ISSN 1198-6727

Fisheries Centre Research Reports

2007 Volume 15 Number 7

Ecosystem-based Global Fishing Policy Scenarios

Fisheries Centre, University of British Columbia, Canada

Ecosystem-based Global Fishing Policy Scenarios

Authored by
Jackie Alder, Sylvie Guénette, Jordan Beblow, William Cheung and Villy Christensen

Fisheries Centre Research Reports 15(7)
91 pages © published 2007 by

The Fisheries Centre,
University of British Columbia

2202 Main Mall
Vancouver, B.C., Canada, V6T 1Z4

ISSN 1198-6727

Fisheries Centre Research Reports 15(7)
2007

ECOSYSTEM-BASED GLOBAL FISHING POLICY SCENARIOS

Authored by
Jackie Alder, Sylvie Guénette, Jordan Beblow, William Cheung and Villy Christensen

CONTENTS

Page

DIRECTOR'S FOREWORD 2
Ecosystem-based global fishing policy scenarios 3
Abstract 3
Introduction 4
Background 5
Materials and methods 8
Effort reconstruction 8
Prices 10
Jobs per unit of catch value 11
The model 11
Model structure and data used 12
Fitting procedure 13
Optimization routine 13
Indicators 14
Assessments and scenarios 14
GEO4 scenarios 15
International Assessment of Agricultural Science Technology and Development 15
GLOBIO – mapping human impacts on the biosphere 16
Depletion index (DI) calculation 16
Model Uncertainty 18
Results 18
Discussion 33
Acknowledgements 34
References 35
Appendices 41

Research Report from the Fisheries Centre at UBC
Netherlands Environmental Assessment Agency (MNP)[i]

Fisheries Centre Research Reports are abstracted in the FAO Aquatic Sciences and Fisheries Abstracts (ASFA) ISSN 1198-6727

[i] http://www.mnp.nl/en/themasites/image/model_details/biodiversity/index.html

DIRECTOR'S FOREWORD

The world's marine fisheries are in trouble, but there are, among fisheries scientists, strong disagreement about the extent of this crisis, if any. One factor which tends to affect the view taken as to the global state of fisheries is the geographic area, and hence the fisheries and management systems, with which people are familiar. Thus, one may expect the fisheries scientists and the marine biologists from areas or countries with well-managed fisheries and healthy ecosystems to assume that global fisheries and ecosystems are in similar states, while those colleagues working in areas where fisheries management doesn't work, and the stock are overfished, would assume that a similar situation occurs at the global scale.

Such subjective bias can be overcome using two different approaches. The first consists of using a preset 'sampling scheme' for the fisheries and ecosystems used for extrapolation to the global scale. The second approach, in contrast, is to use a 'census', wherein 'all' fisheries and ecosystems of the world are somehow used for global inferences. This approach can be implemented (*i*) in stratified fashion, using large chunk of the world ocean as strata, and adding up the result to get a global picture, or (*ii*) working right away on a global basis. It is the first of these implementation methods which was used here, but the second will follow, as briefly mentioned below.

EcoOcean is the first iteration of a global marine model which addresses many of the past problems associated with assessing the future of fisheries at the global scale. The development of EcoOcean was based on the global fisheries-related datasets made available by the *Sea Around Us* Project, which, by complementing and standardizing the catch and effort data available from the Food and Agriculture Organization of the United Nations (FAO), makes global analyses of fisheries possible.

The fleet statistics provided a basis to develop a global effort database for the years 1950 to 1998 (the last year for which global data are available from FAO), which provided effort trends that are the primary driver of the model. The development of an integrated global database of fishing effort across all oceans from 1950 to the present was a requirement toward the construction of the global model and is described in detail in this report. This database will be used in other studies where information on global effort is required. Other databases, e.g., for distant water fishing vessels, were also created and used to drive the model, and are described in this report.

The development of EcoOcean was in response to a growing demand for tools to explore the future of fisheries and marine biodiversity. EcoOcean, which is spatially defined by the 19 FAO fishing areas covering the world's oceans, is driven by the effort of five fleets, with different trajectories in each FAO area. The model output from EcoOcean can be used to describe how biomass, landings, profits and the marine trophic index may change under different policy scenarios in different areas of the world. EcoOcean provides a common reporting platform so that the outcomes of the different scenarios can be compared within and between geographic areas, as well as for fleets and fisheries.

The application of EcoOcean to explore the scenarios proposed by the Global Environment Outlook 4 (GEO4) and the International Assessment for Agricultural Science, Technology and Development IAASTD) demonstrates the usefulness of this policy tool, while the outputs themselves provide policy makers with plausible results on which to base future decisions regarding management of fisheries and marine ecosystems.

The next step for EcoOcean is obviously, the application of this tool to smaller strata, i.e., the 64 Large Marine Ecosystems which have been defined for the world ocean, and ultimately, to the 180,000 half degree cells into which the *Sea Around Us* Project has divided this same ocean. This will obviously require the refinement of all databases created by that project, itself a useful venture, for both the project itself, and the wider community with which it shares data.

Daniel Pauly,
Director, Fisheries Centre

ECOSYSTEM-BASED GLOBAL FISHING POLICY SCENARIOS [a]

Jackie Alder, Sylvie Guénette, Jordan Beblow, William Cheung and Villy Christensen

Fisheries Centre, Aquatic Ecosystems Research Laboratory (AERL), University of British Columbia. 2202 Main Mall, Vancouver, BC, Canada V6T 1Z4,
j.alder@fisheries.ubc.ca; s.guénette@fisheries.ubc.ca; j.beblow@fisheries.ubc.ca; w.cheung@fisheries.ubc.ca; v.christensen@fisheries.ubc.ca

ABSTRACT

The future of fisheries and marine ecosystems at the global scale, until recently, was often expressed in terms of qualitative storylines with limited quantitative information on how aspects of fisheries such as landings, profits and biodiversity would respond, which constrained the comparing of outcomes across geographic areas. However, the construction of a stratified global model, EcoOcean, has met many of the challenges of quantitatively assessing the future of fisheries under different scenarios. Using the Ecopath with Ecosim (EwE) software, a series of 19 marine ecosystem models representing the 19 FAO areas of the world's oceans and seas was constructed. The models were populated using global datasets of catches, ex-vessel prices, biomass and distant water fleets from the *Sea Around Us* Project and the fleet statistics from the Food and Agriculture Organization of the United Nations (FAO). The fleet statistics were used to develop a global database of fishing effort for the five fishing fleets in the model from 1950 to 1998, the last year for which the data are available. Modelling the five fisheries over the 19 FAO areas from 1950 to 2003 resulted in an aggregated global total that was within 10% of the reported total for any given year. This gave some confidence that the models are providing plausible results for different scenarios, in particular for the four scenarios of the Global Environment Outlook 4 and the four scenarios of the International Assessment for Agricultural Science, Technology and Development. This work also provided the opportunity to look at the future of marine biodiversity to 2048, using a depletion index as a proxy for changes in species composition and abundance under the different scenarios.

This report presents the background and development of EcoOcean, the model structure, a detailed description of the effort reconstruction, and the underlying datasets that are used to construct and drive the models, especially prices and jobs. The report also discusses the implications of EcoOcean as a policy tool and how it can be further refined to be of wider use and to reduce the uncertainty of the modelled outputs.

The application of EcoOcean to GEO4 and the IAASTD resulted in plausible outcomes under the different policy scenarios, and the outcomes differed across geographic areas as well as across scenarios. Some policy scenarios called for increasing landings or profits, rebuilding ecosystems, or a combination of all three with and without subsidies. In cases where effort increased, landings and therefore profits increased; however, any increase in landings was achieved by increases in groups that are not currently fished in large quantities. In many cases increased landings resulted in declining marine trophic levels, and increased depletion risks.

[a] Cite as: Alder, J., Guénette, S., Beblow, J., Cheung, W. and Christensen, V. 2007. Ecosystem-based global fishing policy scenarios. Fisheries Centre Research Reports 15(7). Fisheries Centre, University of British Columbia [ISSN 1198-6727].

INTRODUCTION

Recent ecological studies including the recent IPCC[2] have focused the world's attention on the need to consider how future policy can be shaped to address environmental issues. Policy makers have a number of tools at their disposal to make well-reasoned policies that will effect change in the world's ecosystems, while addressing other issues affecting humankind, especially poverty and economic development as articulated in the Millennium Development Goals (Anonymous, 2007). The global crisis in marine fisheries is included in the suite of issues to be addressed, because the world's fisheries contributes to food security, as well as assistance in the economic development for many countries, especially so for developing coastal countries (Pauly *et al.*, 2005).

One tool that is gaining recognition for this purpose is scenario analysis. It was first used in strategic planning during the cold war (Khan and Weiner, 1967) and was key to the Shell Oil Company coping with the oil crisis of the 1970s (Wack, 1985a, 1985b). Its use assisting in policy formulation in natural resources management and sustainable development sectors, especially at the global scale, emerged in the 1970s (Raskin *et al.*, 2005). There was little development of scenario analysis until late in the 1980s, when concerns over climate change and sustainable development took off. A number of climate change scenarios were thus developed in the 1990s with the IPCC (Raskin, 2000) providing a framework for the further development of scenarios analyses. Development of scenarios within the IPCC area has shaped much of how scenarios are used, reported and evaluated in other studies including the Millennium Ecosystem Assessment, GEO4[3], IAASTD[4], OECD[5] and GLOBIO Project[6].

The development of the global model ***EcoOcean***, which we report on here, was a response to a growing demand for analyses of how, especially fisheries, may impact the future of marine systems for policy making at regional and global scales. In particular, there was a demand for a global oceans model for the United Nations' Global Environment Outlook 4 (GEO4) and IAASTD as inputs into future scenarios under different policy options. Scenarios as used here can be defined as "*plausible, challenging and relevant stories about how the future might unfold which can be told in both words and numbers. They are not forecasts, projections, predictions or recommendations. They are about envisioning future pathways and accounting for critical uncertainties*"(Raskin *et al.*, 2005).

In this context the EcoOcean model was developed as a tool to explore fisheries and more broadly, marine policy options and not to predict the future. As Peterson et al.(2003) note, predictive modelling works for simulating well-understood systems over the short-term, but as complexity and the modelling time frame increase, predictive power declines. In such systems, the system state is well specified and mathematical algorithms are available to describe relationships used in the quantitative predictions (Raskin, 2005). Much progress has been made in describing such relationships through ecosystem modelling (Christensen and Walters, 2005) and a natural progression has been to bring these models into the field of scenario analysis.

While ecosystem modelling has been used extensively for research purposes, it is only now beginning to be used as part of the fisheries policy process, and has yet to be used for large marine regions. As fishery policy moves beyond the objectives for single-species management there is indeed no choice but to adopt more elaborate ecosystem models. Policy choices for ecosystem-based fisheries management involve exploring the impact of non-traditional policy choices and our abilities to perform such explorations are severely limited. In the past, we have based comparisons of ecosystem-related policy choices on methods ranging from very simple risk avoidance models, to simple food chain or trophic cascade models, to very complex food web

---

[2] IPCC = Intergovernmental Panel on Climate Change
[3] GEO4 = United Nations' Global Environment Outlook 4 (UNEP 2007)
[4] IAASTD = International Assessment for Agricultural Science Technology and Development (Fernandez in press)
[5] OECD = Organization for Economic Co-operation and Development
[6] GLOBIO = Global Methodology for Mapping Human Impacts on the Biosphere (see www.globio.info)

models that attempt to explore possible reverberating effects going beyond direct predator-prey interactions. Much of the recent ecosystem modelling work has been aimed mainly at assessing risks of the more complex reverberating effects such as 'cultivation-depensation' effects (Walters and Kitchell, 2001), on the assumption that complex interactions are likely to result in counter-intuitive responses (Yodzis, 2001)

Based on the Ecopath with Ecosim (EwE) approach and software, we developed a new model, EcoOcean, to explore scenarios for the world's oceans. Christensen and Walters (2004) give a detailed discussion of EwE. The model was constructed using 43 functional groups that are common to the world's oceans including FAO's 19 marine statistical areas. The groups were selected with special consideration for exploited fish species, but are intended to jointly include all major groups in the oceans. The fish groups are based on size categories, and feeding and habitat characteristics. Fishing effort is the most important driver for the ecosystem model simulations. The 19 FAO areas were considered large enough to encompass the range of most marine fish and invertebrates as well as accommodating the world's major fishing fleets. Five major fleet categories, i.e., demersal, distant-water fleet, baitfish tuna (purse seine), tuna long-line and small pelagic are used to distinguish different fishing effort based on historical information. This model structure allows for maximum flexibility in meeting different global assessment objectives, while still providing a valid representation of the marine systems.

Background

Scenario analyses can have quantitative modelling and qualitative narrative components; providing systematic and replicable representations as well as contrasting social visions and descriptions (Raskin *et al.*, 2005). The process of developing scenarios itself often expands people's perspectives and identifies key issues that might have been missed or dismissed at the initial stages of planning or assessment. Qualitative components help to describe values, behaviours and institutions, while quantitative components provide structure and rigour (Raskin *et al.*, 2005). A review of previous scenarios over the last three decades illustrates the benefits and limits of using models and narratives, which assessments such as the GEO4 and IAASTD can build upon in combining quantitative outputs of models such as EcoOcean with insightful narratives.

The scenarios that are explored are often contrasting social, economic and ecological states (e.g. peace vs. war, globalization vs. regional and extinction vs. restoration) and policies (reactive vs. proactive, adaptive vs. technological) as seen in the Millennium Ecosystem Assessment (Carpenter and Pingali, 2005). In doing so, the risks and benefits of policies and the trade-offs that are needed to effect sound policy formulation are identified as well as examining the interactions among the drivers of change. The Millennium Ecosystem Assessment includes a detailed review of significant scenarios over the last decade (Carpenter and Pingali, 2005).

Recent scenarios initiatives were either regional or global in scale and integrated social, economic and ecological features while covering a number of futures with a mix of qualitative and quantitative analyses. The marine realm was poorly represented other than being incorporated into other models such as climate (sea temperature) or hydrological (evaporation from oceans). This is the first time the marine realm including fisheries has been comprehensively included in such analyses. However, this is not the first exercise to look at the future of fisheries; there have been past efforts.

Projections were made as early as the 1970s on the world's fisheries that suggested that landings would level off at approximately 100 million tonnes, and there is a current consensus that marine fisheries have levelled off at 80 million tonnes with the recent suite of commercially-caught species (Gulland, 1970; Pauly, 1996; Csirke, 2005). In addition to these predictions there have been five studies that use scenarios with different foci to describe how fisheries policies may develop past 2010 (Table 1). When the focus was on ecology, policies would be developed to meet sustainability goals and rebuild ecosystems. With an economic focus policies would be implemented primarily to provide for sustained economic growth through market forces with the assumption that for long-term growth environmental policies would also be developed; a policy focus centred on government intervention in both the market and environment was undertaken to achieve national goals.

Table 1: The focus or theme of the various scenarios that have been explored in selected studies of fisheries.

		Focus/Theme			
Study	**Scale**	**Ecology**	**Economics**	**Policy**	**Business as usual**
FAO & other fisheries organizations	Global	-	-	-	Status quo
Pope (1989)	Global	Leisure	ForeignEx/ Fish farm	-	Larder
Parrish (1998)	Global	-	-	-	Loss of species
(Cury and Cayré, 2001)	Global	-	-	-	Loss of fishing
Pauly (2002)	Global	Benign Utopia	Hunting	-	Finis mundi/ muddling through
Pauly *et al.* (2005)	Regional	Optimizing old growth	Optimizing rent	Mandated restoration	Catch values and jobs
MA	Regional	Adapting mosaic	Techno garden	Global orchestration	Order from strength
(Costanza, 2000)*	Global	Ecotopia	-	Big government	Mad Max
GEO3 (UNEP, 2003)	Global with regional	Sustainability first	Markets first	Policy first	Security
(Pinnegar *et al.*, 2006)	United Kingdom	Global commons	World market/ local stewardship	-	Fortress Britain

* Star Trek scenario is not considered (science fiction)

Pope (1989) was the first researcher to investigate the future of fisheries using scenarios. Since then other researchers have also explored the future of fisheries (Parrish, 1998; Cury and Cayré, 2001; Pauly, 2002; Pauly *et al.*, 2005). The fishing scenarios indicated that only those scenarios with significant reductions in effort and targeting fish at lower trophic levels would be effective in rebuilding depleted stocks and maintaining other stocks. Those scenarios that used current trends or increased effort whether for commercial or recreational fisheries all indicated collapses in stocks and ecosystems; they differed primarily in their rates of decline. Recent global scenarios such as GEO3 and the Millennium Assessment have included fisheries, but only as regional case studies.

EcoOcean model

EcoOcean, as noted above, is based on the Ecopath with Ecosim (EwE) modelling approach and software, and includes a total of 43 functional groupings. The spatial resolution in this initial version of the EcoOcean model is based on FAO's 19 marine statistical areas, and it is run with monthly time steps for the time period from 1950 (Figure 1). The model is parameterized using an array of global databases, most of which are developed by or made available through the *Sea Around Us* Project (www.seaaroundus.org).

Information about spatial fishing effort by fleet categories was used to drive the models over time. The models for the FAO areas were tuned to time series data of catches and biomass trends for the period 1950 to the present, while forward-looking scenarios involved optimization routines used to evaluate the impact of the scenarios on harvesting of marine living resources.

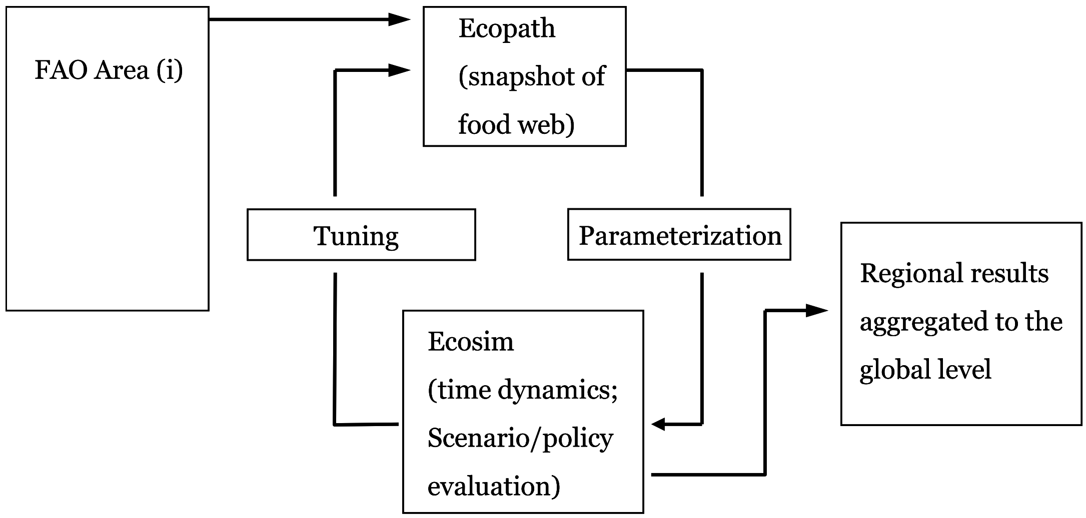

Figure 1. Process for EcoOcean model

Most populations of marine fish and invertebrates have a limited range, and the FAO statistical areas (Figure 2) provide a manageable spatial resolution for how to cut the world into a reasonable number of spatial units, each characterized by having limited connection to neighbouring areas and each with a manageable number of fleet categories for which it may be possible to evaluate trade-offs.

The bottom line is that, for current purposes, the oceans should be considered as spatially-separated production systems. Therefore when examining future scenarios and performing optimizations for this we cannot have fleets competing across regions. For example fisheries in the Caribbean are not shut down and their effort moved to the Indian Ocean, even if it hypothetically should make sense for economical reasons.

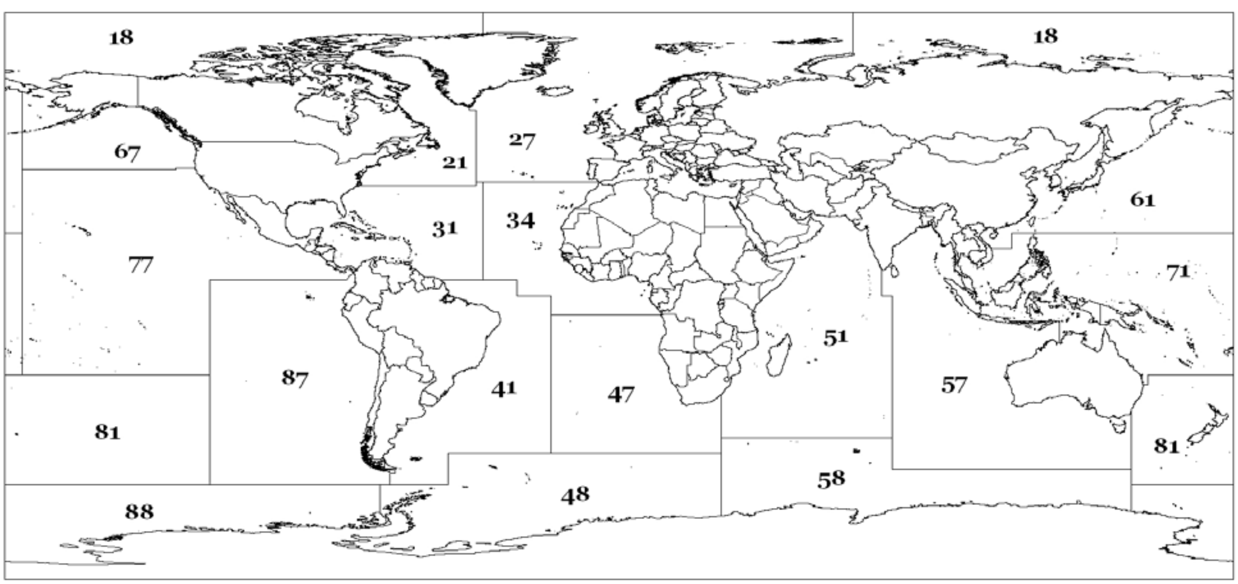

Figure 2. World map with marine FAO statistical areas delineated.

MATERIALS AND METHODS

Effort reconstruction

The effort data, expressed in gross registered tonnage (GRT)[7], were obtained from the FAO fisheries statistical books prior to 1970 and from the FAO website, starting in 1970 (FAO, 2006). Additional effort data were obtained from numerous other sources as described below. Effort for vessels targeting tuna was obtained from tuna regional fisheries management organizations (Atlantic – ICCAT[8], Indian – IOTC[9] and Pacific – SPC-OFP[10]). The delineation of coastal countries into a given FAO area was conducted using a world map with an FAO boundary layer added (Figure 2). Where countries were contiguous to several FAO areas, (e.g., Australia and USA), effort was assigned to FAO areas as a function of the respective length of the coast, number of ports, or direct information of effort distribution (see Appendix A). Exceptions to this were Canada and Mexico, where up until 1970 effort had been reported by coast, and the 1970 effort for these two countries was used to allocate the effort in subsequent years. For Russia, France, Morocco, Australia and the USA, the allocation was based on the number of ports and their relative importance (Gelchu and Pauly, 2007). There were also countries, like Thailand for which effort was distributed using ancillary data, e.g. catch by FAO area. In this example, for the year 1996, 70% of all landings came from the Gulf of Thailand (FAO area 71), and the remaining for the Andaman Sea (Vibunpant *et al.*, 2003), which is in FAO area 57 (see Appendix D for further details).

As mentioned previously fleet types included in the model are: distant water, small pelagics, demersal, tuna longline and tuna baitfish (purse seine). The demersal fleets are assumed to target both invertebrates and demersal fish. Although we have catch and biomass indices for whales, seals and their relatives, effort indices for these two fleet types have not been estimated at the present time.

The initial assumption that vessels larger than 500 GRT were primarily part of a distant water fleet (DWF) was brought into question by examining data for Canada and Morocco. In Morocco, the industrial national fleet contained freezer-trawlers of 200 to 900 GRT as well as trawlers of 140-250 GRT (Baddyr and Guénette, 2001). In Canada, class 5 vessels (500-1000 GRT) were responsible for a large part of the effort (hours fished) and catch of cod and groundfish in Newfoundland (Guénette, 2000). Based on the Northwest Atlantic Fishing Organization database (NAFO, 2006), Canadian vessels of more than 500 GRT carried out an average of 42% of the total effort targeted toward groundfish and invertebrates between the years 1960-2003. Vessels registered in coastal countries of FAO area 21 (Canada, USA, Greenland, and St. Pierre and Miquelon) and larger than 500 GRT, were responsible for an average of 10% of the effort and 13% of the catch over the period 1950-2002. Conversely, distant water fleet vessels fishing in NAFO area 21 were mainly of class 5 and larger, but smaller vessels still contributed 24% of the total effort directed toward groundfish and invertebrates. Spanish vessels smaller than 500 GRT were responsible for 58% of the reported effort between the years 1960 to 2003. Thus, large vessels were kept in the FAO area 21 coastal fleet. For other countries, vessels larger than 500 GRT were subtracted from the total GRT of the FAO areas and used to create a DWF index. For convenience Morocco was treated like the other countries in FAO area 34 (i.e., large vessels were not included in the coastal fleet). With the exceptions noted above taken into account, vessels in the 5-500 GRT range constitute the coastal fleets.

---

[7] Gross registered tonnage is a measurement of the enclosed area of a ship, excluding non-productive spaces such as crew quarters. One GRT is equivalent to 2.83 cubic metres (FAO, 2007);
[8] ICCAT – International Commission for the Conservation of Atlantic Tunas (public domain);
[9] IOTC – Indian Ocean Tuna Commission (public domain);
[10] SPC-OFP – Secretariat of the Pacific Community Offshore Fisheries Programme (public domain).

Coastal fleet

As previously mentioned, effort data for the period 1950-1998, were gathered in GRT and/or total vessel number. A coastal fleet fishing trend index for each country was calculated based on the trend of GRT for the period 1970-1998 using 1970 as the reference year, because it is the first year of a consistently-reported effort series. The back-calculation from 1970 to 1950 was done using GRT when available or, in some cases, the trend in number of vessels, assuming that the average vessels size did not change appreciably during this period. Effort data were interpolated for missing years where there was a gap in the data (i.e., from 1971-1975 for the FAO data), and the effort index for 1999-2003 was assumed to be equal to that of 1998. The index for each area is a weighted sum of all countries, for which the weight attributed to each country is calculated as the product of the average fishing power for the period 1970-1998 and the proportion of effort carried out in the FAO area (Appendix A).

Total GRT and/or total vessel number were not available for all coastal countries. For example the effort data available for Australia at the time of reporting, are limited to trawling vessels that are larger than 150 GRT. For countries such as India, Bangladesh, and Indonesia, the available effort data do not reflect the large artisanal fisheries that land more than half of the marine catch of three countries (FAO, 1980, 1983). While we were not able to reconstruct the artisanal fleets for India and Indonesia, we were able to reconstruct the trends of the industrial fleet, thus adding to what is known from FAO data (See Appendix D for a summary of each country in FAO area 57).

Finally, the coastal fleet effort was allocated into either the groundfish (including invertebrates) or small pelagics fleets by using three effort point estimates (1970, 1980 and 1990) based on the vessel type and size, and the mean days fished per year (Gelchu and Pauly, 2007). An exception to this rule is the NE Pacific FAO area 67. This area comprises fleet effort from Canada (British Columbia - BC) and the United States (Alaska, Washington, Oregon and northern California). Due to the extent that this information available for the BC fleet data, and the relative lack of information available for fleet effort for the other four areas, the index established for BC was used as an index for the whole region, with the assumption that Oregon, Washington, and Alaska followed a similar trend in groundfish and small pelagics fleet dynamics. There were two main sources of data for the BC effort reconstruction: the Fisheries Statistics of British Columbia and the Annual Statistical Review of Canadian Fisheries for the years 1957-1987. Information on gear type shows that, up until the early 1990s, effort in the BC fleet was primarily pelagic-based, targeting small and medium pelagics (e.g. Pacific herring and sockeye salmon). By the late 1990s, the effort has, to a larger extent, turned towards groundfish, due in part to the decline in salmon fisheries, and is the result of a higher-value invertebrate fishery (see Appendix B).

Distant water fleet

The total GRT of large vessels compiled from the FAO database (1970-1998) was completed with data as compiled in Ganapathiraju (2007) obtained from the NOAA[11], and the ICES data for the years 1950-1970 (Gelchu, 2006). Given that before 1970, most large vessels were based in Europe (data compiled by ICES) and in the former USSR (no data available), the effort index for the period 1950-1970 reflects the development of the European fleet and assumes that the USSR fleet followed a similar development to that of the European.

The distant water fleet (DWF) presented an additional challenge in that the destination and amount of fishing of each fleet are very incompletely known. As a first approximation, the total DWF effort was allocated proportionally to the spatial distribution of the catch reported for the distant water fleet as presented on the *Sea Around Us* website (Watson *et al.*, 2004).

[11] National Oceanic and Atmospheric Administration

Tuna fleets

The tuna longline catch for the Atlantic and Indian oceans, collected by species (major tuna species and billfish), was calculated by 5° cells then attributed to FAO areas. The nominal catch by country was allocated to an FAO area according to the observed space/time distribution for the fleets operating in each area. In the absence of spatial information for a country, nominal catches were distributed for observed space/time proportion for all countries combined. For years with no spatial information, it was the catch distribution of the last known year data point that was applied to subsequent years, until the next year-point with spatial data. Pacific data were obtained from SPC-OFP, but do not contain southern or northern Pacific bluefin tuna.

Effort for tuna longline was estimated by dividing the catch (aggregated by area, month, and year) by the aggregated catch per unit effort (CPUE) for a given country. Catch per unit effort (CPUE) was calculated as the sum of major tuna species (albacore, bluefin, bigeye, and yellowfin) and swordfish biomass per hook (most catch statistics were reported as biomass and not by numbers). There were areas where CPUE data were not available, and for these cases the CPUE used was for all the fleets (aggregated by area, month and year). The effort for the purse seine fleet was calculated in days at sea following the same allocation and distribution methods as noted above (H. Keith, Fisheries Centre UBC, pers. comm.).

Catch allocation to fleet

The small pelagic fleet targeted small and medium pelagics. Longline tuna fleet was assumed to target the adult large pelagics while the baitfish fleet (purse seine) targeted the juvenile stanza. Sharks were by-catch of the demersal and tuna longline fisheries. Demersal fleets were assumed to target groundfish and invertebrates. Distant water fleets were assumed to target both groundfish and pelagic fish. The proportion of catch for each functional group was roughly proportional to the respective GRT of demersal and distant water fleets, and adjusted to fit the data.

Prices

There are several databases for fish prices; most, however, are either freight on board (FOB)[12] or prices for processed fish and fish products as published by the United Nations Food and Agriculture Organization (FAO). The *Sea Around Us* database is the only global ex-vessel prices database publicly available (Sumaila *et al.*, 2007). Ex-vessel prices were used because landings are an output of the model and the use of other types of prices would over-estimate the value of the landings since the added value from processing is included. Moreover, it is the ex-vessel price that motivates commercial fishers to go fishing (Sumaila *et al.*, 2007).

The 31,675 price observations (based on 875 taxa and 35 countries) in the ex-vessel price database were sourced from a number of countries and organizations, and where information was missing the price was estimated using a rule-based decision process contingent on regional and global average ex-vessel prices. Where prices were expressed in local currencies they were converted to USD using the International Monetary Fund database for currencies (Sumaila *et al.*, 2007) This also allowed for the estimation of values at a national scale, which could then be aggregated into regional and global values for the four scenarios and IAASTD baseline which are of particular interest to UNEP[13] and the World Bank. Further details on this database can be found in Sumaila et al. (2007).

We used the *Sea Around Us* ex-vessel price database to estimate the value of landings for each scenario. Real 2000 prices were aggregated by functional groups for each FAO area. An average

[12] FOB means that the seller pays for transportation of the goods to the port of shipment, plus loading costs. The buyer pays freight, insurance, unloading costs and transportation from the arrival port to the final destination.
[13] UNEP = United Nations Environment Programme

price taken over the last three years where a catch/market price was available was then estimated and subsequently applied to the modelled landings.

Jobs per unit of catch value

The value used for the number of jobs generated for each slice of 1000 tonnes of catch was derived from information compiled for eastern Canada describing the number of jobs and landed value by boat, size class and gears (Sumaila *et al.*, 2001). The Canadian compilation was preferred over the Norwegian description of the fleets, also available in the report, because Canada's fleets are more diversified. For the immediate needs of this project, we assumed that the estimates for Canada could be applied in all regions of the world, which is obviously not correct. The number of jobs per unit of catch value was a function of the calculated value for an assemblage of gear and boat types from the Canadian fleet as described below, and also functions of an adjustment of the actual price for tuna and the number of crew members on tuna vessels (Rodwell, L 2006, Forum Fisheries Agency, Honiara Solomon Islands, pers. comm. with Jackie Alder, November 28) (See Table 2). Table 3 displays the vessel class and gear types assigned to each fleet with the following assumptions. The distant water fleet was characterized by all vessels of class size of 5 and larger using both demersal and pelagic gears. In the absence of specific data for tuna boats, the baitboat fleet (purse seine and pole and lines (Sumaila *et al.*, 2007)) was assumed to be similar to the surrounding nets operated on boats of size 2 to 4. Similarly, the tuna longline fleet was assumed to have similar characteristics to those of longliners of size 3 and 4. Finally the small pelagic fleet was assumed to be composed of mid-water gears (mobile seine, mid-water trawl, surrounding nets) operated on boat sizes 1 to 5.

Table 2. Crew per unit of value of the catch and ratio used in the modelling for each fleet.

Fleet	Crew/value	Ratio
Demersal	0.041	1
DWF 1)	0.012	0.29
Baitboat tuna 2)	0.078	1.89
Longline tuna 3)	0.028	0.69
Small pelagics	0.070	1.69

1) Large vessels of the demersal and pelagic fleets

2) Value reduced because tuna price is 2 times higher and the crew by vessel 3 times larger (based on tuna data: 18 crew member per vessel)

3) Assumed to be equal to the larger hook and line boats, same value per tonnes, but 3 times as much crew

Table 3. Vessel classes and gear types associated with fleets.

Fleet	Vessel class	Gear types
Demersal	1-4	Bottom trawls, dredges, traps, and liftnets, etc
DWF	5 and greater	Demersal and pelagic
Baitboat tuna	2-4	Purse seine and pole and line
Longline tuna	3 and 4	Longline
Small pelagics	1-5	Mobile seine, mid-water trawl, surrounding nets, etc

THE MODEL

Ecosystem models account for the biomass (in $t{\cdot}km^{-2}$) of each functional group (composed of a single species or of a group of species), their diet composition, consumption per unit of biomass (Q/B), natural and fishing mortality, accumulation of biomass (BA), net migration, and other mortality. The principle behind this ecosystem modelling approach is that biomass and energy are conserved on a yearly basis, i.e. that future biomass can be estimated from current biomass plus change in biomass due to growth, recruitment, predation, fisheries, etc. (Walters *et al.*, 1997).

The Ecopath model, the snapshot of the ecosystem structure in the first year of the time series we want to consider (1950 in this case) is, formally written:

$$P_i = F_i + B_i \cdot M2_i + E_i + BA_i + P_i \cdot (1-EE_i) \qquad \ldots 1)$$

where P_i is the total production rate of group i, F_i is the total fishery catch rate on i, $M2_i$ is the total predation rate for group i, B_i the biomass of the group, E_i the net migration rate (emigration – immigration), BA_i is the biomass accumulation rate for i, while $P_i \cdot (1-EE_i) = M0_i$ is the 'other mortality' rate for i. EE_i can be understood as the proportion of the total mortality of group i that is explained in the model. This value varies between models. Only 3 of the 4 basic input parameters (B, P/B, Q/B, and EE) are initially entered in Ecopath, the fourth one being estimated by Ecopath. For instance, in absence of information on biomass one can set EE to a reasonable value and obtain an estimated value of biomass.

Ecosim is a tool for dynamic simulations based on the Ecopath model, an instantaneous representation of the ecosystem in time. Ecosim uses a system of differential equations to describe the changes in biomass and flow within the system over time, by accounting for change in predation, consumption rate and fishing (Walters *et al.*, 1997; Christensen *et al.*, 2005). Thus, the rate of change of biomass of group i (B_i) is described by:

$$dB_i \cdot (dt)^{-1} = g_i \sum_j Q_{ji} - \sum_j Q_{ij} + I_i - (m_i + F_i + e_i) B_i \qquad \ldots 2)$$

where g_i is the net growth efficiency (P/Q); Q_{ji} and Q_{ij} are the consumption rate of group j by group i and the consumption of group i by group j respectively; I_i is the immigration flow in $t \cdot km^{-2}$; m_i is non-predation mortality; F_i is fishing mortality; and e_i is emigration rate (Christensen and Walters, 2004a).

The regulation of prey-predator relationships is defined by the concept of foraging arena (Walters and Martell, 2004), where prey behaviour impacts the predation rate. Prey pools are, for any given predators, assumed at any given time to be split in vulnerable and non-vulnerable sub-pools. We model the rate of exchange between these pools through a parameter called vulnerability (range: 1 to infinity), which also expresses how much the predation mortality for any given predator-prey group can increase if the abundance of the predator increases drastically. A low vulnerability thus means that the interaction is bottom-up controlled; more production leads to more food being made available for the predators. The predators will, in this situation, be close to their carrying capacity, and there will be substantial density-dependence for the predator's growth and survival. The opposite, high vulnerability, means that the given predator is far from its carrying capacity, more predators translates to more predation, and there will be little density-dependence in the predator population dynamics. When fitting the ecosystem model to time reference data, a major part is to obtain values for the vulnerability parameters – by deduction for how far the individual predators in each area are from their carrying capacity.

Model structure and data used

The model contains 43 functional groups comprising 25 groups of fish, 3 marine mammals, 1 marine bird group, 11 invertebrates, 2 primary producers, and 1 detritus group. Tunas were separated into 2 stanzas: juveniles (group 42) and adults (group 3), to account for the difference in growth, mortality and the type of fisheries that target them. The stanzas are linked and their respective production per unit of biomass (P/B year^{-1}), consumption per unit of biomass (Q/B year^{-1}), and growth calculated from a baseline estimate for a leading group (the adults in our case). Growth for each stanza is calculated following the von Bertalanffy growth curve and initially assuming stable survivorship (Christensen *et al.*, 2005). Based on parameters used in previous models of a pelagic ecosystem (Kitchell *et al.*, 1999), the P/B of adult tuna was set at 0.2 year^{-1} and that of juveniles at 2 year^{-1}. The initial biomass of adult tuna was set at 0.2 $t \cdot km^{-2}$ and later adjusted, along with the P/B of juveniles, to fit the time series. See Appendix C for a list of the parameters used in each model.

The biomass time series trend data for fish and invertebrates were extracted from a *Sea Around Us* database, compiled by Jordan Beblow and Dawit Tesfamichael, containing data for over 2500 stocks around the world. The catch time series was extracted from the *Sea Around Us* database, based mainly on spatialized catches from FAO (Watson *et al.*, 2004). The biomass and catches of marine mammals for years 1950-2002 were extracted from a database compiled by Line Bang Christensen, Jordan Beblow and collaborators (Christensen, 2006). Biomass trends by species and sub-area were first regrouped by FAO area and functional groups. A summary of the biomass trend by functional group was derived by calculating the weighted average of available time series. We were confronted with several problems in doing so:

1. Time series covered various periods. It was sometimes sufficient to start calculating an index at a year for which we have values in all time series for a group. In other cases, some time series had to be ignored because they were too short (i.e., less than four years). There were also instances where two or more species from a particular group had opposite trend data, thus biasing the weighted index in a particular direction. In this instance, we focused on the species which had, either the larger number of stock assessments, or the longer time series, and/or was the species that 'best' represented the overall trend of the group as a whole;

2. In several cases, units of surveys varied greatly (CPUE vs. biomass). In the absence of further information on these groups, they were assigned a weight equal to the minimal biomass of groundfish encountered in the area.

The final weight of each functional group in the model was calculated as follow:

1. The average biomass or catch for the study period was used to attribute a weight to each functional group;

2. Each functional group was assigned a weight based on a weighted average rescaled from 0 to 1 for biomass time series and from 0 to 5 for catch time series. A larger weight to catches accounted for the greater confidence attributed to catches.

The P/B and Q/B values for marine mammals were taken from a compilation of marine mammal species assembled for the Gulf of Alaska model (Guénette, 2005). P/B values used for other functional groups were chosen to take into account their size and life span. For most groups, we chose to define a reasonable value of production/consumption ratio and let Ecopath calculate the Q/B value. Biomass entered for the remaining functional groups, mainly primary producers and invertebrates, were taken from the *Sea Around Us* database. In the absence of total biomass for the remaining functional groups, initial values of *EE* were entered and modified later on during the fitting process to the time series.

Values for the diet matrix were based on information available for the general feeding habits of the species that comprise each group; i.e., from stomach content surveys available on FishBase (Froese and Pauly, 2007).

Fitting procedure

Model fitting was achieved by two means. First, it was sometimes necessary to modify the biomass in Ecopath by changing the initial value of *EE*. For example, given the large catches reported in most FAO areas, the large biomass of sharks resulting from simulations fitted better to the observed data when it was assumed that a large biomass was present in 1950, and thus that *EE* was quite low. Second, vulnerabilities for each predator were estimated using a non-linear search procedure in Ecosim. Suitable vulnerabilities were estimated to minimise the sum of squares of differences between model predictions and the catch and biomass time series data.

Optimization routine

Scenario evaluations were based on the 'optimum policy search' module implemented in the EwE software (Christensen and Walters, 2004a; Christensen and Walters, 2004b).

The policy module uses a very efficient, nonlinear optimization procedure (modified Davidson-Fletcher-Powell search, see Fletcher (1987) to optimize an objective function which, in our case, considers the following objectives:

- *Economic rent*: calculation of total profits from all fleets combined. Requires estimates of value of landed catch as well as of cost of fishing operations;
- *Social considerations*: estimated as the number of jobs supported by the fisheries. Jobs are assumed to be a linear function of the value of the catch, scaled using a fleet specific ratio of number of jobs to landed value (as explained above). Setting equal factors for all fleets equates to optimization for landed value of the catches;
- *Ecosystem structure*: calculated as the longevity-weighted summed biomass over ecosystems groupings. Mature (and perhaps stable) ecosystems are among other things, characterized by a predominance of long-lived individuals (Odum, 1969). Ecosystem rebuilding was defined as the rebuilding of all long-lived species, i.e., of large-bodied fish of all habitats, birds, and all marine mammals. This included a total of 13 groups; the biomass of each were weighted based on their longevity (estimated as the inverse of their respective annual P/B ratio).

Some situations can result in loss instead of profits (costs larger than revenues), which implies that some form of subsidies would be necessary for the fisheries to continue. In the optimization routine, costs could be allowed or forbidden to exceed the revenues depending on the scenarios. We modified the standard search routine of Ecosim as follows for the present study.

1. We used the last fitted year (2003) as a baseline for the optimizations (providing the economic reference data) rather than the year represented by the Ecopath model (1950);
2. We capped the maximum effort change that was allowed from year to year at a factor of 2 indicating that effort could at most double or be halved from year to year by adding a penalty function to the optimization function described above.

Indicators

Scenarios were compared on the basis of the effort given as optimum, revenues, biomass and catches for important functional groups. In addition, we used two ecosystem indicators to explore aspects of ecosystem structure. A biomass diversity index, based on Kempton's Q75 index (Ainsworth and Pitcher, 2006), was used to synthesise information on the number of species (in this case functional groups) that compose the biomass of the ecosystem. It was used as an index for studying model behaviour, assuming that more stable ecosystems will tend to have a more even distribution of biomass across the functional groups. The biomass diversity index evaluates model behaviour, and perhaps system response to the policy measures.

A second index, the marine trophic index (MTI), is calculated as the average trophic level of the catch and is used to describe how the fishery and ecosystem may interact as a result of modelled policy measures (Pauly and Watson, 2005). The index is often used to evaluate the degree of "fishing down the food web" (Pauly *et al.*, 1998). The MTI is one of the core indicators being used by the Convention on Biological Diversity (Secretariat of CBD). The mean trophic level of landings (TL) was computed, for each year k, from:

$$TL_k = \mathrm{sum}_i(TL_i \cdot Y_{ik})/\mathrm{sum}_i(Y_{ik}) \quad ...3)$$

where Y_i refers to the landings of functional group i, as included in fisheries statistics

ASSESSMENTS AND SCENARIOS

The development of EcoOcean was in response to requests from three global assessment projects: the GEO4, which has a strong environment focus; the IAASTD, which has a strong focus on knowledge development and transfer and includes fisheries from a capture and aquaculture perspective; and the GLOBIO project, which is exploring global changes in biodiversity. All three assessments are using scenarios. GEO4 is based on scenarios developed from GEO3 (UNEP,

2003) with weightings for optimization based on input from regional representatives (e.g., Latin America and the Caribbean) of the GEO4 process. The IAASTD and OECD use variations around a baseline which is not necessarily a '*business as usual*' scenario, but using current trends that are modified by key drivers such as subsidies (Fernandez *et al.*, in press).

GEO4 scenarios

The four GEO4 scenarios explore the future to 2050 with a focus on the environment and human well-being. All scenarios encompass cross-cutting issues such as climate change and energy. The scenarios used qualitative (narrative) and quantitative approaches to describe four futures, which vary with who makes the key decision, how the decisions are made and why certain decisions are made (Rothman *et al.*, 2007). The names of the four scenarios also reflect the theme that dominates or drives decision making, i.e. what is the *first* priority:

- *Markets First*: the private sector, with active government sector support, pursues maximum economic growth, trusting this to be the best path toward the improvement of the environment and human well-being for all;
- *Policy First*: the government sector, with active private and civic sector support, implements strong policies intended to improve the environment and human well-being for all, while still emphasizing economic development;
- *Security First*: the government sector and certain private sector stakeholders compete for control in efforts to improve, or at least maintain, human well-being for select groups;
- *Sustainability First*: the civic, government and private sectors work collaboratively to improve the environment and human well-being for all, with a strong emphasis on equity (Rothman et al., 2007).

The four themes also guided how optimization for landed value, jobs, diversity and whether subsidies would be allowed or not (see Table 4). Latin America areas have different weightings in comparison to the rest of the world, as was the mandate of the representatives of the countries that comprise this area.

Table 4. Weight used for each criterion in policy scenarios in Latin America and all other FAO areas.

Criteria	Market	Policy	Security	Sustainability
Areas 31, 41 and 87 (Latin America)				
Value	1	1	1	0.1
Jobs	0.33	1	0.1	1
Ecosystem structure	2	5	0	10
Subsidies	yes	no	yes	no
All other areas				
Value	1	1	0.3	0.1
Jobs	0.33	1	1	0.1
Ecosystem structure	2	5	0	10
Subsidies	yes	no	yes	no

International Assessment of Agricultural Science Technology and Development

The IAASTD reviewed the current trends and impacts in agriculture knowledge, science and technology (AKST) primarily in a development context, with recommendations on future investment in AKST for developing countries and also for countries with official development assistance (ODA) programs. The IAASTD also examined the potential future for agriculture and AKST using primarily quantitative methods, in particular models depending on the area of interest. For example, for general socio-economic trends, the International Futures Model (IFS) was used, while changes in land use, energy use and forestry under different development scenarios were explored using IMAGE[14]. In the fisheries sector, EcoOcean was used. The IAASTD modelling initiative used reference runs from 2000 to 2050 to indicate how the IAASTD development and sustainability goals would develop over the 50 years, followed by policy experiments which were used to assess how the IAASTD goals might change over the same time period. The policy experiments focused on investments in AKST, climate mitigation, extensive use of biofuels, trade liberalization, changes in water productivity and changes in diets (e.g., less meat consumption). In the fisheries sector, the first reference run was based on optimizing for the value of landings throughout the years modelled, driving it with effort in the year 2003 to 2010; after 2010 only the effort in the small pelagic fleet was allowed to vary. The other reference run was similar, the only difference being effort in the small pelagic fleet increasing annually by 2% after 2010. The 2% growth was used as a proxy for the growth in aquaculture based on FAO's 2006 State of World Aquaculture Report (FAO 2006).

The four policy experiments can be described as:

1. a mix of technology and trade liberalization with subsidies allowed, this resulted in optimizing for profit;
2. a trade liberalization focus by optimizing for profit but without subsidies;
3. an AKST investment which focused on ecosystem rebuilding and allowing effort to increase by 2% annually; and
4. a certification focus which was the first reference run but with trawling reduced, was modelled by reducing effort in the demersal fleet.

The four descriptions also guided optimization for landed value, jobs, diversity and whether subsidies would be allowed or not (see Table 5).

Table 5. Weight used for each criterion in the four policy experiments.

Criteria	**1**	**2**	**3***	**4****
Description	Profit first with subsidies	Profit first without subsidies	Ecosystem rebuilding	Reducing trawling
Value	1	1	1	not optimized
Jobs	0.3	0.1	0.1	-
Ecosystem structure	10	0.1	20	-
Subsidies	yes	no	no	-

* Ran scenario for twenty years (2004-2023), then used the last year of effort from this optimization and increased effort 2% annually for all fleets (2024-2048).
** Decreased tuna longline and demersal fleet effort by 10% over forty-five years, based on the last year of effort (2003)

GLOBIO – mapping human impacts on the biosphere

To date the GLOBIO consortium has developed a global-scale spatial model of the impacts of environmental change on biodiversity. The model is designed to produce policy-relevant indicators for use in assessments, scenario exercises and exploration of the impacts of policy options. The main indicator produced is the mean abundance of the original species belonging to an ecosystem (MSA), that is, the abundance of native wildlife in terrestrial systems. EcoOcean is being used to develop a marine equivalent to the MSA, the depletion index (DI), that will be calculated as part of the overall assessment within EcoOcean.

Depletion index (DI) calculation

We attempt to evaluate the degree of depletion of fish species by accounting for differences in their intrinsic vulnerability to fishing. In the EcoOcean model, species is not represented individually, but are aggregated in functional groups. However, species within the same functional group may have different life history and ecology, and thus have different intrinsic

[14] IMAGE – The Image Development Group – IMAGE 2.0 Model – www.rivm.nl/image

vulnerability to fishing. Intrinsic vulnerability is defined as the inherent capacity of a species to respond to fishing capacity (Cheung *et al.*, 2005). Species with higher intrinsic vulnerability tends to have a faster rate of depletion than the less vulnerable species when they are subjected to similar fishing mortality (Cheung *et al.*, 2005; Cheung, 2007; Cheung *et al.*, 2007; Cheung and Pitcher, in press). Thus, if the EcoOcean model predicts a decline in abundance of a functional group due to fishing, some of its more vulnerable member species may suffer from a larger depletion.

A depletion index (DI) was used to represent the different rates of decline of species that had been aggregated into functional groups. The DI was calculated from prior knowledge of the intrinsic vulnerability and the estimated changes in functional group biomasses. Intrinsic vulnerability was represented by the index developed in Cheung *et al.* (2005), while population status was expressed as a ratio of current to initial biomass. A full description of the algorithm employed here to calculate the depletion index is documented elsewhere (Cheung, 2007; Cheung and Sumaila, in press). Intrinsic vulnerability to fishing of the 733 species of marine fishes with catch data available from the *Sea Around Us* Project database (www.seaaroundus.org) was included in the analysis. Life history data, which include maximum body length with, if available, the von Bertalanffy growth parameter *K*, natural mortality rate, age-at-maturity, longevity, fecundity, spatial aggregation strength (an index of the tendency of a species to aggregate and school, see Cheung *et al.* 2005 for details) and geographic range, were based on the information available from FishBase (Froese and Pauly, 2007) and the *Sea Around Us* Project database. Using the fuzzy logic expert system described in Cheung *et al.* (2005), for each species, we calculated the degree of memberships (scaled from 0 to 1; 0 – no association and 1 – full association) to four levels of intrinsic vulnerability: low, medium, high and very high.

For each species, memberships to different levels of depletion were then calculated from the intrinsic vulnerabilities of species and the decline in biomass of the functional groups to which they are associated. In the model, the relationship between intrinsic vulnerability, biomass change and depletion levels was governed by sets of rules (Table 6). The rules represent qualitative descriptions determining how depletion risks would be inferred from species' intrinsic vulnerability and decline in functional group biomass. Essentially, the higher the intrinsic vulnerability and the larger the decline in biomass of the functional group, the higher is the DI. Memberships to different levels of biomass decline were estimated based on the predicted change in functional group biomass relative to the start of the simulation time-frame (i.e., time = 0). Then, based on pre-defined rules (Table 6), memberships to the level of depletion were calculated. The group resulting DI, which is scaled from 1 to 100 (with 1 = the highest level of depletion), was calculated from the average of the corresponding index values of each level of depletion weighted by its degree of membership.

To represent the overall changes in the depletion risk of the ecosystem over time, average DI of all the 19 ecosystem models and the four simulation scenarios (i.e., Market First, Policy First, Security First and Sustainability First) were calculated. The average ecosystem DI was calculated from the arithmetic mean of DI from all the exploited fish species in an ecosystem model.

Table 6. Heuristic rules that describe the relationship between intrinsic vulnerability, relative abundance and the depletion index (DI).

		Intrinsic vulnerability			
		Low	**Moderate**	**High**	**Very high**
Decline in abundance of species within group (relative to B_o)*	**Very low**	Minimum DI	Minimum DI	Minimum DI	Minimum DI
	Low	Minimum DI	Very low DI	Low DI	Low DI
	Moderate	Very low DI	Low DI	Low DI	Moderate DI
	High	Low DI	Low DI	Moderate DI	High DI
	Very high	Low DI	Moderate DI	High DI	Very high DI
	Extremely high	High/Very high DI	Very high DI	Very high DI	Very high DI

* Default decline in population is calculated as biomass at t_1/biomass at t_o, where t_o is the starting time of the simulation. However, if knowledge on unfished biomass (B_o) is known, the starting biomass can be replaced by B_o.

Model Uncertainty

EcoOcean was developed using the most up-to-date and best available global data, and while it does simulate many of the processes that occur, it is not a full representation of the world's oceans as it comprises several sources of uncertainties (Tables 7 and 8). These uncertainties need to be considered when interpreting the modelled results and in making implications for policy changes. For example, a low level of fit and sparse data that is high in uncertainty in both criterions would lead to a cautious interpretation of the simulation results admitting competing explanations (Table 8). In contrast, a good fit coupled with low confidence in the data would lead to the interpretation that the model may have the right structure, but there may still be questions about some components and processes.

Table 7: Overview of major uncertainties in EcoOcean model

Model Component	**Uncertainty**
Model Structure	Low
Parameters	Input parameters most have medium to low uncertainty; a few have high uncertainty
Effort (driving force) – either direct or relative	Medium to high depending on the FAO area at this stage
Initial condition	Low
Model operation	Medium, especially on the behaviour of small pelagic fish

Table 8: Level of confidence and interpretation of the EcoOcean model results as a function of the level of agreement (fit to the observations) and quality of evidence

		Amount of Evidence (Theory, Observations, Model Outputs)	
		Low	**High**
Level of Agreement	**High**	Established but incomplete *e.g. catches except small pelagics and tuna (lower confidence level) and value*	Well-established *e.g. MTI (marine trophic index)*
	Low	Speculative *e.g. jobs*	Competing explanations

RESULTS

Fitted models

The catch data that we used, extracted from the *Sea Around Us* database, differ from that of FAO only by an average of 2% (Figure 3). This difference between the two databases can be explained in the *Sea Around Us* Project's effort to enhance the FAO dataset with finer scale spatial data, either from alternate data sources like ICES[15] and NAFO[16], or through catch reconstructions. Polar regions were excluded from the modelling exercise because of the lack of biomass and effort data and the incompleteness of the catch data (FAO areas 18, 48, 58 and 88). Globally, the trend in predicted catches follows quite closely that of the observed catches for the first 20 years, and deviates by approximately 16 million tonnes with the *Sea Around Us* data, and by 13 million tonnes with the FAO data near the end of the time period (Figure 3). For the whole time series, the average difference between the predicted catches and those of the *Sea Around Us* and FAO databases amounts to 8% and 10% respectively. Success in correctly predicting catches varies appreciably among FAO areas (Table 9, and see Appendix E for further details for each FAO areas). For eight FAO areas with reasonable fits to the observed catch data, the average difference ranges between 8% and 34% (Table 9).

The gap between predicted and observed catches is particularly important (2-550%) in areas 51, 71, 77 and 87 (table 9). The main source of discrepancy varies for each region, but pelagics accounted for an appreciable percentage of the total difference, ranging from 13% in area 81 to 73% in area 77. A large part of the gap was also caused by medium demersals in area 81 (35%) and 71 (13%), by medium benthopelagics in area 51 (23%), and by shrimps and molluscs in area 71 (46%). The problem with these four areas is the fact that a large part of the effort is missing from the model, be it artisanal (e.g. in areas 51

[15] ICES – International Council for the Exploration of the Sea
[16] NAFO – Northwest Atlantic Fisheries Organization

and 57) or industrial (e.g. the Australian fleet, see Appendix E). This problem is plaguing Asian as well as African countries.

Although the average difference between the observed and predicted catch amounted only to 12%, area 67 was difficult to model because: 1. the fishing history is very different in the southern part of the area (Washington and Oregon (USA), and British Columbia (Canada) compared to the northern part (Alaska, (USA)) and therefore fishing mortality would have started and peaked at different times and the species targeted were inherently different; 2. the area encompassed several climatic regimes governed by the Alaska gyre and the California Current and to which species within a given functional group would respond differently depending on their location (Appendix E).

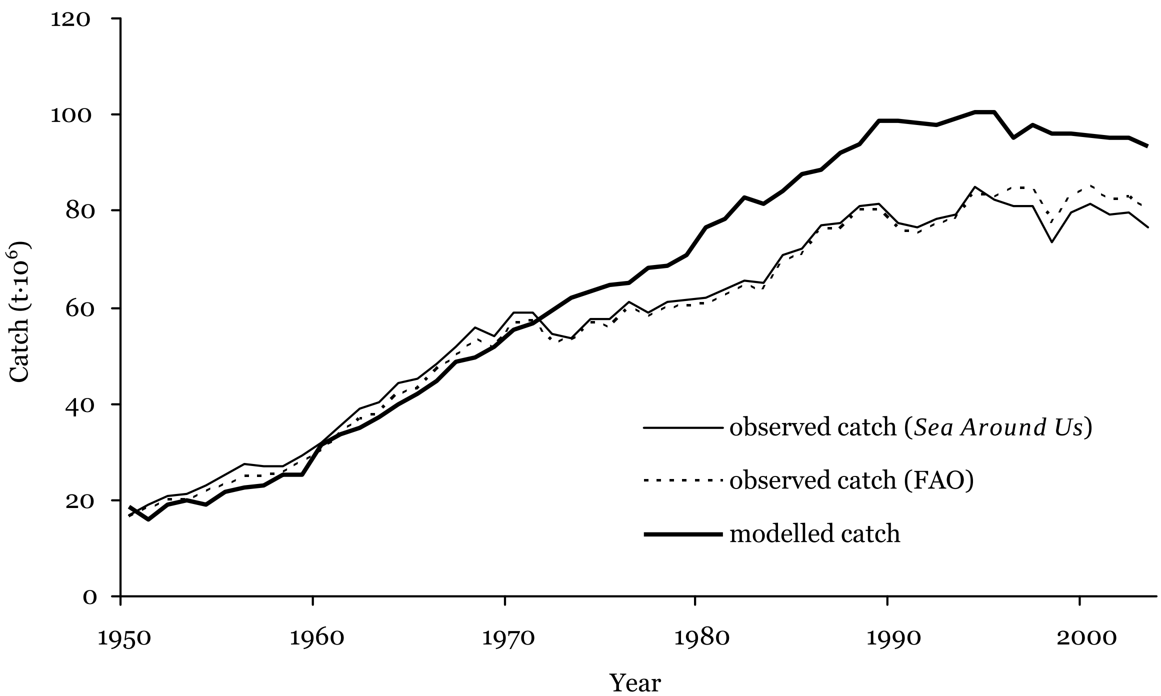

Figure 3. Observed global marine catch from the *Sea Around Us* and FAO databases and the predicted catch for all FAO areas, with the exception of the polar regions (FAO areas 18, 48, 58 and 88).

Table 9. Percentage difference between modelled catch and observed (*Sea Around Us*) catch. FAO areas are denoted across the top row.

	21	27	31	34	37	41	47	51	57	61	67	71	77	81	87	Overall % Differences
1950																11
1951																-16
1952																-8
1953																-7
1954																-18
1955																-14
1956																-18
1957																-15
1958																-6
1959																-13
1960																-2
1961																-4
1962																-10
1963																-7
1964																-10
1965																-7
1966																-7
1967																-6
1968																-11
1969																-4
1970																-6
1971																-4
1972																9
1973																15
1974																11
1975																12
1976																7
1977																16
1978																12
1979																15
1980																24
1981																23
1982																26
1983																26
1984																19
1985																22
1986																15
1987																19
1988																16
1989																21
1990																28
1991																28
1992																25
1993																25
1994																18
1995																22
1996																17
1997																21
1998																31
1999																20
2000																17
2001																20
2002																20
2003																22
Mean	34	-19	8	40	-18	-4	-26	336	24	-19	12	62	127	11	-9	

= 0-25% = 26-50% = 51-100% = >100%

The catch of important commercial groundfish such as cod (large benthopelagics) and large sharks was generally correctly predicted (e.g. area 21 and 27, Figure 4 and 5), while smaller sized groundfish were predicted with variable success. In area 47 (Namibia/South Africa), catches for pelagics, medium demersal and benthopelagics, shrimps and lobsters were predicted particularly well, although biomass predictions were rather poor (when time series were long enough, Appendix E). These examples illustrate that the model was able to predict catches for species submitted to high levels of fishing mortality when environmental indices do not play as an important role (as occurs with the small pelagics).

In addition to high levels of fishing mortality, in terms of fitting biomass times series, factors such as an area's relative uniformity of oceanographic systems, and/or if stock trends were similar amongst the component species of a functional group, were also determinants in how biomass series were predicted. As was the case with fitting the catch for large benthopelagics and large sharks for areas 21 and 27, the biomass fitting for these two groups in these two areas was also successful (Figures 4 and 5). An example of an area with heterogeneous climate systems, area 27 (Northeast Atlantic) includes the relatively warm waters of Spain and Portugal, the North Sea, and the Barents Sea. Not surprisingly in this case, it was difficult to match biomass and catch time series (Figure 5), especially for small and medium pelagics as the environmental drivers were bound to differ and have various levels of impacts on the ecosystem (see graphs E3 and E22 in Appendix E for example). These impacts related directly to how the species comprising a functional group related, in terms of stock trends. As seen in graphs E3 and E22 (Appendix E), calculating a single index for a group with contrasting trends was not ideal.

The problem in fitting the catch and biomass of small and medium pelagics has been encountered for at least one pelagic group in all regions and especially those that include an upwelling, such as areas 77 (California current), 87 (Humboldt Current), and 47 (Benguela Current). For these areas variations in biomass and catches of small and medium pelagics are often dramatic and linked to climate indices. Moreover, resulting changes in microalgae production and composition are thought to be the reason behind the alternate dominance of sardine and anchovy in upwelling systems (Guénette *et al.*, in press). In the present model, both species belong to the same functional group (small pelagics), which precludes ever capturing this dynamic. Thus, in area 47 (Namibia/South Africa) for example, catches for pelagics, medium demersal and benthopelagics, shrimps and lobsters were predicted particularly well although biomass predictions were rather poor (when time series were long enough, Appendix E).

Low fishing mortality (F) was also a factor in how catch and biomass were fitted. In areas 51, 57, 61 and 71**,** catches were not well-predicted and in particular for areas 51 and 71 where the catch was generally overestimated. These results are likely due to the fact that the artisanal catch and effort were not included in the model, and thus fishing mortalities are rather low for several commercial groups, which is unlikely for this region of the world. In area 37, a similar effect may be occurring with the number of small fishing fleets that are not captured by the industrial fleet data.

The difference between the predicted and observed catches (36%) in FAO area 21 is mainly due to the molluscs and invertebrates, which explain 72% of the difference (Figure 6). The increase of effort towards molluscs is difficult to obtain in the present model given that there is no way to account for the change in target species that occurred as groundfish biomasses declined. This was often the main reason for the mediocre fit for lobster, shrimps and molluscs catches obtained in several areas. By contrast, the fit was remarkable in areas 31, 34, 41, and 47 (Figure 6).

Tuna catch was rarely very well-predicted except perhaps in areas 37, 47, 77, 81 (Appendix E) and biomass even more rarely. The dynamics for tuna leave a lot to be desired in the present model structure as adults of all species belong in the same group (#3, large pelagics) and all their juveniles in the large pelagic, juvenile group (#42). This resulted in an overestimation of the production for these two groups as the long-lived bluefin tuna (*Thunnus maccoyii* and *T. thynnus*) is unlikely to be as productive as that of the short-lived small-bodied skipjack tuna (*Katsuwonus pelamis*).

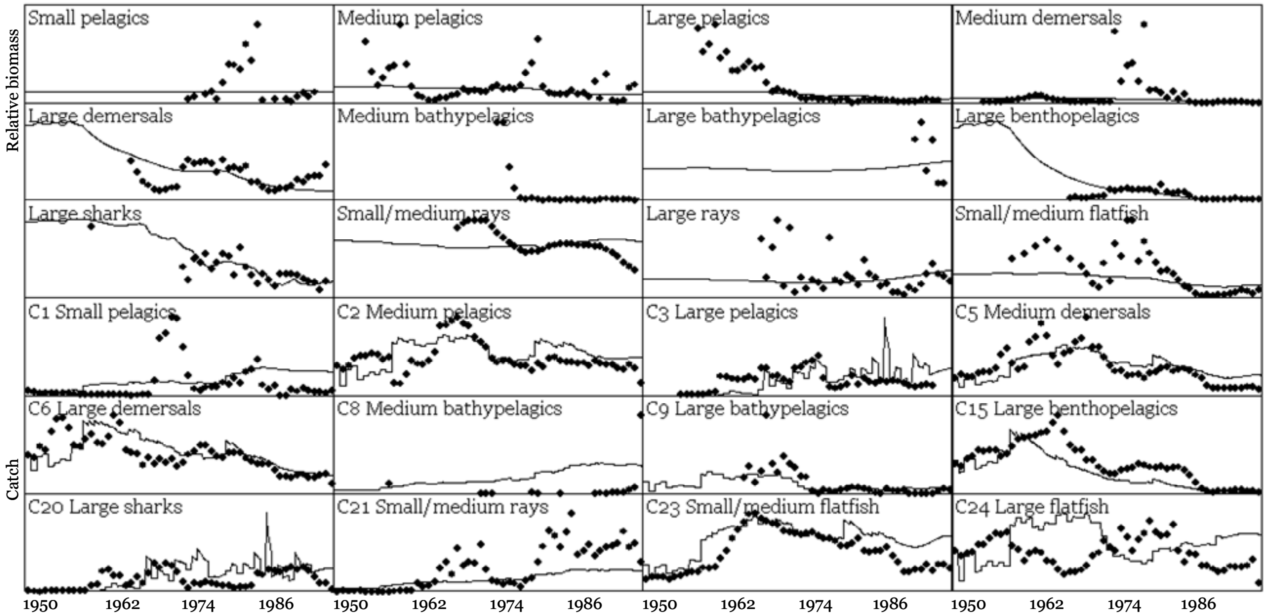

Figure 4. Area 21. Predicted (solid line) and observed (dots) relative biomass and catch (group numbers preceded by 'C') of various groups for the time period 1950-2003.

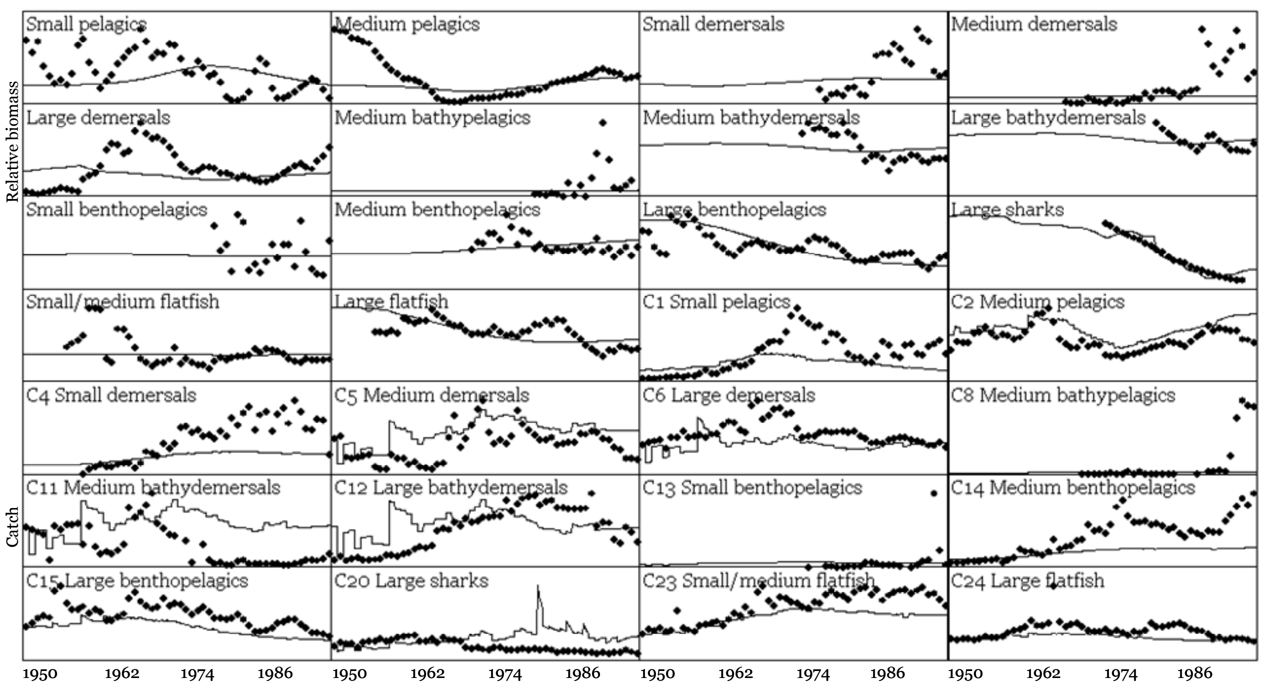

Figure 5. Area 27. Predicted (solid line) and observed (dots) relative biomass and catch (group numbers preceded by 'C') of various groups for the time period 1950-2003.

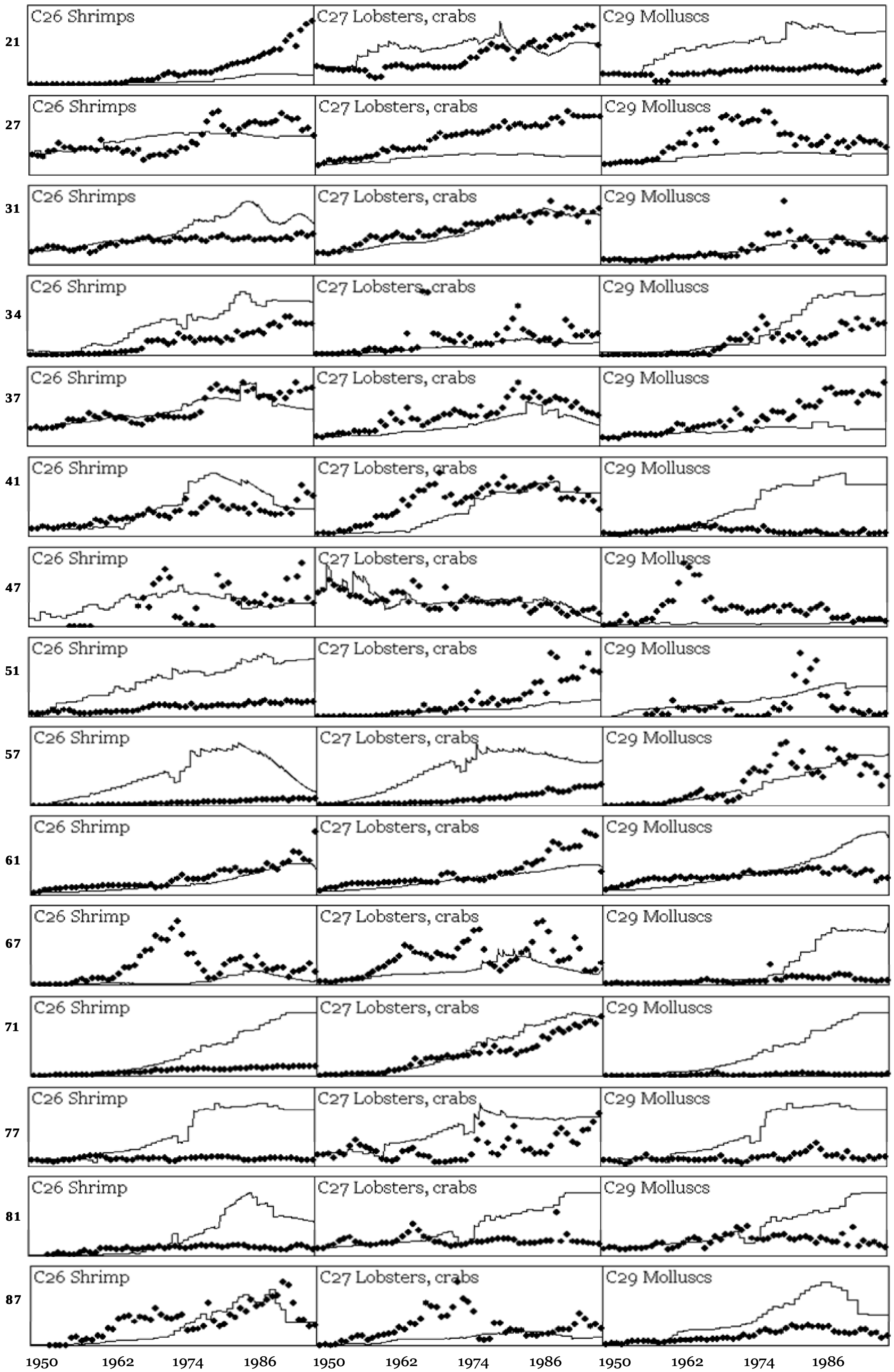

Figure 6. Modelled (solid line) and observed (dots) catch of shrimp, lobsters/crabs and molluscs for the time period 1950-2003. FAO marine statistical area numbers are indicated to the left of the plots.

GEO4 Scenarios exploration

All scenarios proposed an increase in effort, and as a consequence landings generally increased (Figure 7). All scenarios in the Pacific Ocean resulted in large increases in landings while those in the Indian Ocean produced the least changes. The Indian Ocean results are mainly due to area 51 in which a large increase of effort did not produce a corresponding increase in landings. In general, the *sustainability first* scenario resulted in the least increase in landings, and in some areas decreased demersal fleet effort, which often led to biomass reconstruction of large groundfish (e.g., FAO 21, figure E2). In several areas, the optimization resulted in an increased effort directed on tuna which augmented the landings. This is an artefact of the model structure as explained earlier.

As most of the large-bodied groundfish were already overexploited in 2003, an increase in demersal fleet effort resulted in further decline in large groundfish. Thus, landings were increased by augmenting the proportion of secondary groundfish groups and the proportion of invertebrates. The small pelagics fleet effort was often increased and landings increased, sometimes spectacularly, though in reality this is unlikely to happen and reflects the lack of fit to the biomass data as explained earlier. As a consequence, the marine trophic index (MTI) generally decreased in all oceans (Figure 8).

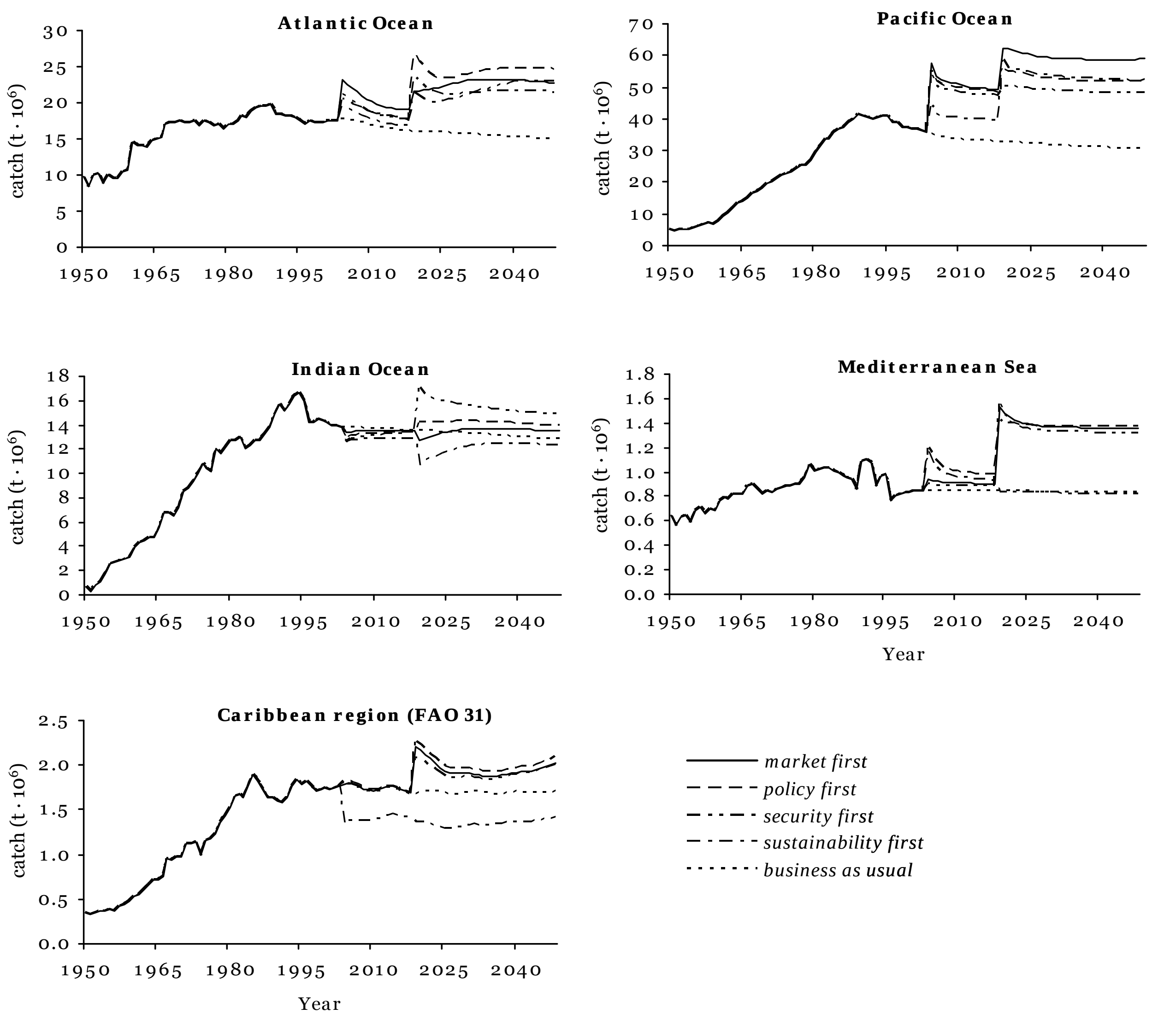

Figure 7. Marine fish landings by ocean for the four fishing policy scenarios. *Business as usual* is the 2003 effort carried forward until 2048.

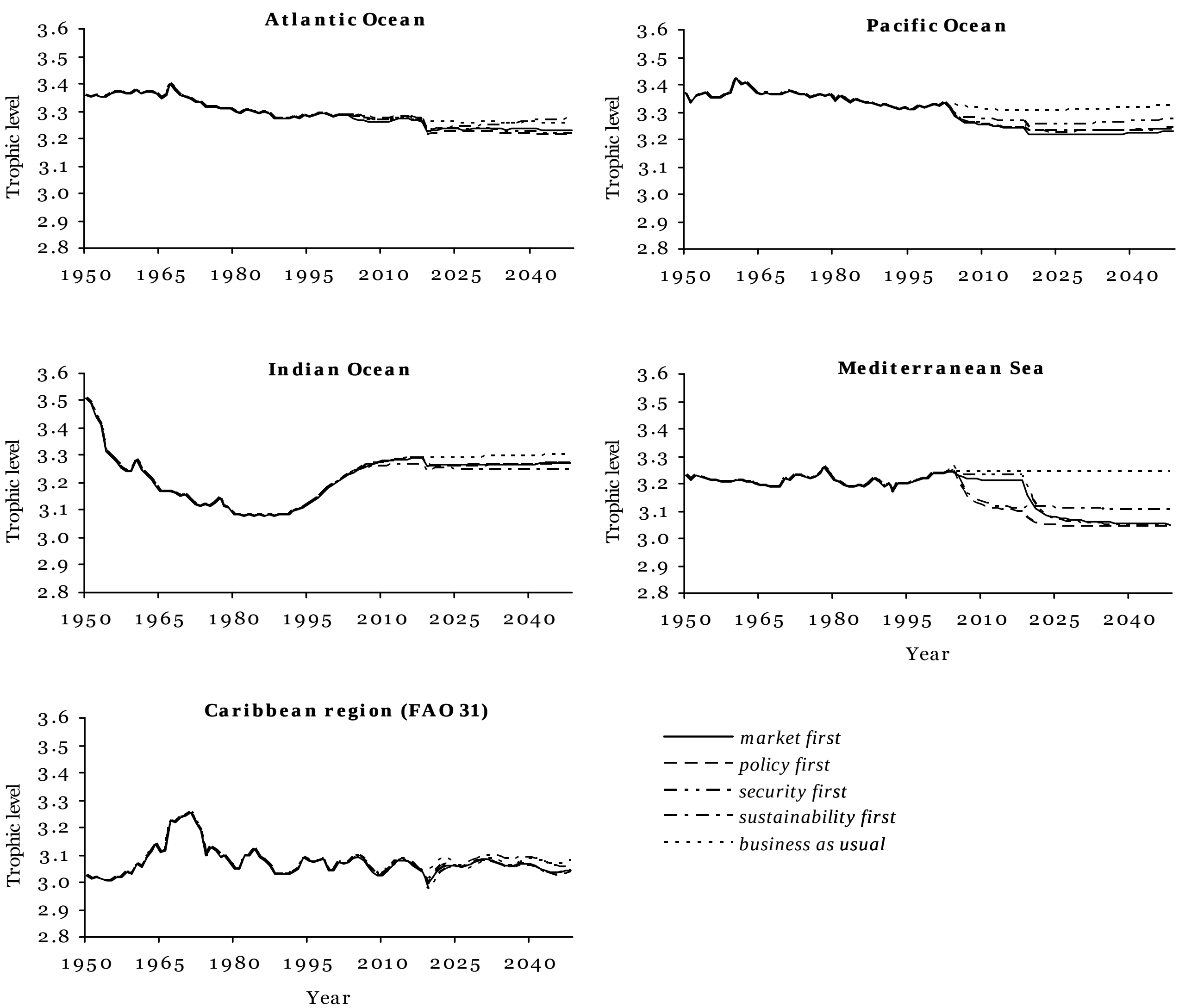

Figure 8. Marine trophic index by ocean for the four fishing policy scenarios. *Business as usual* is the 2003 effort carried forward until 2048.

The decline in MTI confirms that as demersal effort increased (see Appendix E for effort graphs), landings increased, but usually at lower trophic levels (Figure 8). With the exception of the Mediterranean Sea and the Caribbean region, the Kempton's Q relative index decreased as well for the three main oceans (Figure 9). In the Mediterranean Sea and Caribbean region, the increase appears to be a result of the predation impact of a few top predators (e.g., large sharks and large benthopelagics) being lowered as their biomasses decrease, allowing for increase in dominance of lower trophic levels.

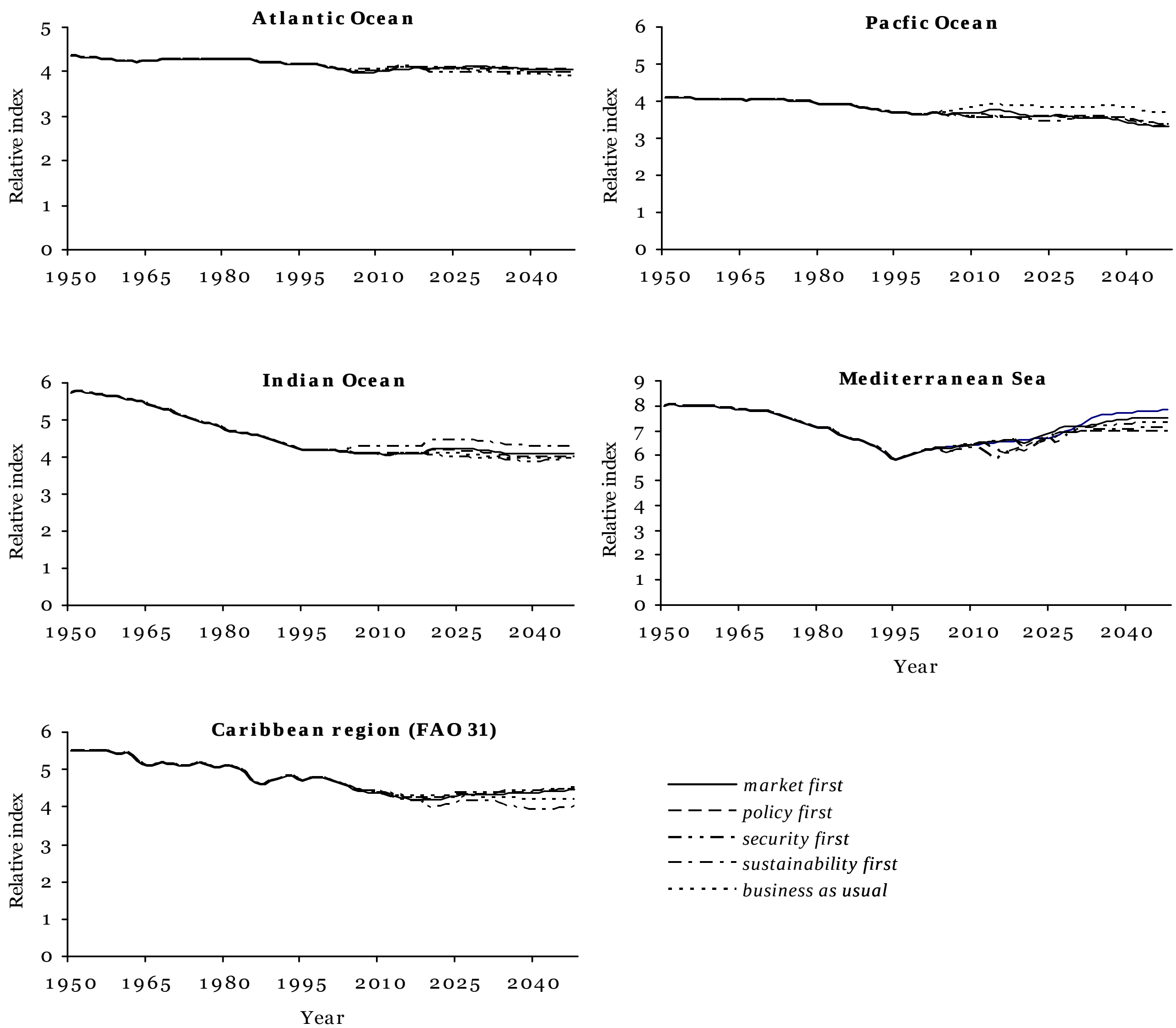

Figure 9. Kempton's Q index by ocean for the four fishing policy scenarios. *Business as usual* is the 2003 effort carried forward until 2048.

IAASTD Scenarios exploration

Scenarios one and two proposed an increase in effort and, as a consequence, landings increased for the scenarios in the Atlantic and Pacific Ocean (Figure 10). For the Atlantic, the increase in demersal and small pelagic fleet effort resulted in an increase in demersal and invertebrate landings, while the increase in small pelagic effort did not translate into increased pelagic landings. In the Pacific, effort increased for all fleets for scenario one and solely the small pelagic effort decreased for scenario two. For scenario three, which emphasised ecosystem rebuilding, with a 2% annual effort increase over the last 25 years of the scenario, landings decreased for all areas for the first twenty years of the scenario run, while subsequently landings increased as effort increased. In the Indian Ocean, the effort for all fleets except the small pelagic decreased or remaining constant. Scenarios one and two proposed an increase in small pelagic effort, which resulted in an increase in small and medium pelagic landings (Figure 10 and 12). The increase in small and medium pelagics landings in the Indian Ocean is primarily for area 57, as landings have declined over the time span of the scenario for area 51, with the exception of scenario three as previously mentioned, and overall landings have decreased in the Indian Ocean (Figure 10).

As previously mentioned for the GEO4 scenario exploration, most of the large-bodied groundfish were already overexploited in 2003, and an increase in demersal fleet effort resulted in further decline of this group (Figure 11). Thus, landings were increased by augmenting the proportion of secondary groundfish groups and the proportion of invertebrates. The small pelagics fleet effort was often increased and landings increased sometimes spectacularly, though in reality this is unlikely to happen and reflects the lack of fit to the biomass data as explained earlier. As a consequence, the marine trophic index (MTI) generally decreased in all oceans (Figure 13). An exception to this would be for scenario four, where the 10% decrease in tuna longline and demersal fleet effort over the last 45 years of the scenario run resulted in a decrease in demersal and large tuna landings, and as a result the MTI increased or remained constant for all oceans (Figure 13).

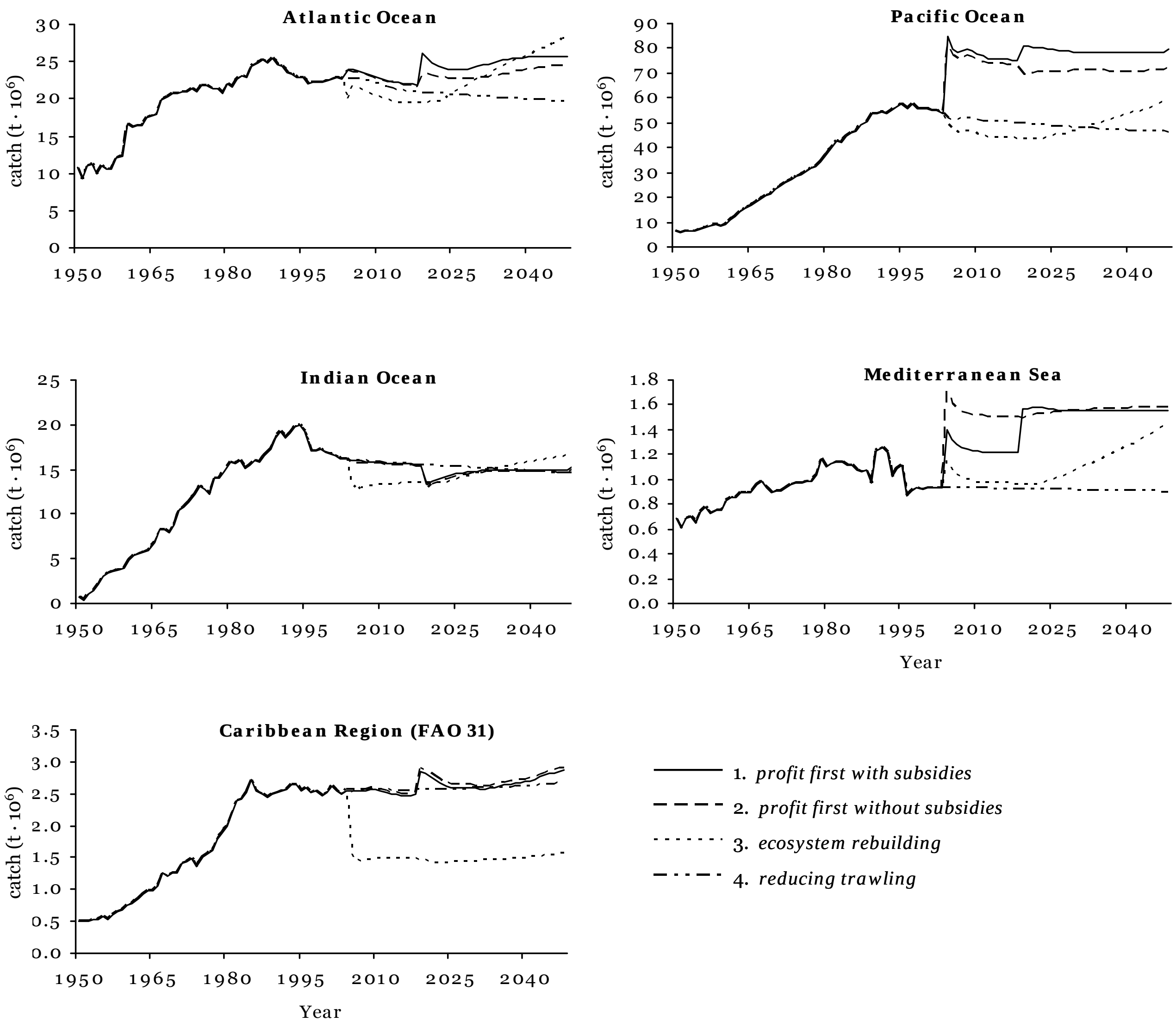

Figure 10. Landings by ocean for the four IAASTD policy scenarios.

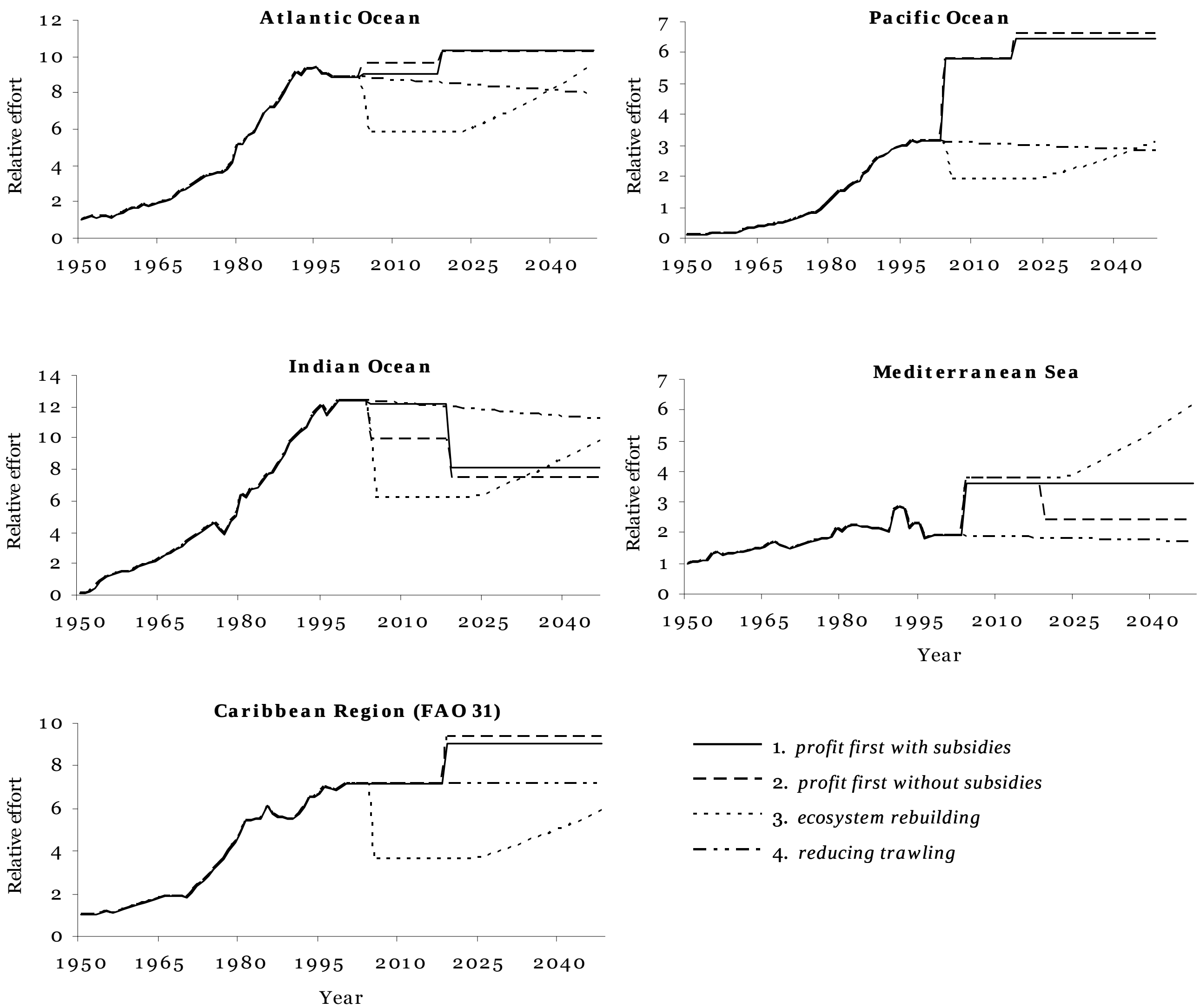

Figure 11. Average demersal effort by ocean for the four IAASTD policy scenarios.

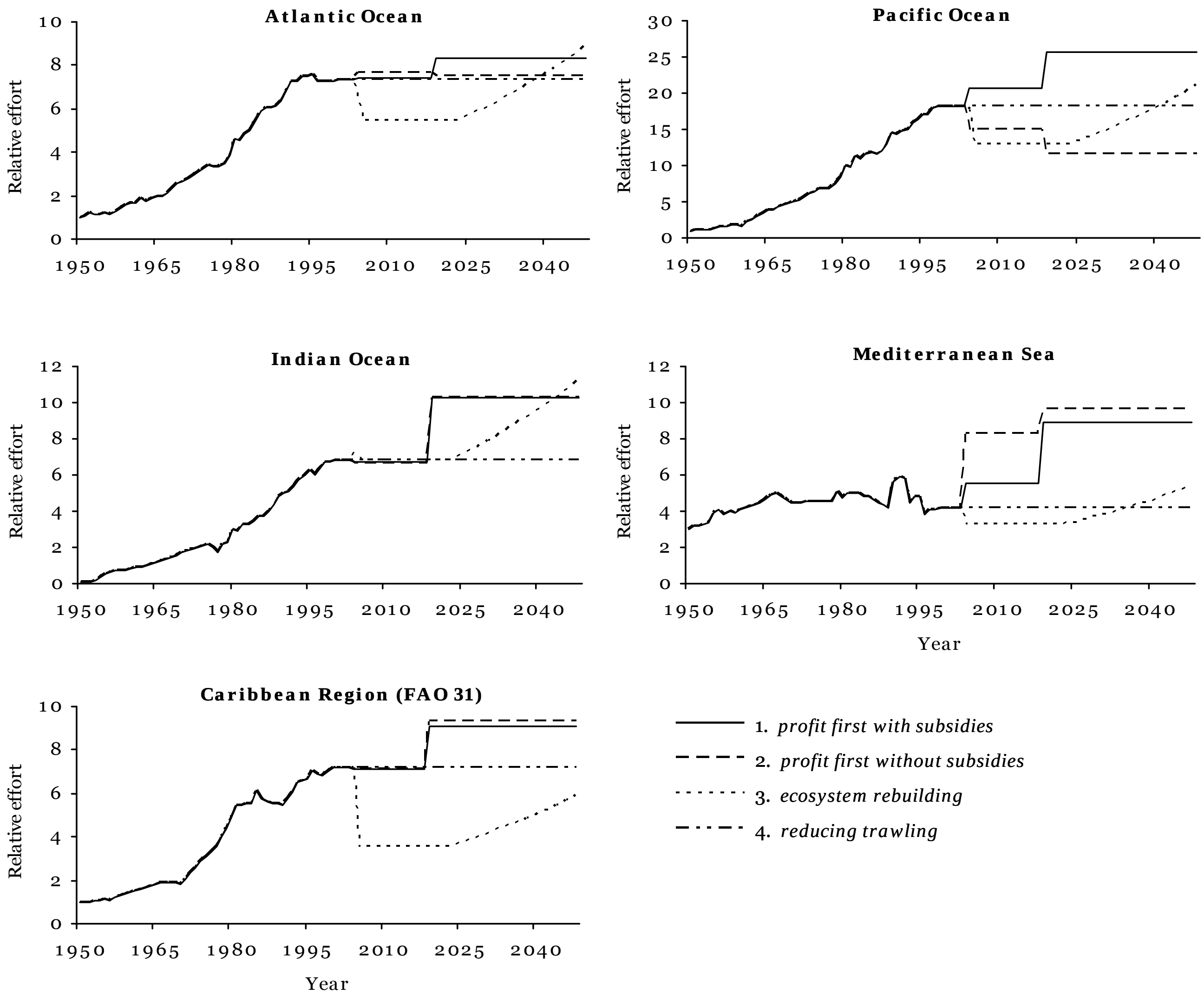

Figure 12. Average small pelagic effort by ocean for the four IAASTD policy scenarios

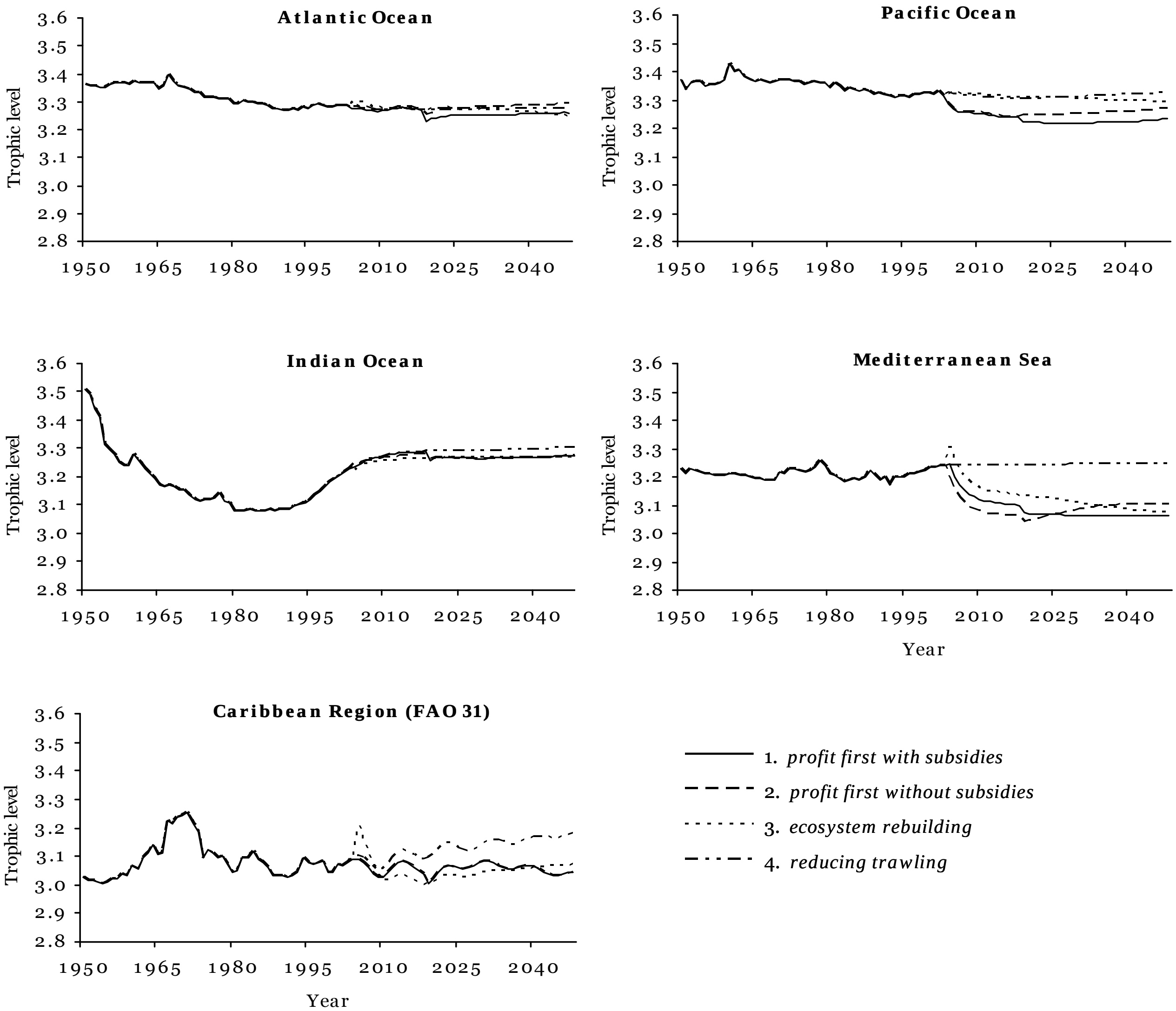

Figure 13. Marine trophic index by ocean for the four IAASTD policy scenarios

Depletion index

By comparing the calculated DI of the ecosystems between year 2007 (present) and 2047 under different scenarios, we can predict the changes in conservation status during this period (Figure 14). The *policy first* and *security first* scenarios resulted in further reduction in DI (i.e., further depletion) in most FAO areas except 57 and 61. The *market first* scenarios resulted in a reduction in DI in FAO areas 31, 37, 41, 47, 67, 71, 77 and 81. Surprisingly, under the *sustainability first* scenario, among the 14 FAO areas (the three Antarctic FAO areas are excluded here because of poor representation by the models), changes in DI from 2007 to 2047 were positive (i.e., reduction in depletion risk) in five FAO areas only (Areas 21, 34, 47, 51 and 57). The projected increase in depletion risk under the *sustainability first* scenario is partly a result of the trade-off between rebuilding less intrinsically vulnerable species while some more vulnerable species (large demersal fishes and elasmobranchs) may have been further depleted. For area 61 the focus was on rebuilding tuna (large and young) with demersal and small pelagic effort relatively high in relation to the other scenarios (see Figure E21 in Appendix E).

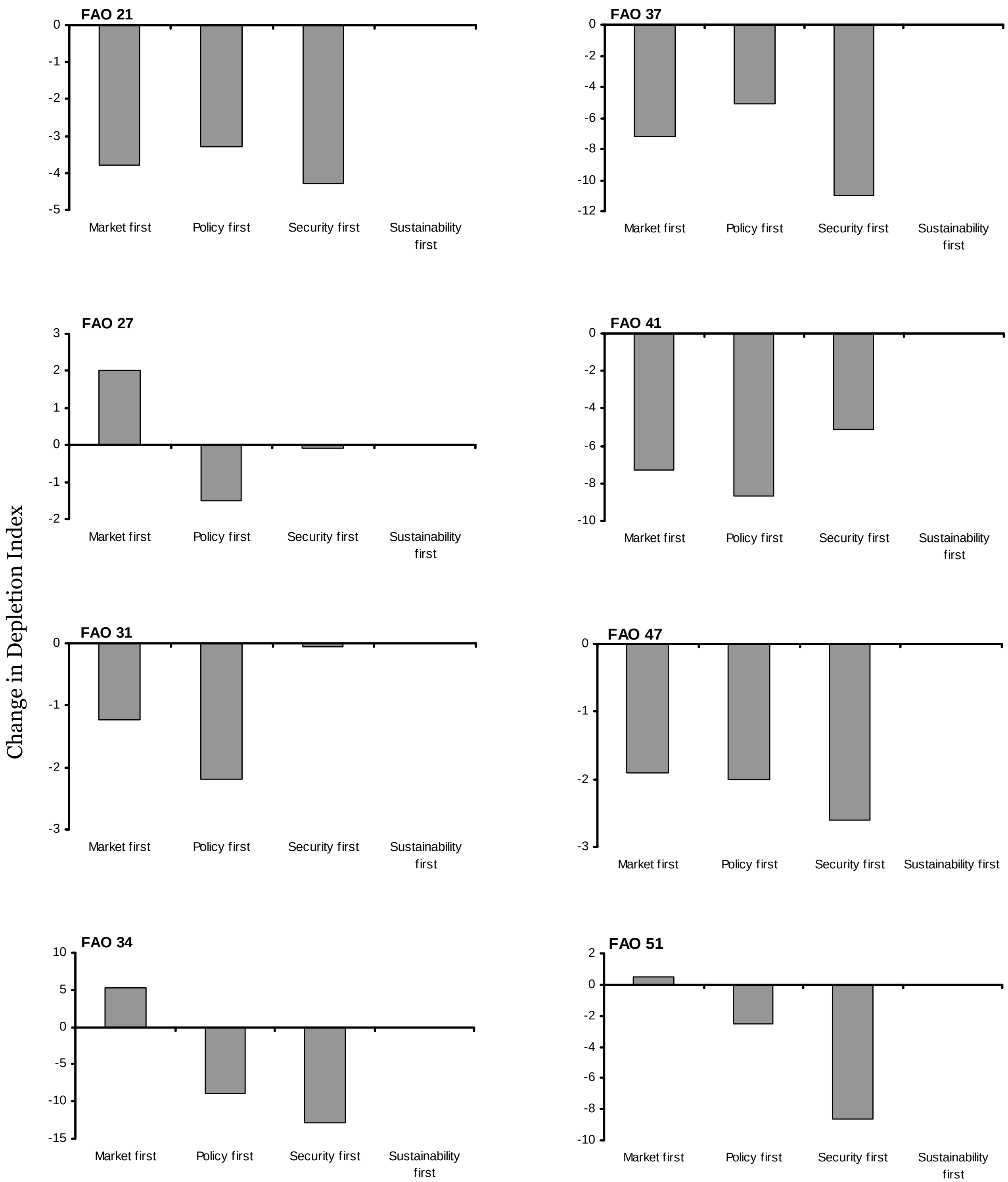

Figure 14a. Changes in the calculated depletion index (DI) from year 2007 to 2047 in FAO areas 21 to 51 and under different scenarios (*market first*, *policy first*, *security first* and *sustainability first*). Positive changes in DI indicate reduction in depletion risk while, negative changes indicate increase in depletion risk.

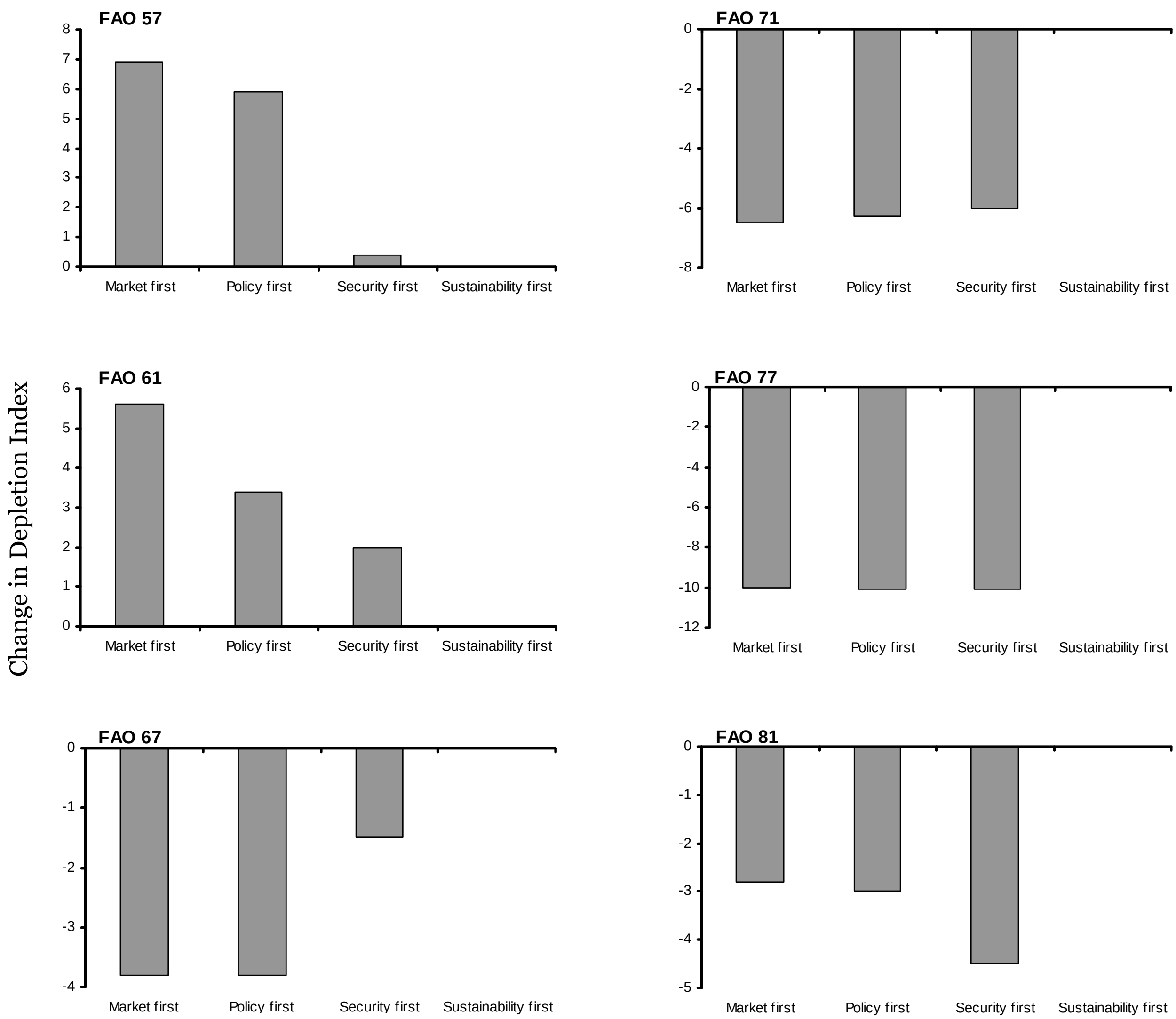

Figure 14b. Changes in the calculated depletion index (DI) from year 2007 to 2047 in FAO areas 57 to 81 and under different scenarios (*market first*, *policy first*, *security first* and *sustainability first*). Positive changes in DI indicate reduction in depletion risk while negative changes indicate increase in depletion risk.

DISCUSSION

The use of EcoOcean to assess the future of fisheries under the GEO4 and IAAST scenarios has demonstrated that it is a viable policy tool. On the global scale, the modelled landings fit to the reported FAO landing data was generally within 10% over the 50 years of available data and therefore on large aggregated scales, EcoOcean provides plausible results under different future policy options. The modelling of different policy scenarios such as allowing or not allowing subsidies resulted in discernable responses, and these responses were in the directions that were expected. For example, allowing subsidies in one scenario resulted in higher profits compared to another scenario which did not allow subsidies. The development of EcoOcean also provided a platform to analyze the future changes in marine biodiversity using the biodiversity depletion index (DI) The depletion index provides a metric which can be used in combination with GLOBIO, a terrestrial model for biodiversity assessment, to provide an overall global assessment of future biodiversity change.

The depletion index outputs for the GEO4 scenarios using EcoOcean provided a platform for exploring how the risk of depleting species and species groups will change under these scenarios in the different FAO areas. Overall, the modelled output performed as expected with the *sustainability first* scenario providing the lowest relative rate of change in the DI, and under some scenarios and areas the risk decreased. Over the 14 areas studied the average rank of the DI relative to the other scenarios was 1.9, while the other scenarios relative rankings were 2.3 (*market first*) and 2.9 (*policy first* and *security first*). It was anticipated that the other three scenarios would perform differently in different areas, since the fisheries and associated effort vary considerably between FAO areas. These different DI values and their relative rankings provide informative insights for decision makers on which policy approaches to take to reduce the risk of depleting marine species in their EEZs.

Modelling the four GEO4 scenarios using EcoOcean provided interesting and contrasting outcomes with major differences between scenarios and geographic regions evident. Overall, the modelling suggested that landings can be increased in most FAO regions under most scenarios; however, this increase in landings would not involve the suite of species that are currently commercially landed or preferred by consumers. The increase is only possible by fishing species not currently exploited at commercial levels such as small to medium bentho-demersal fish. In fact, in some areas, preferred species such as demersals and large pelagics decline over time in all scenarios. However, in all cases increasing landings and therefore profits is a trade-off with diversity. In almost all scenarios and areas, where landings increased, the mean trophic level decreased substantially as seen in the Mediterranean, or to a lesser extent in the Caribbean.

The scenarios proposed in the IAASTD initiative successfully used EcoOcean to explore the changes in knowledge and technology. Again the outcomes differed with regions and scenarios. Those scenarios where policies indicated increased effort, landings increased, but as in the GEO4 scenarios, there was a decline in the marine trophic index. The structure of EcoOcean allows for examination of the different groups of marine organisms modelled, and in the IAASTD scenarios, landings for demersal fish changed in different ways under the different scenarios, demonstrating the further potential for the use of EcoOcean as a policy tool.

Although EcoOcean has proven to be a useful policy tool for exploring fisheries and marine policies, there is scope for improving the accuracy and reducing the level of uncertainty associated with the model, as discussed below. In general the models were able to predict catches for species submitted to high levels of fishing mortality and when environmental indices do not play as an important role as with the small pelagics. For example in area 21, the northwest Atlantic, the catch of large benthopelagics (e.g. cod) fitted well to the time series.

The large geographic boundaries for some of the FAO marine statistical areas made it difficult to account for the entire fishing history of areas such as 67 (northeast Pacific) and 27 (northeast Atlantic). Area 27 encompass the Barents Sea, a high latitude/polar ecosystem, and the North Sea, which makes it difficult to follow small and medium pelagics in one unit as they were submitted to different climate regimes during the same time (Figure E3). The northeast Pacific (area 67) suffers from the same problem as area 27. This region covers a large geographic area that is subjected to different climate regimes governed by the California current and the Alaskan gyre which can not be modelled over such a large area. In addition, the fisheries development and management was not necessarily similar in all parts of area 67. As a consequence of different climate regimes, salmon stocks do not have the same biomass trends in the southern part as in Alaska; southern and northern rockfish stocks (*Sebastes sp.*, medium demersals) show opposite trends in biomass (Figure D22); pollock (*Theragra chalcogramma*, large benthopelagics) stock from the Bering Sea show a different trend than that of the Gulf of Alaska (Figure E22). As a result, it was difficult to obtain a synthetic biomass index for a group or groups that varied so greatly through a long time-span. The next version of EcoOcean, structured with much smaller areas (half-degree cells) should be able to address these problems.

The structure of the demersal fleet capturing invertebrates as well as groundfish groups presented some difficulties in tracking change in fishing targets. This was apparent in FAO area 21, as cod and other large-bodied groundfish declined, the demersal fleet turned to invertebrates, notably shrimps and crabs (groups 26 and 27). Unfortunately, the fleet structure included in the model cannot track these changes and as a result, the model could not predict the observed increase in shrimp/crab landings.

The non-consideration of artisanal effort and catch for countries such as Indonesia and the Philippines and for many countries in Africa, due to lack of time, is probably a major source of discrepancy. The disparate nature of artisanal information could be one of the main factors for low fishing mortalities seen for several commercial groups, which is unlikely for many of these regions (Chuenpagdee *et al.*, 2006). In addition to artisanal effort, there were cases where commercial effort was not available; for example for Australia, at the time of reporting the GRT and vessel information available was solely for trawlers.

Data and grouping of tuna does not differentiate between long-lived slow-growing species such as bluefin tuna (e.g. northern bluefin, *Thunnus thynnus*, K= 0.05-0.06) with short-lived species such as the skipjack tuna (*Katsuwonus pelamis*, K= 0.3-0.5). The next version of EcoOcean should be able to differentiate between these species. In the current model, production is too high, which mimics the short-lived species conferring high resilience to tuna in general.

For the Polar Regions (FAO areas 18, 48, 58 and 88), the Antarctic and Arctic models are at the development stage, as the catch history is incomplete for these areas, and biomass time series and effort data are lacking. However, work is underway to remedy this situation (Booth and Watts, 2007; Pauly and Swartz, 2007) at least in terms of catch reconstructions.

As discussed above, many of the gaps and limitations of EcoOcean can be addressed in the short-term. A spatial resolution based on 0.5 degree cells instead of the current FAO area resolution will improve the predicted results since this will allow inclusion of oceanographic conditions which small pelagics are sensitive to, and therefore better estimates can be obtained. However, improvements in the model can not be maximized without improving the quality of the data for landings, effort and biomass that is used in the model. Efforts are underway within the *Sea Around Us* Project to improve these data, which will be incorporated in EcoOcean as they become available and as data from sources other than FAO are released.

ACKNOWLEDGEMENTS

We would like to thank the Netherlands Environmental Assessment Agency (Project S/550028/01/MB) and the United Nations Environment Program for their generous financial support in developing EcoOcean, and the Pew Charitable Trusts of Philadelphia for their financial support, via the *Sea Around Us* Project, to J. Alder and V. Christensen. We would also like to thank colleagues at the Fisheries Centre for their invaluable assistance in collecting the necessary data and inputs for the development of the model, in particular D. Pauly, R. Ahrens, S. Booth, B. Campbell, L. Christensen, C. Close, P. Ganapathiraju, A. Gelchu, V. Karpouzi, H. Keith, V. Lam, M. Richards, D. Tesfamichael and R. Watson.

REFERENCES

Ainsworth, C.H. and Pitcher, T. (2006) Modifying Kempton's species diversity index for use with ecosystem simulation models. Ecological Indicators 6: 623-630.

Anonymous (1960) Fisheries statistics of British Columbia 1959. Canadian Department of Fisheries, Bureau of Statistics, Ottawa.

Anonymous (1961) Fisheries statistics of British Columbia 1960. Canadian Department of Fisheries, Bureau of Statistics, Ottawa.

Anonymous (1962) Fisheries statistics of British Columbia 1961. Canadian Department of Fisheries, Bureau of Statistics, Ottawa.

Anonymous (1963) Fisheries statistics of British Columbia 1962. Canadian Department of Fisheries, Bureau of Statistics, Ottawa.

Anonymous (1965) Fisheries statistics of British Columbia 1964. Canadian Department of Fisheries, Bureau of Statistics, Ottawa.

Anonymous (1966) Fisheries statistics of British Columbia 1965. Canadian Department of Fisheries, Bureau of Statistics, Ottawa.

Anonymous (1967) Fisheries statistics of British Columbia 1966. Canadian Department of Fisheries, Bureau of Statistics, Ottawa.

Anonymous (1968) Fisheries statistics of British Columbia 1967. Canadian Department of Fisheries, Bureau of Statistics, Ottawa.

Anonymous (1969) Fisheries statistics of British Columbia 1968. Economics Branch, Pacific Region, Department of Fisheries of Canada, Vancouver.

Anonymous (1970) Fisheries statistics of British Columbia 1969. Economics Branch, Pacific Region, Department of Fisheries of Canada, Vancouver.

Anonymous (1971) Fisheries statistics of British Columbia 1970. Economics Branch, Pacific Region, Department of Fisheries of Canada, Vancouver.

Anonymous (1972) Fisheries statistics of British Columbia 1971. Economics Branch, Pacific Region, Department of Fisheries of Canada, Vancouver.

Anonymous (1973) Annual review of Canadian fisheries, 1957-72. Volume 5, Environment Canada - Fisheries and Marine Service Intelligence Services Division, Ottawa.

Anonymous (1973) Fisheries statistics of British Columbia 1972. Economics Branch, Pacific Region, Department of Fisheries of Canada, Vancouver.

Anonymous (1974) Fisheries statistics of British Columbia 1973. Economics Branch, Pacific Region, Department of Fisheries of Canada, Vancouver.

Anonymous (1975) Fisheries statistics of British Columbia 1974. Economics Branch, Pacific Region, Department of Fisheries of Canada, Vancouver.

Anonymous (1976) Fisheries statistics of British Columbia 1975. Economics Branch, Pacific Region, Department of Fisheries of Canada, Vancouver.

Anonymous (1978) Annual statistical review of Canadian fisheries 1977. Volume 10, Environment Canada - Fisheries and Marine Service Intelligence Services Division, Ottawa.

Anonymous (1979) Annual statistical review of Canadian fisheries 1978. Volume 11, Economy Policy Branch, Economic Development directorate, Fisheries and Oceans Canada, Ottawa.

Anonymous (1980) Annual statistical review of Canadian fisheries 1979. Volume 12, Economy Policy Branch, Economic Development directorate, Fisheries and Oceans Canada, Ottawa.

Anonymous (1982) Annual statistical review of Canadian fisheries 1981. Volume 14, Economy Policy Branch, Economic Development directorate, Fisheries and Oceans Canada, Ottawa.

Anonymous (1983) Annual statistical review of Canadian fisheries 1982. Volume 15, Economy Policy Branch, Economic Development directorate, Fisheries and Oceans Canada, Ottawa.

Anonymous (1984) Annual statistical review of Canadian fisheries 1983. Volume 16, Economy Policy Branch, Economic Development directorate, Fisheries and Oceans Canada, Ottawa.

Anonymous (1986) Annual statistical review of Canadian fisheries 1985. Volume 18, Economy Policy Branch, Economic Development directorate, Fisheries and Oceans Canada, Ottawa.

Anonymous (1987) Annual statistical review of Canadian fisheries 1984. Volume 17, Economy Policy Branch, Economic Development directorate, Fisheries and Oceans Canada, Ottawa.

Anonymous (1987) Annual statistical review of Canadian fisheries 1986. Volume 19, Economy Policy Branch, Economic Development directorate, Fisheries and Oceans Canada, Ottawa.

Anonymous (1987) Annual statistical review of Canadian fisheries 1987. Volume 20, Economy Policy Branch, Economic Development directorate, Fisheries and Oceans Canada, Ottawa.

Anonymous (2003) Capelin in the Iceland-East Greenland-Jan Mayen area (Subareas V and XIV and Division IIa west of 5°W). ICES - Advisory Committee on Fishery Management (ACFM), Copenhagen.

Anonymous (2003) Herring in Divisions VIa (South) and VIIb,c. ICES - Advisory Committee on Fishery Management (ACFM), Copenhagen.

Anonymous (2007) UN Millennium Development Goals. United Nations. www.un.org/millenniumgoals/index.html.

Baddyr, M. and Guénette, S. (2001) The fisheries off the Atlantic coast of Morocco 1950-1997. p. 191-205 *In:* Zeller, D., Watson, R. and Pauly, D., (eds.), Fisheries impacts on North Atlantic ecosystems: Catch, effort and national/regional data sets. Fisheries Centre, University of British Columbia, Vancouver, BC, Canada.

Block, B.A., Teo, S.L.H., Walli, A., Boustany, A., Stokesbury, M.J.W., Farwell, C.J., Weng, K.C., Dewar, H. and Williams, T.D. (2005) Electronic tagging and population structure of Atlantic bluefin tuna. Nature 434: 1121-1127.

Boonchuwongse, P. and Dechboon, W. (2003) Socioeconomic assessment of marine fisheries of Thailand. p. 577-628 *In:* Silvestre, G., Garces, L., Stobutzki, I., Ahmed, M., Valmonte-Santos, R.A., Luna, C., Lachica-Aliño, L., Munro, P., Christensen, V. and Pauly, D., (eds.), Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries. WorldFish Center, Penang, Malaysia.

Booth, S. and Watts, P. (2007) Canada's arctic marine fish catches. p. 3-16 In: Zeller, D. and Pauly, D., (eds.), Reconstruction of marine fisheries catches for key countries and regions (1950-2005). Fisheries Centre Research Reports 15(2), Fisheries Centre, University of British Columbia, Canada, Vancouver.

Butcher, J.G. (2004) The Closing of the Frontier: A History of the Marine Fisheries of Southeast Asia c. 1850-2000. Institute of Southeast Asian Studies, Singapore, 443 p.

Carlsson, J., McDowell, J.R., Carlsson, J.E.L. and Graves, J.E. (2007) Genetic identity of YOY bluefin tuna from the Eastern and Western Atlantic spawning areas. Journal of Heredity 98: 23-28.

Carpenter, S.R. and Pingali, P.L. (2005) Ecosystems and human well-being: Scenarios. Findings of the Scenarios Working Group, Volume 2, Millennium Ecosystem Assessment. Island Press, Washington, DC, 560 p.

Cheung, W.W.L. (2007) Vulnerability of Marine Fishes to Fishing: from Global Overview to the Northern South China Sea. Ph.D. The University of British Columbia, Vancouver.

Cheung, W.W.L. and Pitcher, T.J. (in press) Evaluating the status of exploited taxa in the northern South China Sea using intrinsic vulnerability and spatially explicit catch-per-unit-effort data. Fisheries Research.

Cheung, W.W.L., Pitcher, T.J. and Pauly, D. (2005) A fuzzy logic expert system to estimate intrinsic extinction vulnerability of marine fishes to fishing. Biological Conservation 124: 97-111.

Cheung, W.W.L. and Sumaila, R. (in press) Trade-offs between conservation and socio-economic objectives in managing a tropical marine ecosystem. Ecological Economics.

Cheung, W.W.L., Watson, R., Morato, T., Pitcher, T.J. and Pauly, D. (2007) Intrinsic vulnerability in the global fish catch. Marine Ecology Progress Series 333: 1-12.

Christensen, L.B. (2006) Marine mammal populations: reconstructing historical abundances at the global scale. Fisheries Centre Research Reports 14(9), The Fisheries Centre, UBC, Vancouver, BC, Canada, 161 p.

Christensen, V. and Walters, C.J. (2004a) Ecopath with Ecosim: methods, capabilities and limitations. Ecological Modelling 172: 109-139.

Christensen, V. and Walters, C.J. (2004b) Trade-offs in ecosystem-scale optimization of fisheries management policies. Bulletin of Marine Science 74: 549-562.

Christensen, V. and Walters, C.J. (2005) Using ecosystem modelling for fisheries management: Where are we? ICES CM 2005/M:19.

Christensen, V., Walters, C.J. and Pauly, D. (2005) Ecopath with Ecosim: a user's guide. Fisheries, Centre, University of British Columbia, Vancouver, BC, Canada. www.ecopath.org/index.php?name=Publications&sub=ViewPublications&value=ManualsPub, 154 p.

Chuenpagdee, R., Liguori, L., Palomares, M.-L. and Pauly, D. (2006) Bottom-Up, global estimates of small-scale marine fisheries catches. Fisheries Centre Research Reports 14(8), Fisheries Centre, UBC, Vancouver, BC, Canada, 105 p.

Costanza, R. (2000) Visions of alternative (unpredictable) futures and their use in policy analysis. Conservation Ecology 4 (1): 5.

Csirke, J. (2005) Global production and state of marine fishery resources. FAO Fisheries Technical Papers 457, FAO, Rome, 242 p.

Cury, P. and Cayré, P. (2001) Hunting became a secondary activity 2000 years ago: marine fishing did the same in 2021. Fish and Fisheries 2: 162-169.

DFO (2003) Licensing Information - Pacific Region. Department of Fisheries and Oceans Canada. [www.pac.dfo-mpo.gc.ca/ops/fm/Licensing/Default_e.htm].

Dorn, M., Barbeaux, S., Guttormsen, M., Megrey, B., Hollowed, A., Wilkins, M. and Spalinger, K. (2003) Assessment of walleye pollock in the Gulf of Alaska. NPFMC Bering Sea/Aleutian Island SAFE, North Pacific Fishery Management Council, Anchorage, AK, 33-148 p.

FAO (1980) Report of the consultation on stock assessment for small-scale fisheries in the Bay of Bengal - Chittagong, Bangladesh 16-21 June, 1980 - Volume 1 - proceedings. BOBP/REP/10.1, FAO, Madras, India.

FAO (1982) Marine small-scale fisheries of India: A general description. BOBP/INF/3, FAO, Madras, India.

FAO (1983) Marine small-scale fisheries of Tamil Nadu: A general description. BOBP/INF/5, FAO, Madras, India.

FAO (1988) Fisheries statistics in the Bay of Bengal. BOBP/WP/59, FAO 34 p.

FAO (2006) FAO Fishery Information, Data and Statistics Unit (FIDI) - Fishery Statistical Collections. FIGIS Data Collection. FAO, Rome.

Fernandez, M., Rosegrant, M.W., Sinha, A., Alder, J., Ahammad, H., Fraiture, C., Eickhout, B., Fonesca, J., Huang, J., Koyama, O., Omezzine, A.M., Pingali, P.L., Ramirez, R., Ringler, C., Robinson, S., Shapiro, H., Thornton, P. and Vuuren, D.V. (in press) Looking into the future for agriculture and AKST (agriculture, knowledge, science and technology) Chapter 5 *In:* International Assessment of Agricultural Science and Technology Development. World Bank, Washington, DC.

Fletcher, R. (1987) Practical Methods of Optimization, 2 edition. Wiley-Interscience, Chichester, N.Y., 450 p.

Froese, R. and Pauly, D. (2007) Fishbase. World Wide Web electronic publication www.Fishbase.org.

Ganapathiraju, P. (2007) Global database of distant water fishing vessels above 500 GRT for the period 1950-2005 (Work in progress). Fisheries Centre, University of British Columbia, Vancouver, BC, Canada.

Gelchu, A. and Pauly, D. (2007) Growth and distribution of port-based global fishing effort within countries' EEZs from 1970 to 1995. Fisheries Centre Research Reports 15(4), The Fisheries Centre, University of British Columbia, Vancouver, BC, Canada, 99 p.

Gelchu, A.A. (2006) Growth and distribution of port-based global fishing effort within countries EEZs. Doctor of Philosophy Dissertation, University of British Columbia, Vancouver 157 p.

Guénette, S. (2000) Marine reserves for the northern cod. Doctor of Philosophy Dissertation, University of British Columbia, Vancouver, BC, Canada 111 p.

Guénette, S. (2005) Model of the Southeast Alaska. p. 106-178 *In:* Guénette, S. and Christensen, V., (eds.), Foodweb models and data for studying fisheries and environmental impact on Eastern Pacific ecosystems. Fisheries Centre, University of British Columbia, Vancouver, BC, Canada.

Guénette, S., Christensen, V. and Pauly, D. (in press) Trophic modeling of the Peruvian upwelling ecosystem: towards reconciliation of multiple datasets. Progress in Oceanography.

Gulland, J.A. (1970) The fish resources of the ocean. FAO Fisheries Technical Paper 97, FAO 425 p.

Ianelli, J.N., Barbeaux, S., Honkalehto, T., Walters, G. and Williamson, N. (2003) Eastern Bering Sea Walleye Pollock Stock Assessment. NPFMC Bering Sea/Aleutian Islands SAFE, North Pacific Fishery Management Council, Anchorage, AK, 88 p.

Khan, H. and Weiner, A. (1967) The Year 2000. MacMillan, New York p.

Kitchell, J.F., Boggs, C.H., He, X. and Walters, C.J. (1999) Keystone predators in the Central Pacific. p. 665-682 *In:* Ecosystem Approaches for Fisheries Management. Alaska Sea Grant College Program.

Mas-Riera, J., Lombarte, A., Gordoa, A. and Macpherson, E. (1990) Influence of Benguela upwelling on the structure of demersal fish populations off Namibia. Marine Biology 104: 175-182.

NAFO (2006) North Atlantic Fisheries Organization database 21B. NAFO www.nafo.int/.

Odum, E.P. (1969) The strategy of ecosystem development. Science 10: 262-270.

Parrish, R.H. (1998) Life history strategies for marine fishes in the late Holocene. p. 525-535 *In:* Durand, M.H., Cury, P., Mendelssohn, R., Roy, C. and Pauly, D., (eds.), Global Versus Local Change in Upwelling Areas. Orstom, Paris.

Pauly, D. (1996) One hundred million tonnes of fish, and fisheries research. Fisheries Research 25: 25-38.

Pauly, D. (2002) Global change, fisheries and the integrity of marine ecosystems: the future has already begun. p. 227-239 *In:* Pimentel, D., Westra, L. and Ross, R.F., (eds.), Ecological integrity: integrating environment, conservation and health. Island Press, Washington, DC.

Pauly, D., Alder, J., Bakun, A., Heileman, S., Kock, K.-H., Mace, P., Perrin, W., Stergiou, K., Sumaila, R., Vierros, M., Freire, K., Sadovy, Y., Christensen, V., Kaschner, K., Palomares, M.-L., Tyedmers, P., Wabnitz, C., Watson, R. and Worm, B. (2005) Marine Fisheries Systems. p. 477-512 *In:* Hassan, R., Scholes, R. and Ash, N., (eds.), Current State and Trends: Findings of the Condition and Trends Working Group. Ecosystems and Human Well-being. Island Press, Washington, DC.

Pauly, D., Alder, J., Christensen, V., Tyedmers, P. and Watson, R. (2003) The Future for Fisheries. Science 302: 1359-1361.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. and Torres, F.J. (1998) Fishing down marine food webs. Science 279: 860 - 863.

Pauly, D. and Swartz, W. (2007) Marine fish catches in North Siberia (Russia, FAO Area 18). p. 17-33 *In:* Zeller, D. and Pauly, D., (eds.), Reconstruction of marine fisheries catches for key countries and regions (1950-2005). Fisheries Centre Research Reports 15(2), Fisheries Centre, University of British Columbia, Canada, Vancouver.

Pauly, D. and Watson, R. (2005) Background and interpretation of the 'Marine Trophic Index' as a measure of biodiversity. Philosophical Transactions of the Royal Society B 360: 415-423.

Peterson, G.D., Cumming, G.S. and Carpenter, S.R. (2003) Scenario planning: a tool for conservation in an uncertain world. Conservation Biology 17: 358-366.

Pinnegar, J.K., Viner, D., Hadley, D., Dye, S., Berkout, H.M.F. and Simpson, M. (2006) Alternative future scenarios for marine ecosystems. Technical Report, Cefas, Lowestoft, U.K., 109 p.

Pope, J. (1989) Fisheries research and management for the North Sea; the next hundred years. Dana 8: 33-43.

Radovich, J. (1982) The collapse of the California sardine fishery: what have we learned? Vol. XXIII, CalCOFI, La Jolla, California, 23 p.

Raskin, P. (2000) Regional scenarios for environmental sustainability: a literature review. UNEP, Nairobi, 18 p.

Raskin, P. (2005) Global Scenarios: Background Review for the Millennium Ecosystem Assessment. Ecosystems 8: 133-142.

Raskin, P., Monks, F., Ribeiro, T., Van Vuuren, D. and Zurek, M. (2005) Global scenarios in historical perspective. p. 35-43 *In:* Concheiro, A.A. and Field, C., (eds.), Millennium Ecosystem Assessment, Ecosystems and Human Well-Being: Scenarios. Island Press, Washington, DC.

Rogers, J.B. (2003) Darkblotched Rockfish (Sebastes crameri) 2003 Stock Status and Rebuilding Update. Pacific Fishery Management Council, Newport, Oregon, 56 p.

Rothman, D.S., Agard, J., Almaco, J., Alder, J., Al-Zubari, W.K., Aus Der Beek, T., Chenje, M., Eickhout, B., Flörke, M., Galt, M., Ghosh, N., Hemmings, A., Hernandez-Pedresa, G., Hijioka, Y., Hughes, B., Hunsberger, C., Kainuma, M., Kartha, S., Miles, L., Msangi, S., Ochola, W.O., Madruga, R.P., Pirc-Velkarvh, A., Ribeiro, T., Ringler, C., Rogan-Finnemore, M., Sall, A., Shaldach, R., Stanners, D., Sydnor, M., Ruijven, B.V., Vuuren, D.V., Verburg, P., Verzano, K. and Zöckler, C. (2007) The Future Today. GEO4: The Outlook - Towards 2015 and Beyond. UNEP, Nairobi, 395-454 p.

Sivasubramaniam, K. (1985) Marine fishery resources of the Bay of Bengal. BOBP/WP/36, FAO, Colombo, Sri Lanka.

Spencer, P.D. and Ianelli, J.N. (2003) Northern Rockfish: Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. NPFMC Bering Sea/Aleutian Island SAFE North Pacific Fishery Management Council, Anchorage, AK, 611-652 p.

Sumaila, U.R., Liu, Y. and Tyedmers, P. (2001) Small versus large-scale fishing operations in the North Atlantic. Fisheries Centre Research Reports 9(5), Fisheries Centre, University of British Columbia, Vancouver, BC, Canada, 28-35 p.

Sumaila, U.R., Marsden, A.D., Watson, R. and Pauly, D. (2007) A global ex-vessel fish price database: construction and applications. Journal of Bioeconomics 9: 36-51.

UNEP (2003) Outlook 2003-32. Chapter 4: outlook 2003-32. UNEP, Nairobi, 82 p.

Vibunpant, S., Khongchai, N., Seng-Eid, J., Eiamsa-ard, M. and Supongpan, M. (2003) Trophic Model of the Coastal Fisheries Ecosystem in the Gulf of Thailand. p. 577-628 *In:* Silvestre, G., Garces, L., Stobutzki, I., Ahmed, M., Valmonte-Santos, R.A., Luna, C., Lachica-Aliño, L., Munro, P., Christensen, V. and Pauly, D., (eds.), Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries. WorldFish Center, Penang, Malaysia.

Wack, P. (1985a) Scenarios: shooting the rapids. Harvard Business Review 63: 139-150.

Wack, P. (1985b) Scenarios: uncharted waters ahead. Harvard Business Review 63: 73-89.

Walters, C.J., Christensen, V. and Pauly, D. (1997) Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. Reviews in Fish Biology and Fisheries 7: 139-172.

Walters, C.J. and Martell, S.J.D. (2004) Fisheries Ecology and Management. Princeton University Press, 448 p.

Walters, C.W. and Kitchell, J.F. (2001) Cultivation/depensation effects on juvenile survival and recruitment: implications for the theory of fishing. Canadian Journal of Fisheries and Aquatic Sciences 58: 39-50.

Watson, R.A., Kitchingman, A., Gelchu, A. and Pauly, D. (2004) Mapping global fisheries: sharpening our focus. Fish and Fisheries 5: 168-177.

Willmann, R., Boonchuwong, P., Piumsombun, S., Shriver, A. and Johnston, R. (2001) Fisheries management costs in Thai marine fisheries. International Institute of Fisheries Economics and Trade 11 p.

Yndestad, H. (2003) The code of the long-term biomass cycles in the Barents Sea. ICES Journal of Marine Science 60: 1251-1264.

Yodzis, P. (2001) Must top predators be culled for the sake of fisheries? Trends in Ecology and Evolution 16: 78-83.

APPENDICES

Appendix A

Table A1. Effort allocation of countries by FAO area(s)

Country *	**21**	**27**	**31**	**34**	**37**	**41**	**47**	**51**	**57**	**61**	**67**	**71**	**77**	**81**	**87**	
Australia	-	-	-	-	-	-	-	-	0.56	-	-	0.28	-	0.16	-	1
Canada	0.67	-	-	-	-	-	-	-	-	-	0.33	-	-	-	-	1
France	-	0.84	-	-	0.16	-	-	-	-	-	-	-	-	-	-	1
Greenland	0.50	0.50	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Guatemala	-	-	0.2	-	-	-	-	-	-	-	-	-	0.80	-	-	1
Honduras	-	-	0.8	-	-	-	-	-	-	-	-	-	0.20	-	-	1
India	-	-	-	-	-	-	-	0.33	0.67	-	-	-	-	-	-	1
Indonesia	-	-	-	-	-	-	-	-	0.50	-	-	0.50	-	-	-	1
Malaysia	-	-	-	-	-	-	-	-	0.99	-	-	0.01	-	-	-	1
Mexico	-	-	0.5	-	-	-	-	-	-	-	-	-	0.50	-	-	1
Morocco	-	-	-	0.94	0.06	-	-	-	-	-	-	-	-	-	-	1
Nicaragua	-	-	0.5	-	-	-	-	-	-	-	-	-	0.50	-	-	1
Panama	-	-	0.5	-	-	-	-	-	-	-	-	-	0.50	-	-	1
South Africa	-	-	-	-	-	-	0.80	0.20	-	-	-	-	-	-	-	1
Spain	-	0.50	-	-	0.50	-	-	-	-	-	-	-	-	-	-	1
Thailand	-	-	-	-	-	-	-	-	0.30	-	-	0.70	-	-	-	1
USA	0.20	-	0.3	-	-	-	-	-	-	-	0.20	-	0.30	-	-	1
USSR in Europe	-	0.32	-	-	0.14	-	-	-	-	0.54	-	-	-	-	-	1
Viet Nam	-	-	-	-	-	-	-	-	-	0.60	-	0.40	-	-	-	1

* Coastal countries not listed in the above table are part of only one FAO area. See *Figure 2* for a map displaying the FAO areas.

Appendix B: Index for pelagic and demersal effort in FAO Area 67 (Northeast Pacific)

	Groundfish	Pelagic
1950	0.28	0.72
1951	0.28	0.72
1952	0.28	0.72
1953	0.28	0.72
1954	0.28	0.72
1955	0.28	0.72
1956	0.28	0.72
1957	0.28	0.72
1958	0.28	0.72
1959	**0.28**	**0.72**
1960	0.26	0.74
1961	0.23	0.77
1962	0.21	0.79
1963	0.19	0.81
1964	0.16	0.84
1965	0.14	0.86
1966	0.12	0.88
1967	0.09	0.91
1968	**0.07**	**0.93**
1969	**0.13**	**0.87**
1970	**0.06**	**0.94**
1971	**0.08**	**0.92**
1972	0.1	0.9
1973	0.12	0.88
1974	0.13	0.87
1975	**0.15**	**0.85**
1976	0.15	0.85
1977	0.15	0.85
1978	0.15	0.85
1979	0.15	0.85
1980	0.15	0.85
1981	0.15	0.85
1982	0.15	0.85
1983	0.15	0.85
1984	0.15	0.85
1985	0.15	0.85
1986	0.15	0.85
1987	0.15	0.85
1988	0.19	0.81
1989	0.23	0.77
1990	0.26	0.74
1991	0.30	0.70
1992	0.34	0.66
1993	0.38	0.62
1994	0.42	0.58
1995	0.46	0.54
1996	0.49	0.51
1997	0.53	0.47
1998	**0.57**	**0.43**
1999	**0.51**	**0.49**
2000	**0.68**	**0.32**
2001	**0.66**	**0.34**
2002	**0.67**	**0.33**
2003	**0.67**	**0.33**

Bold denotes anchor points from references cited below. All other points are interpolated and extrapolated.

The index is derived from GRT data for the years 1959, 1968-1975. These points were used to get a course average GRT/year for both the pelagic gear and the demersal gear. Data for 1998-2003 gave only total vessel number by gear. The average GRT/year was multiplied by the total vessel number/gear type to get a coarse GRT total. This allowed for an index for the years 1998-2003.

(Anonymous, 1960, 1961, 1962, 1963, 1965, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1973, 1974, 1975, 1976, 1978, 1979, 1980, 1982, 1983, 1984, 1986, 1987, 1987, 1987; DFO, 2003).

Appendix C

Table C1. Structure of the ecosystem used and initial parameters entered in each FAO model.

Group	Group name	Biomass[1]	P/B	Q/B	EE	P/Q
1	Small pelagics	-	0.9	-	0.95	0.25
2	Medium pelagics	-	0.5	-	0.95	0.25
3	Large pelagics	-	0.2	12	-	-
4	Small demersals	-	1.5	-	0.95	0.25
5	Medium demersal	-	0.6	-	0.90	0.20
6	Large demersals	-	0.3	-	0.70	0.15
7	Small bathypelagics	-	0.5	-	0.95	0.25
8	Medium bathypelagics	-	0.3	-	0.90	0.25
9	Large bathypelagics	-	0.1	-	0.70	0.25
10	Small bathydemersals	-	0.5	-	0.95	0.30
11	Medium bathydemersals	-	0.3	-	0.90	0.25
12	Large bathydemersals	-	0.1	-	0.70	0.25
13	Small benthopelagics	-	0.6	-	0.95	0.25
14	Medium benthopelagics	-	0.4	-	0.90	0.25
15	Large benthopelagics	-	0.2	-	0.70	0.25
16	Small reef-fish	-	1.0	-	0.95	0.25
17	Medium reef-fish	-	0.6	-	0.95	0.20
18	Large reef-fish	-	0.3	-	0.70	0.15
19	Small/medium sharks	-	0.5	-	0.90	0.20
20	Large sharks	-	0.2	-	0.50	0.15
21	Small/medium rays	-	0.5	-	0.90	0.20
22	Large rays	-	0.2	-	0.70	0.15
23	Small/medium flatfish	-	0.8	-	0.90	0.25
24	Large flatfish	-	0.3	-	0.70	0.15
25	Cephalopods	-	2.0	10	0.70	-
26	Shrimp	-	2.5	-	0.95	0.15
27	Lobsters, crabs	-	2.0	-	0.90	0.15
28	Jellyfish	-	10.0	-	-	0.20
29	Molluscs	-	2.0	-	0.90	0.25
30	Krill	-	5.0	-	0.90	0.15
31	Baleen whales[1]	-	0.03	11	-	-
32	Toothed whales[1]	-	0.05	25	-	-
33	Seals[1]	-	0.15	50	-	-
34	Birds	0.001	0.10	100	-	-
35	Macrobenthos	7.0762	3.0	-	-	0.25
36	Meiobenthos	12.682	10.0	-	-	0.25
37	Corals	0.1	1.0	1.5	-	-
38	Softcorals, sponges, etc	2	0.2	-	-	0.30
39	Zooplankton, other	-	30.0	-	0.90	0.25
40	Phytoplankton	9	490.25	-	-	-
41	Benthic Plants	2	10.0	-	-	-
42	Young large pelagics	-	2.0	-	-	-
43	Detritus	-	-	-	-	-

[1] Biomass values for FAO areas as an example

Appendix D: Effort reconstruction for FAO Area 57

Australia

The FAO fleet database website which has data online for the period 1970-1998, is limited in Australian data to trawler vessels that are greater than 150 GRT. Prior to 1970, the information available in the FAO printed reports (1950-1970) contained vessel delineation as 'general fisheries,' 'oyster fisheries,' or 'pearl/trochus fisheries'. Overall the effort reconstruction for Australia is incomplete, and further detailed fleet information is required.

Bangladesh

As with India and Myanmar, the Bangladesh fishery is primarily artisanal, with 2.5% of the marine fleet motorized for the years 1974/75 (FAO, 1980). The fleet consists of small non-motorized vessels that land their catch within 48 km from shore (FAO, 1988). The dominant gear types are bagnets and gillnets. Information provided at the FAO fleet database website shows that the commercial fisheries fleet in Bangladesh is comprised of trawlers and multipurpose vessels.

India

In generating effort data to account for catch series, it was a challenge for a country such as India, where predominately in the eastern states, and up until the 1980's, the bulk of the catch came from artisanal fisheries. Up until 1980, non-motorized traditional crafts landed up to 70 percent of the overall marine catch in the Bay of Bengal (FAO, 1983). A large artisanal fleet is also prevalent in Bangladesh, Myanmar and Indonesia.

Prior to 1970, the extent to which India's vessel classifications were published in FAO was limited to 'powered craft'; 'publicly' or 'privately owned'. By utilizing data from the Bay of Bengal Programme, and focusing on the eastern states of Tamil Nadu, Andhra Pradesh, West Bengal and Orissa, vessel classification in terms of mechanized or non-mechanized as well as motorized was further delineated. Mechanized is defined in this case as having purse seine or trawling gear. This enabled for back extrapolation of vessel type and subsequently, GRT or vessel number, from the FAO dataset (1970-1995), where vessel numbers (in particular) were limited.

To allocate the total effort for India into FAO area 57 and 51 anchors points were required. What percentage of the overall effort for India was for area 57? Utilizing a reference from 1980, which focused on the state distribution of mechanized boats for all of India, a percentage of 33% was calculated for the Eastern Indian states. One-third of the overall GRT or total vessel number was apportioned to FAO area 57 (FAO, 1982) based on this anchor point (see Table D1).

Indonesia

Prior to 1970, the information available for the Indonesian fishing fleet in the FAO printed reports was limited to 'motorboat,' 'non-motorized,' and 'sailboats'. Caution should be used in interpreting the overall GRT index for Indonesia, as it does not take into account the artisanal fleet, though Butcher (2004) notes that small artisanal vessels land the majority of the catch.

Malaysia

Although Singapore separated from Malaysia to become an independent republic in 1965, there are no Singapore vessel numbers interspersed with the Malaysian fleet data. In the printed FAO reports prior to 1970, Malaysia is annotated as Federation of Malaya for the period 1950-1957 and annotated West Malaysia for the period 1958-1969. On the FAO website for data from 1970-1995, the country is listed in its current truncated form, Malaysia. The data transition in terms of fleet numbers from 'Federation of Malaysia' to 'West Malaysia' suggest that prior to 1958, a large proportion of the fishing was occurring in the west, and a 1983 census provides support to this, with 72% of the landings stemming from West Peninsular Malaysia (Sivasubramaniam, 1985). All effort gathered in terms of vessel numbers and GRT was assigned to West Peninsular Malaysia and therefore contributed to the overall fishing effort for FAO area 57 and not FAO area 71 (East Peninsular Malaysia).

Myanmar (formerly the Socialist Republic of the Union of Burma)

At the time of the effort compilation, there was no detailed fleet time series for Myanmar. A point estimate for motorized and non-motorized vessels is available for 1982, with 95% of the fleet being non-motorized, implying to a large artisanal fishery (Sivasubramaniam, 1985).

Sri Lanka

Prior to 2001 Sri Lanka was part of FAO area 51. The area change to FAO 57 was approved as of 2001 (ftp://ftp.fao.org/fi/maps/fig_h3_51_2.gif). Effort and catch were allocated to area 57. Effort in GRT was not available prior to 1970, but total vessel number did provide a reasonable trend of the effort change temporally.

Thailand

Prior to 1970, the fleet information available in the FAO printed books for the commercial fisheries was for 'powered crafts'.

Prior to the 1977 proclamation of an Exclusive Economic Zone (EEZ) by the countries whose waters were exploited by Thai vessels, the Thai fishing fleet operated on four major fishing grounds: the Gulf of Thailand, the Andaman Sea, the South China Sea and the Bay of Bengal (Boonchuwongse and Dechboon, 2003).

In 1996 70% of total marine landings came from the Gulf of Thailand (FAO area 71) (Vibunpant *et al.*, 2003) and in 1999, about 80% of Thailand's total marine fisheries management expenditures was for the Gulf Thailand and the rest for the Andaman Sea (FAO area 57) (Willmann *et al.*, 2001). Thus, a 30% allocation of the total effort for Thailand was used for FAO area 57.

Table D1. State-wide distribution of mechanized boats in India (1980) (FAO, 1982)*

	Trawlers	Gill netters	Purse seiners	Dol-netters	Others	Total
East coast						
West Bengal	-	740	-	-	-	740
Orissa	350	116	-	-	-	466
Andhra Pradesh	580	-	-	-	-	580
Tamil Nadu	2614	143	-	-	-	2757
Pondicherry	160	3	-	-	-	163
Andaman Islands	-	-	-	-	-	10
					subtotal	4716
West coast						
Kerala	2630	362	37	-	9	3038
Karnataka	1553	28	325	-	98	2004
Goa	494	274	66	-	74	908
Gujarat	1209	1547	-	650	7	3413
Lakshadweep	-	-	-	-	-	10
Maharashtra	-	-	-	-	-	152
					subtotal	9525
					India total	14241

*From the above data for 1980, 4716/14241 = ~1/3 of the mechanized boats were on the east coast of India

Appendix E: GEO4 Results by FAO area

FAO 18, Arctic

Although there are recent catch reconstructions for the Canadian (Booth and Watts, 2007) and Siberian Arctic (Pauly and Swartz, 2007), a stats and effort reconstruction for the entire FAO area has not yet been completed, making development of a model for this area impractical.

FAO 21, Northwest Atlantic

Model results

The area 21 model was successful at predicting several of the catch time series, especially commercially important groups such as the medium and large demersals (C5 and C6), and large benthopelagics (cod and related fish) (Figure E1). The decline in large benthopelagics, demersal fish, and shark biomasses was well predicted. The fact that the demersal fleet captures all invertebrates as well as groundfish groups resulted in a problem in tracking change in fishing target in this region. Indeed, as cod and other large-bodied groundfish declined, the demersal fleet turned to invertebrates, notably shrimps and crabs (groups 26 and 27). Unfortunately, the fleet structure included in the model cannot track these changes and as a result, the model could not predict the observed increase in shrimp/crab landings.

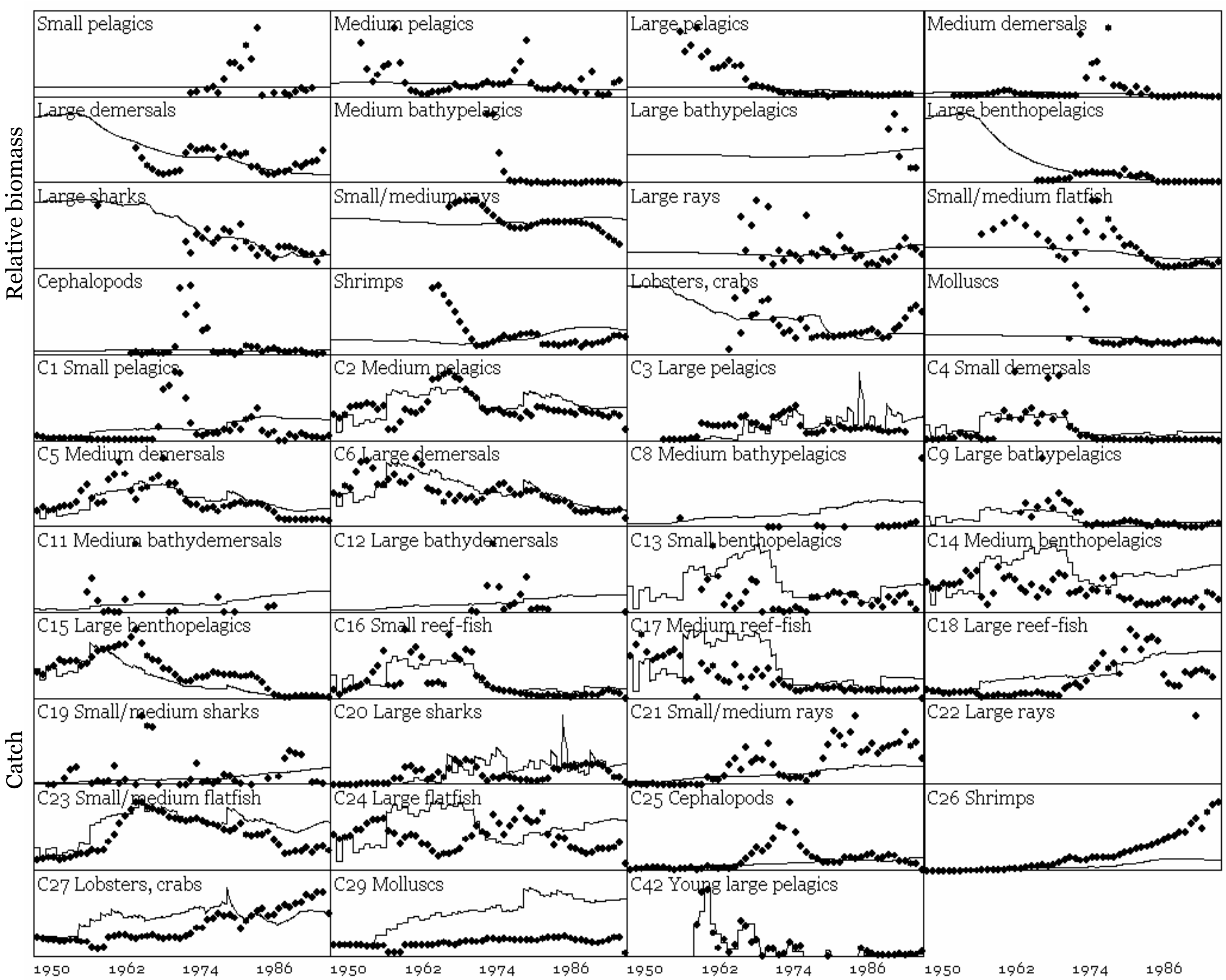

Figure E1. Area 21 -Observed (dots) and predicted (lines) results of fitting Ecosim to relative biomass time series and catch (graph titles starting with 'C' followed by the group number and name) from 1950-2003.

Optimization results

Most scenarios propose a sharp decrease in demersal effort starting in 2004 for 15 years, at which point effort increased slightly in all scenarios except the *sustainability first* in which effort was further decreased (Figure E2). As a result, this scenario resulted in an overall increase in landings of large demersal groups' in particular for large benthopelagics, with the biomass of this group showing a significant increase in the last 15 years of the simulation (Figure E2 and Table E1). Overall, with the exception of the *sustainability first* scenario, an increase in demersal effort translated into an increase in landings of invertebrate groups and smaller increase to large demersal groups over the first ten years of the simulation and maintenance of this level through the last 30 years. For the *business as usual* scenario, the maintenance of the 2003 effort for the demersal effort, resulted in a small decrease in landings over the simulation period of the large demersal groups. The decrease in effort had the largest effect on the landings of the small and medium demersal groups, which decreased for all scenarios. The effort of the small pelagic fleet was also decreased for all scenarios except again for the sustainability scenario in which effort was kept slightly lower than that of 2003 (Figure E2). This also caused the biomass of small and medium pelagics to increase. The MTI increased under the *sustainability first* scenario, decreased under the *business as usual* scenario, and decreased slightly for the other three scenarios. By decreasing demersal effort, the ecosystem appears to improve, with the *Q* value increasing for all scenarios in relation to 2003.

Table E1. Species composition (main species only) of those functional fish groups in area 21 that showed an increase in landings in the last 30 years of the *sustainability first* and *business as usual* scenarios.

Group description*	Genus/species	Common name
6. Large demersals	*Morone saxatilis*	Striped bass
	Pollachius virens	Saithe
	Melanogrammus aeglefinus	Haddock
	Anarhichas lupus	Wolf-fish
	Anarhichas minor	Spotted wolffish
	Urophycis tenuis	White hake
8. Medium bathypelagics	*Coryphaenoides rupestris*	Roundnose grenadier
	Sebastes mentella	Deepwater redfish
	Antimora rostrata	Blue antimora
9. Large bathypelagics	*Lampris guttatus*	Opah
	Lepidocybium flavobrunneum	Escolar
15. Large benthopelagics	*Sebastes marinus*	Ocean perch
	Salmo salar	Atlantic salmon
	Gadus morhua	Atlantic cod
	Macrourus berglax	Onion-eye grenadier

* Note: In addition to the fish groups, two invertebrate groups also increased, i.e., shrimp and lobsters, crabs

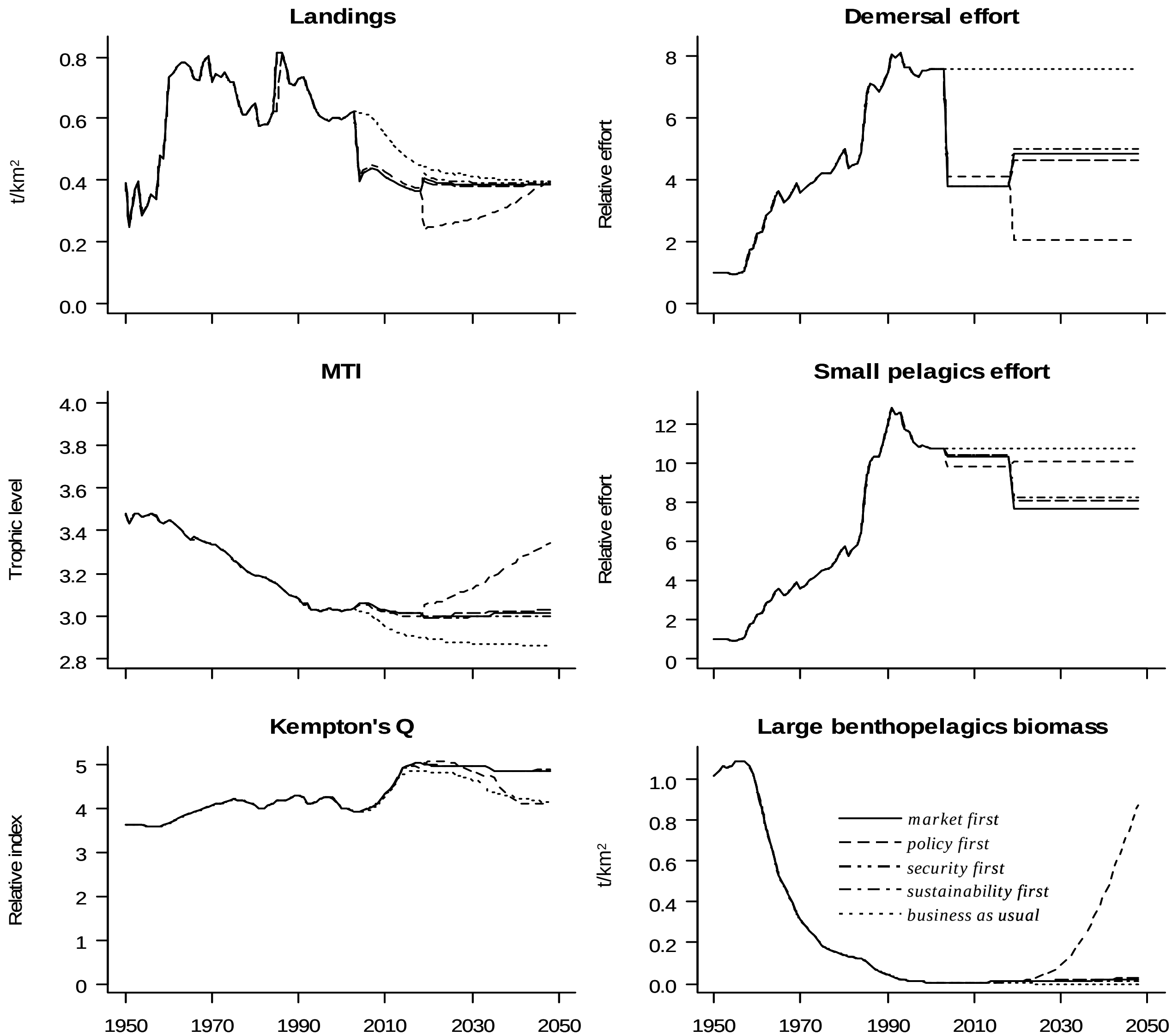

Figure E2. Results of Ecosim policy scenarios for area 21, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 27, Northeast Atlantic

In area 27, we were able to fit several catch series, with the notable exception of the small pelagics (Figure E4). The model was unable to predict the observed large variations in biomass for the small and medium pelagics for two reasons: 1. It did not include a climate index, although climatic factors are likely influencing their production; 2. Given the different climatic regimes prevailing in the North Sea and the Barents Sea and their different ecosystem structure, their biomass time series for pelagics show different trends (Figure E3). Thus, it would be beneficial to consider smaller regions within the area 27 and to include proper climate indices drivers for each of them to obtain a better fit to pelagics catches and biomass trends. Biomass declines were well predicted for large benthopelagics, (e.g., cod, *Gadus morhua*), large sharks (*Squalus acanthias*), and large flatfish (*Pleuronectes platessa*), all of which were heavily fished during the study period.

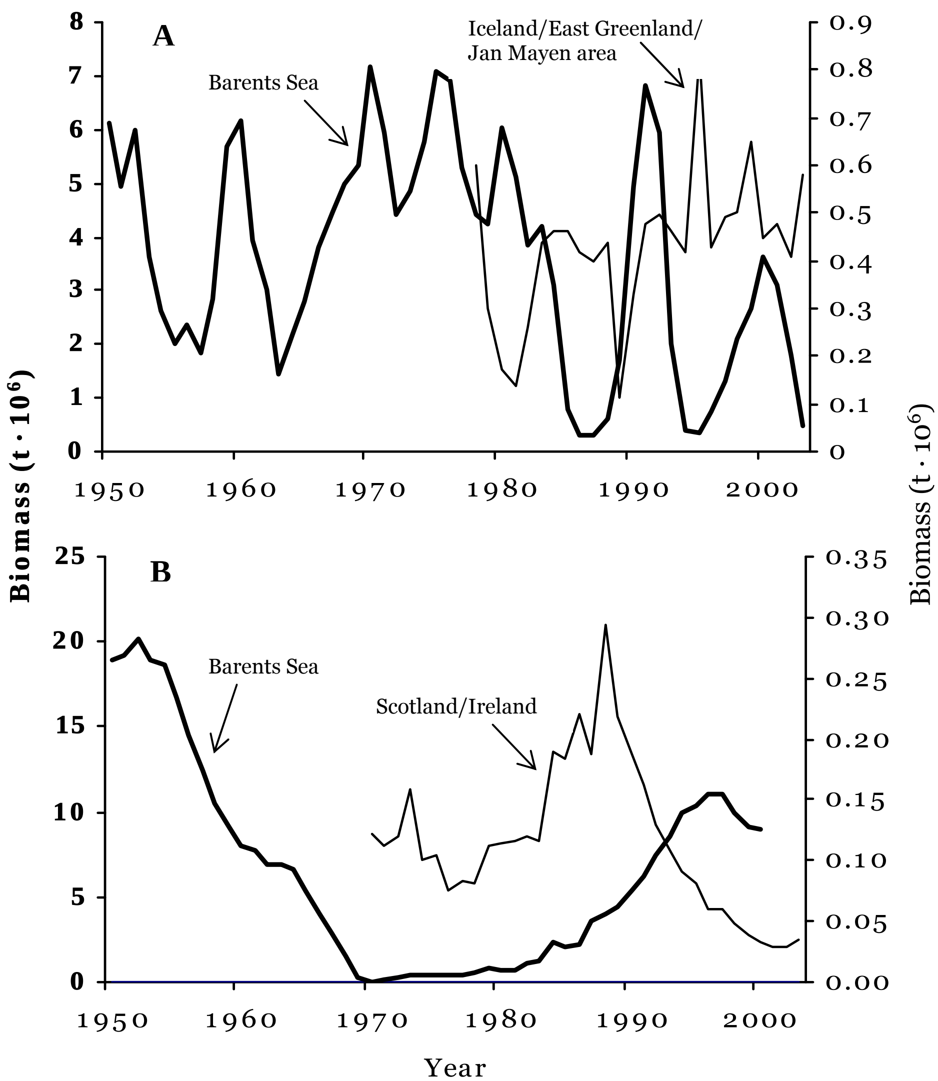

Figure E3. FAO 27 - Contrasting biomass trends for **A**, small pelagics and **B**, medium pelagics. Graph **A** displays stock trends for *Mallotus villosus* in the Barents Sea (bold line) and for Iceland/East Greenland/Jan Mayen area (thin line)(Anonymous, 2003; Yndestad, 2003). Graph **B** displays stock trends for *Clupea harengus* in the Barents Sea (bold line) and on the west coast of Scotland and Ireland (thin line) (Anonymous, 2003; Yndestad, 2003).

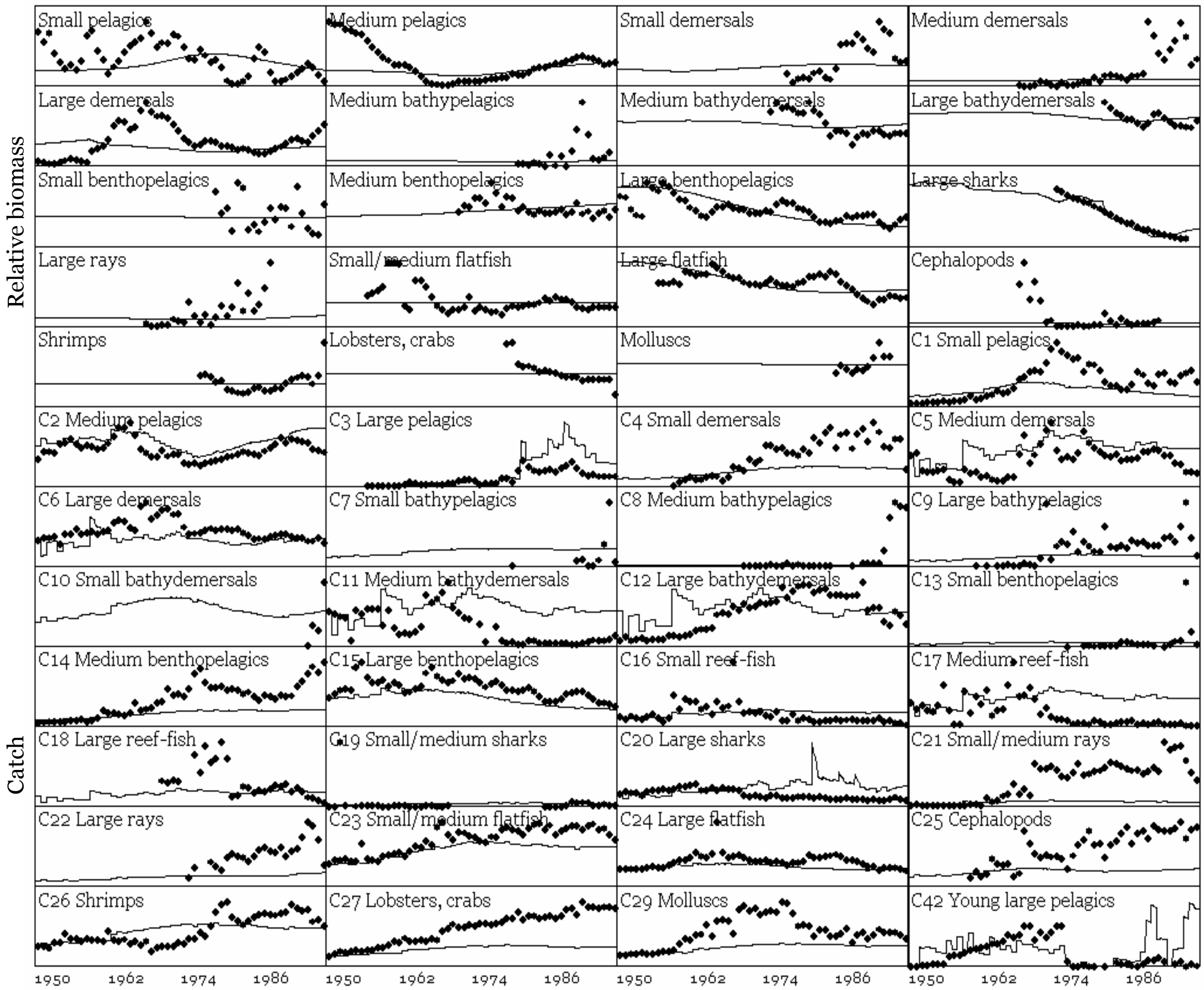

Figure E4. FAO 27- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

All scenarios resulted in an increase in pelagic and tuna baitfish effort, and a decrease in demersal effort in various proportions (Figure E5). For example, the *sustainability first* scenario targeted more the small pelagics and tuna and less the demersal than the *security first* scenario (Table E2). Thus, in the last 30 years of the simulation, landings resulting from the *sustainability first* scenario were twice that of 2003 for tuna and about 10 times as high for small pelagics. These counterintuitive results are due to the fact that small pelagics and tuna dynamics are still not well captured by the model. Better results would be achieved by separating long-lived/low-production species of tuna from the short-lived/high production species. Landings increased for all large demersal groups as a result of the decrease in effort for all scenarios, with the largest biomass reconstruction exhibited for the *sustainability first* scenario, where large benthopelagics show significant reconstruction over the last 30 years of the optimization (Figure E5). The MTI for each scenario reflects the level of effort targeting small pelagics and the resulting increase in their landings. Overall the Kempton's Q remains quite similar for all scenarios, with ecosystem stability increasing slightly for the *sustainability first* scenario.

Table E2. Species composition (main species only) of those functional fish groups in area 27 that showed an increase in landings in the last 30 years of the *sustainability first* and *market first* scenarios.

Group description	Genus/species	Common name
1. Small pelagics	*Engraulis encrasicolus*	European anchovy
	Sardina pilchardus	European pilchard
	Sprattus sprattus	European sprat
	Clupea harengus membras	Baltic herring
	Mallotus villosus	Capelin
3. Large pelagics	*Thunnus obesus*	Bigeye tuna
	Katsuwonus pelamis	Skipjack tuna
	Thunnus albacares	Yellowfin tuna
	Thunnus atlanticus	Blackfin tuna
	Thunnus maccoyii	Southern bluefin tuna
	Thunnus alalunga	Albacore
	Thunnus thynnus	Northern bluefin tuna
11. Medium bathydemersals	*Argentina silus*	Greater argentine
	Beryx decadactylus	Alfonsino
	Epigonus telescopus	Bulls-eye
	Helicolenus dactylopterus	Blackbelly rosefish
	Pontinus kuhlii	Offshore rockfish
	Trigla lyra	Piper gurnard
12. Large bathydemersals	*Alepocephalus bairdii*	Bairds smooth-head
	Polyprion americanus	Wreckfish
	Lophius budegassa	Black-bellied angler
	Lophius piscatorius	Angler
	Lepidopus caudatus	Silver scabbardfish
	Genypterus capensis	Kingklip
15. Large benthopelagics	*Argyrosomus regius*	Meagre
	Trichiurus lepturus	Largehead hairtail
	Phycis blennoides	Greater forkbeard
	Aphanopus carbo	Black scabbardfish
	Anarhichas denticulatus	Northern wolffish
	Gadus morhua	Atlantic cod
	Dentex dentex	Common dentex
	Macrourus berglax	Onion-eye grenadier
	Zeus faber	John dory
	Oncorhynchus mykiss	Rainbow trout
	Salmo salar	Atlantic salmon
	Spectrunculus grandis	Pudgy cuskeel
	Seriola lalandi	Yellowtail amberjack
	Pollachius pollachius	Pollack
	Pagrus pagrus	Common seabream

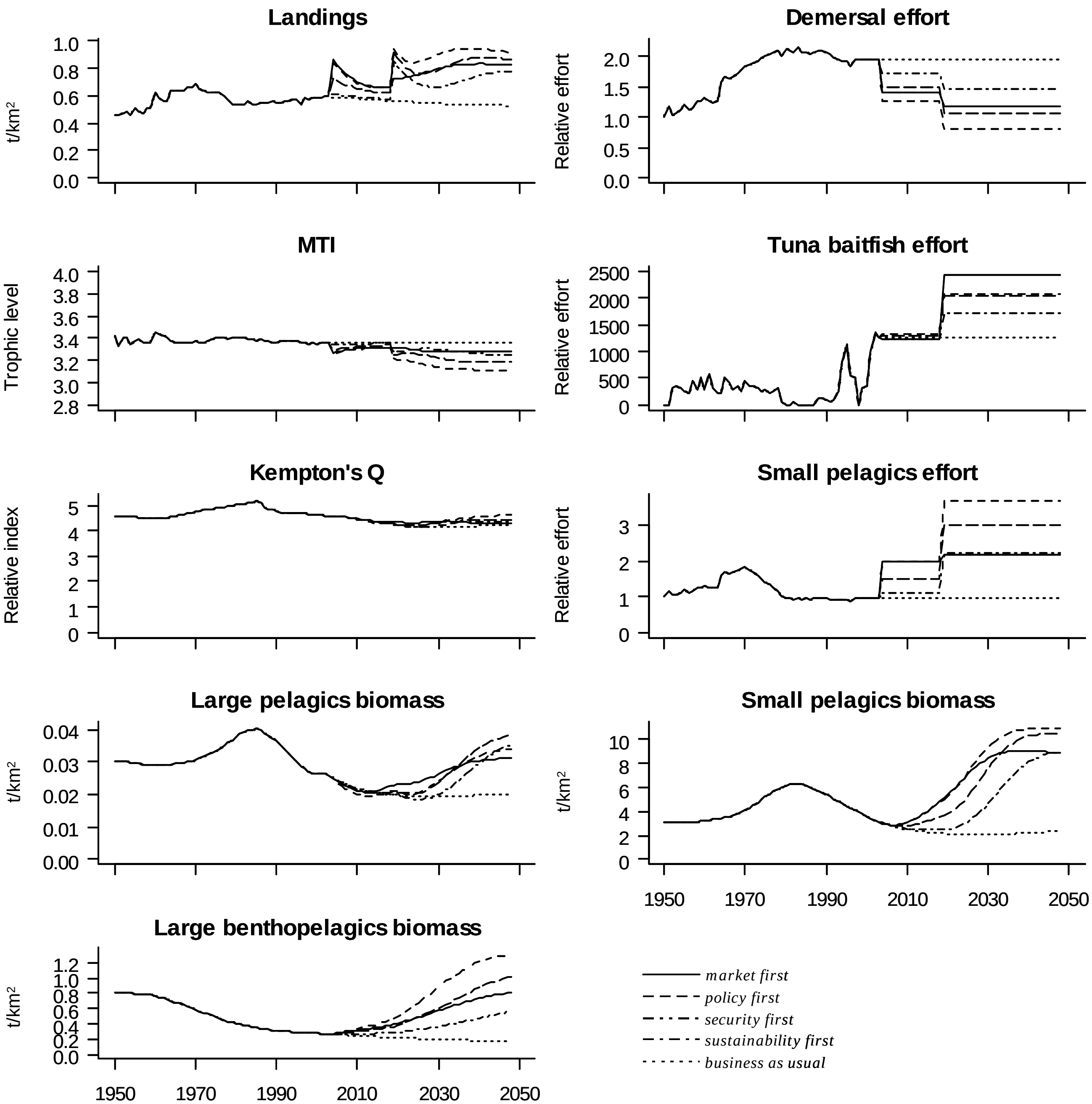

Figure E5. Results of Ecosim policy scenarios for area 27, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048

FAO 31, Caribbean Region

The area 31 model was able to predict the biomass of large pelagic (tuna) and large shark biomasses and the catches of pelagics (C1 and C2) demersals (C5) and reef-fish (C16-C18) as well as lobsters (C27) and molluscs (C29) (Figure E6). This area is the only one in which the recreational fishery (in Florida, USA), not included in this model, could have appreciable impact on several target species. This could explain the discrepancy for medium and large benthopelagics, (e.g., *Trachinotus carolinus*).

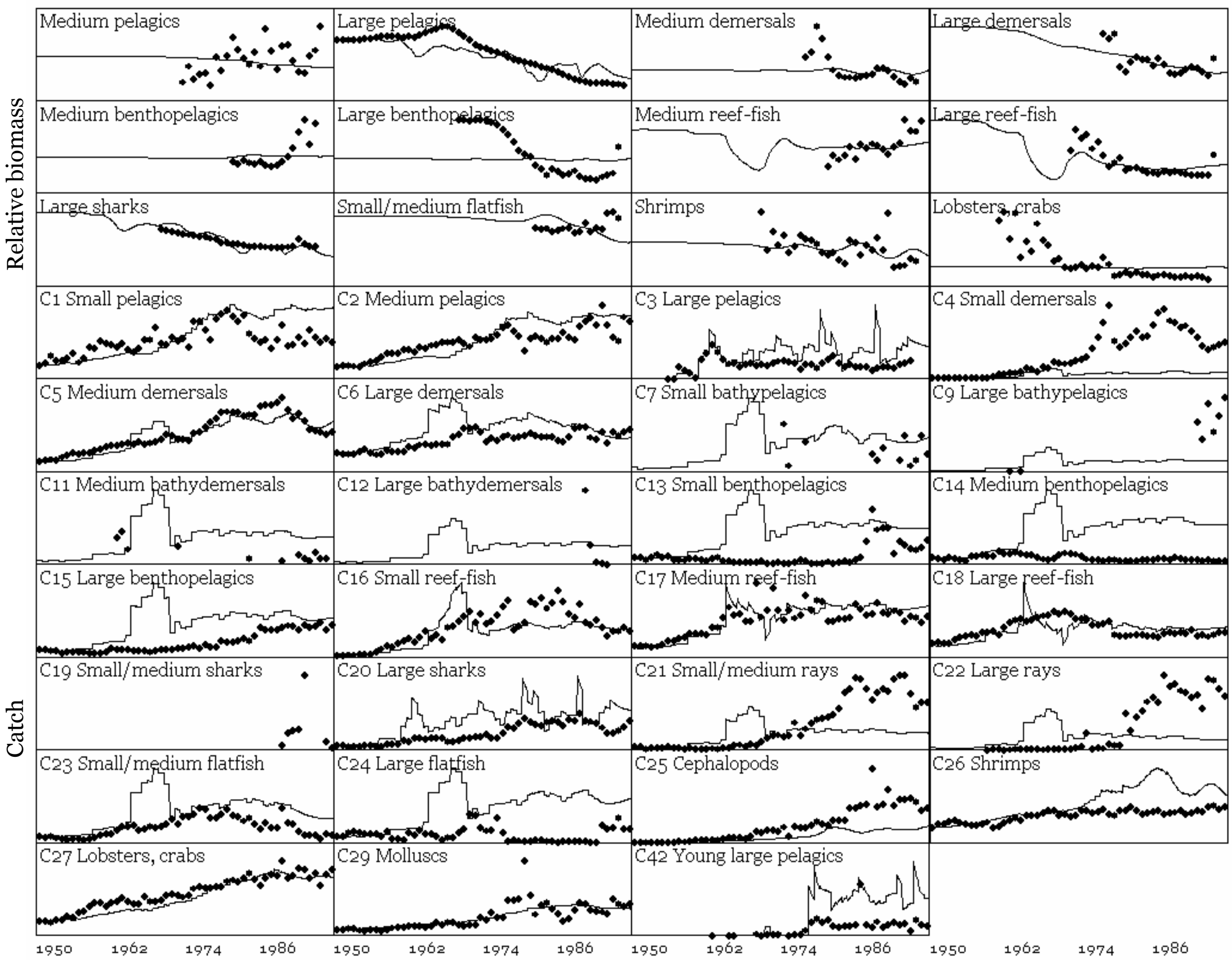

Figure E6. FAO31- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

All scenarios but *sustainability first* propose an increase in effort of both demersal and pelagics fleets (Figure E7) which resulted in a relatively small increase in landings (Figure E7). The increase in demersal effort in the *market first* scenario, for example, resulted in increased landings of medium demersals, large bathypelagics, small reef-fish and invertebrates groups (i.e. ,cephalopods, shrimps, lobsters and molluscs). With the exception of the invertebrate groups and some species of medium demersals (i.e. *Merluccius bilinearis* and *Micropogonias furnieri*) the increase in landings is due to species of lower commercial importance (Table E3). Thus, the MTI increased slightly for the *sustainability first* scenario and stayed close to the *business as usual* values for all other scenarios. The Q value for the *sustainability first* and *business as usual* scenarios remained relatively constant, while the *market first* and *policy first* scenarios increased, which likely corresponds to a decrease in biomass of the top predators. This is a result of a small increase in demersal and small pelagic effort over the first 15 years of the simulation and a larger increase over the last 30 years.

Table E3. Species composition (main species only) of those functional fish groups in area 31 that showed an increase in landings in the last 30 years of the *sustainability first* and *market first* scenarios.

Group description*		Genus/species	Common name
4. Small demersals	e.g.	Gerreidae and *Sphoeroides* spp.	Mojarras, globefishes
5. Medium demersals		*Micropogonias furnieri*	Whitemouth croaker
		Mugil liza	Liza
		Merluccius bilinearis	Silver hake
		Menticirrhus littoralis	Gulf kingcroaker
		Selene setapinnis	Atlantic moonfish
		Leiostomus xanthurus	Spot croaker
		Caulolatilus chrysops	Atlantic goldeye tilefish
		Micropogonias undulatus	Atlantic croaker
		Rhomboplites aurorubens	Vermilion snapper
9. Large bathypelagics		*Lepidocybium flavobrunneum*	Escolar
		Lampris guttatus	Opah
16. Small reef-associated		Monacanthidae	Filefishes
		Pomacanthidae	Angelfishes
		Serranidae	Sea basses/groupers/fairy basslets
		Holocentridae	Squirrelfishes, soldierfishes
		Labridae	Wrasses

* Note: In addition to the fish groups, three invertebrate groups also increased, i.e., shrimp, lobsters/ crabs and demersal molluscs

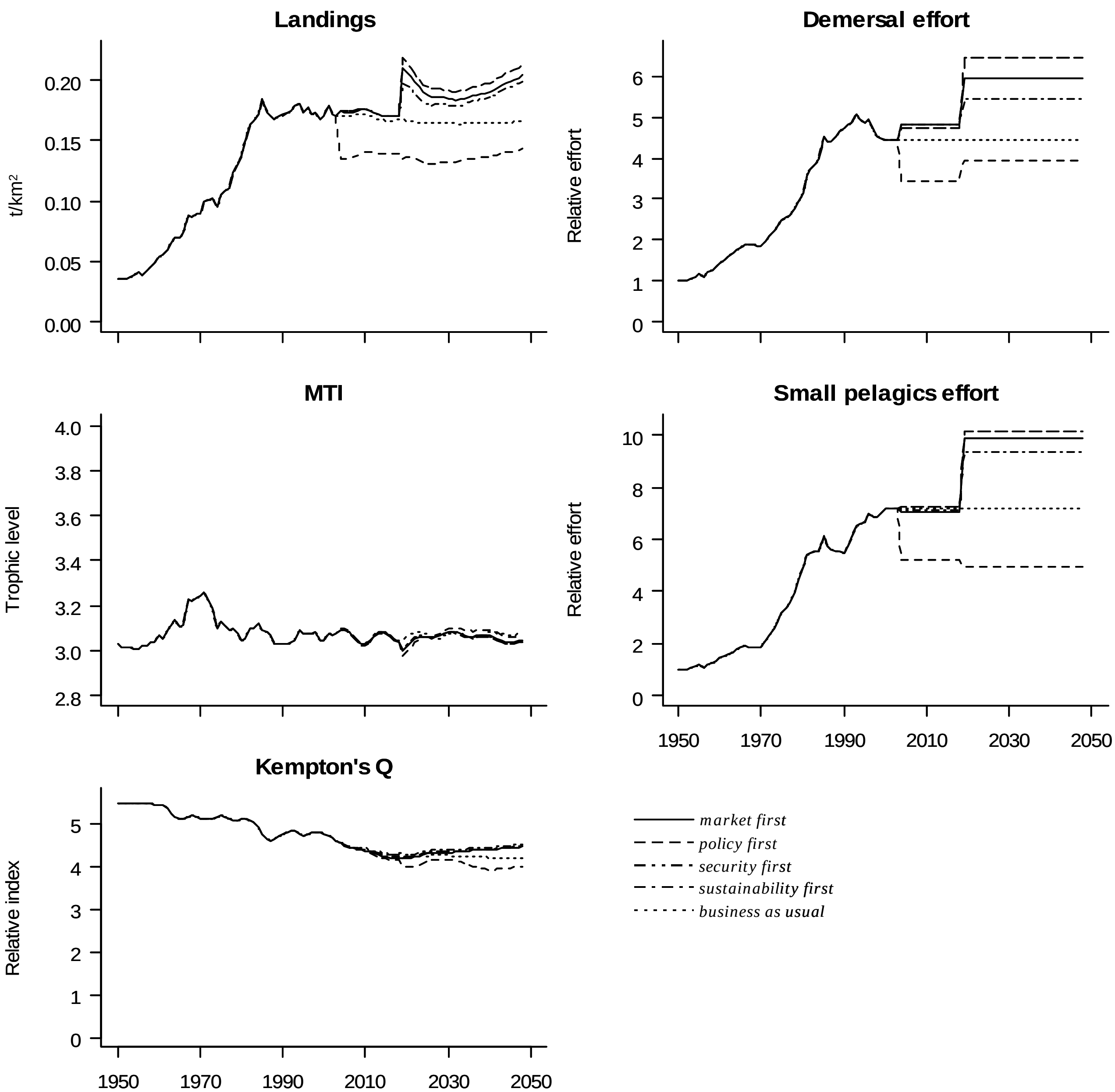

Figure E7. Results of Ecosim policy scenarios for area 31, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 34, Northwest Africa

The area 34 model made reasonable predictions for large pelagics, and medium and large demersals biomasses, but not for small and medium pelagics, as no upwelling index was included (Figure E8). In several cases, the predicted catches were quite close to the observed values, especially for the medium demersals (C5). Similarly to what occurred with the demersal effort in area 21, however, the increase in interest for invertebrates could not be matched by the model because of the effort structure for the demersal fleet.

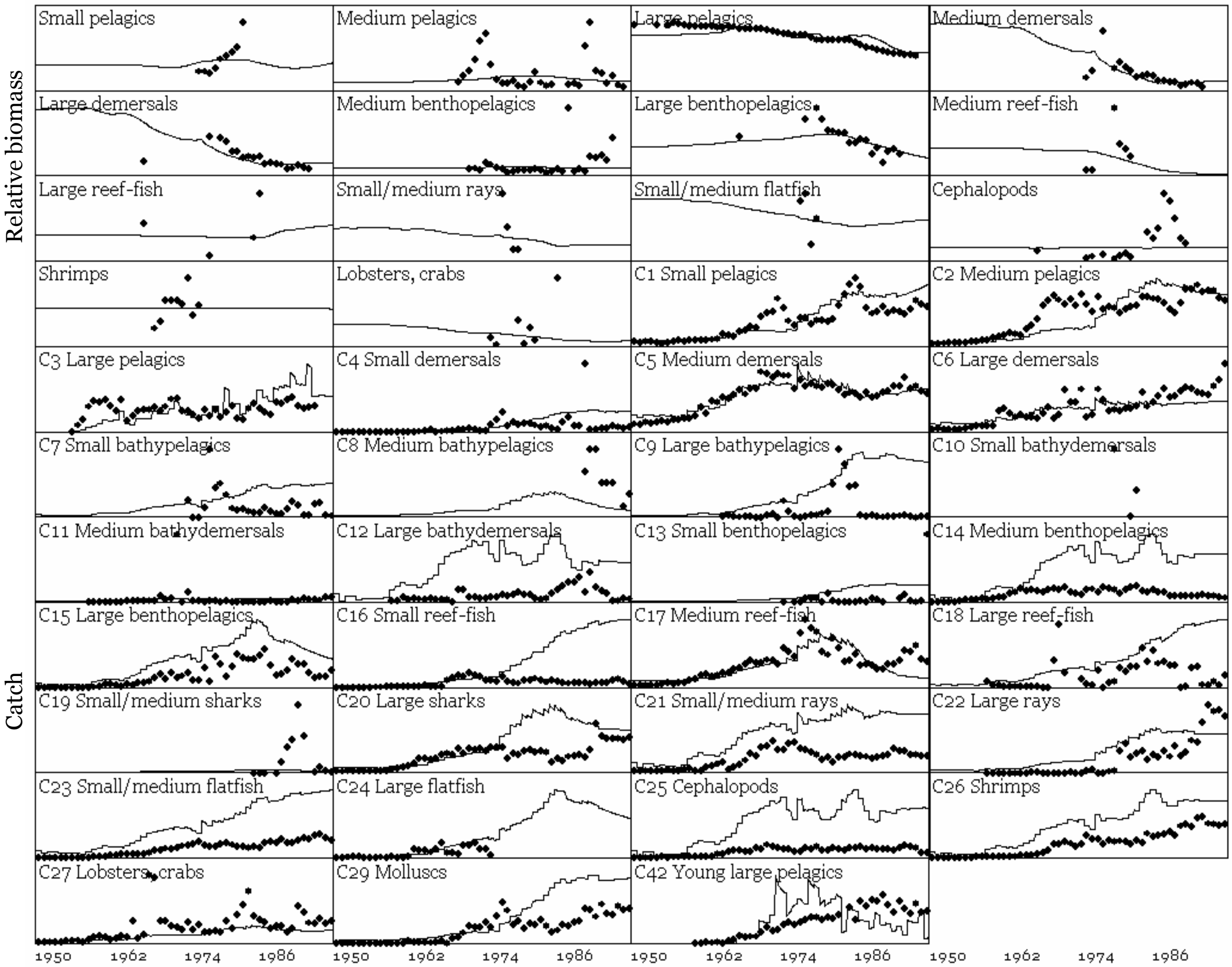

Figure E8. FAO 34- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (series starting with 'C' then the group number) and biomass time series from 1950-2003.

All scenarios except the *sustainability first* propose an increase in effort for demersal, small pelagic and distant water fleets (Figure E9). For the tuna longline fleet, an increase in effort is proposed for the *sustainability first* scenario, and a decrease in effort proposed for the *security first* scenario over the initial 15 years of the optimization (Figure E9). The doubling of effort did produce less than twice the landings, though. Here, the MTI decreased continually since 1950 and declined further in the *policy* and *security* first scenario. This is illustrated by the *security first* scenario which resulted in an increased proportion of invertebrates (cephalopods, lobsters, shrimp and molluscs), small demersals and medium and large bathydemersals (i.e. *Merluccius polli* and *Polyprion americanus)* (Table E4). The Q value also decreased for the two scenarios over the same time period. The increase in demersal effort for the *security first* scenario resulted in a decline in biomass of large demersals and large benthopelagics throughout the optimization routine (Figure E9). The increase in tuna effort and landings implies that the representation of tuna dynamics should be improved in the model.

Table E4. Species composition (main species only) of those functional fish groups in area 34 that showed an increase in landings in the last 30 years of the *sustainability first* and *security first* scenarios.

Group description*	Genus/species	Common name
1. Small pelagics	*Hyporhamphus ihi*	Garfish
	Engraulis encrasicolus	European anchovy
	Sardina pilchardus	European pilchard
3. Large pelagics	*Thunnus obesus*	Bigeye tuna
	Thunnus thynnus	Northern bluefin tuna
	Makaira nigricans	Atlantic blue marlin
	Thunnus albacares	Yellowfin tuna
	Tetrapturus albidus	Atlantic white marlin
	Thunnus alalunga	Albacore
	Tetrapturus pfluegeri	Longbill spearfish
	Xiphias gladius	Swordfish
	Coryphaena hippurus	Common dolphinfish
	Istiophorus albicans	Atlantic sailfish
	Orcynopsis unicolor	Plain bonito
	Sarda sarda	Atlantic bonito
	Makaira indica	Black marlin
	Katsuwonus pelamis	Skipjack tuna
	Euthynnus alletteratus	Little tunny
4. Small demersals	*Macroramphosus scolopax*	Longspine snipefish
	Brachydeuterus auritus	Bigeye grunt
11. Medium bathydemersals	*Merluccius polli*	Benguela hake
	Lophius vaillanti	Shortspine African angler
12. Large bathydemersals	*Lophius budegassa*	Black-bellied angler
	Polyprion americanus	Wreckfish
	Lepidopus caudatus	Silver scabbardfish
17. Medium reef-associated	Scaridae	Parrotfishes
	Ephippidae	Spadefishes, batfishes and scats
	Mullidae	Goatfishes
	Acanthuridae	Surgeonfishes, tangs, unicornfishes
	Haemulidae	Grunts
	Balistidae	Triggerfishes
	Muraenidae	Moray eels

* Note: In addition to the fish groups, three invertebrate groups also increased, i.e., cephalopods, shrimp and demersal molluscs

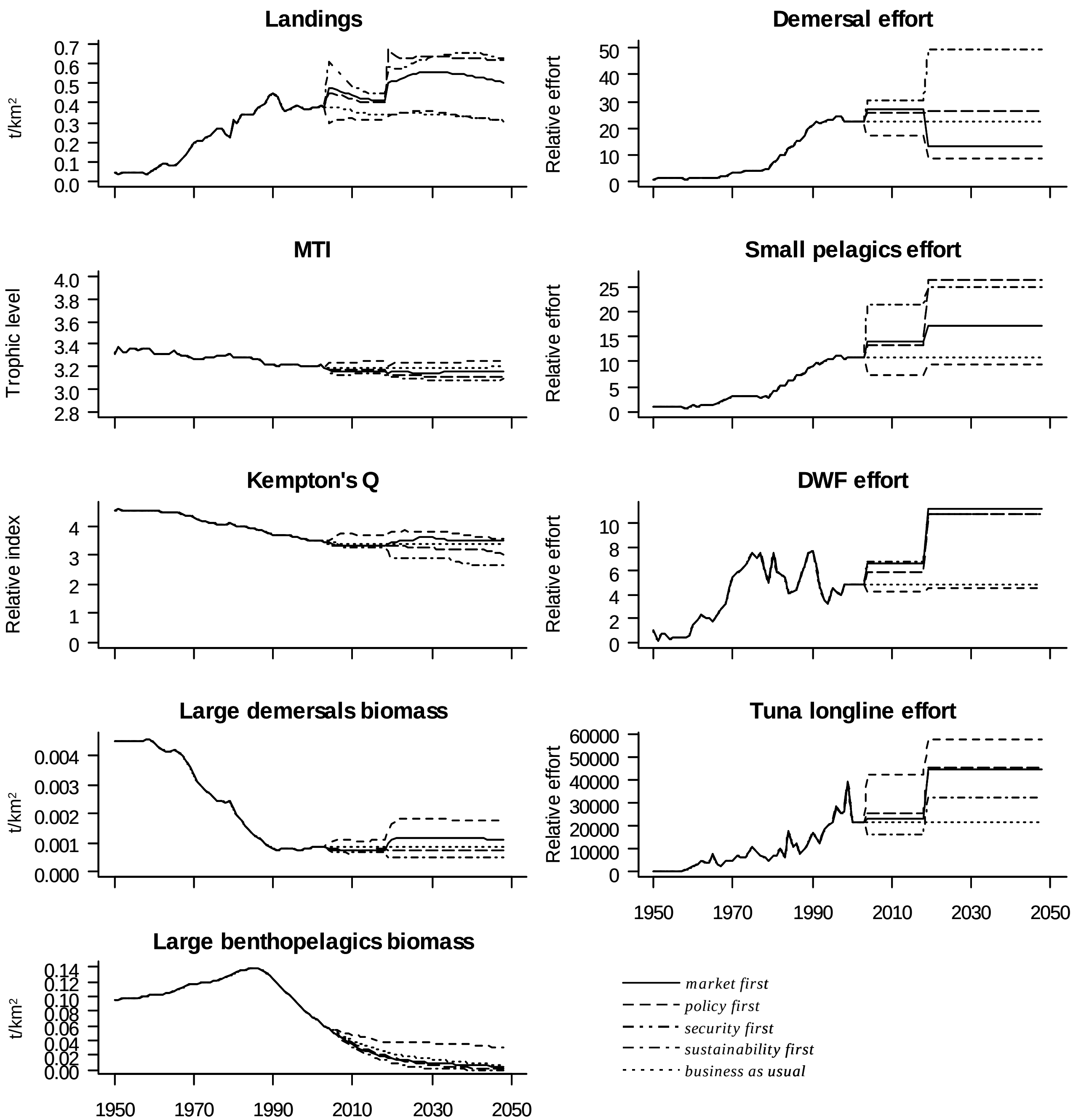

Figure E9. Results of Ecosim policy scenarios for area 34, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 37, Mediterranean Sea

More than 75% of biomass trends for area 37 were taken from the International bottom trawl survey in the Mediterranean Sea (MEDITS) that were conducted by sub-areas, often covering only short time periods. As a result, it was difficult to establish representative biomass indices for groups when and where, the data showed contrasting trends. The model did not fit well the biomass time series for small pelagics and small/medium demersals. Again, climate indices should be included in the model to help with the dynamics of small and medium pelagics. The catch for medium and large pelagics (C2, C3 and C42), medium benthopelagics (C14), shrimps (C26) and crabs (C27) were well predicted (Figure E10).

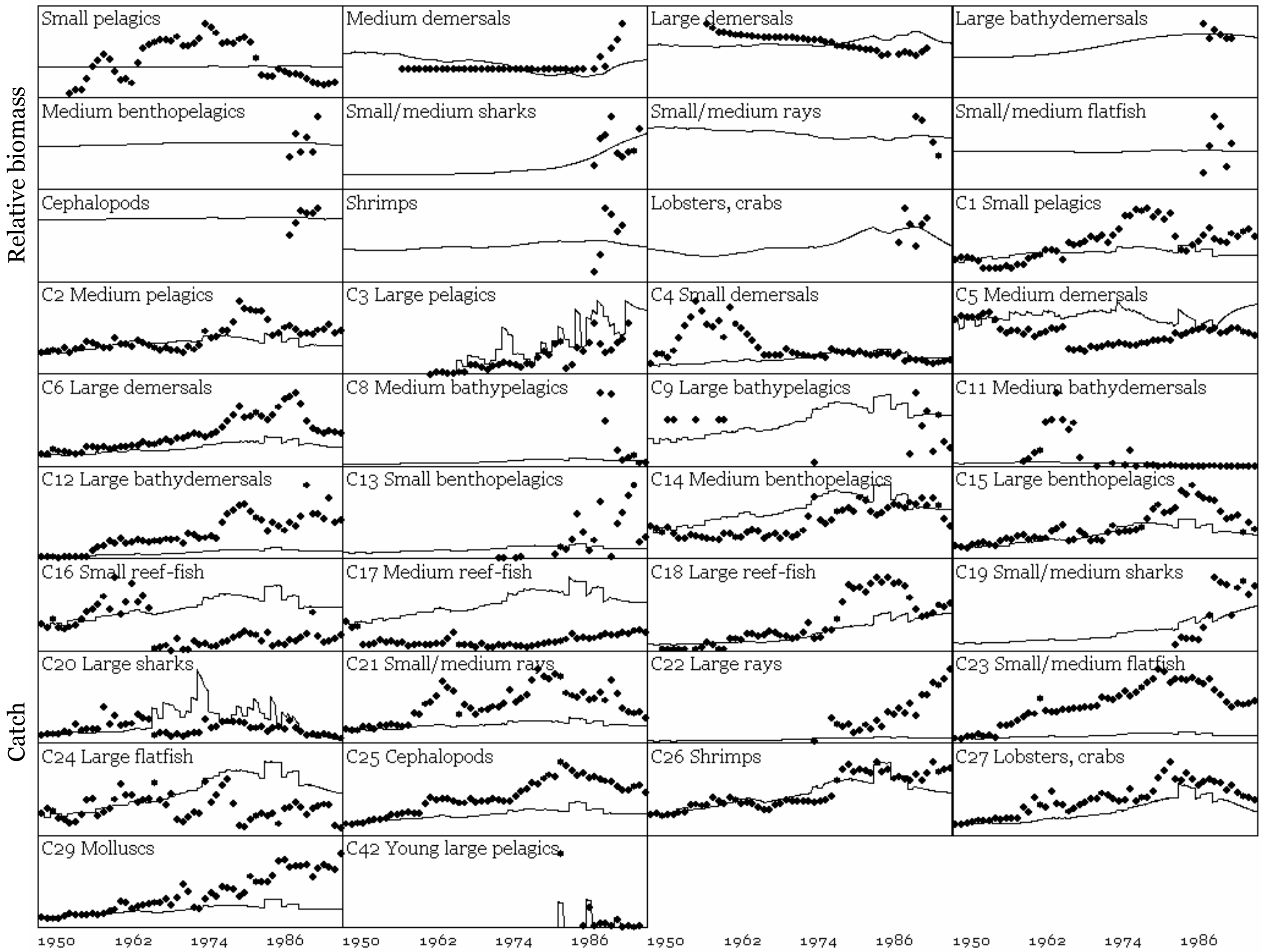

Figure E10. FAO 37- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

All scenarios resulted in an increase in demersal fleet effort. The *sustainability first* scenario differ markedly from the others by being the only one to raise the tuna longline fleet effort when the others left it at the 2003 level, and the only one that decreased effort of the small pelagic fleet (Figure E11). Increase in landings for the *policy*, *market* and *security* first scenarios, were due primarily to an increase in the demersal and small pelagic fleet effort, resulting in larger landings of low trophic levels groups (invertebrates, small demersals – Table E5). Increases in landings of medium bathydemersals, small sharks, large rays and small-large flatfish did not help increasing the MTI as their respective catch was relatively small in comparison to the invertebrates. The increase in tuna longline effort for the *sustainability first* scenario resulted in increased landings, as well as a decrease in biomass of the large pelagics (Figure E11). The fact that the *sustainability first* scenario increases the tuna longline effort, point to a challenge when lower productive species like northern bluefin tuna (*Thunnus thynnus*) are in the same group as higher productive species like the skipjack tuna (*Katsuwonus pelanis*), as there is evidence of overexploitation of northern bluefin tuna in the Mediterranean (Block *et al.*, 2005; Carlsson *et al.*, 2007). The Kempton's Q value increases for all scenarios, which is likely a result of the decline in biomass of a few top predators.

Table E5. Species composition (main species only) of those functional fish groups in area 37 that showed an increase in landings in the last 30 years of the *policy first* and the *business as usual* scenarios.

Group description*	Genus/species	Common name
4. Small demersals	*Atherina boyeri*	Big-scale sand smelt
	Spicara maena	Blotched picarel
	Gobius niger	Black goby
19. Small/medium sharks	*Galeus melastomus*	Blackmouth catshark
	Etmopterus spinax	Velvet belly lantern shark
22. Large rays	*Raja clavata*	Thornback ray
23. Small/medium flatfish	*Scophthalmus rhombus*	Brill
	Platichthys flesus	Flounder
	Lepidorhombus whiffiagonis	Megrim
	Dicologlossa cuneata	Wedge sole
	Solea solea	Common sole
24. Large flatfish	*Scophthalmus maximus*	Turbot
	Pleuronectes platessus	European plaice

* Note: In addition to the fish groups, three invertebrate groups also increased, i.e., shrimp, lobsters/crabs and demersal molluscs

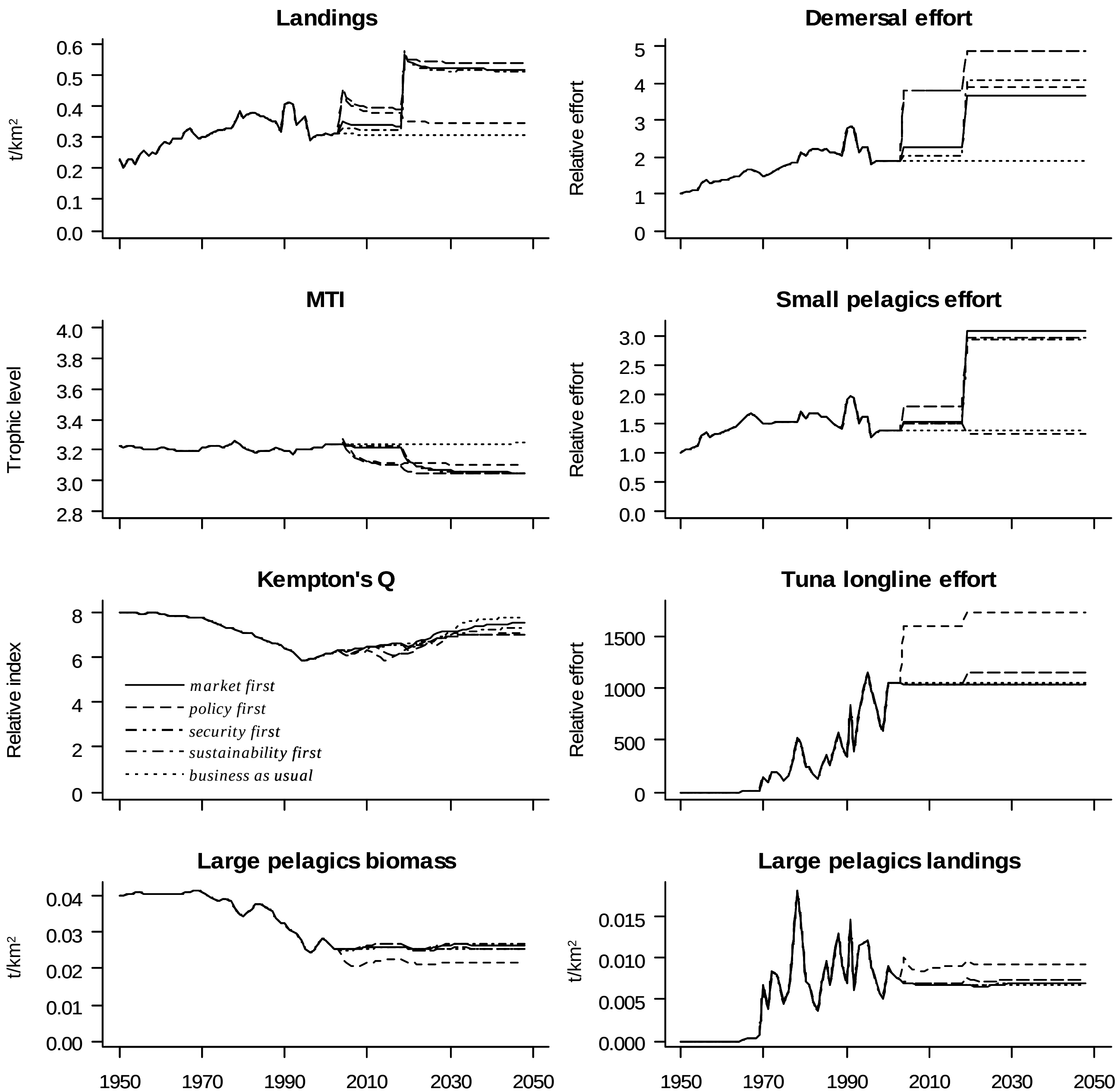

Figure E11. Results of Ecosim policy scenarios for area 37, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 41, Southwest Atlantic

There were a limited number of biomass trend series available for area 41 and those available were not well fitted by the model (Figure E12). The small and medium pelagics would need the inclusion of a climate index to explain their trends in biomass. Better fit to the catch series was achieved, especially for the large demersals (C6, e.g. *Pogonias cromis* and *Conger orbignyanus*), medium and large sharks (C19 and C20), and medium flatfish (C23).

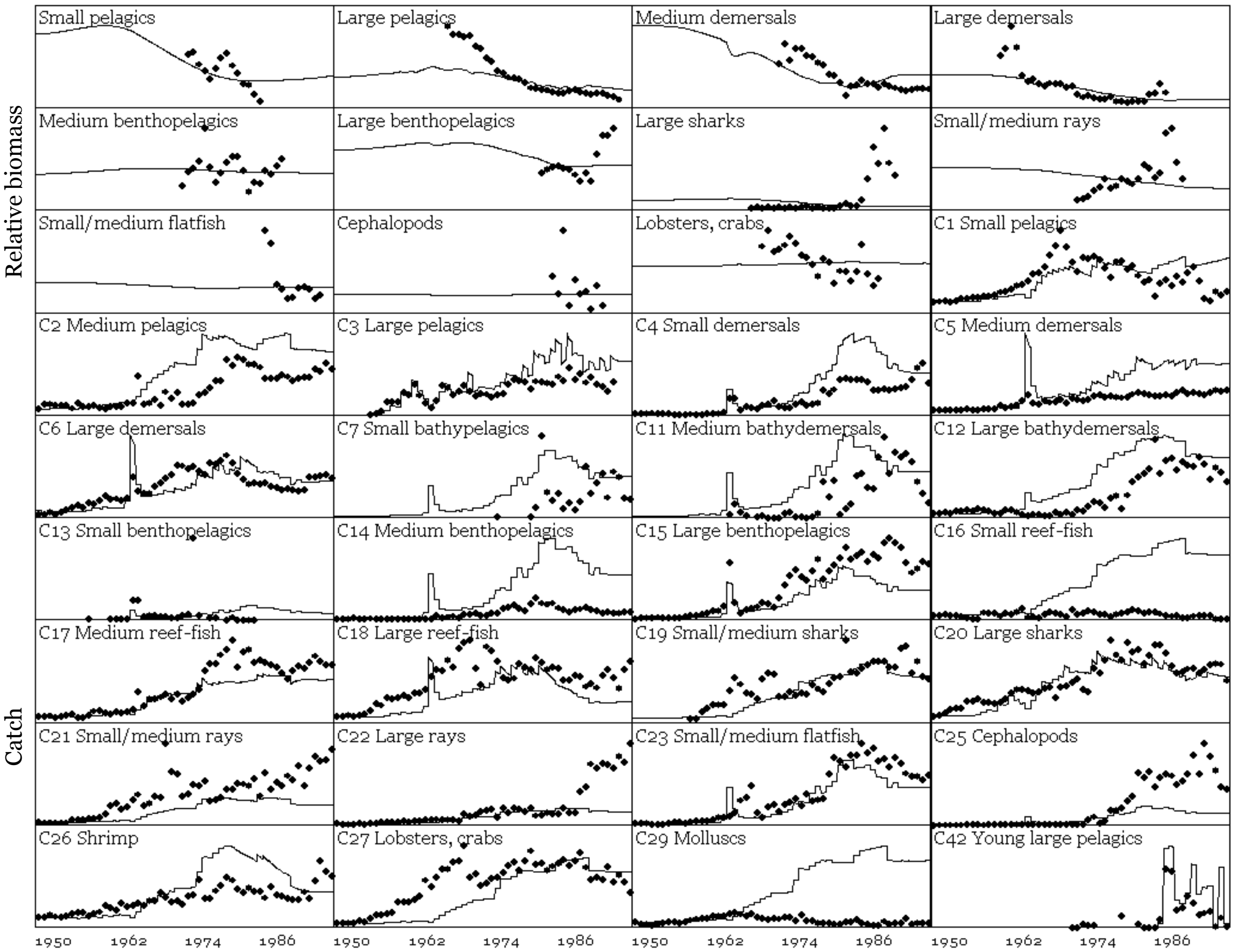

Figure E12. FAO 41- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

All scenarios proposed an increase in demersal, small pelagics, and tuna longline fleets (Figure E13). The resulting catch was composed of a larger proportion of small pelagics and demersals, thus primarily low trophic level groups– small reef-fish, medium sharks, shrimps, lobsters and molluscs (Table E6). The MTI and Q value are decreasing over the last 30 years of the optimization for all scenarios, which coincides with a large increase in demersal effort over the same time period. Little rebuilding of biomass was achieved by any scenario.

Table E6. Species composition (main species only) of those functional fish groups in area 41 that showed an increase in landings in the last 30 years of the *policy first* and the *business as usual* scenarios.

Group description*	Genus/species	Common name
1. Small pelagics	*Engraulis anchoita*	Argentine anchoita
	Brevoortia aurea	Brazilian menhaden
	Sardinella brasiliensis	Brazilian sardinella
	Sprattus fuegensis	Falkland sprat
2. Medium pelagics	*Chloroscombrus chrysurus*	Atlantic bumper
	Champsocephalus gunnari	Mackerel icefish
	Caranx crysos	Blue runner
	Hemiramphus brasiliensis	Ballyhoo
	Elops saurus	Ladyfish
	Scomber japonicus	Chub mackerel
	Auxis	Frigate tuna
	Opisthonema oglinum	Atlantic thread herring
	Brevoortia pectinata	Argentine menhaden
5. Medium demersals	*Conodon nobilis*	Barred grunt
	Parona signata	Parona leatherjacket
	Selene setapinnis	Atlantic moonfish
	Gobionotothen gibberifrons	Humped rockcod
	Macrodon ancylodon	King weakfish
	Micropogonias furnieri	Whitemouth croaker
	Urophycis brasiliensis	Brazilian codling
	Salilota australis	Tadpole codling
	Diplodus argenteus	South American silver porgy
	Cynoscion striatus	South American striped weakfish
	Chaenocephalus aceratus	Blackfin icefish
	Percophis brasiliensis	Brazilian flathead
	Nemadactylus bergi	White morwong
	Umbrina canosai	Argentine croaker
6. Large demersals	*Lutjanus purpureus*	Southern red snapper
	Pseudopercis semifasciata	Pigletfish
	Pogonias cromis	Black drum
	Conger orbignyanus	Argentine conger
19. Small/medium sharks	*Mustelus schmitti*	Narrownose smooth-hound

* Note: In addition to the fish groups, three invertebrate groups also increased, i.e., shrimp, lobsters/crabs and demersal molluscs

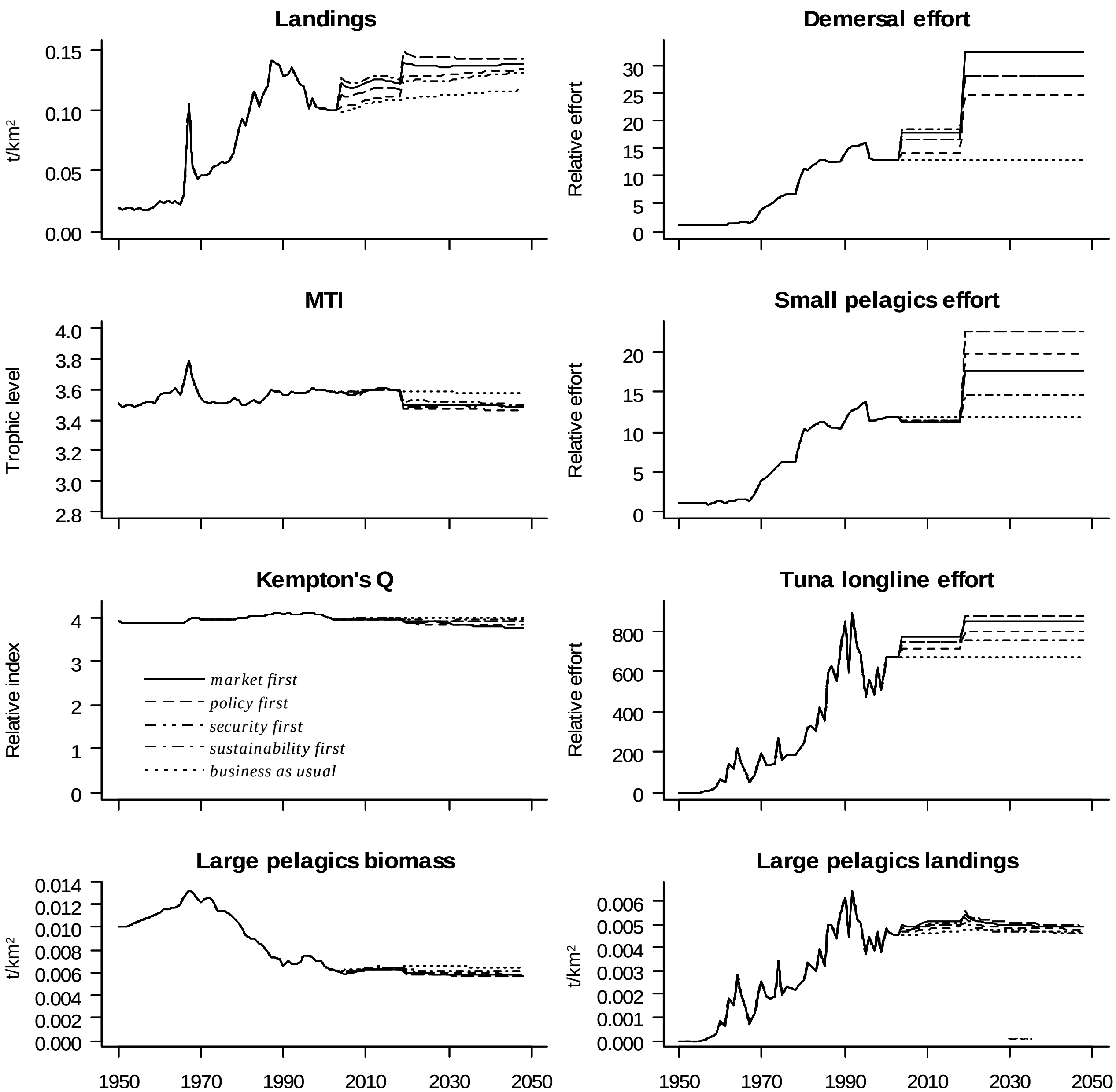

Figure E13. Results of Ecosim policy scenarios for area 41, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 47, Southeast Atlantic

The area 47 model was able to fit several catch times series, especially the pelagics (C1-C3), medium demersals (C5), medium benthopelagics (C14), and lobster/crab (C27), but none of the biomass time series were well fitted (Figure E14). This also seems to be a model where climate indices (Benguela upwelling indices) could contribute significantly to better predictions, especially for the medium pelagics (i.e., *Sardinops sagax* and *Trachurus capensis*) and large bathydemersals groups, (e.g., *Merluccius* spp. and *Genypterus capensis*), for which there are long time series (Mas-Riera *et al.*, 1990).

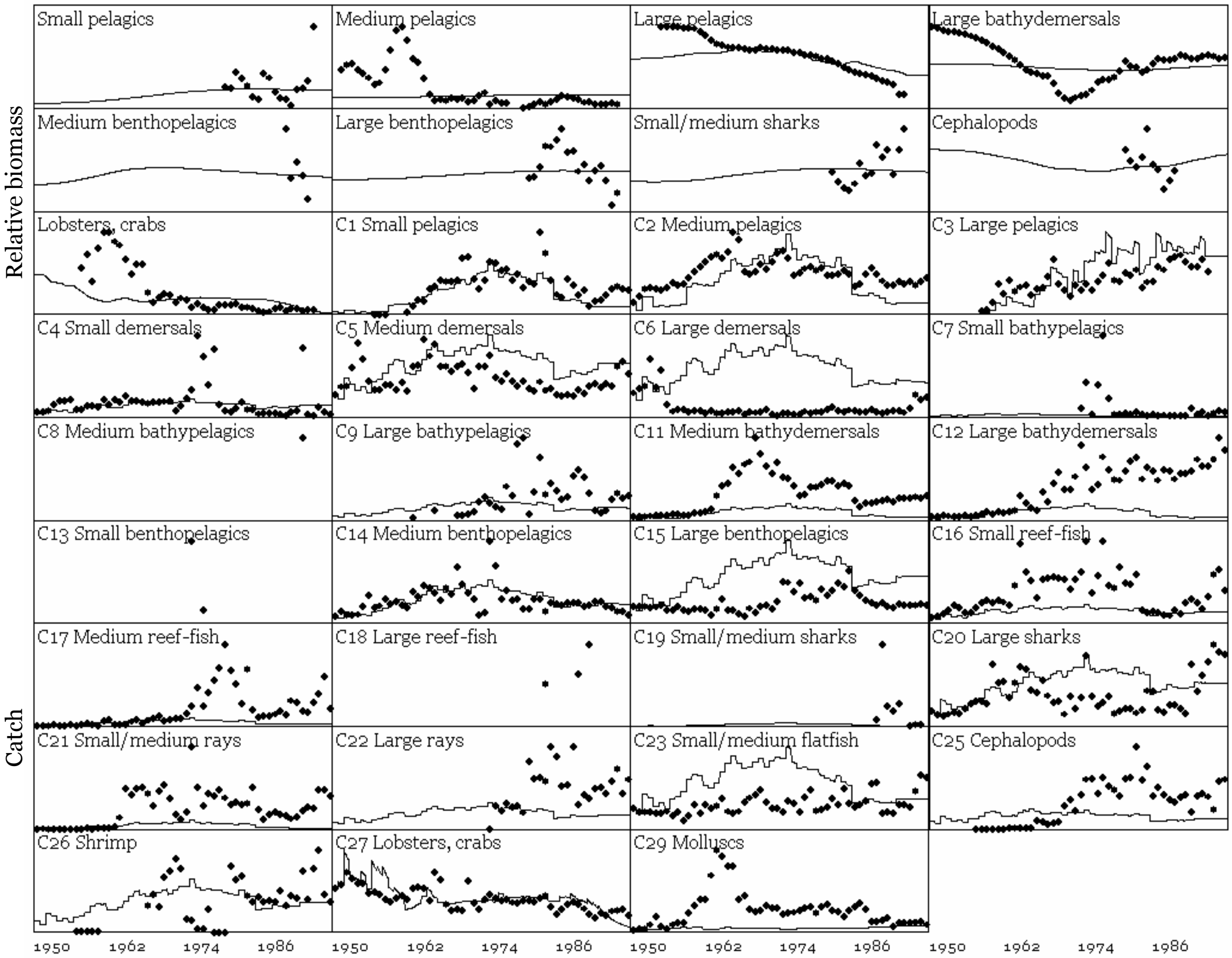

Figure E14. FAO 47- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

The effort of the small pelagics fleet was doubled in all scenarios (Figure E15). The demersal effort was doubled in all scenarios except the *sustainability first* in which the tuna longline was increased instead. As landings increased, in the *market first* scenario for example, small and medium pelagics landings increased, as well as those of most groundfish of all sizes, and cephalopods; with the results seen by a decreasing MTI and Q value over the optimization period (Table E7 and Figure E15). Such a large increase in effort had an effect of the biomass of several groups such as the large demersals that declined by 72% in the *market first* scenario (Figure E15). The increase in small pelagic fleet effort did have an effect on the biomass of the small pelagics with a small decline over the optimization period.

Table E7. Species composition (main species only) of those functional fish groups in area 47 that showed an increase in landings in the last 30 years of the *market first* and the *business as usual* scenarios.

Group description*	Genus/species	Common name
1. Small pelagics	*Engraulis capensis*	Cape anchovy
	Lampanyctodes hectoris	Hectors lanternfish
	Etrumeus whiteheadi	Whiteheads round herring
2. Medium pelagics	*Sardinella aurita*	Round sardinella
	Caranx hippos	Crevalle jack
	Chloroscombrus chrysurus	Atlantic bumper
	Pseudopentaceros richardsoni	Pelagic armorhead
	Sardinops sagax	South American pilchard
	Scomber japonicus	Chub mackerel
	Trachurus capensis	Cape horse mackerel
7. Small bathypelagics	*Oreosomatidae*	Oreos
11. Medium bathydemersals	*Merluccius polli*	Benguela hake
	Pterothrissus belloci	Longfin bonefish
	Emmelichthys nitidus	Redbait
	Helicolenus dactylopterus	Blackbelly rosefish
12. Large bathydemersals	*Lepidopus caudatus*	Silver scabbardfish
	Dissostichus eleginoides	Patagonian toothfish
	Genypterus capensis	Kingklip
	Merluccius capensis	Shallow-water Cape hake
	Polyprion americanus	Wreckfish
23. Small/medium flatfish	*Austroglossus microlepis*	West coast sole
	Austroglossus	Southern soles
	Cynoglossidae	Tonguefishes

* Note: In addition to the above groups, small/medium rays and one invertebrate group also increased, i.e., cephalopods

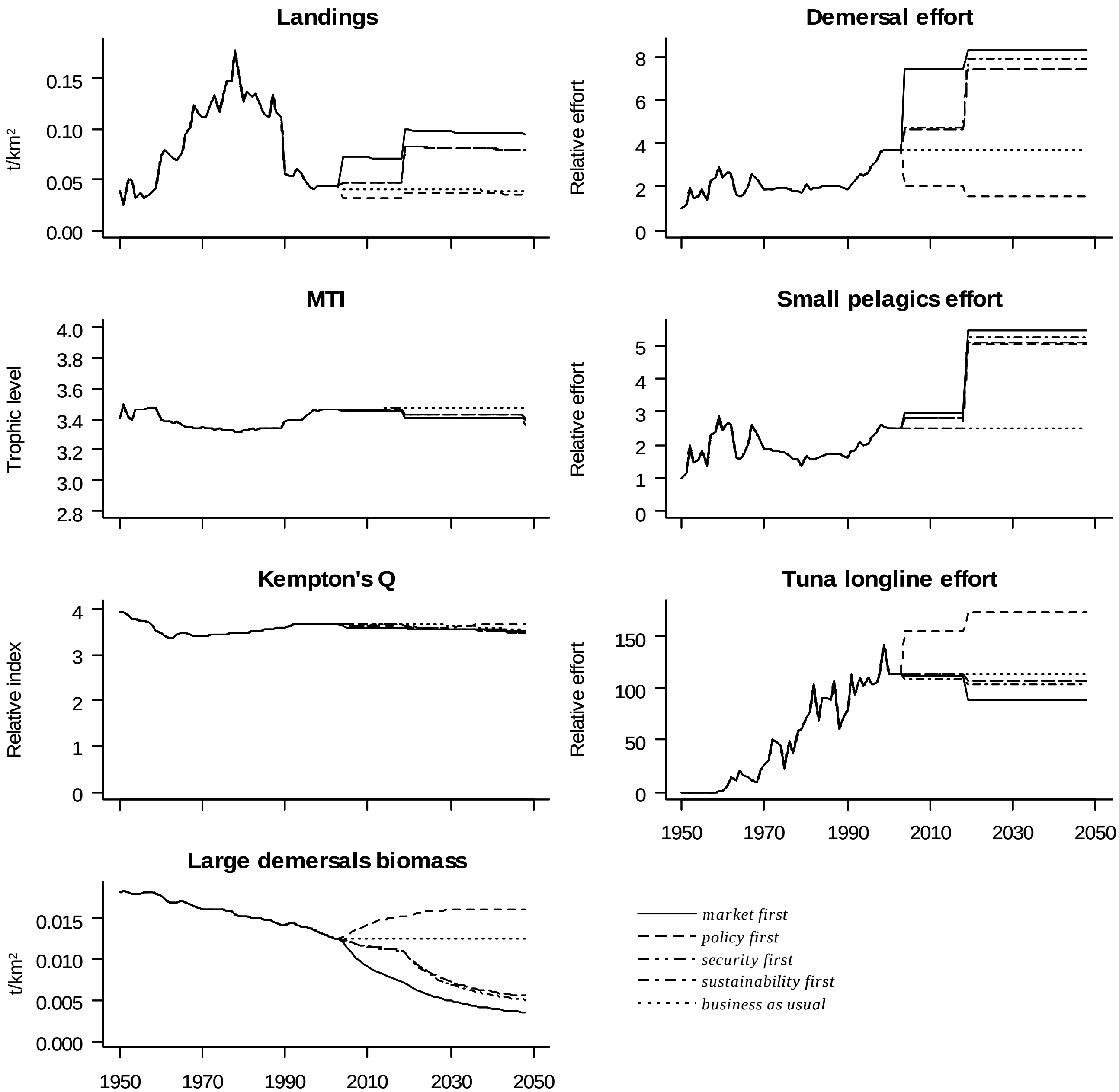

Figure E15. Results of Ecosim policy scenarios for area 47**,** optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 48, Antarctic (South Atlantic)

There are catch data available for area 48, but due to a lack of biomass time series and incomplete effort data, we are not able to produce a reliable and valid model for this area. The catches for the year 2003 amount to approximately 126,000 tonnes, i.e., only 0.2% of the world total. In the context of global policy scenarios, the catches are not likely to have major implications.

FAO 51, West Indian Ocean

There were a limited number of biomass trend series available for area 51 and those available were not well fitted by the model (Figure E16). Catches were not well predicted and were generally overestimated except for the small bathypelagics (C7). These results are probably due to the fact that the artisanal catch and effort were not included in the model and thus fishing mortalities are rather low for several commercial groups, which is unlikely for this region of the world.

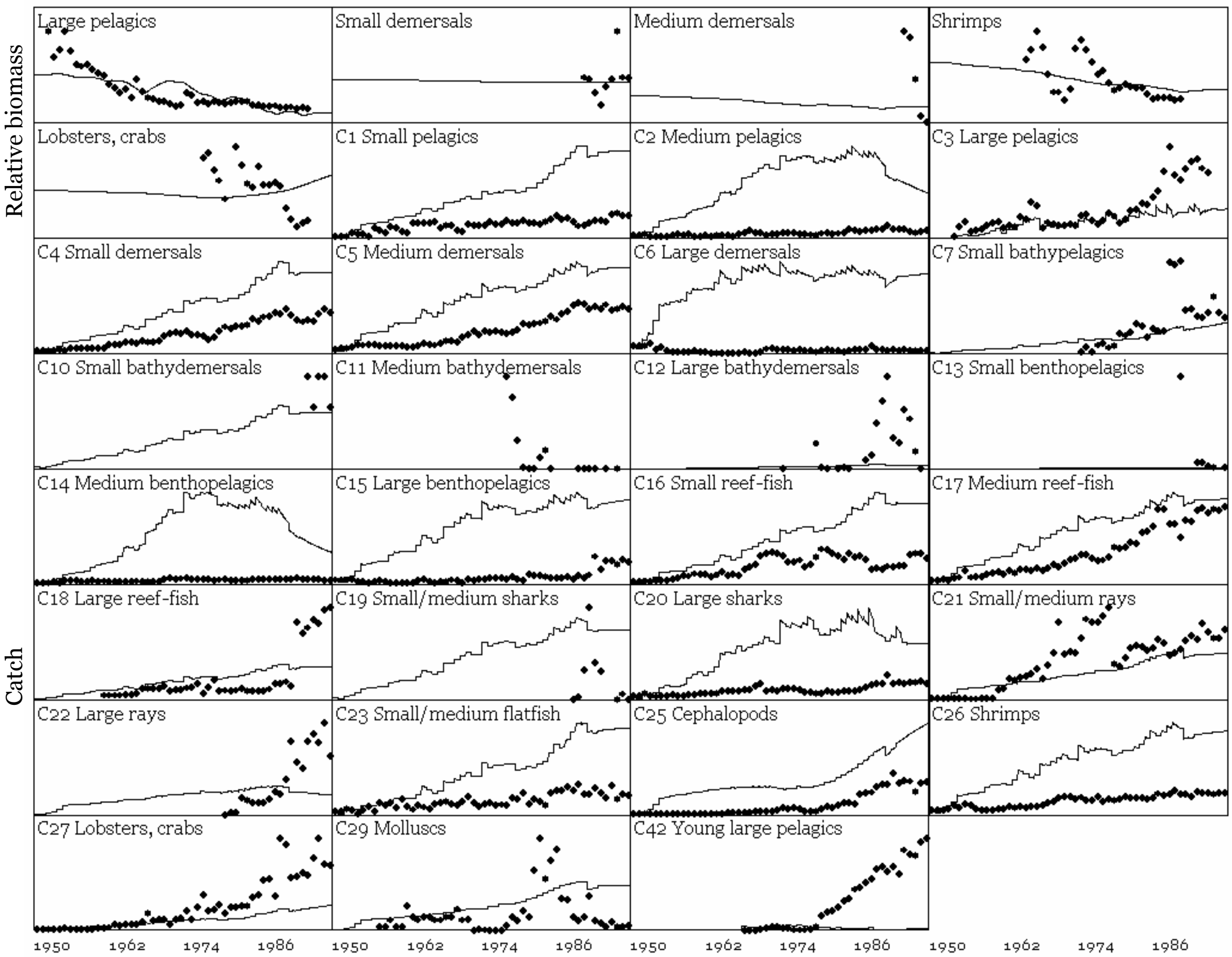

Figure E16. FAO 51-Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

The scenarios differ mainly by the level of demersal effort projected (Figure E17). Only the *sustainability first* scenario resulted in a slight decrease in effort. The *security first* scenario proposed to double the demersal effort, which was not sustainable as landings rapidly decreased as effort continued to increase (Figure E17). The catch composition was dominated by small sized bathypelagics and bathydemersals, invertebrates and sharks (Table E8). These results are not to be trusted given the limited success in fitting the model to data.

Table E8. Species composition (main species only) of those functional fish groups in area 51 that showed an increase in landings in the last 30 years of the *security first* and the *sustainability first* scenarios.

Group description*	Genus/species	Common name
3. Large pelagics	*Katsuwonus pelamis*	Skipjack tuna
	Thunnus alalunga	Albacore
	Thunnus albacares	Yellowfin tuna
	Thunnus maccoyii	Southern bluefin tuna
	Thunnus obesus	Bigeye tuna
	Thunnus tonggol	Longtail tuna
4. Small demersals	*Liza klunzingeri*	Klunzingers mullet
6. Large demersals	*Platycephalus indicus*	Bartail flathead
	Eleutheronema tetradactylum	Fourfinger threadfin
	Lates calcarifer	Barramundi
	Argyrosomus hololepidotus	Southern meagre
	Petrus rupestris	Red steenbras
7. Small bathypelagics	*Benthosema pterotum*	Skinnycheek lanternfish
10. Small bathydemersals e.g.	Caproidae and *Epigonus* spp.	Cardinalfishes and boarfishes
11. Medium bathydemersals	*Helicolenus dactylopterus*	Blackbelly rosefish
	Synagrops japonicus	Japanese splitfin
12. Large bathydemersals	*Dissostichus eleginoides*	Patagonian toothfish
	Lepidopus caudatus	Silver scabbardfish
	Polyprion americanus	Wreckfish
20. Large sharks	*Carcharhinus obscurus*	Dusky shark
	Lamna nasus	Porbeagle
	Carcharhinus sorrah	Spottail shark
	Prionace glauca	Blue shark
	Isurus oxyrinchus	Shortfin mako
	Sphyrnidae	Hammer-/bonnet-/scoop-head sharks

* Note: In addition to the fish groups, three invertebrate groups also increased, i.e., cephalopods, lobsters/crabs and demersal molluscs

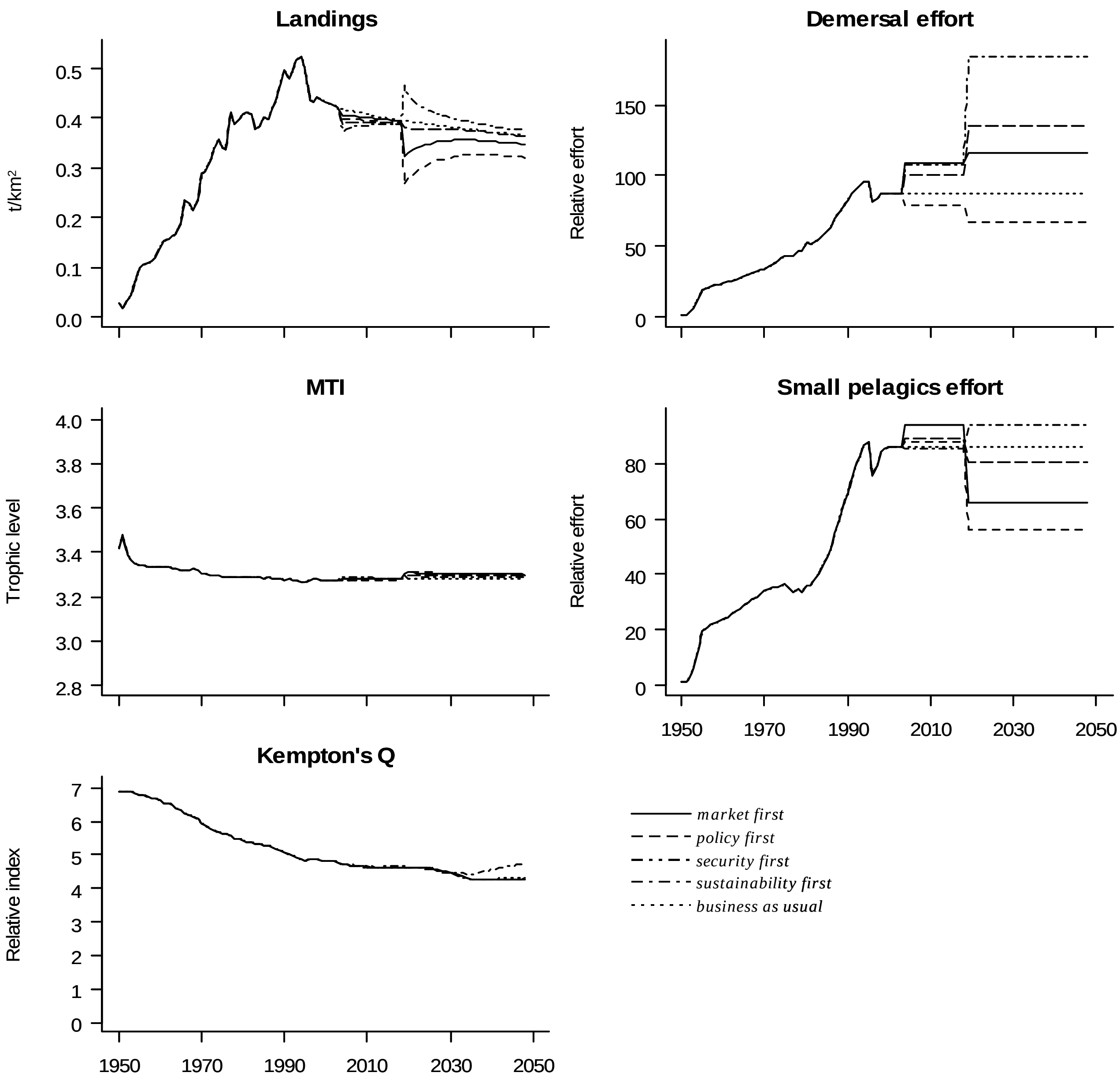

Figure E17. Results of Ecosim policy scenarios for area 51, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 57, East Indian Ocean

Biomass data availability for area 57 is limited, especially for the Bay of Bengal, but the model was able to fit large sharks and lobsters/crabs time series (Figure E18). The model was also able to predict catches for several groups such as small and medium pelagics (C1, C2), small demersals (C4), medium benthopelagics (C14), medium flatfish (C23) and cephalopods (C25). For groups that were not fitted well, this was probably due to the fact that the artisanal catch and effort, especially for India, were not included in the model and thus, fishing mortalities are rather low for several commercial groups, which is unlikely for this region of the world. In addition there is a lack of information on industrial effort available for Australia. Another factor in fitting data for this area was the diversity of stocks that arise from species within groups that are ranging from south-eastern Australia to the Bay of Bengal.

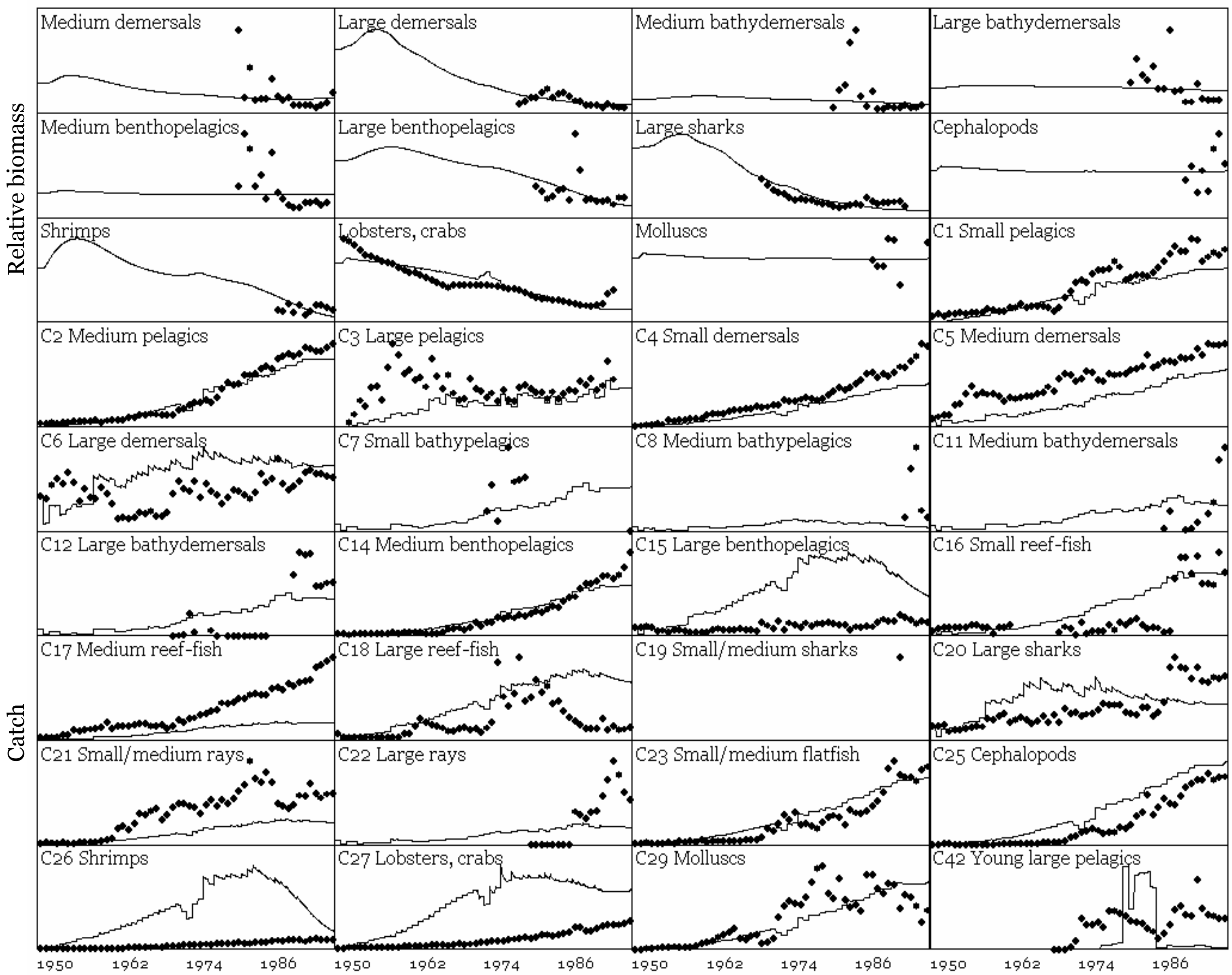

Figure E18. FAO 57- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

All scenarios proposed to double the 2003 small pelagics fleet effort in the last 30 years while only the *security first* scenario projected an increase of demersal fleet effort (Figure E19). The resulting increase in landings comes mainly from small and medium pelagics in all scenarios. The increase in demersal fleet effort in the *security first*, resulted in an increase of small and medium demersal, and cephalopods (Table E9). In the *sustainability first* scenario, where demersal effort has decreased the most, there is a recovery of biomass for the large demersals and for groundfish in general, compared to that of 2003 (Figure E19).

Table E9. Species composition (main species only) of those functional fish groups in area 57 that showed an increase in landings in the last 30 years of the *security first* and the *sustainability first* scenarios.

Group description*	**Genus/species**	**Common name**
1. Small pelagics	*Dussumieria acuta*	Rainbow sardine
	Pellona ditchela	Indian pellona
	Anodontostoma chacunda	Chacunda gizzard shad
	Bregmaceros mcclellandi	Spotted codlet
	Sardinella longiceps	Indian oil sardine
	Sardinella gibbosa	Goldstripe sardinella
	Selaroides leptolepis	Yellowstripe scad
	Sardinella lemuru	Bali sardinella
2. Medium pelagics	*Hilsa kelee*	Kelee shad
	Scomberomorus lineolatus	Streaked seerfish
	Arripis georgianus	Australian ruff
	Tenualosa toli	Toli shad
	Tenualosa ilisha	Hilsa shad
	Megalaspis cordyla	Torpedo scad
	Rastrelliger kanagurta	Indian mackerel
	Scomberomorus guttatus	Indo-Pacific king mackerel
	Lactarius lactarius	False trevally
	Decapterus russelli	Indian scad
	Selar crumenophthalmus	Bigeye scad
	Arripis trutta	Eastern Australian salmon
4. Small demersals e.g.	Leiognathidae and *Nemipterus* spp.	Slipmouths and threadfin breams
5. Medium demersals	*Pterygotrigla polyommata*	Latchet
6. Large demersals	*Lates calcarifer*	Barramundi
	Chrysophrys auratus	Squirefish
	Argyrosomus hololepidotus	Southern meagre
	Muraenesox cinereus	Daggertooth pike conger
	Macruronus novaezelandiae	Blue grenadier
23. Small/medium flatfish	*Psettodes erumei*	Indian spiny turbot

* Note: In addition to the fish groups, one invertebrate group also increased, i.e., cephalopods

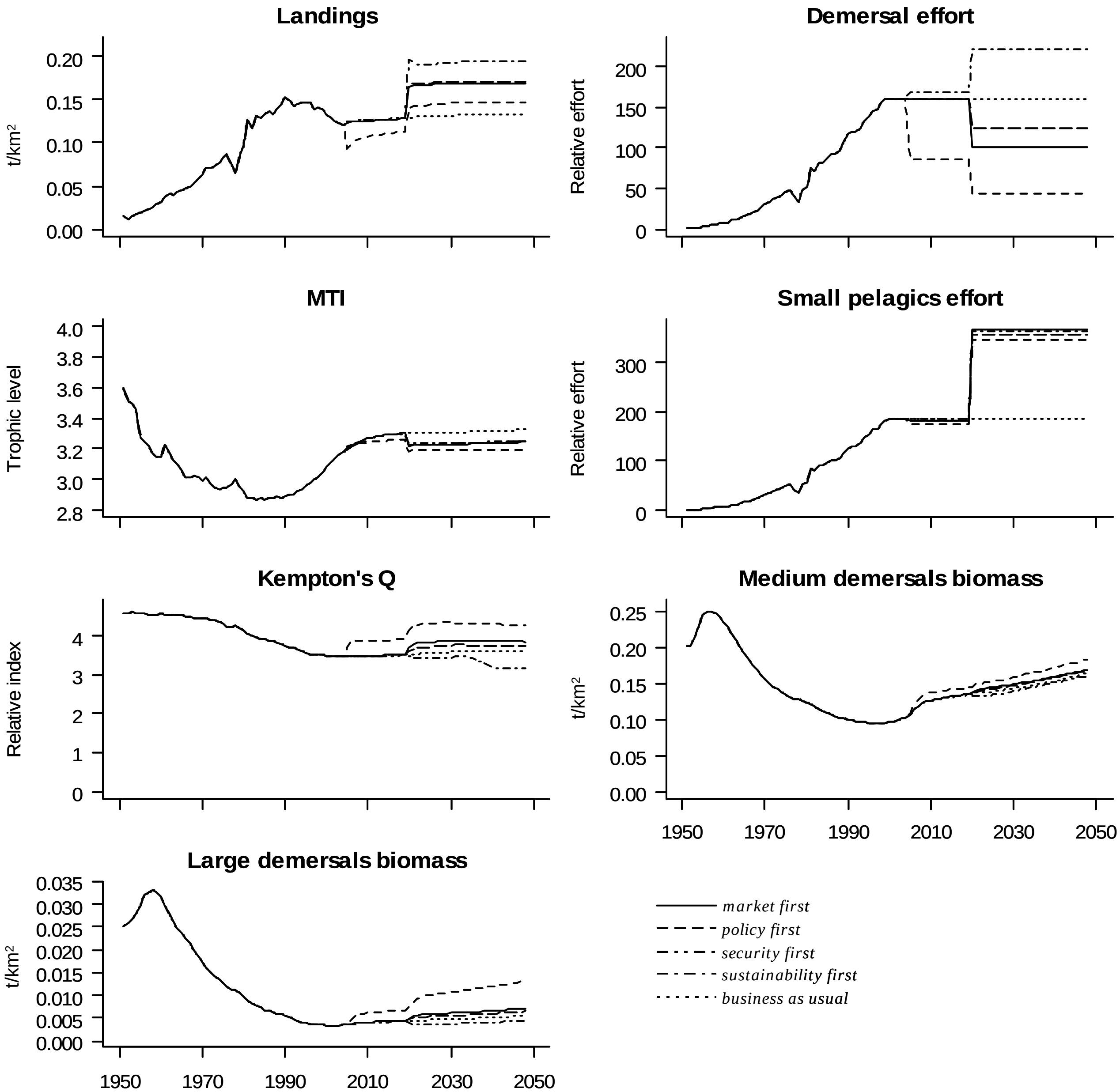

Figure E19. Results of Ecosim policy scenarios for area 57, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 58, Antarctic (South Indian)

For the Antarctic we do not at this time, have enough time series information to reliably fit an Ecosim model. The catch totals for the year 2003 amount to approximately 13,900 tonnes, i.e., only 0.02% of the world total. In the context of global policy scenarios, the catches are not likely to have major implications.

FAO 61, Northwest Pacific

The model was able to predict the catch of several commercially significant groups such as the medium pelagics (C2), medium and large demersals (C5, C6), medium benthopelagics (C14), large sharks (C20), and shrimps (C26) (Figure E20). The biomass time series, however, were not fitted properly. These results are probably due to the fact that the artisanal catch and effort were not included in the model and thus, fishing mortalities are rather low for several commercial groups, which is unlikely for this region of the world.

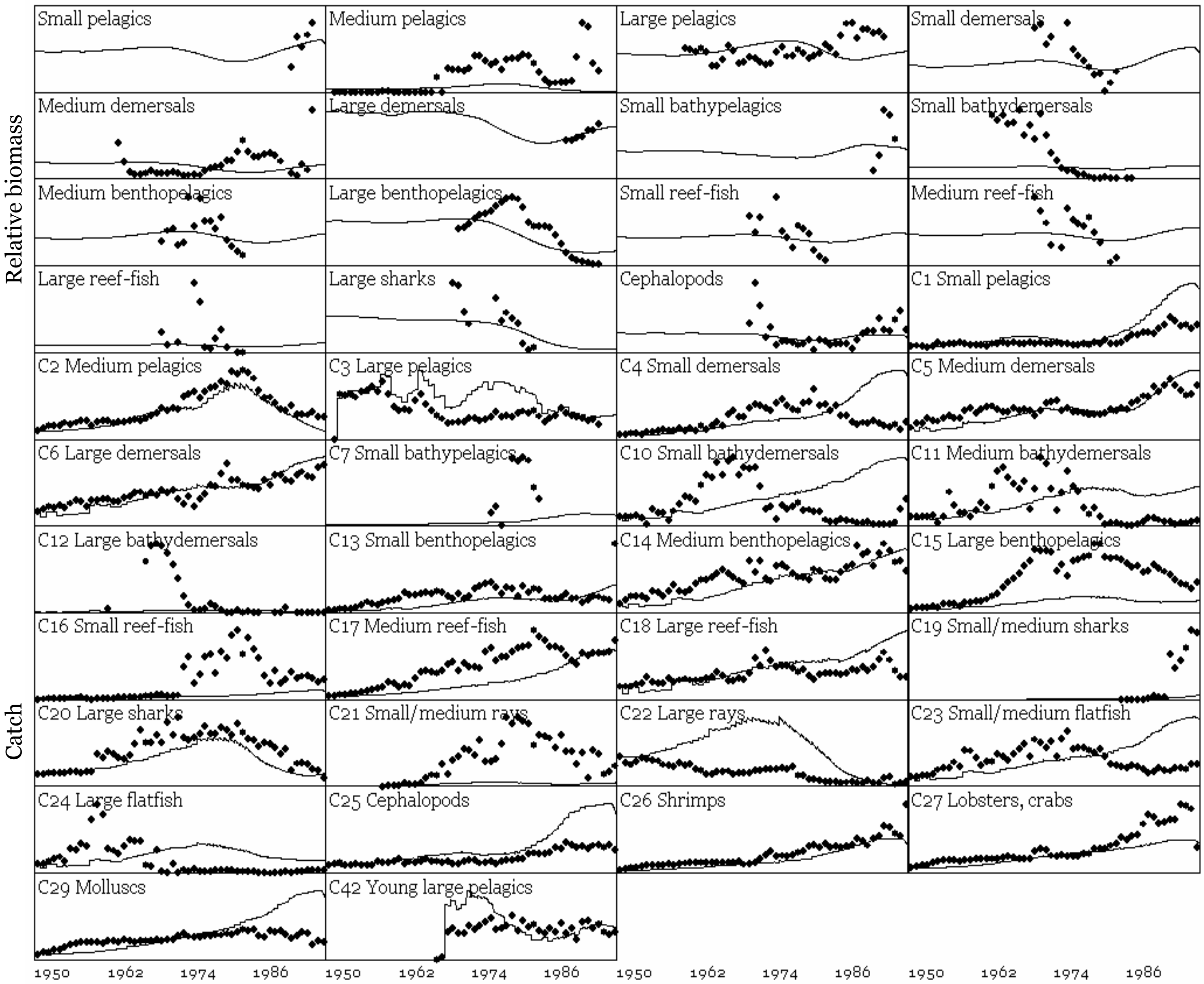

Figure E20. FAO area 61- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

Surprisingly in this case, most scenarios kept levels of demersal and tuna longline efforts similar to that of 2003 except for the *sustainability first* scenario. In this case, the focus was on rebuilding the tuna (large and young). Effort was decreased for the first fifteen years of the simulation, with biomass rebuilding compared to 2003 (Figure E21). The landings were thus increased by increasing the demersal fleet effort, resulting in an increase in landings of primarily lower trophic level groups: i.e., small demersals, small bathypelagics, small bathydemersals, small benthopelagics, small reef-fish, small/medium sharks, and molluscs (Table E10). The increase in landings of lower trophic level species can be seen in the decline of the MTI and Q value for the *sustainability first* scenario, moving towards decreased ecosystem stability (Figure E21).

Table E10. Species composition (main species only) of those functional fish groups in area 61 that showed an increase in landings in the last 30 years of the *sustainability first* and the *business as usual* scenarios.

Group description*	Genus/species	Common name
4. Small demersals	*Stephanolepis cirrhifer*	Thread-sail filefish
	Ammodytes personatus	Pacific sandeel
7. Small bathypelagics	*Maurolicus muelleri*	Pearlsides
10. Small bathydemersals	*Arctoscopus japonicus*	Sailfin sandfish
13. Small benthopelagics	*Ariomma indica*	Indian ariomma
	Glossanodon semifasciatus	Deepsea smelt
	Hypoptychus dybowskii	Korean sandeel
	Psenopsis anomala	Melon seed
	Pennahia argentata	White croaker
16. Small reef-associated	*Priacanthus macracanthus*	Red bigeye

* Note: In addition to the fish groups, one invertebrate group also increased, demersal molluscs

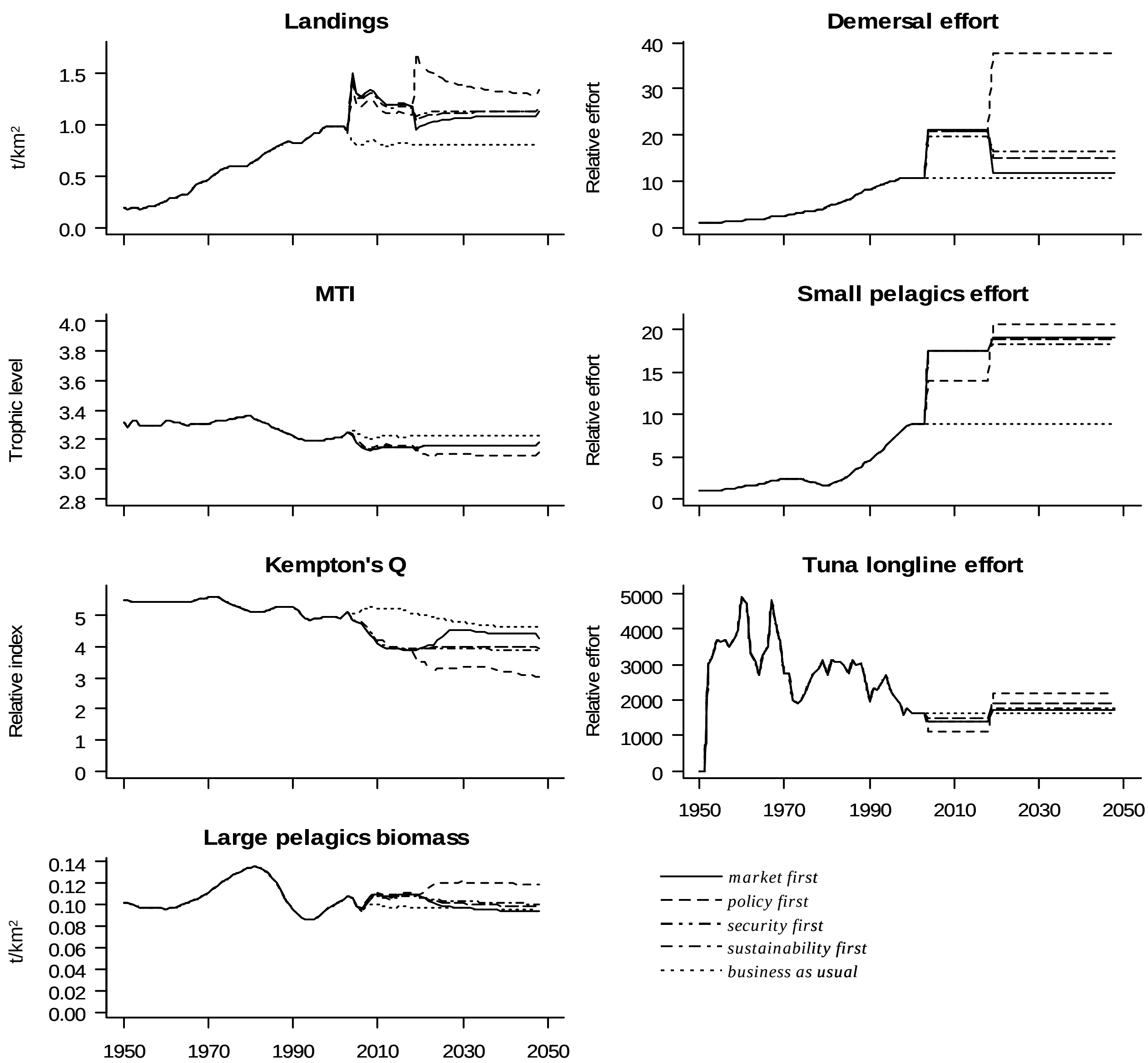

Figure E21. Results of Ecosim policy scenarios for area 61, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 67, Northeast Pacific

FAO area 67 suffers from the same problem as area 27. This region covers a large geographic area that is affected by different climate regimes i.e., the California current and the Alaskan gyre. In addition, the fisheries development and management was not necessarily similar in all parts of area 67. As a consequence, salmon stocks do not have the same biomass trends in the southern part than in Alaska; southern and northern rockfish stocks (*Sebastes* spp., medium demersals) show opposite trends in biomass (Figure E22); Pollock (*Theragra chalcogramma*, large benthopelagics) stock from the Bering Sea show a different trend than that of the Gulf of Alaska (Figure E22). For all these reasons, this model was difficult to fit well; only the large demersal, large reef-fish biomasses, and flatfish catches were reasonably well fitted (Figure E23). Although catches for large benthopelagics seem well fitted, their biomass does not and cannot reflect both the story of pollock, which includes contradictory trends, and of chum salmon. Better results would be achieved by dividing the area into smaller homogenous units, and including climate indices, as will be done in the next phase of this study.

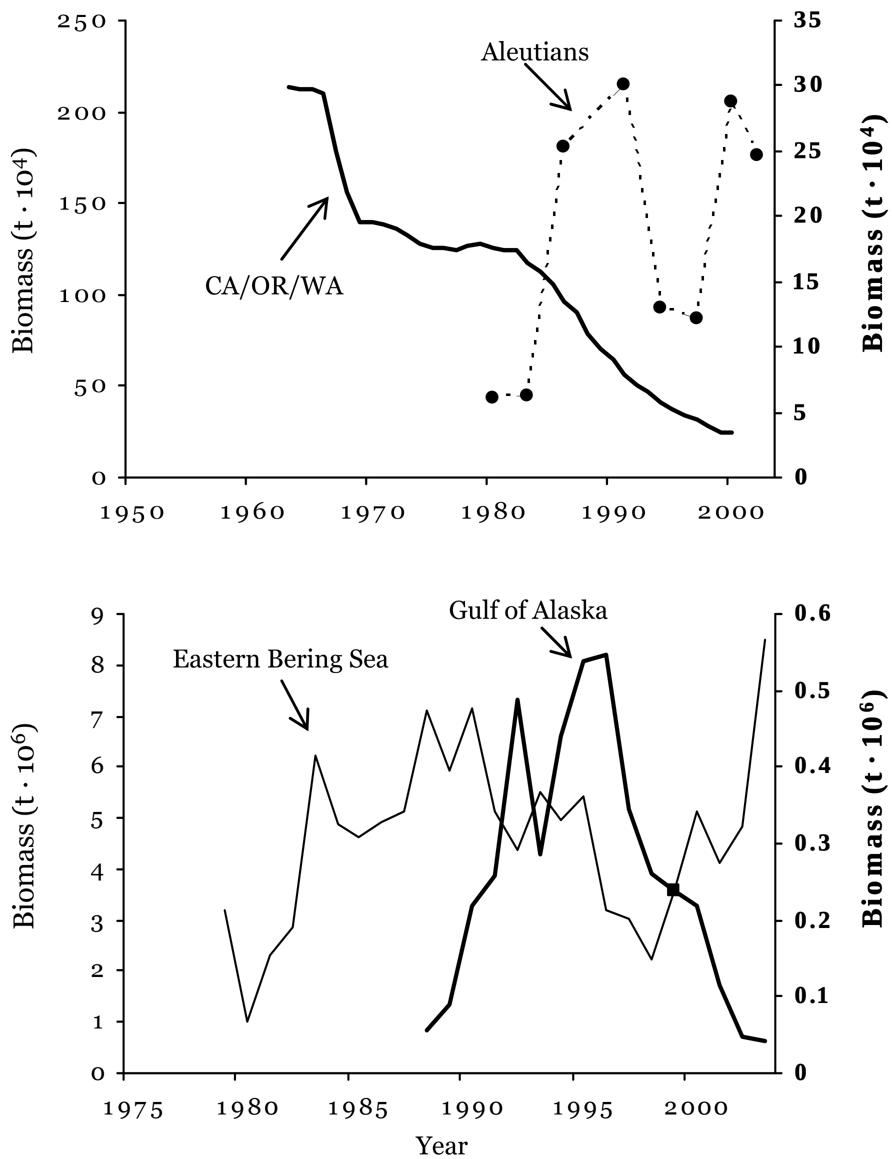

Figure E22. Biomass trends with opposite tendencies in FAO area 67. Graph **A** shows two species of *Sebastes* displaying inverted trends. Solid circles (●) in graph **A** indicate survey years (Rogers, 2003; Spencer and Ianelli, 2003) and dashed lines (--) are interpolated data points. Graph **B** shows two trends of *Theragra chalcogramma*, one in the Eastern Bering Sea and one in the Gulf of Alaska (Dorn *et al.*, 2003; Ianelli *et al.*, 2003). Data point for the Gulf of Alaska in 1999 (●) in graph **B** is interpolated.

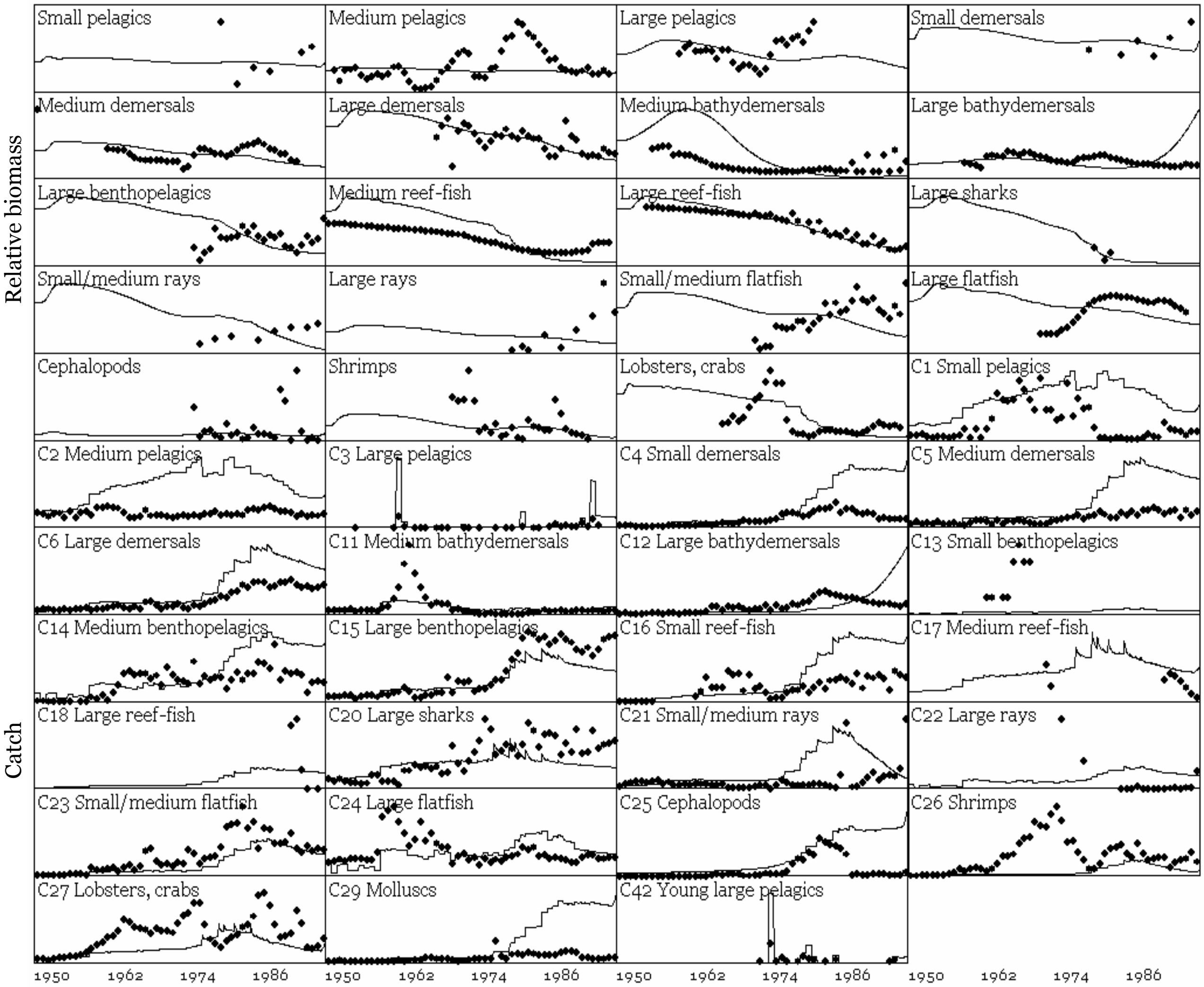

Figure E23. FAO 67- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

Given the limitations mentioned above, interpretations of optimization results can only be limited. All scenarios propose an increase in small pelagics fleet effort, and except for the *sustainability first* scenario, an increase in demersal effort (Figure E24). This would lead to a further decrease in biomass of large fish functional groups (benthopelagics, demersal, sharks), and a decrease in trophic level by increasing landings of small and medium pelagics and smaller small demersals, small/medium benthopelagics, large rays, shrimp and mollusc (Table E11).

Table E11. Species composition (main species only) of those functional fish groups in area 67 that showed an increase in landings in the last 30 years of the *sustainability first* and *market first* scenarios.

Group description*		Genus/species	Common name
1. Small pelagics		*Hypomesus pretiosus*	Surf smelt
		Engraulis mordax	Californian anchovy
2. Medium pelagics		*Sardinops sagax*	South American pilchard
		Trachurus symmetricus	Pacific jack mackerel
		Oncorhynchus nerka	Sockeye salmon
		Cololabis saira	Pacific saury
		Scomber japonicus	Chub mackerel
		Clupea pallasii	Pacific herring
		Alosa sapidissima	American shad
		Thaleichthys pacificus	Eulachon
		Sebastes entomelas	Widow rockfish
4. Small demersals	e.g.	Cottidae	Sculpins
14. Medium benthopelagics		*Genyonemus lineatus*	White croaker
22. Large rays		*Dasyatis akajei*	Red stingray

* Note: In addition to the fish groups, two invertebrate groups also increased, i.e., shrimp and demersal molluscs

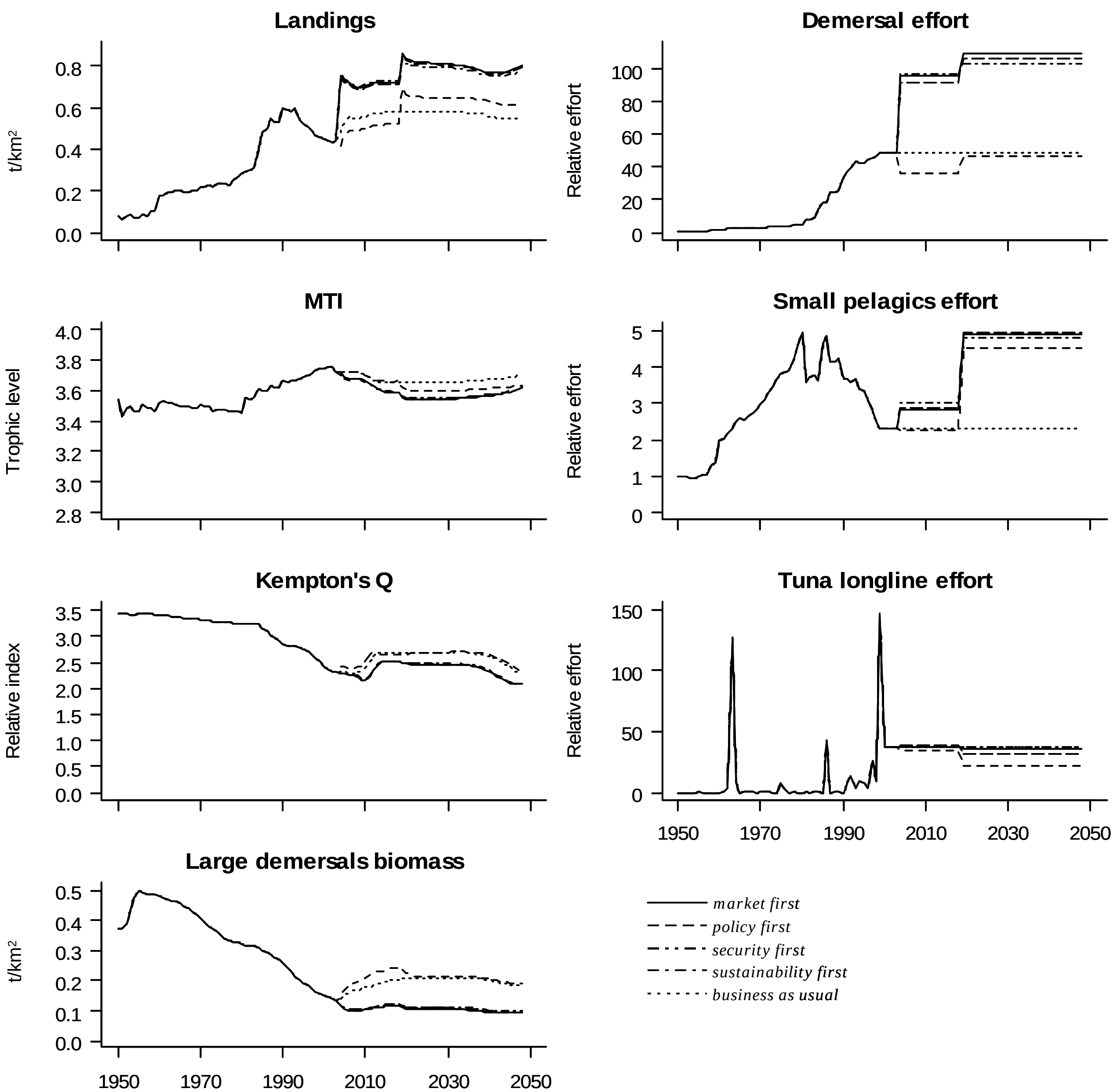

Figure E24. Results of Ecosim policy scenarios for area 67, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 71, Northwest Oceania

We disposed of very few biomass time series for this region and it was still difficult to fit their trends. The model was able to fit some of the catch series such as medium benthopelagics (C14), medium reef-fish (C17), the small tuna (C42) and crabs (C27) (Figure E25). In this area as in areas 51 and 57, the lack of information on artisanal effort and catch for countries like Indonesia and the Philippines is probably a major source of discrepancy, in addition to the lack of information on industrial effort for Australia. The lack of information on the artisinal fishery is probably one of the main factors for low fishing mortalities seen for several commercial groups, which is unlikely for this region of the world.

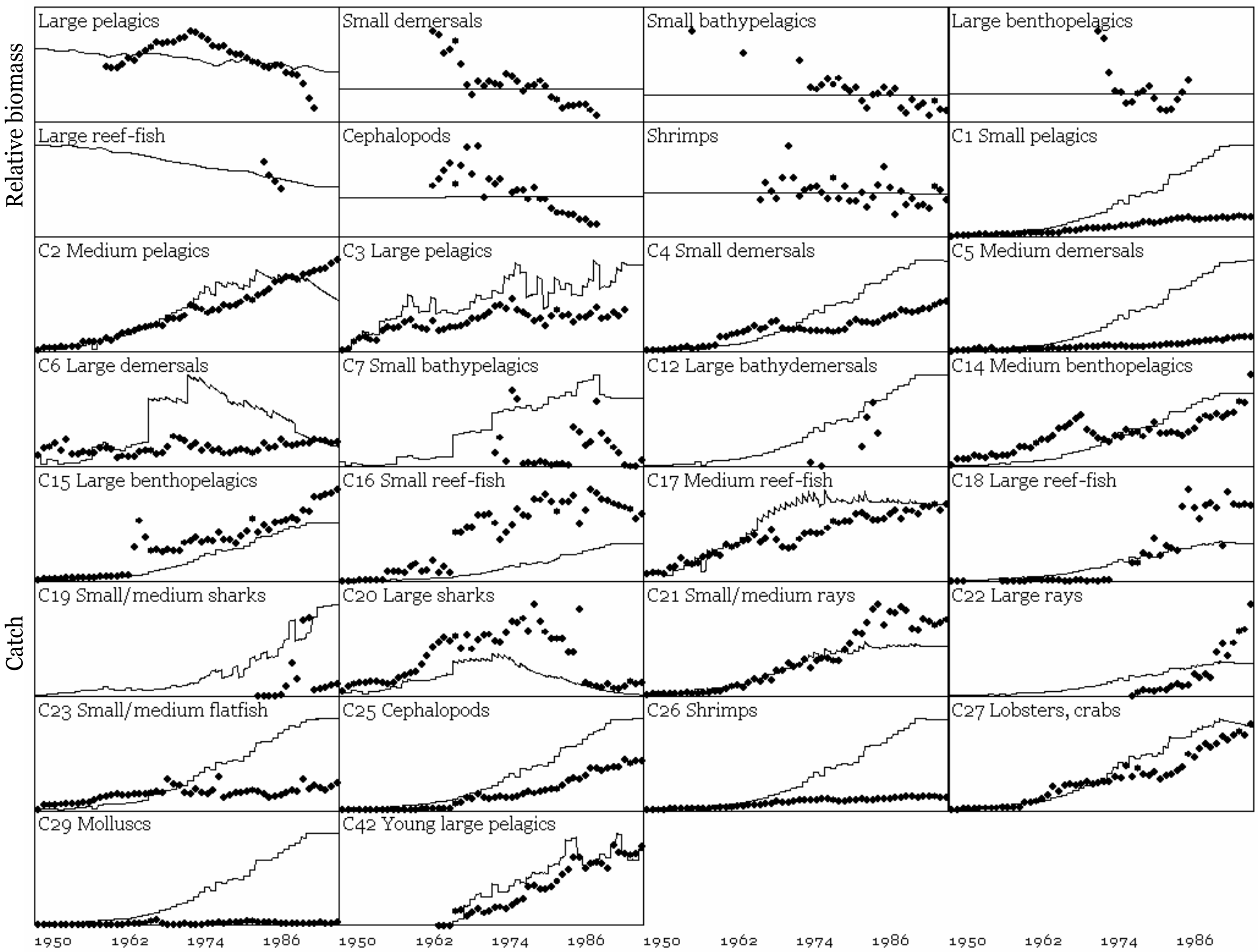

Figure E25. FAO 71- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

All scenarios propose to increase effort for the demersal and small pelagic fleets and decrease that of the tuna longline fleet (Figure E26). The increase in demersal effort has resulted in an increase in landings of most groups including small and secondary fish targets, cephalopods, shrimp and molluscs (Table E12), with an overall decrease in MTI for all scenarios except *business as usual*, which maintained the 2003 level. As a consequence, the biomass of most large fish (large demersals, large sharks, large reef-fish and large rays) has declined (Figure E26). In contrast, results from the *business as usual* scenario, in which demersal effort is maintained to the 2003 value, the large reef-fish are maintaining their biomass. The Kempton's Q value for the *market first* scenario is interesting in that the decline in top predators, results in an initial increase in the Q value over the first 15 years as predation is eased, then the value declines over the last 30 years, in conjunction with continuing increase in demersal fishing effort.

Table E12. Species composition (main species only) of those functional fish groups in area 71 that showed an increase in landings in the last 30 years of the *market first* and *business as usual* scenarios.

Group description*		Genus/species	Common name
1. Small pelagics		*Sardinella gibbosa*	Goldstripe sardinella
		Selaroides leptolepis	Yellowstripe scad
		Decapterus maruadsi	Japanese scad
		Pellona ditchela	Indian pellona
		Anodontostoma chacunda	Chacunda gizzard shad
		Sardinella lemuru	Bali sardinella
		Herklotsichthys quadrimaculatus	Bluestripe herring
		Spratelloides gracilis	Silverstriped round herring
		Dussumieria acuta	Rainbow sardine
4. Small demersals	e.g.	Gobiidae and *Nemipterus* spp.	Gobies and threadfin breams
5. Medium demersals		*Pomadasys argenteus*	Silver grunt
		Trachurus japonicus	Japanese jack mackerel
		Chelidonichthys kumu	Bluefin gurnard
12. Large bathydemersals		*Beryx splendens*	Alfonsino
14. Medium benthopelagics		*Pampus argenteus*	Silver pomfret
		Centroberyx affinis	Redfish
		Parastromateus niger	Black pomfret
		Harpadon nehereus	Bombay duck
16. Small reef-associated	e.g.	Serranidae and Labridae	Groupers and wrasses
18. Large reef-associated		*Lutjanus argentimaculatus*	Mangrove red snapper
23. Small/medium flatfish		*Psettodes erumei*	Indian spiny turbot
		Paralichthys olivaceus	Bastard halibut

* Note: In addition to the above groups, small/medium rays and three invertebrate groups also increased, i.e., cephalopods, shrimp and demersal molluscs

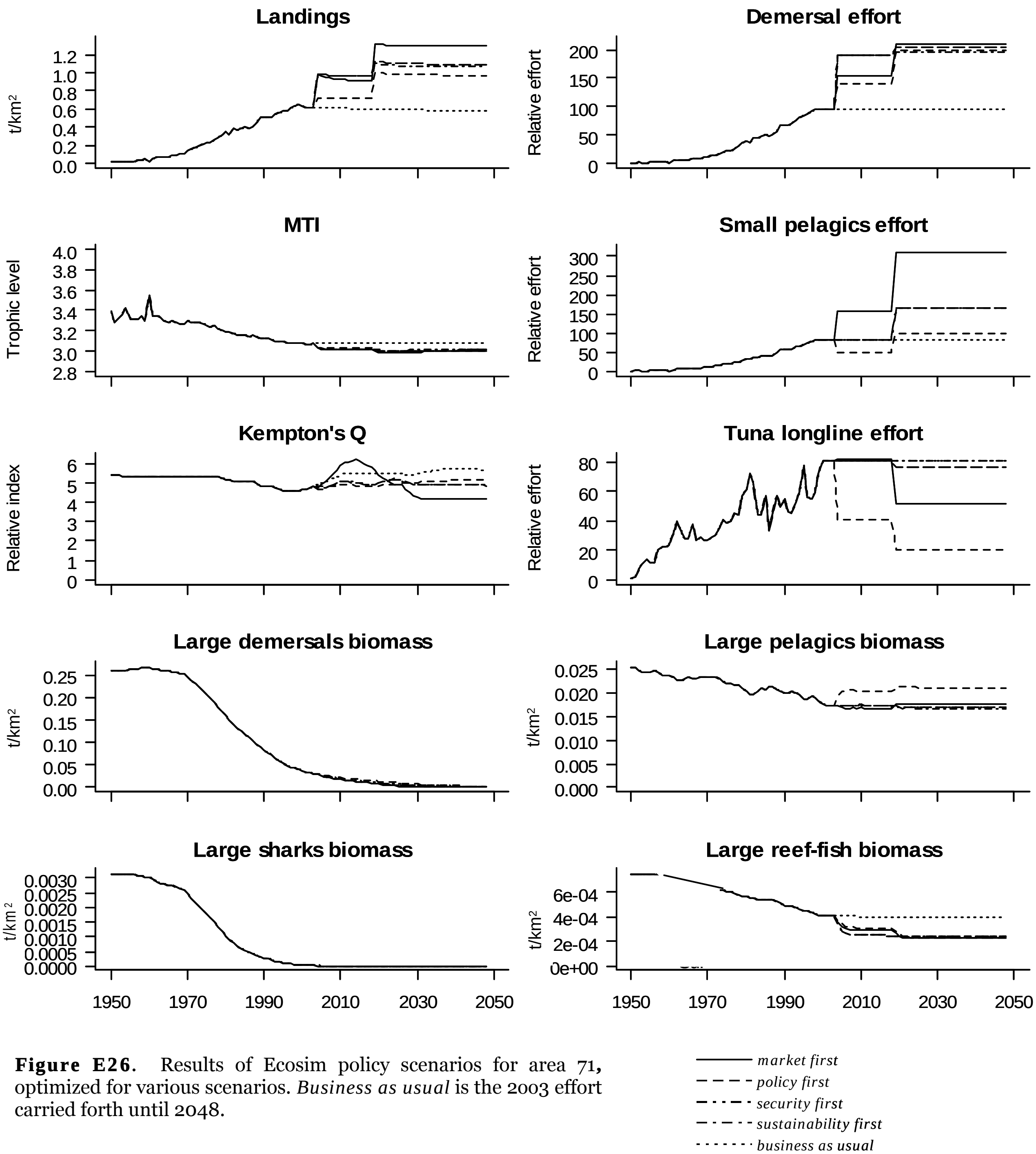

Figure E26. Results of Ecosim policy scenarios for area 71, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 77, California current

The model was able to predict the biomass of large benthopelagics and large reef-fish. The biomass of small and medium pelagics, which should be driven by climatic regimes as well as fishing, was not well predicted by the model (Figure E27). Note that the collapse of the California sardine occurred prior to 1950 (Radovich, 1982), so the trend included in the model is starting at the low point of the stock/group. The model was able to predict catches for several groups: the small and large pelagics (C1, C3), small and medium demersals (C4, C5), large sharks (C20), and small flatfish (C23).

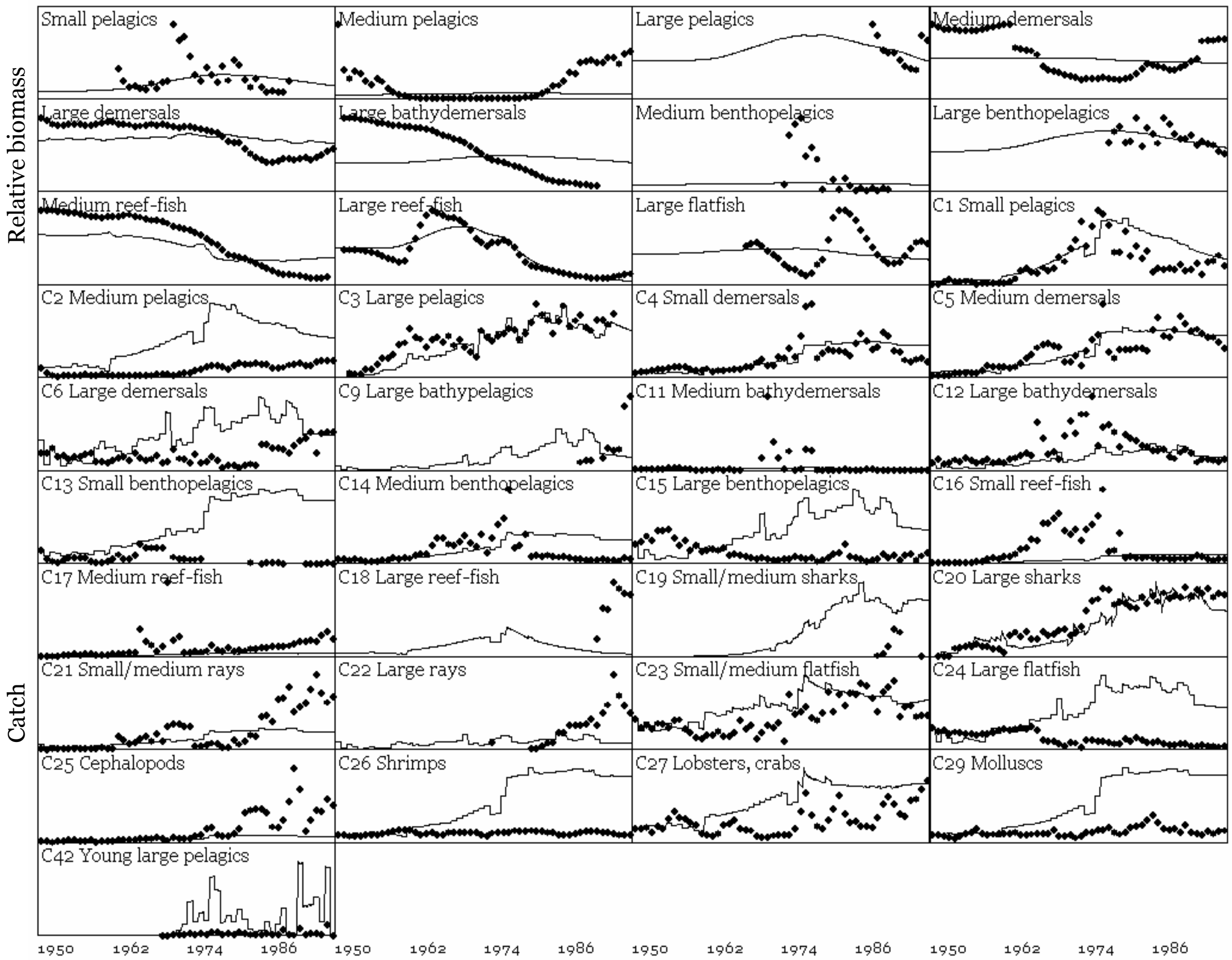

Figure E27. FAO area 77- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

With the exceptions of the distant water and tuna baitboat fleets, where 2003 effort was maintained, all scenarios proposed to increase effort for the other three fleets, a result that is to be taken with a grain of salt, given the problems identified while fitting the model (Figure E28). As landings increased, the MTI and Q value decreased, reflecting the fact that the composition of the catch turned to smaller fish (small demersals, medium bathydemersals, and small/medium flatfish), shrimps and molluscs (Table E13).

Table E13. Species composition (main species only) of those functional fish groups in area 77 that showed an increase in landings in the last 30 years of the *market first* and *business as usual* scenarios.

Group description		Genus/species	Common name
1. Small demersals		*Brachydeuterus auritus*	Bigeye grunt
11. Medium bathydemersals	e.g.	Myxinidae	Hagfishes
23. Small/medium flatfish		*Lepidopsetta bilineata*	Rock sole
		Atheresthes stomias	Arrowtooth flounder
		Eopsetta jordani	Petrale sole
		Glyptocephalus zachirus	Rex sole
		Microstomus pacificus	Dover sole
		Psettichthys melanostictus	Pacific sand sole
		Parophrys vetula	English sole

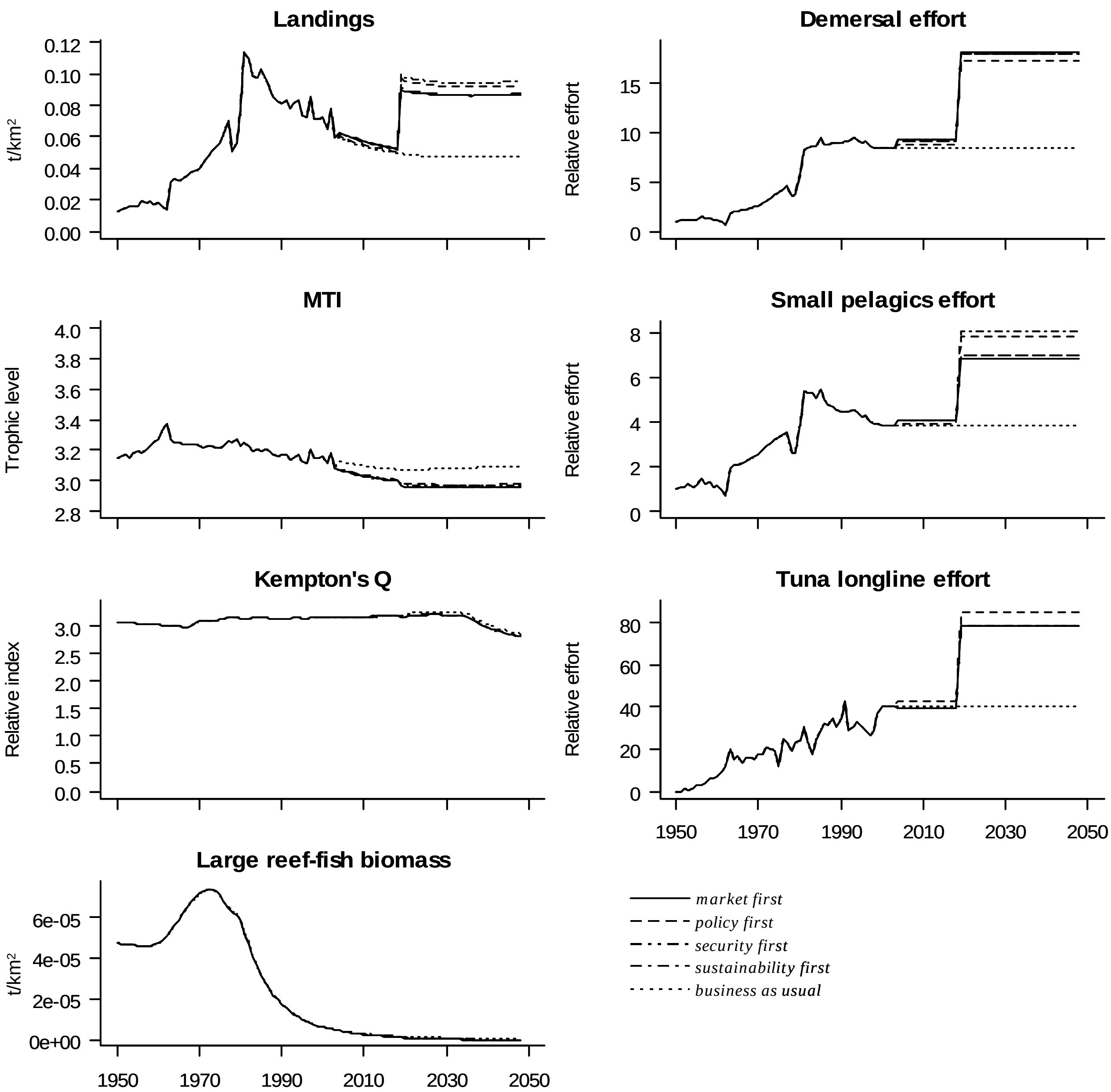

Figure E28. Results of Ecosim policy scenarios for area 77, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 81, Southwest Pacific

At this time, data is limited for this region of Oceania and time series are generally short. The model was not able to fit the observed biomasses. Catches were also not well-fitted with the exception of the large tuna (C3, C42), large sharks (C20), and cephalopods (C25) (Figure E29). This area is also affected by the lack of information on industrial effort for Australia.

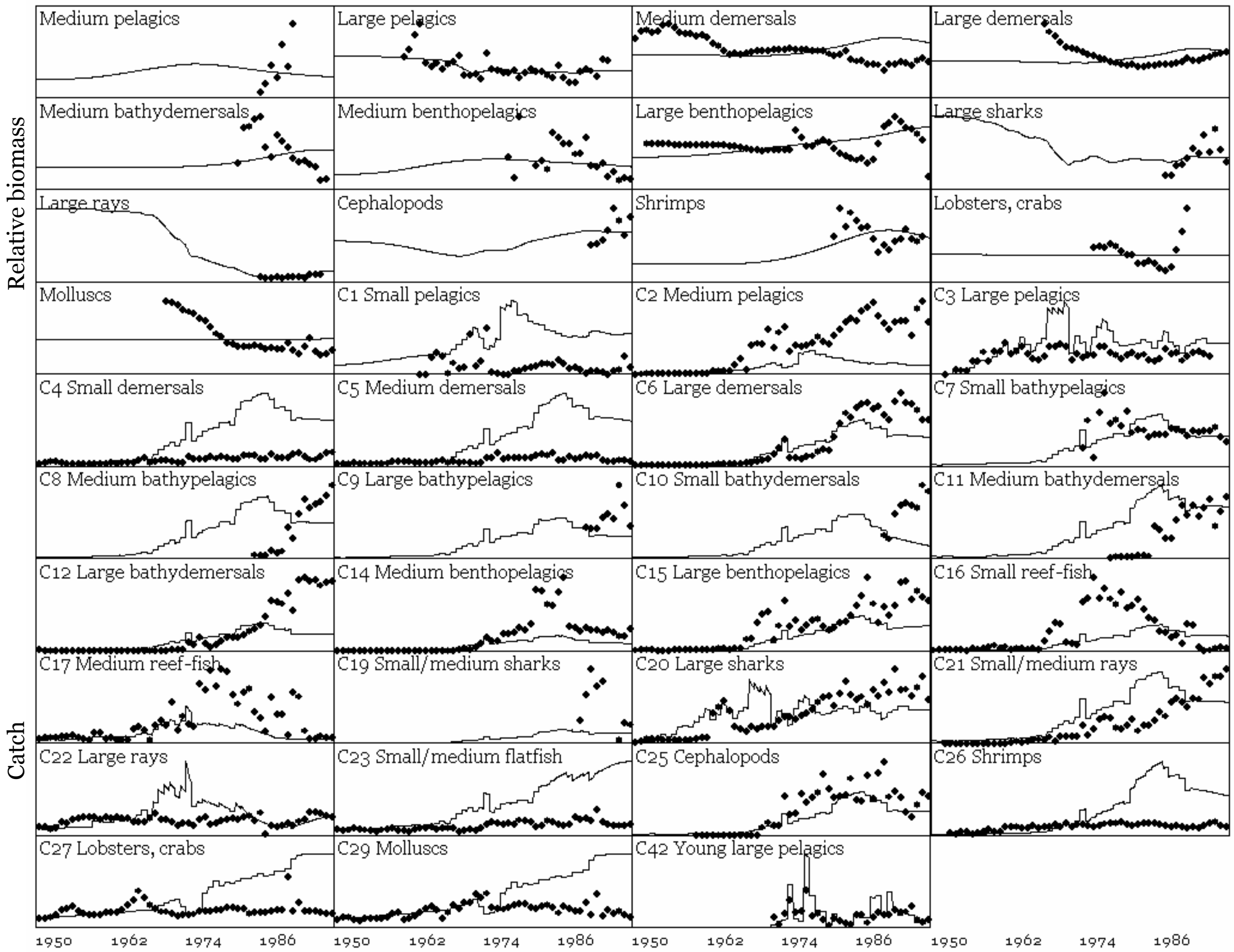

Figure E29. FAO area 81- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (graph title starting with 'C' then the group number) and biomass time series from 1950-2003.

The *sustainability first* scenario proposed a decrease in effort for all fleets except for the demersal fleet for which effort was doubled after the first 15 years (Figure E30). All other scenarios proposed an increase in effort of the demersal, small pelagics and tuna longline fleets. The increase in demersal effort resulted in an increase in landings of most demersal groups mostly dominated by lower trophic levels groups: small/medium demersals, small reef-fish, small rays, cephalopods, shrimps and molluscs (Table E14). As a result the MTI decreased in all cases, while the Q value remained constant (Figure E30).

Table E14. Species composition (main species only) of those functional fish groups in area 81 that showed an increase in landings in the last 30 years of the *market first* and *business as usual* scenarios.

Group description*		Genus/species	Common name
1. Small pelagics	e.g.	Engraulidae	Anchovies
3. Large pelagics		*Thunnus obesus*	Bigeye tuna
		Thunnus albacares	Yellowfin tuna
		Thunnus alalunga	Albacore
		Katsuwonus pelamis	Skipjack tuna
		Thunnus tonggol	Longtail tuna
		Thunnus orientalis	Pacific bluefin tuna
		Thunnus maccoyii	Southern bluefin tuna
15. Large benthopelagics		*Atractoscion aequidens*	Geelbeck croaker
		Oncorhynchus tshawytscha	Chinook salmon
		Micromesistius australis	Southern blue whiting
		Ruvettus pretiosus	Oilfish
		Pseudocaranx dentex	White trevally
		Merluccius australis	Southern hake
		Thyrsites atun	Snoek
		Zeus faber	John dory
		Rexea solandri	Silver gemfish
19. Small/medium sharks	e.g.	*Etmopterus* spp.	Lanternsharks
22. Large rays	e.g.	Myliobatidae	Rays
23. Small/medium flatfish	e.g.	*Rhombosolea* spp.	Flounders

* Note: In addition to the fish groups, two invertebrate group also increased, i.e., lobsters/crabs and demersal molluscs

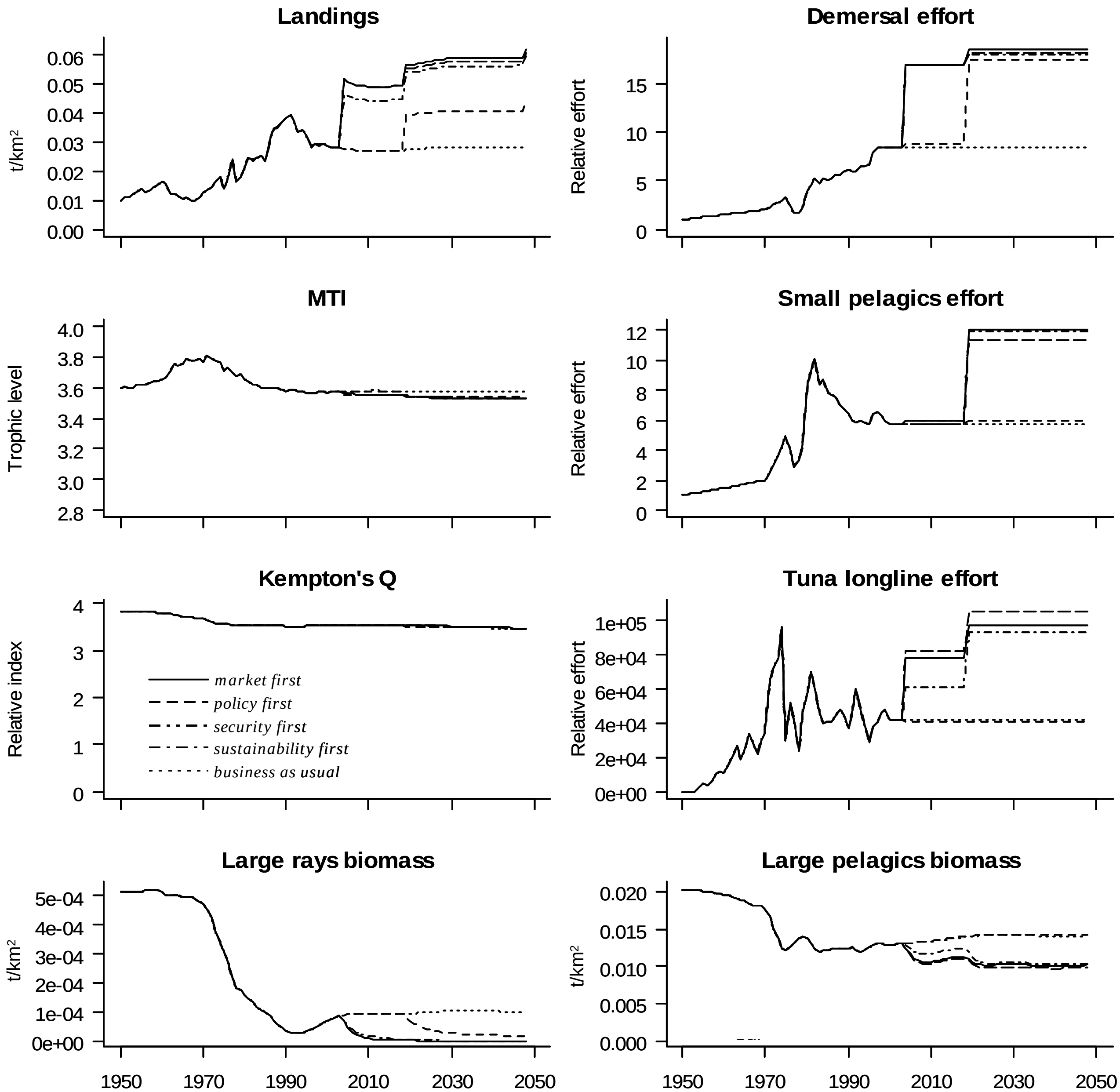

Figure E30. Results of Ecosim policy scenarios for area 81, optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 87, Southeast Pacific

Area 87 is an interesting case study, which includes an upwelling ecosystem well-studied for its large biomass of small pelagics and the spectacular collapse of anchovy caused by El Niño events in the 1970s. The collapse of anchovy was soon followed by an increase in sardine. Since both species belong to the same functional group, the biomass trend cannot account for both species and the dynamics cannot be reproduced by the model (Figure E31). Finally, the model does not include climate indices which are known to explain a large part of biomass variations, so it is no surprise that the small and medium pelagics are not well fitted. Only catches for large sharks (C20) were well predicted by the model.

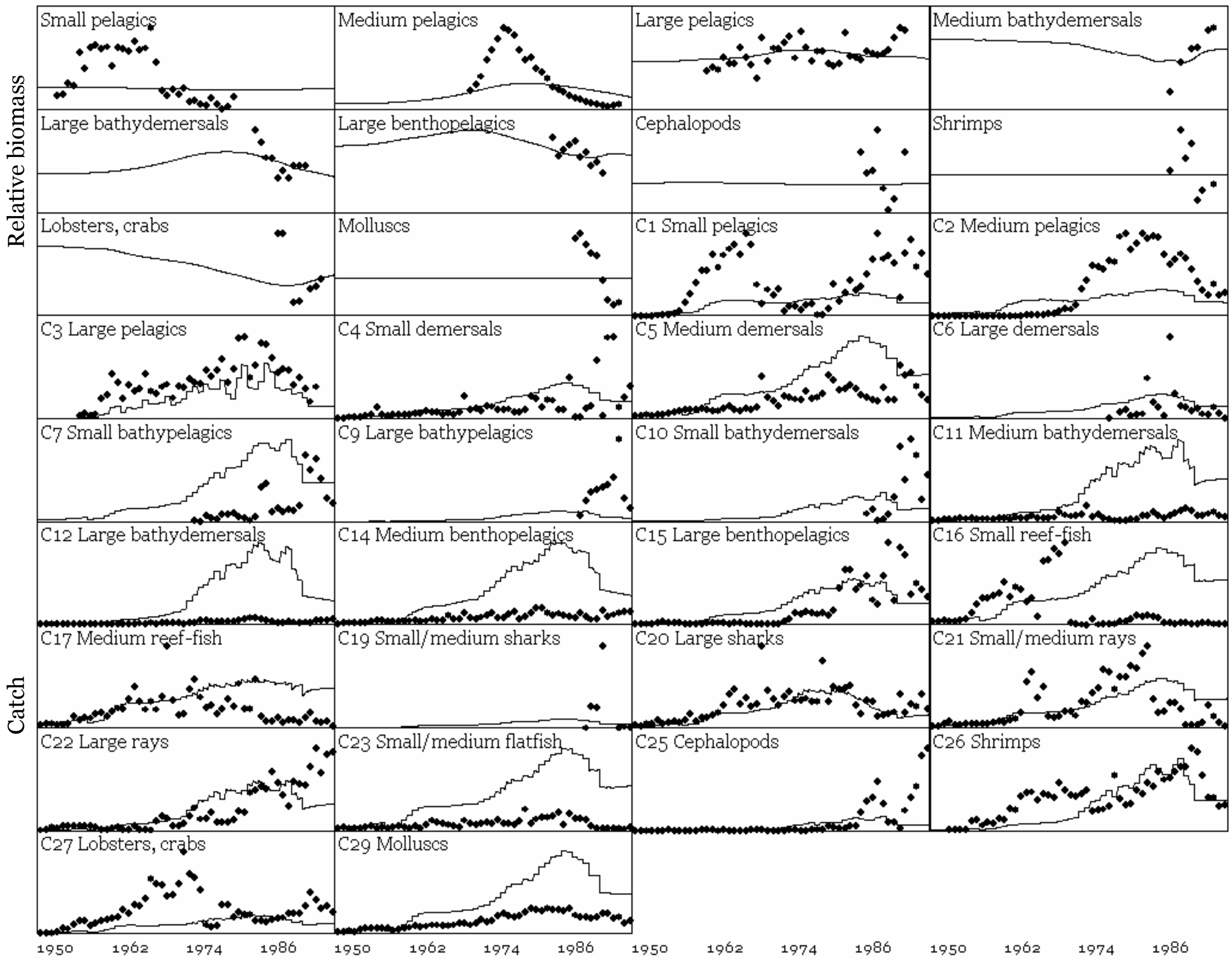

Figure E31. FAO area 87- Observed (dots) and predicted (lines) results of fitting Ecosim to catch (series starting with 'C' then the group number) and biomass time series from 1950-2003.

Given the lack of fit of the model, the simulation results should be taken with caution. The scenarios yielded very different strategies in this area. The *sustainability first* scenario increased effort for the demersal and small pelagic fleets, although at a lesser degree than the others, while the *security first* scenario was the one decreasing the small pelagics fleets effort and keeping the demersal effort at the lowest level (Figure E32). The tuna longline fleet was kept close to the 2003 effort level for all scenarios. The MTI increased over the last 30 years of the optimization in the *security first* scenario, given the decrease in demersal and small pelagic effort and the stabilization and recovery of the large pelagics and large demersals respectively (Figure E32 and Table E15).

Table E15. Species composition (main species only) of those functional fish groups in area 87 that showed an increase in landings in the last 30 years of the *market first* and *security first* scenarios.

Group description*		**Genus/species**	**Common name**
1. Small pelagics		*Engraulis ringens*	Anchoveta
		Ethmidium maculatum	Pacific menhaden
		Cetengraulis mysticetus	Pacific anchoveta
		Odontesthes regia	Silverside
		Etrumeus teres	Round herring
		Strangomera bentincki	Araucanian herring
		Opisthonema libertate	Pacific thread herring
5. Medium demersals		*Salilota australis*	Tadpole codling
		Paralonchurus peruanus	Peruvian banded croaker
		Genypterus maculatus	Black cusk-eel
		Cynoscion analis	Peruvian weakfish
		Chelidonichthys kumu	Bluefin gurnard
		Chloroscombrus orqueta	Pacific bumper
6. Large demersals		*Mycteroperca xenarcha*	Broomtail grouper
		Polyprion oxygeneios	Hapuka
10.Small bathydemersals	e.g.	*Epigonus* spp.	Cardinalfishes
16. Small reef-associated	e.g.	Serranidae	Groupers
17. Medium reef-associated		*Epinephelus analogus*	Spotted grouper
		Lutjanus argentiventris	Yellow snapper
21. Small/medium rays		*Rhinobatos planiceps*	Pacific guitarfish
23. Small/medium flatfish	e.g.	Cynoglossidae	Soles and other flatfishes

* Note: In addition to the fish groups, two invertebrate group also increased, i.e., lobsters/crabs and demersal molluscs

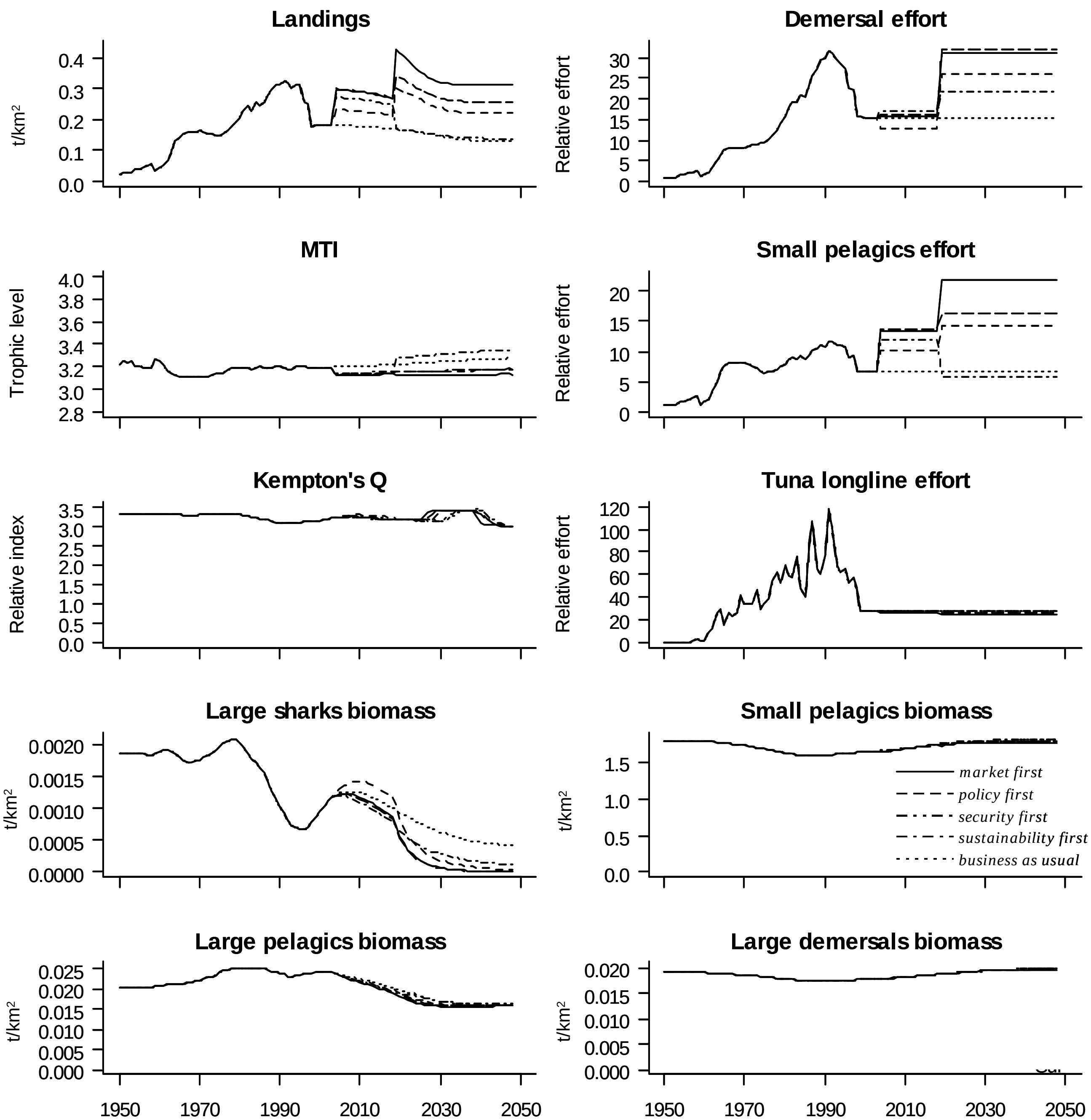

Figure E32. Results of Ecosim policy scenarios for area 87**,** optimized for various scenarios. *Business as usual* is the 2003 effort carried forth until 2048.

FAO 88, Antarctic (South Pacific)

For the Antarctic we do not presently, have enough time series information to be able to generate robust results with an acceptable level of uncertainty from the model. The catch totals for the year 2003 amount to approximately 2200 tonnes, i.e. only 0.003% of the world total. In the context of global policy scenarios, these catches are not likely to have major implications.