al.* 2004); however, at the moment, women's roles are largely relegated to processing in the fisheries market chain (MOFI 2005).

There is a lack of systematic information on Vietnamese fisheries (Pitcher *et al.* 2006; Long *et al.* 2008) and this is impeding assessments of fisheries status. Under-reporting of catch has been identified as an issue in several reports (Pomeroy *et al.* 2009), but there has not been an estimate of the likely true level of catches, which would provide a baseline for management and informed decisions about overcapacity and overexploitation (van Zwieten *et al.* 2002).

Trawls, along with gill nets, purse seine, long lines, lift nets and gill nets are the major gear types used in Vietnamese marine fisheries. There is very little information on gear use in Vietnam, however. the major trawl types are known to be either single or pair trawls (Luong 2001; MOFI

[38] This introduction was provided by Dr. D. Pauly (Fisheries Centre, University of British Columbia).

2005). There is an ongoing problem of larger trawlers of greater than 45 HP illegally fishing in coastal waters due to poor enforcement (Boonstra and Dang 2010). This issue of encroachment of offshore vessels into inshore waters is widespread throughout South East Asia, and contributes to the overfishing of coastal resources and habitat destruction.

Information regarding discards in Vietnam is not readily available. It is suspected that Vietnam has few discards and recent internal estimates of the marine catch were substantially higher than that reported by the FAO (Kelleher 2005). The lack of data on discards may also be due to the high demand for fish of low economic value due for Vietnam's fishmeal and fish sauce industries. There have been estimates that 40-50 % of trawl catch may be comprised of low value, so-called 'trash' fish that supplies the fish sauce industry, which produced 160 million liters of fish sauce in 1998. However, some reports also suggest that trawlers that go on longer fishing trips of up to 20 days, typically discard a large portion of the catch (Edwards *et al.* 2004). This is supported by the fact that a large portion of the Vietnamese fleet has neither adequate capacity nor the technology (i.e., freezer capacity) to maintain substantial by-catch on long fishing trips (Son *et al.* 2005). Furthermore, the vessels that have been documented by Kelleher (2005) may possibly be small-scale inshore vessels, which would not have the capacity to go on long trips.

Catch-MSY method for Vietnamese stocks

For Vietnam, the single-species analyses suggest that the overall catch could be increased by 84 % when considering the top 12 landed species, or 72 % when considering all 52 taxa, given fishing at single species F_{MSY} (Table 57).

Table 57. Catch and MSY (in tonnes) for the 12 taxa that contribute most to Vietnamese catch. Catch:MSY ratios are presented for each of these species, along with averages, straight and weighted by catch contribution in parentheses. Additionally, averages for all of the taxa, e.g., those meeting the specified criteria are presented.

Stock	**Catch**	**MSY**	**Catch:MSY**
North Pacific hake	0	164,236	1.22
Alaska pollock	73,729	66,226	1.11
Californian anchovy	7,622	121,132	0.06
Pacific sardine	57,907	110,369	0.52
Pacific cod	34,093	27,774	1.23
Dungeness crab	23,830	18,387	1.30
Sablefish	10,781	10,296	1.05
Pacific herring	4,116	7,277	0.57
Pacific jack mackerel	2,195	9,008	0.24
Pacific ocean perch	2,902	7,351	0.39
Pink salmon	12,586	10,044	1.25
Arrowtooth flounder	2,110	3,713	0.57
Average of top 12 (weighted)			**0.34 (0.16)**
Average of 52 taxa (weighted)			**0.54 (0.28)**

Model results for Vietnamese ecosystems

We used the Gulf of Thailand model (Vibunpant *et al.* 2003) as a proxy representation of Vietnamese marine ecosystems (Figure 49). The study area is located between 6º-13º N and 99º-104º E with an area of 304,000 km². The Gulf of Thailand is relatively shallow with a mean depth of about 58 m. The model had been fitted to historic time series of data from 1973 to 1993.

The *baseline* simulation results show lower catch in the area under the historical exploitation regime than under the *allFmsy* and optimization simulations when the main target species are taken into account (Table 58., Figure 50a). Total catch is also higher under the *allFmsy* simulation and slightly lower under the *optimization* simulation. The average fishing mortality from 1973 to 1993 is similar in the historical exploitation regime and *optimization* simulation and higher in the *allFmsy* results (Figure 50b).

Table 58. Catch rate (t·km⁻²·year⁻¹) from the historical exploitation period (1: *baseline*) from the Vietnamese ecosystem and the two simulations (2: *allFmsy* and 3: *optimization*). Ratios of catch to MSY represent the comparison of the historical period to the two simulations.

Exploited species / groups	Catch ($t \cdot km^{-2} \cdot year^{-1}$) 1. Baseline	2. AllFmsy	3. Optimization	Catch:MSY 1/2	1/3
Rastrelliger spp.	0.220	0.230	0.110	0.9	1.9
Scomberomorus	0.003	3.96E-10	3.57E-11	>100	>100
Carangidae	0.040	0.030	0.020	1.6	2.9
Pomfret	0.010	3.98E-04	1.53E-05	13.0	>100
Small pelagic	0.200	0.380	0.120	0.5	1.6
False trevally	0.003	0.001	3.38E-04	4.7	9.3
Large piscivores	8.61E-07	0.010	0.020	0.0	0.0
Sciaenidae	0.003	0.050	0.040	0.1	0.1
Saurida spp.	0.040	0.030	0.030	1.1	1.1
Lutjanidae	4.55E-07	0.010	0.010	0.0	0.0
Plectorhynchidae	0.001	0.002	0.002	0.4	0.5
Priacanthus spp.	0.030	0.050	0.030	0.6	1.0
Shrimps	0.310	0.250	0.230	1.3	1.4
Crab, lobsters	0.190	0.490	0.150	0.4	1.3
Demersal piscivores	0.050	0.030	0.030	2.0	2.0
Shellfish	0.110	0.5100	0.500	0.2	0.2
Coastal tuna	0.010	0.010	0.005	1.4	2.0
Sergestid shrimp	0.080	0.130	0.050	0.6	1.6
Total catch (sp table)	**1.280**	**2.210**	**1.320**	**0.6**	**1.0**
Total catch*	**2.840**	**4.010**	**2.570**	**0.7**	**1.1**

* Number of commercial taxa/groups in the model = 31

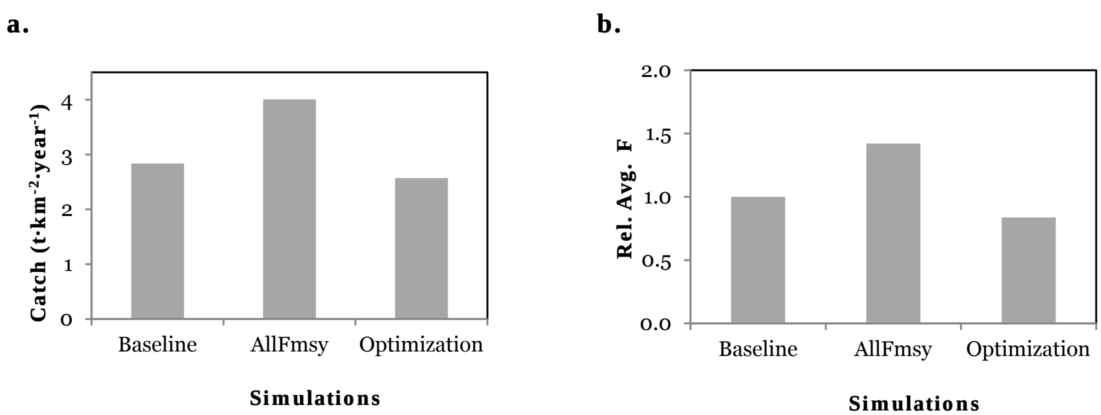


Figure 50. a) Predicted total catches ($t \cdot km^{-2} \cdot year^{-1}$), and b) Average relative fishing mortality (sum of catch / sum of biomass of exploited species for the historical period years from the Vietnamese, relative to the historical period value), under the *baseline*, the *allFmsy* and *optimization* simulations, respectively.

Both the single-species and the ecosystem-based analyses suggest that the overall catch could be increased by 29-72 % given fishing at single species F_{MSY}. However, the catch could not be increased when we account for optimal management, including fishing at F_{MSY}, and including biodiversity and criteria for rebuilding biomass. Part of the reason for the divergence between the catch-based and ecosystem-based models could be the fact that the ecosystem model was fitted to an earlier time period, as well as the limited spatial representation of the model for Vietnamese waters.

Comparison of catch-based and ecosystem model results

For all the countries examined here, both the single-species and the ecosystem-based analyses suggest that overall catches could be increased by approximately 35 % given fishing at single species F_{MSY} (Table 59). However, if one considers biodiversity or rebuilding criteria for exploited species, the approximate increase in catch would be lower. Therefore, as expected, the *optimization* simulation produces a more conservative estimate of the catch potential than does the *allFmsy* simulation, which is based on fishing at F_{MSY}.

If we consider all 38 regions, i.e., including those that do not have *EwE* models available, the average catch:MSY ratio is 0.72 and 0.65, based on the straight and weighted average ratios, respectively. This translates to a potential catch increase of 28 % and 35 %, respectively.

Table 59. Comparative results of catch:MSY ratios from the catch-based models, and ecosystem models illustrating the overall averages for the total number of taxa available for each countries. Weighted averages from the catch-based models are presented in parentheses. The overall average is only calculated from the regions where both methods could be applied (bold).

	Catch-based models		Ecosystem-based models	
Countries	**# total taxa**	**Average ratio**	**AllFmsy**	**Optimization**
Argentina	44	0.63 (0.94)	--	--
Belize	40	1.07 (1.01)	--	--
Brazil	41	0.80 (0.51)	--	--
Canada (Arctic)	10	0.54 (0.46)	--	--
Canada (Atlantic)	**70**	**0.81 (0.49)**	**0.59**	**0.97**
Canada (Pacific)	**33**	**0.53 (0.44)**	**0.51**	**0.89**
Chile	48	0.71 (0.70)	--	--
China	**91**	**0.57 (0.83)**	**1.38**	**2.83**
Denmark	**65**	**0.75 (0.62)**	**0.49**	**0.78**
Iceland	44	0.71 (0.74)	--	--
India	40	1.00 (0.84)	--	--
Indonesia (East)	**46**	**1.01 (0.92)**	**0.64**	**0.81**
Indonesia (West)	45	1.00 (0.87)	--	--
Japan	80	0.62 (0.44)	--	--
Malaysia (East)	**34**	**0.92 (0.89)**	**0.71**	**1.10**
Malaysia (West)	40	0.86 (0.91)	--	--
Mexico (Gulf of Mexico)	31	0.65 (0.36)	--	--
Mexico (Pacific)	**20**	**0.64 (0.88)**	**0.80**	**0.52**
Morocco	**67**	**0.59 (1.08)**	**0.76**	**0.66**
Norway	**74**	**0.71 (0.74)**	**0.70**	**1.02**
Peru	**21**	**0.66 (0.73)**	**0.58**	**0.51**
Philippines	39	0.84 (0.79)	--	--
Russia (Barents Sea)	**29**	**0.57 (0.27)**	**0.70**	**1.02**
Russia (Black Sea)	25	0.74 (0.23)	--	--
Russia (Pacific)	55	0.76 (0.63)	--	--
South Africa	**48**	**0.59 (0.81)**	**0.27**	**0.55**
South Korea	90	0.52 (0.55)	--	--
Spain (Atlantic)	60	0.45 (0.02)	--	--
Spain (Mediterranean)	**68**	**0.81 (0.62)**	**0.54**	**0.68**
Turkey (Black Sea)	47	0.91 (0.55)	--	--
Turkey (Mediterranean)	67	0.99 (0.90)	--	--
United Kingdom	**106**	**0.88 (0.56)**	**0.47**	**0.65**
U.S. (Alaska)	**52**	**0.85 (0.98)**	**0.32**	**0.63**
U.S. (East Coast)	**106**	**0.56 (0.59)**	**0.60**	**0.67**
U.S. (Gulf of Mexico)	**54**	**0.58 (0.51)**	**0.41**	**0.63**
U.S. (Hawaii)	**20**	**0.25 (0.12)**	**0.67**	**0.58**
U.S. (West Coast)	**55**	**0.55 (0.84)**	**0.73**	**0.71**
Vietnam	**52**	**0.54 (0.28)**	**0.71**	**1.10**
Average (of bold values)		**0.67 (0.66)**	**0.63**	**0.87**

Marine protection features by country

Overall, the MPAs designated in the 25 countries covered here vary widely in every aspect, including size, location (distance from coastline), protection level (multiple-use to no-take), management and effectiveness. Each of the countries assessed has its own legislation – applicable at different scales (national, state, municipal, etc.) – for establishing MPAs. For example, the U.K. government's plan for an MPA network includes designations under national, European and international legislation[39]. In contrast, the EEZs of the Philippines and Japan are dominated by numerous small, community-based MPAs instituted and managed at the local level (Weeks *et al.* 2010; Yagi *et al.* 2010).

The MPAs established by each country vary widely in their purpose and level of protection. Some MPAs protect only a limited number of marine species or prevent only certain activities. For example, the main objective of *La Rinconada* Marine Reserve in northern Chile is to protect the last population of an exploited scallop species (Rovira *et al.* 2008). Others cover large areas and do not allow any extractive activities, such as the 253 km² no-take De Hoop MPA in South Africa (Tunley 2009). This variation is most dramatic in the case of U.S. MPAs. For example, in the Monterey Bay National Marine Sanctuary, the only prohibited activities are oil and gas extraction and scientific research (without a permit; Dayton *et al.* 2000), whereas the De Soto MPA off the west coast of Florida prohibits fisheries using certain gear types. Conversely, the large Papahanaumokuakea Marine National Monument covering about 360,000 km² in Hawaii is entirely no-take.

Variability is also manifested simply by the differences in location. The MPAs analyzed here range from 100 % marine to predominately terrestrial with just a small portion of intertidal habitat. As an example, Brazil considers terrestrial protected areas located within the Marine and Coastal Zone (Ministry of the Environment 2010; Szlafsztein 2012) as MPAs. Country-specific delineations such as this can make it difficult to determine accurately the number of 'true' MPAs as well as the areal coverage of marine protection. Over-lapping designations can also complicate the calculation of coverage. For example, Special Areas of Conservation in the U.K. can coincide partially or fully with Special Protection Areas[40].

While it is useful to know the number of MPAs established by each country, it is equally important to have data regarding MPA size. For example, one country may protect only a tiny fraction of its EEZ within numerous small MPAs, while another country efficiently protects the majority of its EEZ within a few large MPAs. Equally important when comparing the number and coverage of MPAs among countries is the size of each country's EEZ. The EEZs considered here range in size from nearly 36,000 km² (Belize) to over 12 million km² (the U.S.; Table 60).

Of the countries included in this report, the U.S., Japan and the Philippines have established the largest number of MPAs (Table 60). With 1,563 MPAs in total, the U.S. lies at the top of this list. However, there is a great degree of overlap among MPAs in the U.S.. The number of MPAs in the Japanese EEZ (1,161; Yagi *et al.* 2010) exceeds the number of MPAs in the Philippines (750) by about 50 %. Some researchers, however, estimate the number of MPAs in the Philippines to be higher (e.g., 1,100; Lowry *et al.* 2009), and thus this figure could be an underestimate. Canada does not lag far behind the Philippines with 609 MPAs. The remaining countries included in this report have relatively few (<200) MPAs. Also notable is the complete absence of Russian MPAs in the Pacific and Turkish MPAs in the Black Sea. Russia and Turkey have 18 and 12 MPAs, respectively. Most of Russia's MPAs lie in the Barents Sea; all of Turkey's MPAs are in the Mediterranean Sea.

[39] http://jncc.defra.gov.uk/page-4549
[40] http://jncc.defra.gov.uk/page-1521

The U.S. claims to have 41 % of its EEZ within some form of MPA due to the relative abundance of medium and large-sized MPAs (Figure 51), which encompass over 7.3 million km² of marine area. However, when large 'fishery MPAs' characterized only by gear restrictions are excluded, approximately 8 % of the US EEZ is protected within MPAs, which are focused on conserving natural and cultural resources[41].

Indonesia, Russia and Brazil follow the U.S. in terms of marine area contained within MPAs, (with 138,900 km², 131,800 km² and 90,100 km², respectively). However, unlike the U.S., a high ranking in terms of the total area of protected waters in these countries does not translate into a high proportion of EEZ protected due to the relatively large size of their EEZs. Approximately 2.3 % of the Indonesian EEZ, 1.7 % of the Russian EEZ and 2.8 % of the Brazilian EEZ is protected.

Russia is ranked as one of the top countries for protected area coverage despite the fact that it has relatively few MPAs in total (18, as mentioned earlier). MPAs in Russia are generally large (Figure 51), meaning this country is efficiently covering a large area with relatively few protected sites. In fact, more than 48 % of Russian waters in the Black Sea are protected within just 4 MPAs, and 8 % of the Russian portion of the Barents Sea is protected within 14 MPAs. In contrast, there are no known MPAs in Pacific sector of the Russian EEZ.

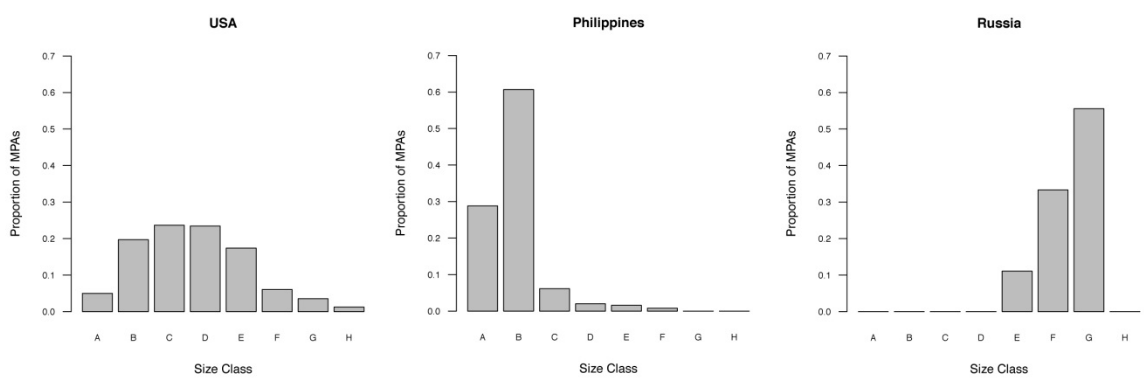


Figure 51. Size distribution of marine protected areas in the U.S., the Philippines and Russia. For each country, MPAs were grouped into size classes according to the total area (*area*) of each MPA, including both terrestrial and marine components. The size classes were defined using a logistic scale due to the predominance of small MPAs, (i.e., Size Class A: *area* ≤ 0.1 km²; B: 0.1 < *area* ≤ 1 km²; C: 1 < *area* ≤ 10 km²; D: 10 < *area* ≤ 100 km²; E: 100 < *area* ≤ 1,000 km²; F: 1,000 < *area* ≤ 10,000 km²; G: 10,000 < *area* ≤ 100,000 km²; H: *area* > 100,000 km²). Histograms represent the proportion of the total number of MPAs in each size class.

Morocco and Norway have protected the least marine area (i.e., less than 1,000 km²; Table 60), followed by Peru, Turkey and Belize with 2,000 to 3,000 km² of protected marine area. With the exception of Belize, MPAs cover less than 1 % of the EEZ of each of these countries. In the case of Belize, the relatively small area of protected waters equates to a high percentage of the EEZ (7 %) due to its small size (35,811 km²). Although information on the marine proportion of MPAs in Vietnam is lacking and could not be calculated, it would likely fall among these lower-ranking countries in terms of protected marine area based on the country's total (terrestrial and marine) coverage (2,304 km²).

[41] http://www.mpa.gov/pdf/helpful-resources/mpa_analysis_2012_0320.pdf

Denmark follows Belize with the third-largest proportion of its EEZ protected (4 %). Thereafter, the U.K. and Brazil have each protected approximately 3 % of their EEZ.

Although the Philippines has a large number of MPAs (which are mostly entirely marine), the area that they cover is not very large (16,388 km²; less than 1 % of the Philippine EEZ). The reason for this is evident in the size-frequency distribution of Philippine MPAs (Figure 51), which reveals that most (about 90 %) are ≤ 1 km² in size. This scenario may be compared to that of Mexico, where most of the 41 MPAs are >100 km² and cover a combined area of 61,506 km² (nearly 2 % of the EEZ).

The results for Iceland show that 0.5 % of the EEZ is within MPAs. However, this calculation does not take into account Iceland's area closures for which detailed information was not readily available. Situated mainly off the northwest, north and east of the island, these areas are managed for fishery benefits (to increase long-term yield; Jaworski *et al.* 2010), but have the potential to also deliver biodiversity conservation benefits. They include temporary and permanent closures, which can apply to only certain gear types[42]. The number and size of these closed areas is unclear. However, Schopka *et al.* (2010) report that in 1993, there were six such areas permanently closed to longline gear and otter trawls, covering approximately 8,000 km² in cod nursery grounds to the north and east of Iceland. Protected areas of this size could make a large positive contribution to the country's efforts to conserve biological diversity.

It should be noted that for a number of countries, information on no-take areas was not readily available, and gaps in results for no-take area and the percentage of EEZ that is no-take (Table 60) do not necessarily mean that no-take zones are lacking in that particular region – although that is a possibility. Rankings of no-take coverage should be interpreted cautiously.

According to data from Qiu *et al.* (2009), most of China's MPAs are no-take (92 %). Compared to other countries presented here, China's no-take areas and percentage of EEZ protected as no-take ares among the highest. Overall, China has designated 35,600 km² or 1.6 % of its EEZ as no-take (Qiu *et al.* 2009). However, these designated no-take areas are in practice implemented mostly as multiple-use areas due to a lack of enforcement. The U.S. and Belize follow China with the largest proportion of EEZ contained in no-take areas (1.1 % and 0.7 %, respectively).

Of the countries for which information on no-take areas was available, Chile and the U.K. have the smallest areas protected from all extractive activities, both in terms of area (4 km² and 7 km², respectively) and percentage of EEZs (both <0.01 %). The UK has three small areas where fishing is prohibited for nature conservation reasons, although there are other *de facto* no-take areas not considered here, such as military exclusion zones (JNCC 2011).

Overall, the portion of the EEZ that is protected is quite low for most countries covered in this report, much lower in fact than the goal defined by the CBD to protect at least 10 % of the world's marine coastal and ecological regions by 2012 (CBD 2006). In 2010, due to lack of progress, the deadline for this target was extended to 2020 (CBD 2010). The U.S. has already achieved this goal, while Belize is also close to reaching 10 % protection.

While this report focuses on only the mainland EEZs of these 25 countries, some have established MPAs beyond the boundaries of their mainland waters. One of the most conspicuous examples being the recent designation of the 150,000-km² *Sala y Gomez* Marine Park within the Easter Island EEZ, which represented a two-fold expansion of the country's MPA coverage (Anon. 2010b). The designation of such large sites, away from high-density human population centers, allows countries to meet their protected area targets while minimizing potential for conflict with local users. However, this MPA is thousands of kilometers from the mainland EEZ, from which it vastly differs in terms of the biodiversity that it protects. Indeed, the mainland Chilean EEZ remains largely unprotected from extractive activities, although it is exposed to numerous anthropogenic threats (Miethke et al. 2007).

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[42] www.fisheries.is/management/fisheries-management/area-closures/

In addition to the MPAs discussed above, countries may employ tools termed 'ancillary' marine conservation measures by the Convention on Biological Diversity (Secretariat of the Convention on Biological Diversity 2004). In Chile, management and exploitation areas for benthic resources (MEABRS) – which explicitly restrict the extraction of benthic resources, and thus, by association, offer some level of protection to other species groups – vastly outnumber other legal instruments for marine conservation in the country. There are hundreds of MEABRS in Chile, covering an area of more than 1,000 km^2 (SERNAPESCA 2005). Yagi *et al.* (2010) argue that large areas of the Japanese EEZ could be considered MPAs, as they are tenure zones managed based on territorial use-rights with limited commercial access.

The vast range of types of MPAs employed by the countries assessed here provides an indication of the variability of the quality of protection. An assessment of coverage alone cannot provide a complete picture of protection, however; one needs to also consider effectiveness (Spalding *et al.* 2008). As an example, Qui *et al.* (2009) explain that while the majority of MPA coverage in China comprises no-take areas – on paper – they are effectively multiple-use areas in practice, as enforcement is lacking. And a 2003 assessment of MPA management in the Philippines found that 68 % of the 156 MPAs surveyed had yet to reach 'enforced' status, with regulations and management activities implemented for at least two years (White *et al.* 2006). This discordance between designation and management is not particular to developing countries, however, as Robb *et al.* (2011) demonstrated for MPAs in the Canadian province of British Columbia. The authors found that although the majority of the 161 MPAs surveyed were assigned to three of the strictest IUCN protected area management categories, which should be free from exploitation, commercial harvesting was permitted in all but one of them. Research like this helps to elucidate the true effectiveness of MPAs and where there is room for improvement. Often, however, MPA effectiveness goes un-assessed, presenting a clear gap in our understanding of the national and global conservation benefits of MPAs.

Table 60. Summary statistics for marine protected area (MPA) numbers and coverage.

	EEZ area (km^2)	# MPAs	% incl. no-take	MPA (km^2) Total	MPA (km^2) Marine	MPA (km^2) No-take	Percentage of EEZ Total	Percentage of EEZ No-take
Argentina	1,081,568	23	0.04	19,168	10,939	1,800	1.01	0.17
Belize	35,811	19	0.84	2,554	2,524	262	7.05	0.73
Brazil	3,192,376	104	0.01	91,731	90,088	363	2.82	0.01
Canada	5,651,926	609	<0.01	302,836	44,954	475	0.80	0.01
Chile	2,006,482	29	0.07	52,222	32,216	4	1.61	<0.01
China	2,282,088	158	0.92		37,700	35,589	1.65	1.6
Denmark	100,215	62		4,568	4,176		4.17	
Iceland	750,461	34		4,293	3,899		0.52	
India	1,629,182	21		21,683	10,218		0.63	
Indonesia	6,081,032	107	0.01	1,834,732	138,918	439	2.28	0.01
Japan (Main Islands)	1,837,616	1,161						
Malaysia (East)	132,395	34		2,048	1,990		1.50	
Malaysia (West)	68,506	16		428	416		0.61	
Malaysia (total)	200,901	50		2,476	2,405		1.20	
Mexico	3,272,632	41	0.10	102,077	61,506	1080	1.88	0.03
Morocco	270,771	6	0.17	959	387	94	0.14	0.03
Norway	1,347,734	18		1,296	814		0.06	
Peru	908,019	2		3,380	2,018		0.22	
Phillippines	2,267,479	750	0.41	18,315	16,388	3247	0.72	0.14
Russia	7,819,417	18		319,038	131,768		1.69	
Russia (Barents Sea)	1,246,761	14		267,422	99,825		8.00	
Russia (Black Sea)	66,063	4		51,616	31,943		48.35	
Russia (Pacific)	3,358,479							
South Africa	1,088,412	22	0.64	4,636	4,346	1842	0.40	0.17
South Korea	473,348	7		3,389	2,713		0.57	
Spain	548,384	44	0.16	3,902	3,095	26	0.56	0.01
Turkey	251,699	12		5,212	2,239		0.89	
Turkey (Black Sea)	169,321							
Turkey (Med Sea)	82,378	12		5,212	2,239		2.72	
United Kingdom	751,220	148	0.02	39,344	22,028	7	2.93	<0.01
USA	12,157,635	1,438	0.12	7,659,808	7,358,152	133314	60.52	1.10
Vietnam	1,397,169	15		2,302				

[1] (Qiu *et al.* 2009), as of August 2008
[2] (Yagi *et al.* 2010)

Discussion

There is general agreement between the two types of analyses performed here, in that both suggest that overall catch could be increased, sometime substantially, by managing the major species in the catch for sustainability. The result differ by country, obviously, given existing management regimes and data quality, but the result are clear regarding the possibility of catch increases.

In the majority of countries, the single species analyses could be validated using elaborate ecosystem models. These models, given their sophistication, provided other relevant information, notably on the biodiversity losses that increased catches would incur. Obviously, such trade-off analyses are tentative, and would have to be refined, were they to provide the basis for policy elaboration in a given country.

Unfortunately, ecosystem models of the required type (fitted to historical time series of data and well documented) were not available for 10 countries. For these, only the single-species analyses were available. However, there is no reason to assume that these countries differ systematically from the 15 countries with models, and thus it can be assumed that our overall findings would apply to them as well.

The catch-based method, calculated for all taxa occurring in the catch at the species-genus level with at least 20 years of data, illustrates that, in general, for most countries, the overall catches could be increased. Notable exceptions include Belize, Morocco, India and Indonesia (both East and West), which have weighted catch:MSY ratios that are very close to one, indicating that catches could not be increased much beyond the present capacity. A caveat to this approach is that the method only relies on catch data, which is subject to issues such as under- or over-reporting, mis-reporting, and missing catches (i.e, IUU). Having the most accurate tally of the catches by species is crucial for determining MSY, as is a knowledge of the fished areas, given that expansion into new fishing grounds renders analyses such as presented here invalid. The catch reconstructions currently undertaken by the *Sea Around Us* Project are addressing these issues.

Our ecosystem modeling approach was applied to 15 countries using 18 well-documented and previously calibrated models. Of those 15 countries, 14 showed an increase of the total catch when fishing all exploited groups at their F_{MSY}. Ecosystem models illustrated that there are mainly two ways of increasing catches. The first implies a rebuilding of the biomass by decreasing the overall fishing mortality, which will produce higher catches when species are rebuilt. The second implies a redistribution of fishing effort to optimize for F_{MSY}, thus avoiding having commercial stocks that are under-fished.

However, when fishing at F_{MSY}, there is no guarantee that some species in the ecosystem will not be strongly depleted, especially non-commercial species that directly depend on species fished at F_{MSY}. The negative consequences of depletion of species when fishing at F_{MSY} were taken into account in our study under the *optimization* simulations. Our ecosystem model results showed that 10 out of 15 countries assessed could experience an increase in catches when maximizing yield while including criteria to maintain biodiversity and prevent depletion of marine species. Fishing mortality under the *optimization* simulations was frequently lower than under the *allFmsy* simulation. In general, our results illustrate that a more sustainable way of exploiting marine resources could yield higher catches while considering biodiversity and conservation issues in exploited ecosystems. However, these may imply fishing at lower levels of fishing mortality than fishing at F_{MSY}.

China was the only country analyzed using ecosystem models whose catch could not be increased under alternative exploitation regimes in comparison with the historical exploitation pattern. These results are likely due to the fact that China has been substantially over-reporting its catches (Watson and Pauly 2001), and that the model that was available covered a different time period than the catch-based model analysis (Cheung 2007b). Future work should re-assess these results using an up to date ecological model for the Chinese EEZ. In fact, future work should include the use of standardized EEZ models to account for the subjectivity in the fitting period analyzed and fitting procedure and any potential impact of differences in modeling structure. Standardized models have been developed in the past for Large Marine Ecosystems (Christensen *et al.* 2009b), thus a similar approach could be used to model marine EEZs.

We would like to note that results of our ecological modeling exercise are not necessarily representative for the current situation in each country, since available models represent the specific period for which the model was fitted to time series data. This is an important point to bear in mind when interpreting results from the ecological modeling simulations. In addition, it is important to note that the optimization simulation was parameterized to maximize the amount of catch, but not the market value of target species. Future analyses should account for this. Ecological modeling results could also incorporate the analysis of additional ecological indicators to assess the specific ecological implications of fishing at F_{MSY} or fishing at more precautionary levels.

The analyses of MPA coverage reveals very slow progress in terms of the protection of marine biodiversity and fisheries resources within the EEZs of the countries considered in this report. All but three countries have set aside less than 3 % of their EEZ waters within the boundaries of MPAs; in fact, most have protected less than 1 % of their EEZ waters. The exceptions to this trend are the U.S., Belize and Denmark, where MPAs collectively encompass over 60 %, 7 % and 4 % of EEZs, respectively. However, these coverage statistics must be viewed with caution. MPAs vary widely in the degree of protection that they provide to associated habitats and species. When considering the protection of fisheries resources, the proportion of EEZ in which fishing is prohibited (i.e., no-take areas) is less than 0.2 % for each country, with the exception of China (1.6 %), the U.S. (1.1 %) and Belize (0.7 %). Additionally, enforcement of MPA objectives is often absent or inadequate, resulting in the global problem of ineffective 'paper parks.'

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