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Examining Management Issues for Incidentally Caught Species in Highly Migratory Species Fisheries in the Western and Central Pacific Ocean

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Examining Management Issues for Incidentally Caught Species in Highly Migratory Species Fisheries in the Western and Central Pacific Ocean

A dissertation submitted in partial satisfaction of the requirements for the degree

Doctor of Environmental Science and Engineering

by

Valerie Ann Chan

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ABSTRACT OF THE DISSERTATION

Examining Management Issues for Incidentally Caught Species

in Highly Migratory Species Fisheries in the Western and Central Pacific Ocean

by

Valerie Ann Chan

Doctor of Environmental Science and Engineering

University of California, Los Angeles, 2014

Professor Richard F. Ambrose, Chair

The Western and Central Pacific Fisheries Commission (WCPFC) is the regional fisheries management organization (RFMO) responsible for managing highly migratory species in the western and central Pacific Ocean (WCPO). Although fisheries in the WCPFC generally target tuna and swordfish species, many other species are also incidentally caught as well. Outside of protected species such as sea turtles and seabirds, the WCPFC has spent limited time considering management for incidentally caught species. This dissertation investigated management issues related to catch of incidental species – specifically for an individual stock of interest and also more broadly evaluating a policy on catch of all incidentally caught species.

In 2010, the WCPFC adopted conservation and management measure (CMM) 2010-01 for North Pacific striped marlin (*Kajikia audax*), and a stock assessment completed in 2012

indicated that the levels of harvest allowed under the CMM would result in overfishing (Lee et al. 2012). Although CMM 2010-01 included a provision that directed the Commission to revise the measure if new information warranted changes, the WCPFC has not to date considered any revisions. If the WCPFC were to revise the measure, it could simply revise the limits applicable to each member and/or prescribe more detailed restrictions such as effort limits and gear modifications.

In the United States, proposed CMMs undergo substantial review internally as well as externally by its stakeholders (e.g., fishermen, processors, environmental non-governmental organizations, etc.) participating on advisory groups and as members of the U.S. delegations to the WCPFC meetings before they are submitted to the WCPFC for consideration. The first part of this dissertation identified factors and criteria considered important in developing a new or revised conservation and management measure for striped marlin, as well as understanding what management options were considered by respondents best to meet those objectives. The Analytical Hierarchy Process (AHP) was used to develop a survey that could quantitatively evaluate preference. Additionally, demographic and short answer questions were included to collect information not covered by the AHP comparisons. Forty participants including representatives from government agencies as well as the fishing industry provided responses to the survey. There were similarities overall, and between government and fishing industry respondents, in the weightings of the various factors with respondents weighting biological factors more than economic, social and political factors when considering management options for north Pacific striped marlin. Management options with the highest ratings were circle hooks and catch limits while the lowest ratings were for a retention ban. Participants had a broad range of opinions on the need to limit catch of striped marlin, and some participants indicated they would be willing to support the need for management if there was more scientific support or information available on its efficacy.

Although several management options exist for managing striped marlin, impacts may vary depending on the option selected and impact extend to species beyond just striped marlin. The second part of this dissertation used an Ecopath with Ecosim model of the central and north Pacific Ocean to evaluate how implementation of different management measures for N. Pacific striped marlin would impact biomasses of striped marlin and other groups. Increases in fishing effort had the greatest impact on relative biomass, with declines in most of the higher level trophic groups and increases in many of the mid-level trophic groups. Measures that limited catch of only striped marlin did not result in impacts to other groups. For example, the use of circle hooks and the elimination of the shallowest hooks from deep longline sets led to increases in striped marlin biomass, with limited effects to other species. This dissertation also compared the impacts of implementation of measures by the U.S. fleet and by other foreign fleets, and predicted recovery of striped marlin to depend on implementation of measures by other foreign fleets; conservation measures adopted unilaterally by the United States would have a minimal impact on biomass recovery for this species as its catch represents a small portion of total catch of N. Pacific striped marlin.

Several tuna RFMOs have adopted retention requirements for skipjack, bigeye and yellowfin tunas caught by purse seine vessels to reduce discards, create disincentives to catch small fish, and incentivize the development and adoption of more selective technologies. Although retention policies in the tuna RFMOs have been limited to target tunas in purse seine fisheries, some stakeholders have advocated for an expansion of those policies, and tuna RFMOs could consider expanding retention policies to a greater number of species and/or to other gear types. The third part of this dissertation discusses the benefits and costs of broader retention policies for purse seine and longline tuna fisheries in the WCPO. Using bycatch data from observers and logbooks from the U.S. purse seine and longline fleets operating in the WCPO, this dissertation documents the types and magnitude of fish discarded. For the purse seine fishery, this information was used to estimate direct impacts of having to off-load at the initial point of landing in key Pacific Island ports. For the longline fishery, estimates of direct impacts were limited to Honolulu and Pago Pago, American Samoa, the two primary ports where U.S. catch is landed. Expanding retention policies beyond the target tunas and to other gear types would further reduce discards and possibly provide stronger incentives to develop and use more selective techniques. Beyond impacts to the ecosystem and fisher behavior, adopting broader retention policies may have other implications, and this dissertation explores those implications on vessels, processors, and communities.

The dissertation of Valerie Ann Chan is approved.

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2014

DEDICATION

For my parents, Barbara and Kelly, and my brother, Daryl

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AWARDS

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CHAPTER ONE: INTRODUCTION

Concerns over the effects of fishing have grown as studies have observed reductions in populations of target species, declines in top predator species, trophic shifts, and the tendency of fisheries to adapt to declining catches by shifting to species from lower trophic levels (Myers and Worm 2003; Frank, Petrie et al. 2005; Pauly, Watson et al. 2005). However, because fisheries provide an important source of food, employment and income worldwide, there is considerable interest in ensuring their sustainability (FAO 2010).

Interest in sustainable management for transboundary fish stocks and other fish stocks not under national jurisdiction have led to the development of regional fisheries management organizations (RFMOs) including the Western and Central Pacific Fisheries Commission (WCPFC). Established in 2004, the WCPFC was the largest in area and by harvest of the highly migratory fish species (HMS) RFMOs to develop, and its objective is "to ensure, through effective management, the long-term conservation and sustainable use of highly migratory fish stocks in the western and central Pacific Ocean…." The WCPFC Convention Area covers almost 20% of the earth's surface and generally encompasses the Pacific Ocean west of 150° W to the Asian continent, but excludes the South China Sea. Currently, the Commission has 26 members, 7 participating territories and 9 cooperating non-members[1] (collectively referred to as CCMs). The Commission meets annually and all decisions on conservation and management

[1] Member to the WCPFC include Australia, China, Canada, Cook Islands, European Union, Federated States of Micronesia, Fiji, France, Indonesia, Japan, Kiribati, Korea, Republic of Marshall Islands, Nauru, New Zealand, Niue, Palau, Papua New Guinea, Philippines, Samoa, Solomon Islands, Chinese Taipei, Tonga, Tuvalu, United States of America and Vanuatu. Participating territories to the WCPFC are American Samoa, Commonwealth of the Northern Mariana Islands, French Polynesia, Guam, New Caledonia, Tokelau, and Wallis and Futuna. Cooperating non-members to the WCPFC are Belize, Democratic People's Republic of Korea, Ecuador, El Salvador, Mexico, Senegal, Vietnam, Panama and Thailand.

measures (CMMs) have been made by consensus[2]. The WCPFC also has several standing committees including the Scientific Committee, the Northern Committee, and the Technical and Compliance Committee which meet prior to the annual Commission meeting.

As of December 2013, the Commission had adopted 59 CMMs and 5 nonbinding resolutions. CMMs cover a range of topics including management of fish stocks, handling of species of concern (e.g. sharks, sea turtles, seabirds, etc.), duties of cooperating non-members, requirements to maintain the Commission's record of fishing vessels, and protocols and requirements related to the regional observer program. Requirements in CMMs typically apply for the duration specified within in the CMM or until the CMM is revised or replaced by another CMM. The Commission has adopted CMMs for many of the fish species for which stock assessments have been completed. Most of these stock assessments have focused on target fish stocks (i.e., tunas and swordfish), but several stock assessments have been done on incidental species such as striped marlin (*Kajikia audax*), blue marlin (*Makaira mazara*), silky shark (*Carcharhinus falciformis*), and oceanic whitetip shark (*Carcharhinus longimanus*) (Davies, Hoyle et al. 2012; Lee, Piner et al. 2012; Rice and Harley 2012; Lee, Chang et al. 2013; Rice and Harley 2013).

Bycatch and discards of non-target and incidental species in fisheries have become increasingly important topics in fisheries management. Estimates of global fisheries discards range between 7-30 million tons per year, and discards rates for fisheries can range from <1% for

[2] If consensus cannot be reached, the convention establishing the WCPFC describes a two-chambered voting system which may be used to adopt measures that do not include allocation components, but the Commission has never exercised this decision-making option. Under a two-chambered voting system, members of the Fisheries Forum Agency (FFA) constitute one chamber, and non-FFA members constitute the other chamber. Decisions may be adopted if there is a ¾ majority in both chambers, and cannot be defeated by less than 3 votes in either chamber. Note, the Fisheries Forum Agency (FFA) is a regional intergovernmental organization formed in 1979 to promote capacity building and build regional solidarity related to the tuna fisheries interests of its Pacific Island members. Members of FFA include are Australia, Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, New Zealand, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu and Vanuatue

tuna pole and line fisheries to over 60% for shrimp trawl fisheries (Alverson 1994; Kelleher 2005). Given that some of these discards include species that are important food fish in many local communities, measures encouraging the minimization of waste, discards and catch of non-target species have been adopted by many organizations, including the FAO in its 1995 FAO Code of Conduct for Responsible Fisheries, the WCPFC in its resolution 2005-03 on non-target fish species, and the European Union in its adoption of landing obligation for its fisheries in its common fisheries policy in 2013.

Bycatch can be defined as the total catch of non-target animals, which includes animals incidentally caught and retained, and animals caught and discarded (Alverson 1994). Discards are differentiated from bycatch as discards may include non-target animals, but may also include target animals that are not retained (Alverson 1994). Also, species that may be targeted in some fisheries may be considered incidental catch in others. For example, bigeye tuna (*Thunnus obesus*) are targeted by some longline vessels but are caught incidentally by purse seine vessels targeting yellowfin tuna (*T. albacares*) and skipjack tuna (*Katsuwonus pelamis*) in the western and central Pacific Ocean (WCPO).

Though there has been some movement to address catches of incidental species in the WCPFC through adoption of CMMs, most of that attention has focused on reducing interactions with protected species (sea turtles, seabirds, and marine mammals), key sharks species , and reducing catches and discards of juvenile target fishes. As mentioned previously, the WCPFC has reviewed stock assessments for a few incidentally caught species, and stock assessments for north Pacific striped marlin, silky sharks and oceanic whitetip sharks indicated that these stocks were depleted and fishing mortality was above fishing mortality at maximum sustainable yield (MSY) (Lee, Piner et al. 2012; Rice and Harley 2012; Rice and Harley 2013). For silky sharks and oceanic whitetip sharks, the WCPFC adopted CMMs 2011-04 and 2013-08, respectively, which prohibited retention of these species. For N. Pacific striped marlin, the WCPFC adopted CMM 2010-01, which imposed catch limits on members and included a provision directing the WCPFC to amend the measure based on information from a new stock assessment. Although a new stock assessment for N. Pacific striped marlin was completed in 2012, to date no changes have been made to the existing measure (Lee, Piner et al. 2012).

The objective of this study was to explore management issues and effects of policies on incidentally caught HMS species. Specifically, I examined management issues for N. Pacific striped marlin by assessing stakeholder opinions on management options and evaluated the potential ecosystem effects of adopting those management options within the convention area. Second, I took a broader view of bycatch management by discussing potential effects of a retain-all policy for longline and purse seine vessels in the WCPO.

The current CMM for N. Pacific striped marlin limits catches of members to 80% of their highest catch between 2000-2003 and grants individual members flexibility in deciding how those limits should be met while noting management examples could include effort reductions, gear modifications and spatial management. To date, catches of striped marlin have remained below the limits prescribed in the CMM in 2010, and had been below those levels since 2005. Projections from the most recent stock assessment suggest that stock biomass should increase if catches of striped marlin were 80% of average catch during 2000-2003 (3,600 mt) or the overarching goal of the measure, and greater increases would be expected if catches of striped marlin were 80% of average catch during 2007-2009 (2,500 mt) (Lee, Piner et al. 2012). However, the CMM is written such that members are allowed to catch up to 80% of the highest catch from 2000-2003. Individual highest catches for Japan, Korea, Chinese Taipei and the

United States, the four main members that harvest striped marlin in the North Pacific, occurred in different years, and thus, if all members were to harvest up to their limits in a given year (~4,600 mt), stock assessment projections suggest that overfishing would continue (Lee, Piner et al. 2012). When CMM 2010-01 was developed, the WCPFC recognized that new information would be available from a new stock assessment, and included a provision stating that the measure should be revised if new information warranted change.

If the CMM for N. Pacific striped marlin were to be revised, I was interested in examining stakeholder opinions on management options for this incidentally caught species. In particular, this study in Chapter 2 surveyed relevant stakeholders including fishermen and government representatives to better understand what factors were considered most important in developing a measure for striped marlin and what management options might be perceived as more effective or acceptable to implement. This study also queried respondents on ineffective management options, lessons from experiences with the U.S. domestic catch limit for bigeye tuna, and receptiveness to an expanded management measure for all marlins. Understanding these opinions and the importance of underlying factors could be helpful in aiding managers to craft future measures for this stock.

While managers should be cognizant about stakeholder opinions, scientific information should also be used to inform management decisions, and in Chapter 3, this study used an ecosystem model to examine how different management scenarios for striped marlin management might affect the stock of N. Pacific striped marlin as well as other species groups. Projections from the stock assessment considered general scenarios with increases, decreases and constant catches, but did not examine effects of specific management actions (Lee, Piner et al. 2012). This study was thus interested in investigating how specific management scenarios, including some considered by stakeholders in the survey in Chapter 2, might affect stock biomass levels for N. Pacific striped marlin and other species, and whether the models would predict any top-down effects from these changes. Individual members have the ability to adopt different management strategies, and this study also examined how adoption of various management strategies by the U.S. longline fishery only, other foreign longline fisheries only, and both the U.S. and foreign longline fisheries might affect stock biomass levels for N. Pacific striped marlin and other species groups. Modeling responses to various management options can inform managers of the predicted effectiveness of policies under consideration, and aid them in future decision making.

Policies on incidental catch can be aimed at a specific species or group of species, or be much broader and encompass all incidental catch. As a disincentive to catch small fish and to promote the adoption of more selective fishing methods, the WCPFC included a provision in CMM 2008-01 on management of bigeye and yellowfin tunas requiring all purse seine vessels to retain all skipjack, yellowfin and bigeye tunas beginning in 2010. Some organizations, including the World Wildlife Fund (WWF) and International Sustainable Seafood Federation (ISSF), have advocated expanding this retention policy to all fishes, and an early draft by the WCPFC Chair in 2011 included a provision that would have imposed a retain-all policy in both the longline and purse seine fisheries in the WCPFC. Although full retention policies have not been included in subsequent conservation measures for skipjack, bigeye, and yellowfin in 2012 or 2013, these ideas have gained greater attention. Additionally, the European Union agreed to revise its Common Fisheries Policy to include a phased ban on discarding on its fisheries in 2013, and this discarding ban has the potential to impact its vessels operating in the WCPO. Expanding the current retention policy from the primary tuna species to all species and from just purse seine vessels to longline vessels could have significant impacts on vessels and the ports they offload to in the Western and Central Pacific. Aside from acknowledging challenges in developing markets for the catch of nonmarket species, few proponents have thoroughly considered other implications of a full retention policy. In Chapter 4, I was interested in quantitatively estimating the additional catch that would be landed if a full retention policy were adopted in the WCPO, as well as qualitatively considering anticipated impacts of a full retention policy on vessels and consumers. Data from logbooks and observers from the U.S. purse seine and longline fleets were employed to characterize the types and magnitude of fish discarded, and used to estimate direct impacts of having to offload at the initial point of landing for key Pacific Island ports. Chapter 4 also includes a discussion on broader implications of a retain-all policy on vessels, processors and communities.

Chapter 5 concludes this dissertation and provides some final observations and thoughts on management of incidental catch in the WCPO.

CHAPTER TWO: STAKEHOLDER OPINIONS ON MANAGEMENT OPTIONS FOR FUTURE CONSERVATION MEASURES FOR NORTH PACIFIC STRIPED MARLIN

Abstract

In 2010, the Western and Central Pacific Fisheries Commission (WCPFC) adopted a conservation and management measure (CMM) for north Pacific striped marlin (*Kajikia audax*) that included a provision directing the commission to revise the measure if information from the new stock assessment warranted changes. Although a new stock assessment was completed in 2012, no revisions to the current CMM have been proposed or made to date. This study examined stakeholder preferences in the event a revised CMM were to be developed for north Pacific striped marlin. The study identified factors and criteria considered important in developing a new or revised conservation and management measure for striped marlin, as well as understanding what management options were considered by respondents best to meet those objectives. The Analytical Hierarchy Process (AHP) was used to develop a survey that could quantitatively evaluate preference. Additionally, demographic and short answer questions were included to collect information not covered by the AHP comparisons. Forty participants including representatives from government agencies as well as the fishing industry provided responses to the survey. There were similarities overall, and between government and fishing industry respondents, in the weightings of the various factors with respondents weighting biological factors more than economic, social and political factors when considering management options for north Pacific striped marlin. Management options with the highest ratings were circle hooks and catch limits while the lowest ratings were for a retention ban. Participants had a broad range of opinions on the need to limit catch of striped marlin, and some

participants indicated they would be willing to support the need for management if there was more scientific support or information available on its efficacy.

Introduction

Management of highly migratory species (HMS) can be particularly challenging due to their ability to move across political boundaries and their widespread spatial extent (Sibert and Hampton 2003; Miller 2007). Most of the HMS regional fisheries management organizations (RFMOs) have focused their efforts on managing target stocks, notably tuna species and swordfish. Attention has also been given to protected and endangered species such as sea turtles and seabirds, and many of the tuna- RFMOs have adopted measures to reduce the likelihood of interaction with protected species or to increase survival for protected species that are caught. With the exception of sharks, much less attention has been given to other fish species that are caught in HMS fisheries. Although tunas and swordfish are the primary target of most pelagic fisheries, other fish species do have commercial value, and if caught incidentally are retained and landed. As an example, ex-vessel value of billfish (excluding swordfish) and other pelagic fish (non-tunas) in the Hawaii longline fishery was almost $14.5 million in 2011, and represented 16% of the ex-vessel value of landings for that fleet (WPRFMC 2013).

Striped marlin (*Kajikia audax*) is an example of a fish species that in some fisheries might be viewed as incidental catch. Although some fisheries may target striped marlin, and striped marlin are particularly prized in sportfishing as gamefish, the largest catches of striped marlin in the north Pacific occur in the longline fishery, which generally targets tunas and swordfish. Catches of striped marlin in the north Pacific have significantly declined over time and a 2012 stock assessment in the western and north Pacific indicated that the stock was severely depleted (Piner, Lee et al. 2013).

In 2010, the Western and Central Pacific Fisheries Commission (WCPFC) adopted conservation and management measure (CMM) 2010-01, a measure aimed at reducing levels of fishing mortality on N. Pacific striped marlin by reducing levels of allowable catch for individual members. Although the CMM imposed catch limits on members, the CMM gave individual members discretion on how such limits should be implemented, though the measure did note examples of effort reductions, gear restrictions and spatial management as possible options. CMM 2010-01 also contained a provision directing members to amend the CMM based on results from a stock assessment planned for completion in 2011. Although a stock assessment for north Pacific striped marlin in the WCPO was completed in 2012, to date the WCPFC has not made any revisions to the CMM.

Catches of north Pacific striped marlin were below the limits prescribed in CMM 2010-01 for 2011-2013, and no members have adopted any domestic regulations implementing a catch limit for north Pacific striped marlin to date. However, if all members were to harvest up to their allowed limits, this level of harvest would result in continued overfishing of the stock (Piner, Lee et al. 2013). Revising the measure to reduce catch to levels that would encourage stock rebuilding would help to ensure successful recovery of this stock.

Although CMM 2010-01 prescribed catch limits, if a new measure were developed, other management options such as gear modifications, minimum size limits or live release could be considered. New or revised CMMs are generally proposed for consideration by individual members or groups of members to the WCPFC. In the United States, proposed CMMs undergo substantial review internally within the government as well as externally by its stakeholders (e.g., fishermen, processors, environmental non-governmental organizations, etc.) participating on advisory groups and as members of the U.S. delegations to the WCPFC meetings before they are submitted to the WCPFC for consideration. Although the U.S. government ultimately retains the right to decide which proposals are forwarded to the Commission, stakeholders can play a strong role in the development of and progress of proposed CMMs. The United States has not to date submitted a proposal related to N. Pacific striped marlin to the WCPFC, but if the United States were to submit a proposal, input from stakeholders would be valuable in formulating a new or revised CMM. This study was interested in identifying the factors considered important by various stakeholders in managing north Pacific striped marlin, what management options might be preferred, whether these preferences were similar or different between stakeholder groups, and opinions on application of management options across gear types and other billfish. In the WCPO, north Pacific striped marlin is predominantly caught by four countries, Japan, Taiwan, Korea, and the United States. This study used a survey to focus on understanding interests of U.S. stakeholders on managing north Pacific striped marlin in the WCPO.

Methods

In order to evaluate preference quantitatively, this study used analytical hierarchy process (AHP) to discern criteria important for decision-making as well as which alternatives are viewed as more or less favorable. AHP is a multi-criteria decision-making process developed by Saaty in the 1970's that has been used to aid decision making in a wide range of sectors including corporate, government and natural resources management (Saaty 1977; Zahedi 1986; Saaty 2004). The AHP process consists of the following four steps (Zahedi 1986):

1) Creating a decision hierarchy consisting of various decision elements (criteria and alternatives) that influence an overarching goal;
2) Collecting input via pairwise comparisons of decision elements;
3) Calculating eigenvectors to estimate weights of decision elements; and

4) Aggregating relative weights of decision weights to arrive at a set of ratings for the alternatives.

Carlsson and Walden (1995) identified several strengths and weaknesses of using AHP as a decision-support tool. Strengths identified included:

1) AHP allows incorporation of all elements related to a decision problem into one model, and can be used to identify interdependencies, and perceived consequences
2) Pairwise comparisons forces users to state relative importance of criteria and decide relative contributions of alternatives to the criteria
3) Software is available and easy to use to build and solve multiple criteria decision problem
4) Hierarchy structure aids in identifying decision elements
5) AHP identifies where users may be inconsistent in their judgments.

Weaknesses identified include:

1) Users almost never respond with “very strong importance” (7) or “extreme importance” (9) because it’s not seen as very different from “strong importance” (5).
2) Users rely heavily on experience and judgment,
3) An arbitrary starting reference point is needed in pairwise comparisons which could change views of a multiple comparison problem
4) Pairwise comparisons eliminate long chains of interdependence which users may perceive.

A few studies have used AHP to evaluate alternatives in the fisheries sector (Kangas 1995; Mardle, Pascoe et al. 2004). Leung et al. (1998) developed an AHP tree based on input from the Western Pacific Management Council to identify criteria contributing to the goal of sustaining a viable pelagic fishery. As striped marlin fall within the pelagic fishery evaluated by Leung et al. (1998) and many of the criteria were applicable, the hierarchical tree for this study used the basic structure and components of the tree designed by Leung et al. (1998), but modified some of the sub-criteria to make it more relevant to striped marlin (Figure 1).

The four main criteria considered in developing a conservation measure for striped marlin were biological, economic, social and political criteria. Sub-criteria were also considered under the economic, social and political criteria. No sub-criteria were included under biological criteria as results from the 2012 stock assessment were not available when this survey was being developed, and so no information was available on fishing mortality or stock biomass. Bycatch was not included because, although striped marlin may not be explicitly targeted like tunas, they do have market value and most striped marlin (95% in the U.S. deep set longline fishery) are retained (Curran and Bigelow 2011). Leung et al. (1998) also included protected species interactions as a sub-criterion under biological criterion, but as this study was only considering one species and not the broad category of pelagic which includes some protected species, this criterion was not deemed to be relevant. Under the economic criteria, the hierarchical tree included fisheries reported to have caught striped marlin, including the deep set longline fishery, shallow set longline fishery, troll fishery and handline fishery. Under social criteria, the three sub-criteria considered were community, access and gear conflict. The community sub-criterion referred to the benefits perceived by general society or a local community of having striped marlin. The access sub-criterion referred to the relative importance of striped marlin to commercial fisheries versus recreational fisheries. The gear conflict sub-criterion referred to competing interests by different commercial fisheries and importance of taking those concerns into account. Finally, the political criteria, the sub-criteria identified include public acceptance and public resistance, and within public resistance, resistance by the four different fisheries that catch striped marlin.

Under the lowest level of criteria or sub-criteria, six management alternatives were presented for consideration: catch limits, minimum size limits, release of all live fish caught, elimination of shallow hooks in longline deep sets, mandatory use of circle hooks in the longline fishery, and ban on the retention of all striped marlin. CMM 2010-01 imposed catch limits on members, and the first alternative was to continue to use catch limits as the preferred way to manage striped marlin. Catch limits for bigeye tuna (*Thunnus obesus*) have been in place in the longline fleet since 2009, and in the U.S., catch of bigeye tuna is monitored and the U.S. longline fishery is closed when it is anticipated to reach its limit.

A second alternative was to require the release of all live striped marlin caught. Observer data from the U.S. longline fishery indicate that 49% and 76% of striped marlin caught by deep sets and shallow sets, respectively, were alive when brought aboard the boat (NMFS, unpublished data). Although most striped marlin were kept regardless of whether they were alive or dead, a small fraction were released alive. This alternative allowed for retention of any striped marlin that were dead when brought aboard the boat to minimize waste in the fishery, but the release of all striped marlin brought aboard live.

A third alternative was to require all longline vessels to fish with circle hooks. Circle hooks are a type of fish hook where the hook is curved back in a circular shape. Several studies have investigated the role of hook type and size on bycatch; in the North Pacific, results have been mixed for marlin but have decreased bycatch of protected species or species of concern like sea turtles and sharks (Read 2007; Serafy, Kerstetter et al. 2009; Walsh, Bigelow et al. 2009).

Curran and Bigelow (2011) investigated differences in catch and condition of species between tuna hooks, J hooks, and circle hooks in the deep set fishery and found that circle hooks resulted in lower catch of striped marlin than tuna hooks, with little difference between J hooks and circle hooks. Circle hooks have been required in the US shallow set fishery since 2004. When the survey for this study was developed circle hooks were not required in the US deep set fishery and so this alternative was envisioned to apply to the deep set fishery. In Dec. 2012, however, regulations were adopted requiring the deep set longline fishery to use circle hooks. Ten of the surveys were conducted after these regulations were adopted, and it is possible that responses received may have been influenced by the new requirements.

A fourth alternative was also specific to the deep set longline fishery in that it eliminated the shallowest hooks on deep sets (the study refers to this option as the no shallow hooks option). Striped marlin spend a majority of their time in the mixed layer (<90 m deep) and are generally caught at depths < 100 m (Boggs 1992; Brill, Holts et al. 1993; Sippel, Davie et al. 2007). Beverly et al. (2009) compared catch of pelagic species between deep sets and deep sets without the shallowest hooks and found a significant decrease in striped marlin catch on the experimental sets. The alternative to eliminate shallow hooks was only applied to the deep set longline fishery, as eliminating shallow hooks from the shallow set fishery would effectively close that fishery and was deemed not feasible.

A fifth alternative was to ban retention of striped marlin. Retention bans have been implemented in some states and countries for various reasons including alleviating gear conflicts, rebuilding stocks and resolving sector conflicts. In October 2012, the Billfish Conservation Act prohibited sale of billfish (except swordfish), including striped marlin, in the continental United States. The Billfish Conservation Act exempted Hawaii, Guam, American Samoa and the

Commonwealth of the Northern Mariana Islands, and these are the only areas in the U.S. where commercial sale of striped marlin are currently permitted and where commercial retention is still possible. Finally, a sixth alternative was to adopt minimum size limits under which striped marlin under a certain size would have to be released.

Based on the identified criteria and alternatives, a survey was created containing pairwise comparisons of the various criteria, sub-criteria, and alternatives (Appendix A). In addition to the pairwise comparisons, limited demographic information was collected to discern if representatives from different sectors (e.g., government, fishing industry, etc) had differing opinions on weights of criteria as well as preferred alternatives. The survey also included a few additional questions to elucidate the knowledge level of participants on stock status, opinions on the need to manage striped marlin catch, additional opinions on alternatives, information on other alternatives, implementation considerations of alternatives, and openness toward a general marlin measure as opposed to a striped marlin measure.

Seventy participants were contacted over the phone, in person, or by email from January 2011-December 2013. Forty participants participated in the survey, and respondents included representatives from government (9), fishing industry (24), advisory council (4), academia (2), environmental non-governmental organization (ENGO) (1), and other (1). For the few participants who self-identified with more than one sector (e.g., government and fishing industry), responses were incorporated into the sector most strongly identified with. Some participants who identified themselves as part of the advisory council also identified themselves as troll or handline fishermen and were incorporated into the fishing industry group. Expert Choice (version 8), a software program by Expert Choice, Inc., was used to calculate the relative weights of all pairwise comparisons as well as inconsistency ratios for each individual. For each question, the sum of all AHP weights totals to 1 with higher scores representing the option most preferred. All respondents who answered the question were included in the arithmetic means; some participants did not respond to all questions. Weightings were only shown where at least five participants contributed to a response. For ease in summarizing the responses, this study chose to show average weightings from all respondents, weightings for the government sector, weightings for those affiliated with fishing industry or self-identified fishermen, weightings for respondents affiliated with the longline fishery, and weightings for respondents affiliated with the troll and handline fisheries. Average weightings by level of knowledge on the stock were also examined, but patterns in response were more similar by sector than by level of knowledge so this study focused on responses by sector.

Saaty (1987) recommended using an inconsistency ratio of 0.1 or less as acceptable though other studies have included data with higher inconsistency ratios (Soma 2003; Himes 2007; Yang, Li et al. 2011). Apostolou and Hassell (1993) examined results of including and excluding results for subjects with inconsistency ratios > 0.1, and concluded that if the primary purpose was to obtain a general understanding of relative importance then including results where consistency ratios were > 0.1 may be acceptable. Average inconsistency ratios were always above 0.1 in this study, suggesting that almost all participants (regardless of group) were inconsistent in their responses (Table 1). Removing responses with inconsistency ratios > 1 resulted in similar average AHP values and rankings that were nearly identical in every comparison except one, so this study opted to include all responses in the average weightings presented.

Survey participants were not randomly selected, but were identified by the study investigators or by fellow survey respondents as individuals interested in management issues on

N. Pacific striped marlin. Thus, participants may not represent all opinions on management of striped marlin, and so care should be exercised in interpreting these results as this survey presents a snapshot of opinions gathered over the time frame of the survey.

Results

As noted above, study participants included representatives from government (9), fishing industry (24), advisory council (4), academia (2), environmental non-governmental organization (ENGO) (1), and other (1). The following summarizes responses collected from the AHP comparison and short answer questions.

AHP Responses

Table 2 contains the arithmetic means for each criterion and sub-criterion for all respondents, for government and fishing industry respondents, and within the fishing industry for longline and handling and troll respondents. All groups indicated that in considering management of north Pacific striped marlin, biological factors were of greatest importance, followed by economic, social and political factors. Within the economic category, government respondents indicated that the most important fishery to focus on was the deep set longline fishery followed by the shallow set longline fishery, troll fishery, and handline fishery. The fishing industry groups (overall and longline and troll and handline) felt the shallow set longline fishery was the most important to consider for economic reasons followed by the deep set longline fishery, troll fishery and handline fishery. Within the social category, all stakeholder groups indicated access was most important when considering management options for north Pacific striped marlin, followed by community and gear conflicts. All groups also indicated that management options should focus more on local interests than societal interests, and all stakeholder groups except troll and handline fishermen felt that management options should focus on maintaining commercial access over recreational access. Within the political category, all stakeholder groups indicated that political acceptance was more important to focus on than political resistance when considering management options for striped marlin.

There was much less agreement across stakeholder groups on preferred management options across criteria (Table 3). When management options were ranked from highest to lowest weightings, circle hooks ranked highest overall in 9 out of the 15 comparisons, and catch limits ranked second highest overall in 8 out of the 15 comparisons. The retention ban was ranked last overall. Government stakeholders preferred catch limits most often, followed by circle hooks, no shallow hooks, live release, minimum size and a retention ban. Longline fishermen gave greatest weightings to circle hooks, followed by live release, no shallow hooks, catch limits, minimum size limits and retention ban.

For biological reasons, circle hooks were the management option most preferred as a management tool overall (Figure 2). Circle hooks were the most preferred management tool by the fishing industry and longline fishermen groups, and no shallow hooks were the most preferred management tool by the government and troll and handline fishermen groups.

When considering economic impacts on the deep set longline fishery, all stakeholder groups except the government group preferred circle hooks most while the government group preferred catch limits. When considering economic impacts on the shallow set fishery, all stakeholder groups preferred circle hooks over the other management options. For the handline fishery, overall and fishing industry participants preferred catch limits and the government group preferred circle hooks. For the troll fishery, minimum size and catch limits were the management options most preferred by all stakeholder groups.

For preserving societal interests, the fishing industry group and longline fishermen group preferred circle hooks while government and troll and handling groups preferred catch limits. To preserve local interests, the two most preferred management options for all groups were circle hooks and catch limits.

All groups preferred circle hooks for commercial fisheries access reasons while live release and catch limits were the management options preferred for recreational fisheries access reasons. Catch limits were preferred over other management options for avoiding gear conflicts.

For public acceptance reasons, troll and handline fishermen preferred catch limits while longline fishermen preferred circle hooks. Stakeholder groups preferred different options when weighting options to mitigate public resistance in the deep set longline fishery. The government sector preferred no shallow hooks, troll and handline fishermen preferred catch limits and longline fishermen preferred circle hooks. There were fewer differences when asked which option would be preferred to avoid public resistance in the shallow set fishery with government and longline groups preferring circle hooks and the troll and handline fishermen preferring greatest weighting to catch limits. All stakeholder groups preferred circle hooks when asked which management option would be preferred to avoid public resistance in the handline fishery. Stakeholder groups were divided in which option would be preferred to avoid public resistance in the troll fishery with government preferring circle hooks and troll and handline fishermen preferring minimum size.

Short Answer Responses

Participants provided responses to short answer questions on their level of knowledge of the stock of N. Pacific striped marlin, and opinions on the need to limit catch of striped marlin, most and least feasible alternatives, lessons learned from experience with the catch limit for bigeye tuna, willingness to consider an expanded billfish measure, and changes to consider in developing a new CMM for N. Pacific striped marlin (Table 4).

Thirty-five percent of respondents considered themselves very knowledgeable or knowledgeable on the stock of N. Pacific striped marlin in the WCPO, and quarter of respondents characterized themselves as not at all knowledgeable about the stock of N. Pacific striped marlin in the WCPO (Table 4A). Almost all government participants considered themselves very knowledgeable to somewhat knowledgeable and only one government participant responded that he was not at all knowledgeable. Two thirds of longline fishermen responded that they were somewhat to very knowledgeable about the stock of N. Pacific striped marlin in the WCPO, and the remaining third responded that they were not at all knowledgeable. A little over half of the troll and handline fishermen responded that they were somewhat knowledgeable or knowledgeable about striped marlin while the remainder responded that they were not at all knowledgeable or didn't know about the stock of N. Pacific striped marlin in the WCPO.

Respondents had a broad range of opinions on whether there was a need to limit catch of north Pacific striped marlin in the WCPO, with 40% of respondents agreeing on the need to limit catch, 35% of respondents disagreeing with the need to limit catch, and the remaining 25% undecided (Table 4B.). Almost all government respondents indicated that they strongly or somewhat agreed with the need to limit catch of north Pacific striped marlin with one respondent indicating he was unsure on the need to limit catch. Respondents from the fishing industry were divided on the need to limit catch of north Pacific striped marlin with 44% disagreeing with the need to limit catch, 25% agreeing with the need to limit catch and the remainder unsure if there was a need to limit catch. No longline respondents agreed with the need to limit catch of striped marlin, and most somewhat or strongly disagreed with the need to limit catch of striped marlin. Half of the troll and handline fishermen agreed with the need to limit catch with a quarter disagreeing on the need to limit catch and a quarter undecided on the need to limit catch of striped marlin.

Participants were asked to identify the most and least feasible alternatives of the six management alternatives considered in this study as well as provide reasons why they felt the alternative was most or least feasible. Of the six management alternatives presented, the most feasible alternatives were from most frequently cited to least frequently cited, circle hooks, eliminating shallowest hooks in the deep set longline fishery, minimum size limit, catch limit, retention ban and live release (Table 4C). Circle hooks were identified as the most feasible alternative by 17 respondents, while eliminating the shallowest hooks in the deep set longline fishery and catch limits were identified as the most feasible alternatives by 11 and 8 respondents, respectively. Circle hooks were identified as most feasible by over half of the longline respondents, while eliminating the shallowest hooks on deep sets were identified as most feasible by almost half of the troll and handline participants. Participants gave a range of responses as reasons for selecting particular management options as most feasible and commonly cited reasons include ease of enforcement, monitoring, implementation, and reductions in hooks.

The least feasible management options were, from most frequently cited to least frequently cited, retention ban, live release, minimum size limit, eliminating shallowest hooks on deep longline sets, circle hooks and catch limits (Table 4E). The retention ban was cited by almost half of all respondents, over half of the longline respondents, and half of the troll and line respondents as the least feasible management option. Live release was the second most cited least feasible management option, and was the most cited option by government respondents and the second most identified option for least feasibility by fishing industry participants. Reasons for selecting various options for least feasible included opposition to discarding dead fish that could be eaten or sold, difficulties in enforcing options, and questions on post-release survivability. Many participants who identified the retention ban as the least feasible alternative cited waste as the reason, and in general, felt strongly that caught fish should not be wasted particularly if already dead. Some questioned whether striped marlin would survive if released alive and questioned the efficacy of releasing live marlin if there is mortality post-release. Enforceability was also a common reason cited for selecting the least favorable alternative. Several respondents stated at sea observers would be the only way to ensure release of live individuals and adherence to any elimination of shallowest hooks on deep longline sets policy.

Most respondents indicated that they were somewhat familiar to very familiar with the catch limits in place for bigeye tuna in the WCPO (Table 4F). Most government and all longline respondents indicated some familiarity with the bigeye catch limits while the troll and handline respondents indicated less familiarity with the catch limits for the longline fishery. Responses varied when participants were asked if a potential catch limit for north Pacific striped marlin should be implemented in the same way as the bigeye catch limits (Table 4G). Seven participants from the fishing industry (longline, troll and handline) stated they felt it should be managed in the same way while eleven (predominantly longline respondents) stated that a catch limit for striped marlin should not be implemented in the same way as with bigeye. Reasons for responses varied, and some suggestions for changes included adding a mechanism to account for overages and underages by allowing some rollover from year to year, individual transferable quotas, and alternative limit periods. Some felt that the bigeye limits were ineffective because of poor monitoring and compliance by foreign fleets. A few respondents also noted that U.S.

longline catch of striped marlin and bigeye tuna were a small portion of overall catch in the WCPO and felt that greater emphasis should be placed on managing fleets that catch greater proportion of the total catch.

Participants had mixed opinions on gear modifications for striped marlin management for troll and handline fisheries (Table 4H). Suggestions included use of different hooks, bait, and live release. In particular, some felt that different hooks (circle hooks or barbless hooks) could reduce interactions or improve survivability, while others felt that they would not be effective. Over half of the respondents felt that all gear types should be managed (Table 4I). Other respondents felt that only longline fisheries should be managed, only fisheries contributing to the greatest amount of fishing mortality should be managed, or only unregulated fisheries should be managed. A few respondents who stated that all gear types should be managed also stated that management should be tailored to each gear type individually.

Over half of the respondents were opposed to an expanded billfish CMM because of misidentification reasons and only 20% of respondents were in favor of an expanded billfish CMM (Table 4J). Most of the government respondents were in favor of a measure that would include other types of billfish while most fishing industry respondents were opposed to an expanded measure that would include other types of billfish. Some respondents stated they would be open to including other species of billfish if there were a demonstrated biological need to manage other species of billfish. Other respondents noted that education on identification might be more effective than adopting broader measures.

Participants had a range of responses when asked what changes should be considered if a new CMM for striped marlin were to be developed (Table 4K). Several participants felt a new CMM should reflect improvements in knowledge as a result of the recent stock assessment.

Others felt that a new CMM should focus on emphasizing gear modifications and a size limit. A few participants felt that compliance and monitoring need to be improved, although this sentiment seemed to reflect a larger dissatisfaction with current compliance and monitoring practices than those related to management of N. Pacific striped marlin.

Discussion

Management Options for Striped Marlin

This study was narrower in scope than the one conducted by Leung et al. (1998) which considered sustainable management of pelagic fisheries in Hawaii, and the similarities seen in some of the rankings between the surveys suggest that some priorities remain the same for management of a single stock as for entire fishery. For the four criteria, our survey found biology to have the highest weightings followed by economic, social and political criteria. These rankings and weightings were similar to those observed by Leung et al. (1998), and their study estimated an even greater weighting for the biological criterion (0.526) relative to social (0.200), economic (0.191) and political (0.083) criteria. DiNardo et al. (1989) also cited biological factors as the most important criteria in an AHP exercise on river herring, and this suggests that biological factors may be one of the most important considerations in fisheries management. Preferences for local interests over societal interests under the community sub-criterion were another area where rankings in this survey were similar to those observed in Leung et al. (1998).

Some priorities were different between this study and that of Leung et al. (1998). These differences result from the different scopes of the studies as well as different circumstances in the timing of the surveys. In the Leung et al. (1998) study, social criteria were perceived as more important than economic criteria, whereas the ranking was both reversed and more pronounced in our study. Leung et al. (1998) conducted their study in 1995 when there was no regional fisheries management organization for highly migratory species in the western Pacific Ocean, and a limited entry system was the primary restriction in place in the longline fishery. In the fifteen years since then, the WCPFC was formed, and a greater number of restrictions (stemming from both international and domestic forums) including gear modifications and catch limits have been placed on the U.S. longline fishery. Restrictions including those that required fishermen to adopt circle hooks as well as rising fuel costs which now account for a larger proportion of costs (NMFS 2013) may explain in part why economic criteria were weighted more highly in our survey than they were the study by Leung et al. (1998).

Our survey found circle hooks and catch limits to be the management alternatives with the highest weightings, and preferences for these management options may have been influenced by participants' past experience (Piet, Jansen et al. 2008; Innes and Pascoe 2010). Both catch limits and circle hooks have been used in the longline fishery to manage catch of bigeye tuna and for protected species reasons, respectively. As regulations requiring circle hooks for deep set longline fishing were adopted in the middle of this survey's deployment, responses by participants after that regulation was implemented may have been influenced by the fact that they were already using this gear modification. However, when results for longline fishermen were separated by those responses received before and after the regulations were required in the deep set fishery, no changes were found in the top alternative preferred (predominantly circle hooks) and in only a few cases were there small switches in rankings for other alternatives. The fact that there was little change in the rankings suggests that influence from previous experience may be limited or may also indicate that preferences for some of the early survey takers could have been influenced at an earlier time. Some participants may have participated on the take-reduction team for false killer whales that agreed to the implementation of circle hooks in the deep set longline fishery and so were aware of the change before it was implemented in regulation. Catch limits for bigeye tuna have been in place since 2009 to manage bigeye tuna, and although survey participants had varying opinions on its effectiveness, familiarity with the bigeye catch limit and its implementation may have contributed to how respondents scored their preferences for striped marlin relative to other management options.

Many participants, particularly longline, handline and troll fishermen, strongly opposed the retention ban option because they were adamantly opposed to wasting fish. Several participants noted that a retention ban would eliminate landings but not reduce catches. Dead fish that would normally provide income would have to be discarded or wasted, and questions of survivability were once again raised. Some troll and handline fishermen noted that in Hawaii, striped marlin as well as other billfish are viewed as culturally important and are consumed in the local community. As noted earlier, Hawaii is one of the few areas in the United States where billfish (other than swordfish) can be sold commercially, and several participants expressed concern that adopting a retention ban for striped marlin would set a precedent for adopting retention bans for other fish.

Respondents indicated varying levels of knowledge about the stock of N. Pacific striped marlin. However, similarities in knowledge levels did not correspond to greater similarities in preferences for management alternatives, and similarities in preferences for management alternatives were much more evident when responses were grouped by sector. A few respondents, particularly some of the government and fishing industry representatives, were more knowledgeable than other respondents about the status of striped marlin. As many respondents from the fishing industry were only somewhat knowledgeable or not at all knowledgeable about the stock of N. Pacific striped marlin, this may have contributed to the overwhelming disagreement by longline fishermen on the need for catch limits for N. Pacific striped marlin. Some questioned the need for management since they were aware that the stock of striped marlin in the Eastern Pacific Ocean (EPO) was considered healthy, and felt it difficult to reconcile between the disparate stock statuses in the WCPO and EPO. Interestingly, this study did not observe levels of perceived knowledge to result in better agreement for specific management options, but this could be due to the small sample size and the paucity of information on effectiveness of the management options considered.

Several participants mentioned that they were willing to support the need for management or various management options such as no shallow hooks or circle hooks if there were more scientific support available (i.e., more than one study). Many studies have examined the effects of circle hooks, and results for striped marlin have been mixed, with studies observing increases (Ward, Epe et al. 2009), no change (Andraka, Mug et al. 2013) and decreases in catchability (Curran and Bigelow 2011). Curran and Bigelow (2011) observed decreased catches in striped marlin with the use of circle hooks. More information on circle hooks and catchability may be available in the future, as regulations requiring circle hooks in the deep set longline fleet came into effect in February 2013.

Post-release survivability was questioned for both live release and minimum size options. One participant mentioned releasing small striped marlin when there were numbers of small fish caught suggesting he believed they survived release, and some participants expressed skepticism over the likelihood of striped marlin particularly small individuals actually surviving the hooking and release process. Several studies have examined post-release mortality of blue marlin, white marlin and sailfish from commercial and recreational fisheries (Graves, Luckhurst et al. 2002; Kerstetter, Luckhurst et al. 2003; Horodysky and Graves 2005; Kerstetter and Graves 2008;

Poisson, Gaertner et al. 2010), and Domeier et al. (2003) to date is the only study investigating post release mortality for striped marlin from recreational gear. If management for striped marlin were desired, more research coupled with dissemination of results of that research to managers and fishermen could help to build support if effectiveness of a particular management option can be demonstrated.

Past experiences with regulatory actions resulting from domestic and international decisions may have influenced responses from many participants. In particular, the shallow set longline fishery was closed for protected species reasons from 2001-2004, and led to changes to the shallow set fishery in 2004 to reduce interactions with turtles, as well as to the deep set fishery in 2012 to reduce interactions with false killer whales. Although the survey did not mention either of these regulatory actions, many longline participants commented on their experiences with those regulatory actions, particularly those related to turtle mitigation. Several of these participants expressed frustration over regulations imposed on the U.S. fishery that are not imposed on other foreign fleets, and some felt that any additional management that would reduce catch was unacceptable. Several fishing industry participants also commented extensively on the perceived lack of monitoring and compliance in the WCPFC, and felt any management to be unfair unless there was improvements in monitoring and compliance in other foreign fleets.

Survey Methods

Our AHP analysis produced high inconsistency ratios, which may have resulted from either problems with the questionnaire leading to inexact responses or participants not giving well thought out responses. Some studies have noted that participants can have difficulties scoring if there are too many options and suggested that the number of factors to consider be limited to seven or fewer (Saaty and Ozdemir 2003; Ozdemir 2005). Our study had six management options, and some participants expressed that they felt it difficult to be consistent with so many comparisons. A few seemed to have had trouble reconciling the different management options with the factor presented and some may have responded through whatever dominant (e.g., economic) lens they viewed each management option. Although Carlsson and Walden (1995) noted that participants were reluctant to score options in the extremes, participants in this study responded with scores across the whole range. Scoring options with extreme values (8's and 9's) may have contributed to high inconsistency scores, but when asked to verify their response, most respondents felt that that was their response even if it seemed to produce something that was inconsistent. Some studies asked participants with high inconsistency ratios to revise their responses (Innes and Pascoe 2010; Pascoe, Innes et al. 2010), but this study was not able to provide immediate feedback during the survey nor was follow-up possible. Some participants noted that it was difficult for them to compare options because they felt the options were not specific enough (e.g., size limit not specified, catch limit not specified) or that options were not necessarily mutually exclusive, so that could have contributed to the range of answers received. Others were hesitant to answer some of the questions because they felt they did not have expertise in that area (e.g., a longline fishermen answering questions on which management options were better for handline or troll fishermen).

Although participants were informed about the survey length before the survey started, some grew impatient when reviewing the AHP comparisons – particularly as the management alternatives for each criteria or subcriteria were repetitive. This could have also factored into high inconsistency scores as respondents may not have thoroughly considered all options before responding. Most respondents seemed to find the short answer questions easier to respond to, or gave anecdotes while responding to the AHP comparisons and it may be that many of the respondents – especially fishermen- were more comfortable with a more open-ended format.

This survey collected information using comparison questions for AHP as well as short answer questions. Responses to questions in both sections indicated that there were a lot of different opinions on the different management options, but both the AHP and short answer responses indicated greater preference for circle hooks and lesser preference for a retention ban. The general agreement in management alternatives for the most and least favorable options suggests that both methods were able to arrive at the same answer though the questions were slightly different. Although AHP was helpful in understanding strength of preference, the short answer questions were able to elicit other relevant information that was not necessarily covered by the AHP hierarchy, and Nielson and Mathiesen (2006) noted that it was useful to pair AHP with qualitative interviews.

Leung et al. (1998) conducted an AHP survey with fisheries council members and suggested that AHP could be a useful tool in evaluating management options in the future. Though our study was able to use AHP to quantify weightings for the various criteria and management options evaluated, we would not suggest using AHP unless feedback can be obtained about areas of inconsistency, and unless participants are willing to take the time necessary to think thoroughly through each of the comparisons. We were able to extract similar rankings from qualitative questions, and we advocate their use in future studies of stakeholder opinions on management options.

Conclusions

Although survey respondents had a diverse range of opinions on the need for additional management for N. Pacific striped marlin, respondents were generally in agreement in preferences on criteria and sub-criteria with strongest agreement along sectors rather than among levels of knowledge of the fish stock. Management alternatives with the greatest support included circle hooks and catch limits perhaps due to familiarity with those alternatives, while the management alternative with the least support was the retention ban, which was strongly opposed due to concerns over waste. Stakeholder responses indicated that biological concerns as well as scientific information were very important to them if a new or revised CMM for N. Pacific were to be developed. Opposition from a number of longline fishermen on the need for changes to the current catch limit for N. Pacific striped marlin suggest that some education and outreach on the status of the stock and risk of overfishing if the current CMM is left in place may be needed if stakeholder support for changes to the current CMM are desired. Additionally, further research into several of the management alternatives such as the use of circle hooks and those alternatives including an element of live release should be undertaken and results disseminated as stakeholders indicated their support for science-based decision making.

Figure 1. Decision hierarchy on criteria to consider in developing a conservation measure for N. Pacific striped marlin and proposed alternatives

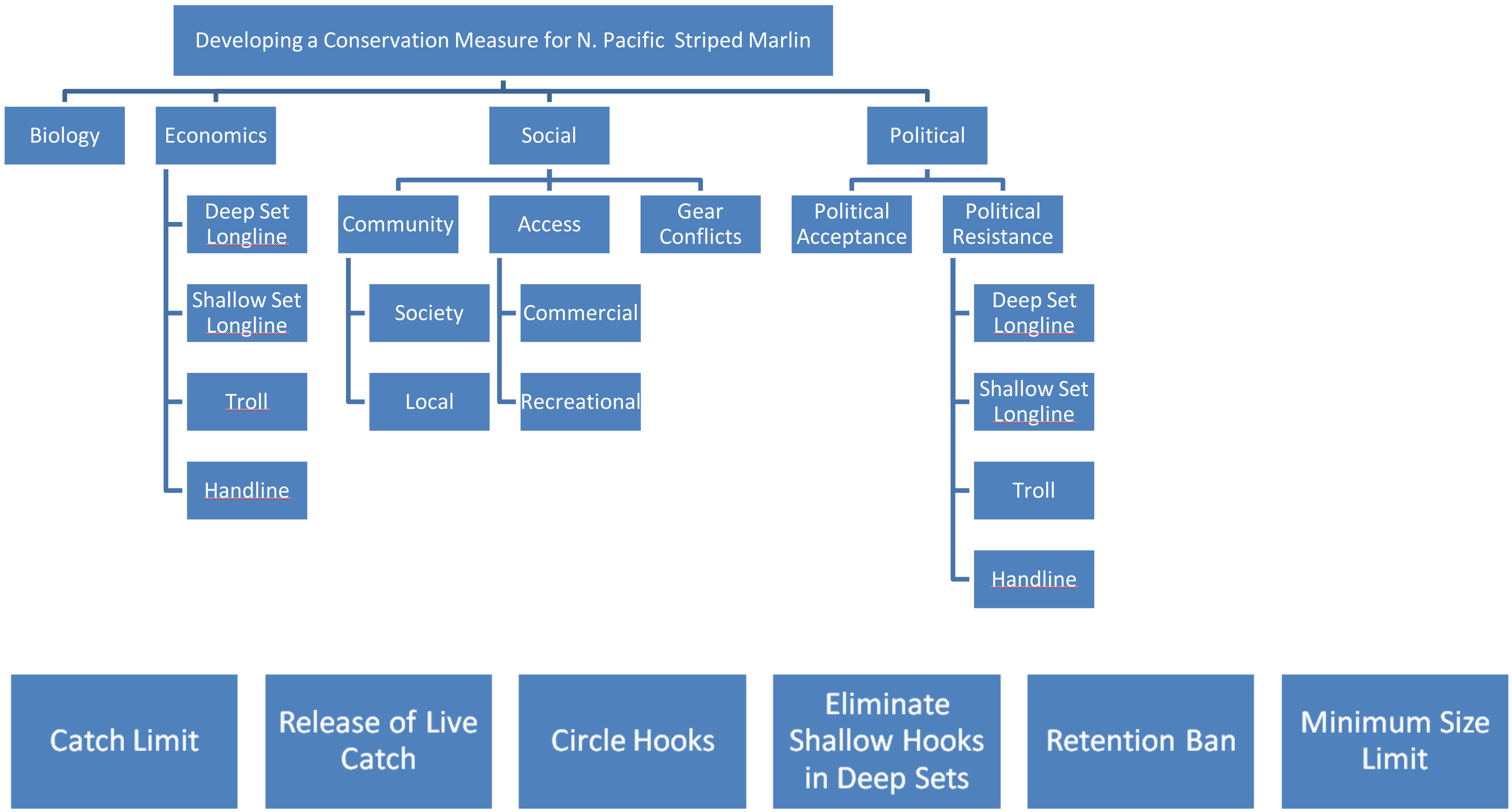

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Figure 2. AHP weightings overall and by stakeholder group for the management options presented. CL = catch limit, LR = live release, CH = circle hooks, RB = retention ban, MS = minimum size and NS = no shallow hooks

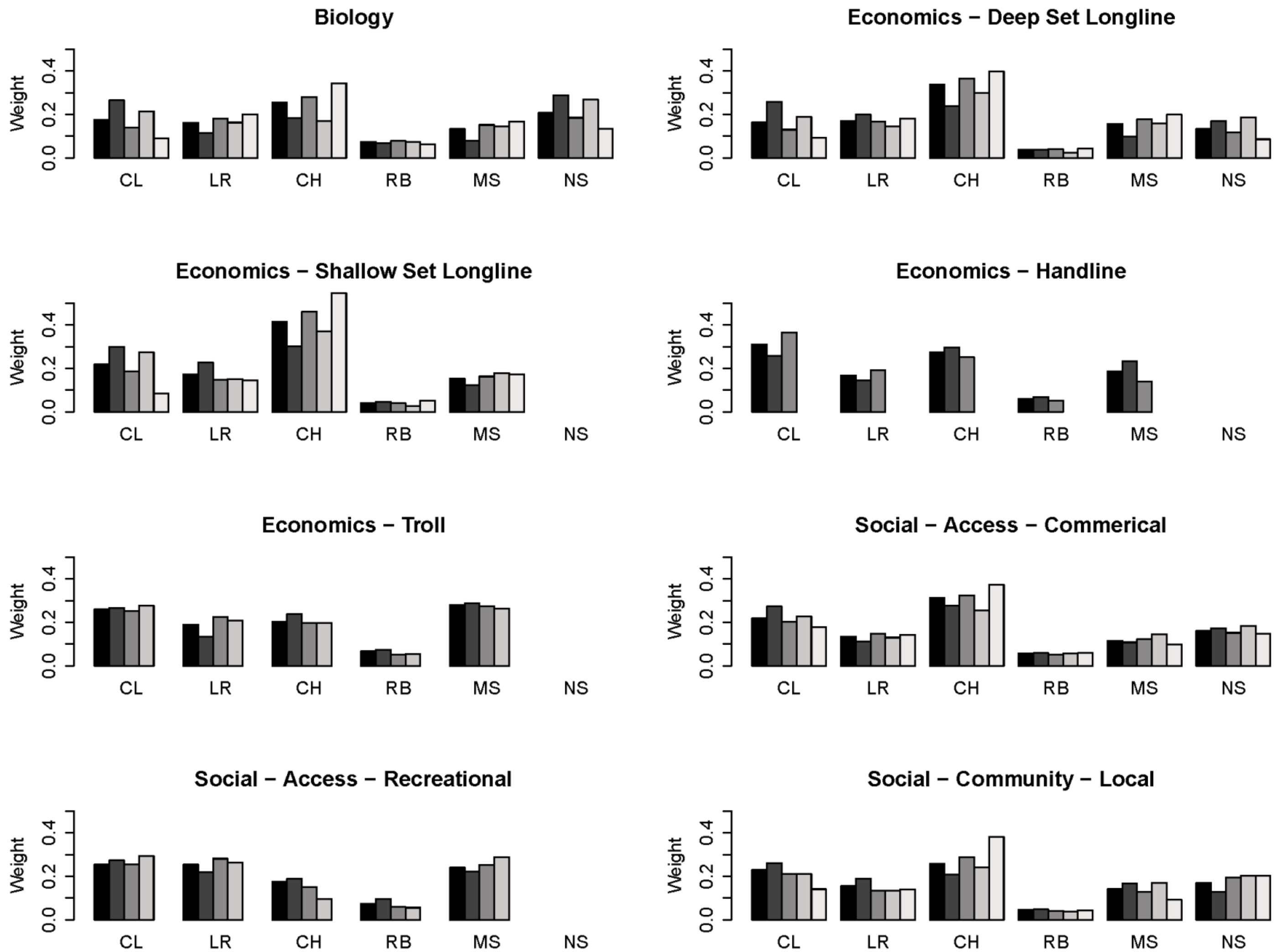


Figure 2. continued

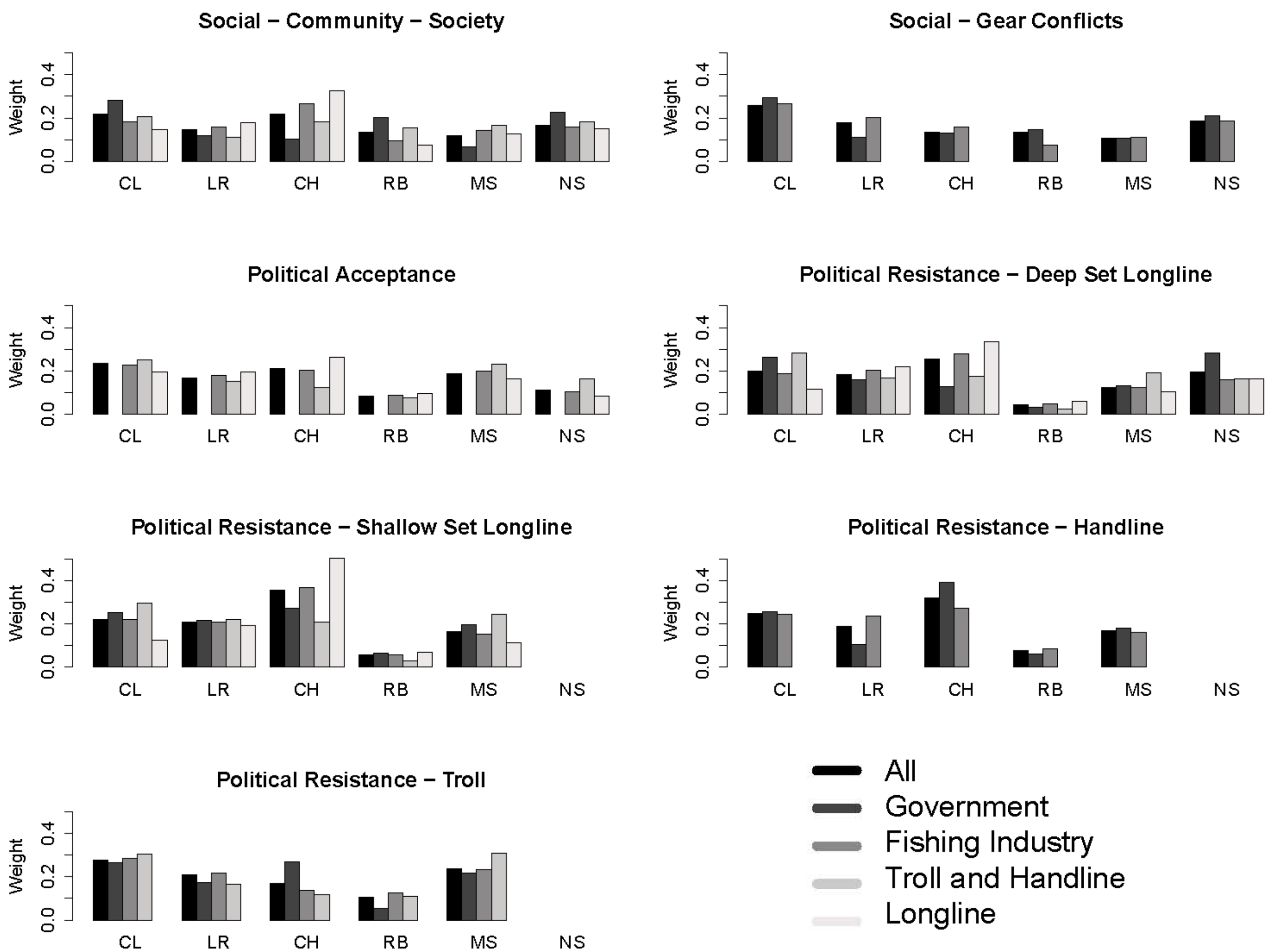


Table 1. Average inconsistency ratios for all respondents for the various criteria and subcriteria evaluated.

Criteria and Subcriteria	Average Inconsistency Scores
Factors	0.39
Biology	0.37
Economic	0.2
Economics-Deep Set Longline	0.29
Economics - Shallow Set Longline	0.24
Economic – Handline	0.19
Economic-Troll	0.23
Social	0.67
Social-Community-Society	0.4
Social-Community-Local	0.32
Social-Access-Commercial	0.25
Social-Access-Recreational	0.36
Political-Acceptance	0.47
Political-Resistance	0.18
Political-Resistance-Deep Set Longline	0.31
Political-Resistance-Shallow Set Longline	0.26
Political-Resistance-Handline	0.19
Political-Resistance-Troll	0.25

Table 2. Average AHP scores overall and for various respondent groups.

		Government	Fishing Industry	Fishermen-Longline	Fishermen-Other	Overall
Factors	Biology	0.473	0.405	0.352	0.503	0.434
	Economic	0.307	0.297	0.338	0.224	0.290
	Social	0.137	0.192	0.173	0.216	0.178
	Political	0.084	0.106	0.103	0.058	0.098
Economic	Deep Set	0.501	0.339	0.305	0.366	0.378
	Shallow Set	0.302	0.359	0.343	0.372	0.344
	Handline	0.091	0.112	0.135	0.089	0.105
	Troll	0.106	0.192	0.218	0.179	0.175
Social	Community	0.333	0.354	0.338	0.354	0.353
	Access	0.377	0.443	0.427	0.476	0.425
	Gear Conflicts	0.290	0.203	0.235	0.171	0.222
	Community-Society	0.442	0.368	0.420	0.329	0.384
	Community-Local	0.558	0.633	0.580	0.671	0.616
	Access-Commercial	0.686	0.569	0.616	0.475	0.587
	Access-Recreational	0.314	0.431	0.384	0.525	0.413
Political	Acceptance	0.558	0.533	0.537	0.528	0.536
	Resistance	0.443	0.467	0.463	0.472	0.465
	Resistance-Deep Set	0.438	0.328	0.261	0.363	0.356
	Resistance-Shallow Set	0.243	0.366	0.375	0.367	0.339
	Resistance-Handline	0.128	0.113	0.153	0.086	0.115
	Resistance-Troll	0.191	0.193	0.211	0.185	0.190

Table 3. Rankings of AHP scores for the six management options for North Pacific striped marlin overall and for various groups where a rank of 1 represents the management option with the highest score and 5 represents the management option with the lowest score. CL = catch limit, LR=live release, CH=circle hooks, RB = retention ban, MS = minimum size, NS = no shallow hooks on deep longline sets.

Factor	Group	CL	LR	CH	RB	MS	NS
Biology	**Overall**	**3**	**4**	**1**	**6**	**5**	**2**
	Government	2	4	3	6	5	1
	Fishing Industry	5	3	1	6	4	2
	Troll and Handline Fishermen	2	4	3	6	5	1
	Longline Fishermen	5	2	1	6	3	4
Economic –Deep Set Longline	**Overall**	**3**	**2**	**1**	**6**	**4**	**5**
	Government	1	3	2	6	5	4
	Fishing Industry	4	3	1	6	2	5
	Troll and Handline Fishermen	2	4	1	6	5	3
	Longline Fishermen	4	3	1	6	2	5
Economic – Shallow Set Longline	**Overall**	**2**	**3**	**1**	**5**	**4**	
	Government	2	3	1	5	4	
	Fishing Industry	2	4	1	5	3	
	Troll and Handline Fishermen	2	4	1	5	3	
	Longline Fishermen	4	3	1	5	2	
Economic-Handline	**Overall**	**1**	**4**	**2**	**5**	**3**	
	Government	2	4	1	5	3	
	Fishing Industry	1	3	2	5	4	
	Troll and Handline Fishermen						
	Longline Fishermen						
Economic-Troll	**Overall**	**2**	**4**	**3**	**5**	**1**	
	Government	2	4	3	5	1	
	Fishing Industry	2	3	4	5	1	
	Troll and Handline Fishermen	1	3	4	5	2	
	Longline Fishermen						
Social-Community-Society	**Overall**	**2**	**4**	**1**	**6**	**5**	**3**
	Government	1	4	5	3	6	2
	Fishing Industry	2	3	1	6	5	3
	Troll and Handline Fishermen	1	6	2	5	4	3
	Longline Fishermen	3	2	1	6	5	4
Social-Community-Local	**Overall**	**2**	**4**	**1**	**6**	**5**	**3**
	Government	1	3	2	6	4	5
	Fishing Industry	2	4	1	6	5	3
	Troll and Handline Fishermen	2	5	1	6	4	3
	Longline Fishermen	2	4	1	6	5	3

Social-Access-Commercial	**Overall**	**2**	**4**	**1**	**6**	**5**	**3**
	Government	2	4	1	6	5	3
	Fishing Industry	2	4	1	6	5	3
	Troll and Handline Fishermen	2	4	1	6	5	3
	Longline Fishermen	2	4	1	6	5	3
Social-Access-Recreational	**Overall**	**1**	**1**	**4**	**5**	**3**	
	Government	1	3	4	5	2	
	Fishing Industry	2	1	4	5	3	
	Troll and Handline Fishermen	1	3	4	5	2	
	Longline Fishermen						
Social-Gear Conflicts	**Overall**	**1**	**3**	**4**	**4**	**6**	**2**
	Government	1	5	4	3	6	2
	Fishing Industry	1	2	4	6	5	3
	Troll and Handline Fishermen						
	Longline Fishermen						
Political-Acceptance	**Overall**	**1**	**4**	**2**	**6**	**3**	**5**
	Government						
	Fishing Industry	1	4	2	6	3	5
	Troll and Handline Fishermen	1	4	5	6	2	3
	Longline Fishermen	3	2	1	5	4	6
Political-Resistance-Deep Set Longline	**Overall**	**2**	**4**	**1**	**6**	**5**	**3**
	Government	2	3	5	6	4	1
	Fishing Industry	3	2	1	6	5	4
	Troll and Handline Fishermen	1	4	3	6	2	5
	Longline Fishermen	4	2	1	6	5	3
Political-Resistance-Shallow Set Longline	**Overall**	**2**	**3**	**1**	**5**	**4**	
	Government	2	3	1	5	4	
	Fishing Industry	2	3	1	5	4	
	Troll and Handline Fishermen	1	3	4	5	2	
	Longline Fishermen	3	2	1	5	4	
Political-Resistance-Handline	**Overall**	**2**	**3**	**1**	**5**	**4**	
	Government	2	4	1	5	3	
	Fishing Industry	2	3	1	5	4	
	Troll and Handline Fishermen						
	Longline Fishermen						
Political-Resistance-Troll	**Overall**	**1**	**3**	**4**	**5**	**2**	
	Government	2	4	1	5	3	
	Fishing Industry	1	3	4	5	2	
	Troll and Handline Fishermen	2	3	4	5	1	
	Longline Fishermen						

Table 4. Summary of participant responses to multiple choice and short answer survey questions

	Total	Government	Fishing Industry	Longline	Troll and Handline
A. Knowledge on stock of N Pacific striped marlin					
Very Knowledgeable	4	2	2	2	
Knowledgeable	10	4	6	4	1
Somewhat Knowledgeable	16	2	13	6	6
Not at all Knowledgeable/Don't Know	10	1	10	5	5
B. Need for management for striped marlin					
Strongly Agree	9	5	3		3
Somewhat Agree	7	3	4		3
Somewhat Disagree	6		6	3	3
Strongly Disagree	8		8	8	
Undecided/Don't Know	10	1	10	6	3
C. Most Feasible Alternative					
Catch Limit	7	3	3	1	2
Circle Hooks	17	4	14	11	3
Live release	4		4	3	1
Minimum Size	8	2	6	2	3
No Shallow Hooks	11	2	9	2	7
Retention Ban	5	3	2		
D. Least Feasible Alternative					
Catch Limit	1		1	1	
Circle Hooks	1	1			
Live Release	12	5	7	1	4
Minimum Size	6	2	4	2	2
No Shallow Hooks	5		5	3	2
Retention Ban	18	2	16	9	7
E. Other Management Alternatives					
Area-Time Restrictions	6	4	2	1	
Catch Shares	4	2	2	1	1
Gear Changes	3	1	2	1	
Effort Limits	3		3	3	
Bait	3		3	1	1
Maximum Size	1	1			
Ban Commercial Sale	1		1	1	
F. Familarity with BET Longline Limits					
Very Familiar	14	5	9	7	1
Familiar	11	2	9	6	1
Somewhat Familiar	10	1	9	3	6

Not at All Familiar	3	1	2		2
Don't Know	1		1		1
G. Should MLS catch limits be managed similarly to the BET catch limit					
Yes	7		7	4	3
No	11	1	10	8	2
Improvements needed in monitoring and Compliance	11	2	8	4	2
Should be Gear Changes before Catch limits	3	1	1		1
Catch Limits should have alternative periods	2	2	1		1
H. Other Gear Modifications for Troll and Handling					
Circle Hooks	12	3	9	3	6
Bait	2		2		2
Live Release	1		1		1
I. Should management be applied across all gear types or focus on specific gears?					
All gear types should be managed	23	3	20	11	7
Only longline should be managed	5	2	3	1	2
Fisheries contributing to the highest mortality should be managed	6	3	2	1	2
Unregulated fisheries should be managed	1		1		1
J. Should CMM cover just striped marlin or expand to other billfish?					
Yes, should include other billfish	9	6	3	3	
No, should only be limited to striped marlin	28	3	24	12	11
K. Changes for a new CMM					
Base Years Reevaluated	1	1			
Gear Modifications	5	1	4	1	3
More Research	2		2	1	1
Improvements in Compliance and Monitoring	4		4	1	2
Catch and Retention	1	1			
Size Limit	4	1	3	1	2
Ban Retention	1		1		1
Reflective of Improvements in Stock Knowledge	4	2	1	1	
Recognize Differences in Fishermen	2		2		1
Revise TAC and Allocation	2	1	1		1
Include Rolling Average	1		1		
No Change	1		1		1
Boat Buybacks	1		1	1	

CHAPTER THREE: ECOSYSTEM EFFECTS OF MANAGEMENT OPTIONS FOR NORTH PACIFIC STRIPED MARLIN (KAJIKIA AUDAX) IN THE WESTERN AND CENTRAL PACIFIC OCEAN

Abstract

Management measures adopted out of concerns for a single species can sometimes impact more species than the intended one. This study used an Ecopath with Ecosim model of the central and north Pacific to evaluate how implementation of different management measures for north Pacific striped marlin (*Kajikia audax*) would impact biomasses of striped marlin and other groups. Increases in fishing effort had the greatest impact on relative biomass, with declines in most of the higher-level trophic groups targeted by fishing and increases in many of the mid-level trophic groups. Measures that limited catch of striped marlin only did not result in impacts to other groups. For example, the use of circle hooks and the elimination of the shallowest hooks from deep longline sets led to increases in striped marlin biomass, with limited effects to other species. This study also compared the impacts of implementation of measures by the U.S. fleet and by other foreign fleets, and predicted recovery of striped marlin to depend on implementation of measures by other foreign fleets; conservation measures adopted unilaterally by the United States would have a minimal impact on biomass recovery for this species as its catch represents a small portion of total catch of N. Pacific striped marlin.

Introduction

Concerns over the status of a single species or group of species of fish often lead fisheries managers to implement management measures designed to reduce fishing pressures for those particular species. Although these management measures may have larger ecosystem impacts, ecosystem impacts are often not considered when specific management measures are developed. Fisheries exert significant impacts to the ecosystem through reductions to top predators and other commercially valuable species (Walters et al. 2005, Halpern et al. 2008, Polovina et al. 2009).

Species such as tunas and billfish occupy similar trophic levels, and management measures adopted for one species may have consequences for the other. Kitchell et al (2004), modeled a scenario in which shallow hooks were eliminated from deep set pelagic longlines and found increases in blue marlin (*Makaira nigricans*) and striped marlin (*Kajikia audax*) biomasses and decreases in adult yellowfin (*Thunnus albacares*) tuna biomass. Effects of measures are not necessarily detrimental to competing species, and could be neutral or positive depending on the restriction. For example, closing a fishery or creating a marine protected area may benefit multiple species in addition to the species targeted for management (Watson et al. 2008).

Management measures can affect not only the biomass of competitive species, but also may alter the biomass of predators and prey species through top-down effects (Heithaus et al. 2008, Baum and Worm 2009). For example, the removal of apex predators by fishing in the Pacific Ocean may cause increases in intermediate and lower trophic level fishes (Polovina et al. 2009). Reducing or eliminating pressures on upper trophic level species may then help increase their biomass, and concurrently result in decreases to biomass of mid-to lower trophic level species (Hinke et al. 2004). Kitchell et al (1999) found the pelagic longline fishery to act as a key predator in the Central and North Pacific Ocean and reductions and/or restrictions to fishing effort were predicted to increase upper trophic level biomass and decrease mid to lower-trophic level biomass.

Recent stock assessments suggest that north Pacific striped marlin is currently overfished and experiencing overfishing (Brodziak and Piner 2010, ISC 2012b), and in 2013 the United States designated this stock as subject to overfishing and overfished under the standards established in the Magnuson-Stevens Fisheries Management and Conservation Act. Overfishing refers to the ratio of fishing mortality rates and occurs when catch is at a level that leads to a drop in recruitment such that fishing mortality is greater than the fishing mortality rate estimated to produce maximum sustainable yield (MSY). Overfished refers to the ratio of overall biomass or spawning biomass and occurs when biomass is below the biomass level estimated to produce MSY.

The Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (commonly known as the Western and Central Pacific Fisheries Commission or WCPFC) was established in 2004 to manage and conserve highly migratory species in WCPO. The WCPFC has adopted a number of conservation and management measures (CMMs) for various species, and in 2012, the WCPFC adopted CMM (CMM 2010-01) for north Pacific striped marlin. CMM 2010-01 imposed limits and in time reductions on members' catch based on historical catch without prescribing how to achieve these reductions. The measure encouraged members to explore various methods for reducing fishing mortality on striped marlin including use of circle hooks and the elimination of the shallowest hook on deep longline sets.

Circle hooks, a type of fish hook curved back into a circular shape, reduce the likelihood of deep hooking, which can reduce mortality in fish, sharks, and turtles that are caught (Kerstetter and Graves 2006, Read 2007, Sales et al. 2010). Circle hooks can reduce catches of sea turtles, but their use has had mixed results in reducing catches of other sharks and fish

(Yokota et al. 2006, Serafy et al. 2009, Ward et al. 2009a, Domingo et al. 2012). Curran and Bigelow (2011) compared catch rates for 18 species in the Hawaii deep-set longline fishery and found catchability to be lesser when using circle hooks instead of J hooks or tuna hooks for all species except bigeye tuna (*T. obesus*) and albacore (*T. alalunga*) (only for J hooks).

The objective of this study is to examine how exercising various management options for north Pacific striped marlin might affect it and other fish species and groups of species in the larger ecosystem. After modifying an existing Ecopath model (Howell et al. 2013), we developed scenarios that varied fishing effort in all fisheries in the WCPO, varied fishing effort just for striped marlin, and varied landings due to the adoption of specific gear modifications that included circle hooks and eliminating the shallowest hook on deep longline sets to identify how striped marlin and other species responded to various scenarios. As WCPFC members may choose different methods to reduce fishing mortality on striped marlin under CMM 2010-01, this study also examined how striped marlin and other species could respond if United States flagged longline fisheries implemented certain mitigation measures, along with if foreign longline fisheries implemented certain mitigation measures, and if both U.S. and foreign longline fisheries adopted the same mitigation measures.

Methods

Ecopath

Ecopath is a mass-balance model widely used to consider energy flows between trophic groups. First developed in the early 1980s to model a coral reef ecosystem, Ecopath and its associated programs, Ecosim and Ecospace, have been employed by over 3,000 users in 124 countries to examine ecosystem-related issues in over 125 aquatic ecosystems worldwide (Polovina 1984, Pauly et al. 2000, Christensen et al. 2008). Ecopath assumes mass balance for a selected period of time, and does not assume a steady state system. The basic equation used in Ecopath is:

$$B_i\left(\frac{P_i}{B_i}\right) EE_i = Y_i + \sum B_j \left(\frac{Q}{B}\right)_j DC_{ji} + BA_i + NM_i$$

where B represents the biomass, P is production, EE is ecotrophic efficiency (the proportion of the production utilized in the system), Y is the fisheries catch per unit area and time, Q is the consumption, DC is the contribution to the diet, BA is biomass accumulation and NM is the net migration. Subscript i represents prey and subscript j represents predator. $\left(\frac{\mathrm{P}}{\mathrm{B}}\right)$ is the production biomass ratio and is generally equivalent to total mortality (Z) (Allen 1971). Total mortality is the sum of fishing mortality (F) and natural mortality (M). For each functional group in the model, information usually gleaned from literature is needed on the production/biomass (P/B), consumption/biomass (Q/B), biomass, proportion of habitat occupied, biomass in habitat area (t/km^2), diet composition and fishing mortality. Not all information may be known for each biomass group, and Ecopath can estimate values for a missing parameter if all other inputs are provided.

Ecosim builds on the original Ecopath model by incorporating temporal dynamics such as time series of fisheries or environmental factors to influence distributions of biomass (Walters et al. 1997). The fundamental Ecosim equation is:

$$\frac{dB_i}{dt} = f_i(B_i) - MB_i - F_iB_i - \sum_{j=1}^{n} C_{ij}\left(B_iB_j\right)$$

If i is a primary producer, then $\mathrm{f_i}(\mathrm{B_i})$ is a function of B_i. If i is a consumer then $f_i(B_i) = g_i \sum C_{ji}\left(B_jB_i\right)$ with g_i representing net growth efficiency and $C_{ji}\left(B_jB_i\right)$ describing consumption rates from $\mathrm{B_j}$ to B_i.

Kitchell et al. (1999) first developed an Ecopath with Ecosim model for the central and north Pacific (CNP) Ocean. Cox et al. (2002) then made some modifications to the CNP model and Howell et al. (2013) further modified the model (referred to as the HLFG model) to focus on the area of the north Pacific fished by the U.S. longline fleet (170°E-150°W and 10°N-40°N). The HLFG model described a smaller area than the original CNP model, contained 28 functional groups including three additional mid-level trophic groups not considered in the original CNP model, and incorporated updated biomass and diet composition values. Functional groups were composed of either species or collections of species that shared similar population dynamics and ecological function. The four tuna species were split into adult and juvenile groups and linked in Ecopath in to account for changes in diet and harvesting on older individuals.

The HLFG model incorporated recent stock assessment values as well as an updated diet composition matrix, and was used as the basis for the Ecopath model in this study. Because this study focused on evaluating effects in the northern portion of the WCPO, the HLFG model area (Figure 3) was expanded westward to 140° E. The model area for this study included 140°E-150°W and 10°N-40°N and covered a surface area of approximately 23,200,000 km^2. This increase in model area resulted in a few modifications made to biomass for several of the higher trophic level groups, fleets (now including Japanese gillnet and pole and line fleets), and fisheries landings. In addition, biomass values were recalculated if new information was available from stock assessments. (Brodziak and Ishimura 2010, Kleiber 2012, Piner 2012, Teo 2012, ISC 2013b, a). The HLFG and the modified model for this study used 1991 as the initial year for the model, as 1991 was the first year catch and effort logbook information, as completed by the vessel operator was available for the Hawaii-based longline fleet, which is the main U.S. fleet that catches striped marlin in the North Pacific. Minor adjustments were made to the diet composition matrix to balance the model. Table 5 shows the values used to produce a balanced model and Table 6 shows the values used in the diet composition matrix for this study. The fishing fleets included in this study are the following: the purse seine fishery; three longline fisheries (the Hawaii shallow set fishery (which targets swordfish), the Hawaii deep set fishery (which targets tuna), and a fishery representing longline vessels from other nations (which is a mixture of shallow and deep set vessels); a troll fishery; the Asian drift gillnet fishery (banned on the high seas after 1993); a Japanese coastal gillnet fishery; and a Japanese pole and line fleet. Landings information for each of these fleets was obtained from catch data compiled by the WCPFC, the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) or from landings information incorporated in stock assessments (ISC 2012a, Kleiber 2012, WCPFC 2012a).

Biomass time series from 1991 to 2011 (or the latest year available) were created for eight species (blue shark, *Prionace glauca*, blue marlin, striped marlin, swordfish, *Xiphias gladius*, albacore, yellowfin tuna, skipjack tuna, *Katsuwonus pelamis*, and bigeye tuna) where recent stock assessment information was available, and estimates included only those stock assessment regions that overlapped with the study area. Howell et al. (2013) modeled phytoplankton biomass time series for the time period of 1991-2010, and these time series were also included. Effort time series for each fishing fleet where information was available were incorporated into the Ecosim portion of the model. No information on changes in fishing effort was available for Japanese gillnet and pole and line fishing, and fishing effort was assumed to be relatively constant.

An initial Ecosim scenario was developed to help identify appropriate vulnerability parameters. Vulnerability is the amount of change in prey mortality caused by a given change in predator biomass. A small vulnerability value implies that a change in predator biomass will not have much influence on prey biomass, while a large vulnerability value implies that a change in predator biomass will strongly impact prey biomass such that prey populations are sensitive to predation pressures. The "Fit to Time Series" tool in Ecosim was used to compute vulnerabilities that produced the least sum of squares between model output and the time series included (Figure 4). Vulnerabilities were derived for each predator-prey interaction (referred to as PP vulnerability) as well as for each predator group interaction (referred to as P vulnerability) such that the same vulnerability value was applied to all prey for each predator. The P vulnerability matrix was slightly modified to prevent biologically unreasonable scenarios (e.g., unexpected population crashes, exponential increase). Vulnerabilities were decreased for other sharks (all sharks except blue sharks), small billfish, yellowfin tuna, albacore, juvenile albacore, juvenile skipjack, mahi mahi (*Coryphaena hippurus*), mesopelagic fishes, and bathymetric forage and raised for blue marlin, mid-level trophic fish and lancetfish (*Alepisaurus ferox*). Scenarios were run using both vulnerability options (PP vulnerability and P vulnerability), and as there were minimal differences between the trends in the two options, vulnerabilities for each predator group were used for the remainder of the scenarios (See Appendix B for information on the analysis done using the predator/prey interaction).

A total of 140 scenarios projected through 2066 (75 years) were run, evaluating the impacts of no change, overall changes in fishing effort to all fleets, requiring gear modifications to longline fisheries through the use of circle hooks and/or elimination of the shallowest hook in deep set longline fisheries, and changes in fishing effort for striped marlin only.

Curran and Bigelow (2011) observed that the use of circle hooks resulted in decreased catches of non-target species in the Hawaii deep set longline fishery. Circle hooks have been required in the Hawaii shallow set fishery for turtle mitigation purposes since 2004 and for cetacean mitigation purposes in the Hawaii deep set fishery since December 2012. To account for this decrease in catchability, the longline fisheries were then split into two fisheries in the Ecopath portion of the model – one including the proportion of catch that would be reduced due to the use of circle hooks and one including the remaining proportion of catch. Fishing effort for longline fisheries was then reduced accordingly for those species where it was expected that the proportion of catch would be reduced by using circle hooks (in 2004 and after for the Hawaii shallow set fishery and in 2012 and after for the Hawaii deep set fishery). All other changes to gear (all circle hook and no shallow hook scenarios) and effort were initiated in 2016 and carried through 2066. Beverly et al. (2009) examined the effect of eliminating the shallowest hook on deep set longline and found that catches would decrease for some species. Similar to what was done for circle hooks, a variant of the model was created that split the Hawaii deep set longline and other longline fisheries landings between those that would be expected under a no circle hook scenario and the remaining catch that would not be caught if the shallowest hook was eliminated.

This study also considered the effects of potential management policies directed at reducing striped marlin catch and examined changes when there were decreases in fishing effort of 0, 20, 40 and 60% for striped marlin only, and also varied the same percentages to the Hawaii longline fleet and for the other fleets that catch striped marlin including the other longline and the Japanese gillnet fishery. Finally, this study considered the effects of increasing or decreasing overall fishing effort by multiplying fishing effort for all fleets by 50% (FE050), 75% (FE075), 90% (FE090), 110% (FE110), 125% (FE125) and 150% (FE150) to consider effects of changing fishing effort (and in turn fishing mortality) for all fisheries. Scenarios with unchanged fishing effort were designated FE100.

This study compared biomass estimates for blue sharks, blue marlin, striped marlin, bigeye tuna, yellowfin tuna, skipjack tuna and albacore tuna when examining the initial model outputs with biomass estimates derived from single species stock assessments. As this study was primarily concerned with trends in biomass and not necessarily the exact biomass levels themselves, this study chose to illustrate and compare changes across scenarios using relative biomass. Relative biomass was the ratio of biomass to the initial biomass level in 1991. As mentioned above, 1991 was selected as the year to begin the model as it was the first year with sufficient data on the Hawaii shallow set fishery. Large-scale industrial fishing has been occurring in the Pacific since the end of World War II, and the use of 1991 as the beginning of the model time frame should not be construed to suggest that biomass levels at that time are in any way representative of an undisturbed or a balanced or healthy ecosystem.

Results

Initial Ecopath and Ecosim (1991-2012) model fits

The initial Ecosim model (hereafter known as the status quo scenario) fit well for mid-trophic (e.g., lancetfish and mahi mahi) and apex functional groups (e.g., blue sharks, marlins and tunas) (Figure 4). Biomass declines were predicted for striped marlin, blue marlin, bigeye tuna, yellowfin tuna and skipjack, biomass increases were predicted for blue sharks and albacore, and these trends were consistent with the trends in the biomass time series produced from respective stock assessments. Increases in biomass were also predicted for mid-level trophic fish, lancetfish, and mahi mahi (see Appendix C), which were similar to increases seen by Howell et al. (2013), and also documented by Polovina et al.(2009).

Changes in Fishing Effort

Functional groups responded to changes in overall fishing effort in several diverse ways: 1) relative biomass decreasing in response to increased fishing effort and relative biomass increasing in response to decreased effort (negative response); 2) relative biomass increasing with increased effort and relative biomass decreasing with decreased effort (positive response); or 3) relative biomass unaffected by changes in fishing effort. Figure 5 depicts representative examples of each response. (Additional figures for other functional groups can be found in Appendix C). Functional groups that exhibited a negative response in relative biomass with fishing effort included blue sharks, striped marlin, swordfish, yellowfin tuna, bigeye tuna, skipjack tuna, mesopelagic molluscs and mesopelagic fishes. Functional groups that exhibited a positive response in relative biomass from increased fishing effort included other sharks, blue marlin, albacore, juvenile albacore, other billfish, mid-trophic level fish, lancetfish, and mahi mahi. Some functional groups did not show a strong positive or negative response, and/or responses in relative biomass across varying levels of fishing effort were quite small (<5% change in relative biomass). These functional groups included juvenile yellowfin tuna, juvenile bigeye tuna, bathypelagic forage fish, epipelagic molluscs, epipelagic fish, invertebrates, mesozooplankton and microzooplankton.

Changes if Shallowest Hooks Removed from Deep Longline Sets

Only two functional groups, striped marlin and blue marlin, responded with noticeable changes in relative biomass in scenarios where the shallowest hooks were eliminated in the Hawaii deep set fishery only, other longline fisheries only or both the Hawaii deep set and other longline fisheries (Figure 6 and Figure 7). For both striped marlin and blue marlin, eliminating shallow hooks in one or both of the fisheries resulted in higher relative biomass, with greatest increases occurring when eliminating shallow hooks from both fisheries, followed by the removal of shallow hooks from other longline fisheries only. The smallest increase in biomass occurred from the removal of shallow hooks from the Hawaii deep set fishery only with only minor increases predicted for striped marlin biomass and moderate increases predicted for blue marlin biomass.

When changes in overall fishing effort were applied in combination with scenarios eliminating the shallowest hooks, striped marlin exhibited the biggest increases in relative biomass when fishing effort was halved, and the smallest increase in relative biomass occurred when fishing effort increased by 50%. At 50% fishing effort, all scenarios including the status quo scenario resulted in relative biomass greater than 1 while at 75% fishing effort only the scenarios that included other longline fisheries resulted in relative biomass greater than 1 though applying no shallow hooks to only the Hawaii deep set fishery did result in overall increases to biomass from the time gear modification was applied. At 110% fishing effort, the only scenario that resulted in relative biomass greater than 1 was the scenario that eliminated the shallowest hooks for both the Hawaii and other longline fleets. Eliminating shallow hooks in just the Hawaii deep set fishery for this and the other increased fishing effort scenarios resulted in relative biomasses similar to the status quo scenario (FE100). Eliminating the shallowest hooks for the other longline fleet resulted in increases to relative biomass in all scenarios except the 150% fishing effort scenario and eliminating shallow hooks in both the Hawaii deep set fishery and other longline fishery resulted in increases to relative biomass in all cases.

As mentioned previously, blue marlin exhibited a positive relationship between biomass and fishing effort, and when changes in overall fishing effort were combined with scenarios eliminating shallow hooks from deep sets, changes in relative biomass were small and declining, but discernible at 50% fishing effort, and much greater and increasing at 150% fishing effort. Relative biomass levels were greater than 1 for scenarios where shallow hooks were eliminated from both the Hawaii deep set fishery and the other longline fisheries and where fishing effort was at status quo (FE100) or increased. Relative biomass levels were also greater than 1 for scenarios where shallow hooks were eliminated from the other longline fisheries and where fishing effort was increased to 125% or 150%. Relative biomass increased in all shallow hook scenarios where fishing effort was at status quo or greater.

Changes if Circle Hooks Required

Requiring circle hooks in the other longline fishery in which they are are currently not required or being employed resulted in differences in relative biomass for striped marlin, blue marlin, albacore, swordfish, blue shark, small billfish, lancetfish, other shark and other billfish. Of those groups, for all except lancetfish and other billfish, requiring circle hooks resulted in an increase in relative biomass across all fishing effort scenarios (Figure 6-Figure 9 depict relative biomass responses for striped marlin, blue marlin, swordfish and blue shark). For blue marlin, requiring circle hooks resulted in that relative biomass being slightly larger than the status quo (FE100) at the beginning of the simulation and then for 90%, status quo, 110% and 125% fishing effort scenarios, relative biomass after implementation of circle hooks was at the end of the 50 year simulation just slightly below the relative biomass at status quo. For lancetfish and for other billfish, circle hooks resulted in a decrease in relative biomass throughout the simulated time period (see Appendix C).

Changes if Striped Marlin Limits Imposed

At status quo (FE100), decreasing fishing effort for only striped marlin led to increases in striped marlin biomass in all scenarios except where no decreases were made in other longline fleets (Figure 10). The greatest increases in striped marlin biomass occurred when reductions in fishing effort were made to other longline fleets and secondarily when reductions in fishing effort were made in the Hawaii fleet. The only scenarios where relative biomass increased beyond 1 were those scenarios where other longline fleets implemented a 60% reduction in fishing effort for striped marlin.

If fishing effort decreased relative to status quo (e.g., to 50%, 75% and 90% fishing effort scenarios), relative biomass for striped marlin increased during the simulation time. At the 50% decreased fishing effort level, all scenarios had a relative biomass greater than 1 at the end of the simulation. At 75% fishing effort all scenarios where there was a 40 and 60% reduction in other longline fleets and a 20% reduction in Hawaii and other longline fisheries had a relative biomass greater than 1 at the end of the simulation.

If fishing effort increased relative to status quo (110%, 125% and 150% fishing effort), fewer scenarios resulted in increasing biomass; and at 150% effort, no reductions in either or both fleets resulted in increased relative biomass over the duration of the simulation.

Discussion

Biomass Reponses to Changes in Fishing Effort

In this study, most of the mid and upper level trophic groups exhibited strong responses to changes in fishing pressure while many of the lower level trophic groups appeared relatively unaffected by changes in fishing pressure. Other studies in the central and north Pacific Ocean have noted a similar pattern of mesopredator release (Kitchell et al. 2002, Polovina et al. 2009). Polovina et al. (2013) created a size-based ecosystem model for the CNP to compare fished and unfished ecosystem size structure and in the fished ecosystem observed overall decreases in abundance for fishes greater than 15 kg, increases in abundance for fishes between 0.1-15 kg, and minimal effects on fishes less than 0.1 kg in size. Polovina et al. (2013) observed minimal cascading in their study and it may be that pelagic fisheries impacts in the north Pacific Ocean have a limited reach such that impacts are only easily identified in upper and mid-level trophic levels and less easily identified in lower trophic levels. Other studies have also observed a dampening of top-down controls in oceanic ecosystems, and causes for this dampening include food web feedbacks that mitigate top-down effects, predator diversity, and climate oscillations (Micheli 1999, Stibor et al. 2004, Frank et al. 2005, Litzow and Ciannelli 2007).

Increased fishing pressure generally leads to decreased biomass, and biomass for most of the higher level trophic groups in this study decreased as fishing effort increased. A few trophic groups, however, including other sharks, blue marlin and albacore, exhibited increasing biomass with increased fishing effort. Ecosim has a limited number of parameters at its disposal to model population dynamics; and for albacore, other factors not included in the model may have led the model to incorrectly infer that increased effort would lead to increased biomass. Biomass estimates from the most recent stock assessment suggest that albacore biomass declined from the mid-1970's to the mid-1980's and early 1990's, and then rapidly increased to levels similar to the 1970's in the 1990's and 2000's (ISC 2011). This rebound in biomass is not likely due to albacore increasing with increased fishing pressure, but due to a period of higher recruitment, which may be responses to large-scale climactic changes (Clark et al. 1975, Kiyofugi 2013). Similar to albacore, Ecopath may not be modeling biomass trends for the other sharks group due to limited information related to catch and vulnerability. In general, worldwide shark populations have declined and stock assessments indicate that several shark species in the WCPO have experienced unsustainable levels of exploitation and populations are quite depleted (Clarke et al. 2013).

Several of the mid-trophic groups, such as mid-trophic level fishes, lancetfish and mahi mahi, also showed increased biomasses with increased fishing effort. Unlike other sharks and albacore where the simulation trends may not reflect reality, this trend of increasing biomass for mid-trophic level species has been noted in other modeling and observational studies (Kitchell et al. 2002, Polovina et al. 2009, Howell et al. 2013). Using observer data, Polovina et al. (2009) documented increases in mid-level trophic fishes in the Hawaii longline catch, and suggested that the removal of top predators was responsible for the increases in mid-level trophic species.

Fishing effort was the most important variable in determining trends in relative biomass. For striped marlin in particular, if fishing effort was halved, increases in biomass occurred in all scenarios; while if fishing effort was increased to 150%, no recovery occurred in any of the scenarios. Fishing effort can be driven by a number of different factors including prices of fish, fuel and labor. Some fleets such as the Japanese longline fleet have significantly contracted in the last two decades while others such as the United States longline fleets have fluctuated due to effort restrictions related to protected species concerns (Haward and Bergin 2001). Fishing effort can be difficult to control, but it is important to note that fishing limitations can strongly impact fish populations even on a short time scale. For several species, including striped marlin, swordfish and blue shark, relative biomasses responded to changes in fishing effort quickly such that significant increases occurred within 10 years of the decrease in fishing effort. For striped marlin in particular, forecasts using the latest stock assessment indicate significant recovery if fishing mortality declines (ISC 2012b).

Although fishing induced mortality has undoubtedly strongly influenced the pelagic ecosystem of the north western Pacific Ocean, this study supports predictions that the largest impacts to occur on higher trophic levels, smaller impacts to occur on mid-level trophic levels and fairly minimal impacts to occur on lower trophic levels. Increases in fishing effort would generally lead to continued declines in higher trophic level groups and increases in mid trophic levels. This observation suggests that fishing does impact ecosystems beyond the initial species targeted, but perhaps in pelagic systems in the north western Pacific Ocean not to the extent that there are drastic changes throughout all trophic levels.

Biomass Responses to Gear Modifications

Our results suggest that adopting gear modifications such as circle hooks and eliminating the shallowest hooks from deep set longline fisheries resulted in changes to relative biomasses. For some higher level trophic groups, these gear modifications resulted in higher relative biomass levels. Use of circle hooks in longline fisheries impacted a greater number of functional groups whereas eliminating the shallowest hook on deep set only appeared to impact blue marlin and striped marlin.

This study used reductions in the catchabilities as calculated by Curran and Bigelow (2011), and all groups except mahi mahi and mid-level trophic fish, where catchabilities were modified due to use of circle hooks, showed noticeable differences when circle hooks were required in the other longline fleets. Other species, particularly from lower trophic groups, showed differences in relative biomass of less than 1% if any were seen at all in response to the use of circle hooks. If circle hooks were implemented for the conservation of a single species (e.g., turtles or striped marlin), there would be impacts to a broader suite of species, but those impacts likely would be limited to species caught and not extend to those groups not already harvested. As studies in other areas have observed increases or no differences in catch rates of various fish species when using circle hooks, particular caution should be exercised in drawing broad conclusions from the results of this study (Kerstetter and Graves 2006, Ward et al. 2009a, Curran and Beverly 2012). However, circle hooks have the potential to reduce catches of striped marlin, and field studies or gear trials should be undertaken in other areas of the WCPO to determine how effective this gear modification could be in a broader context.

Eliminating the shallowest hooks also resulted in changes to relative biomasses for striped marlin and blue marlin, were not predicted to result in changes to relative biomass for other species. Previous research has found that striped marlin are typically caught on the shallowest hooks, and eliminating the shallowest hook from deep longline sets has the potential to decrease catches of striped marlin (Boggs 1992, Kitchell et al. 2004, Beverly et al. 2009). Beverly et al. (2009) compared catch rates in deep set longlines for 18 species of fish where the shallowest hooks were present and were then removed, and they found significant differences in catch for 6 species, including wahoo, mahi mahi, striped marlin, shortbill spearfish, blue marlin and sickle pomfret. Our study applied differences in catch rates to all groups identified by Beverly et al. (2009), but unlike the circle hooks scenario where changes in relative biomass were predicted for almost all groups where catch changes were made, eliminating the shallowest hooks only resulted in changes in relative biomass for striped marlin and blue marlin. Kitchell et al. (2004) also used an Ecopath model to examine effects from removal of the shallowest hooks using catch information from Boggs (1992) and found changes were limited to blue marlin, other marlins (this group included striped marlin) and bigeye tuna. Kitchell et al. (2004) chose not to incorporate changes in fishing mortality to mahi mahi due to uncertainty in fishing mortality as they believed mahi mahi were infrequently retained. Information from Hawaii longline logbooks indicate that for the U.S. longline fleet, mahi mahi are almost always retained when caught, but incorporating decreased fishing mortality in this study on mahi mahi did not have any noticeable impacts. Changes in relative biomass from eliminating the shallowest hooks on deep longline sets were much more limited, and results from this study suggest that some gear modifications may have a much more restricted impact than what might be expected. Eliminating shallow hooks to reduce striped marlin catch would at the same time affect blue marlin, but other species may not be noticeably affected.

Longline gear modifications were predicted to produce changes in relative biomass in many, but not all, of the groups where catch rates were expected to change. Many gear modifications are adopted to conserve a particular species, and this study observed that the adoption of circle hooks in other longline fleets and the elimination of the shallowest hooks in deep set longline fleets, had impacts beyond those to striped marlin so additional impacts to other species could be anticipated if either of these gear modifications were adopted. This study did not observe impacts to extend noticeably to other groups not already directly impacted by fishing suggesting that the trophic cascading effect may be limited or an artifact of this model.

Biomass Responses to Limits on Striped Marlin

Reducing catches could result in recovery of striped marlin biomass if reductions were applied to all fisheries or to the fisheries with the largest sources of fishing mortality. The U.S. catch of striped marlin in the WCPO is a small portion of the total catch there by the entire fishery, and thus it is unsurprising that fishing effort reductions applied only to the U.S. longline fleet are projected to have minimal impacts on striped marlin biomass while fishing reductions in other fleets that are equal or greater than those taken by the U.S. fleet have much larger impacts. ISC (2012b) forecasted that striped marlin biomass would increase if catches were maintained at 2,500 mt per year. If decreases in striped marlin catch continue at the levels reported in 2010, relative biomass may increase when this stock is re-examined in future stock assessments (ISC 2012b).

Reducing striped marlin catches in other fisheries did not result in noticeable differences in biomass for any other groups in this study, even though changes to relative biomass for striped marlin varied with relative biomasses ranging from near 0 to 1.5. Results from this model suggest that striped marlin has a limited role in influencing the relative biomass of other species – whether they be competing species or prey species.

Biomass Responses to Domestic and International Conservation and Management

Catch and effort limits and gear modifications may be adopted by individual countries or collectively through regional fisheries management organization (RFMO) decisions. The degree to which a single nation's effort can impact a species depends on whether the country is a major participant in the fishery, and measures adopted unilaterally by one country may or may not result in desired results, particularly for pelagic species. For example, in 2001, concerns for sea turtles led to a closure of the shallow set fishery that targeted swordfish in Hawaii from 2001-2004. Bartram and Kaneko (2004) calculated catch to bycatch ratios for turtles, sharks and fish for various domestic and foreign fleets, and estimated that the closure of the shallow set fishery by the United States indirectly led to increases in sea turtle takes as swordfish that was previously sourced from U.S. flagged vessels was replaced by swordfish from fleets with higher bycatch rates. Thus although U.S. domestic closures were intended to protect turtles, this closure did not affect foreign fleets which in addition to having higher bycatch ratios, increased production of swordfish by over 25% which caused other negative economic impacts for domestic interests (Chan and Pan 2012).

The Hawaii-based shallow set longline fishery was required to use circle hooks beginning in 2004, and then the deep set longline fishery was also required to use the same in 2012 for protected species reasons. Circle hooks for longline fisheries have been encouraged, but have not been required at the international level by the United States. It is believed that if other flagged longline fleets were to adopt circle hooks, several species notably striped marlin, blue shark, swordfish and blue marlin could likely benefit. In the Pacific, the Hawaii deep set and shallow fisheries are small relative to other flagged longline fleets, and this becomes evident in the modeled responses to scenarios where gear modifications or striped marlin policies were applied to U.S. fisheries only, to other longline fisheries and to both fisheries. The largest benefits occurred when policies were applied to all fisheries, but the impacts were almost as large when only applied to non-U.S. longline fisheries. For the striped marlin-only scenarios, the level of relative biomass at the end of the projections were strongly affected when reductions were applied to the other fisheries catching striped marlin (longline and Japanese gillnet), and very minimally so when only applied to the Hawaii fisheries.

Conclusions

Fishing effort was predicted to strongly impact relative biomasses for many mid- and upper- level trophic groups in the north western and central Pacific Ocean. Reductions in biomass at upper trophic levels appeared to result in increased biomass levels of mid-trophic level fish, and although these biomass changes suggested there were some effects on the food chain, cascading to lower trophic levels were not seen. Gear modifications and striped marlin-specific reductions did have impacts on relative biomass levels for a few species, but were generally limited to the species whose catches were predicted to decline.

Several of the scenarios evaluated indicated that striped marlin biomass could increase with reductions in overall fishing effort, adoption of circle hooks in the international longline fleet, elimination of the shallowest hooks in the deep set longline fisheries and also by direct reductions in catches for those fisheries that harvest striped marlin. Greater reductions resulted in faster recoveries while smaller reductions resulted in slower recoveries. This study suggests that it is possible for striped marlin populations to recover, but such recovery will require international cooperation. The catch of striped marlin by the Hawaii longline fleet is a small portion of overall catch in the WCPO, and management efforts by the United States alone would not likely have a meaningful effect on the population of north Pacific striped marlin.

Figure 3. Map of the study area used in the Ecopath model.

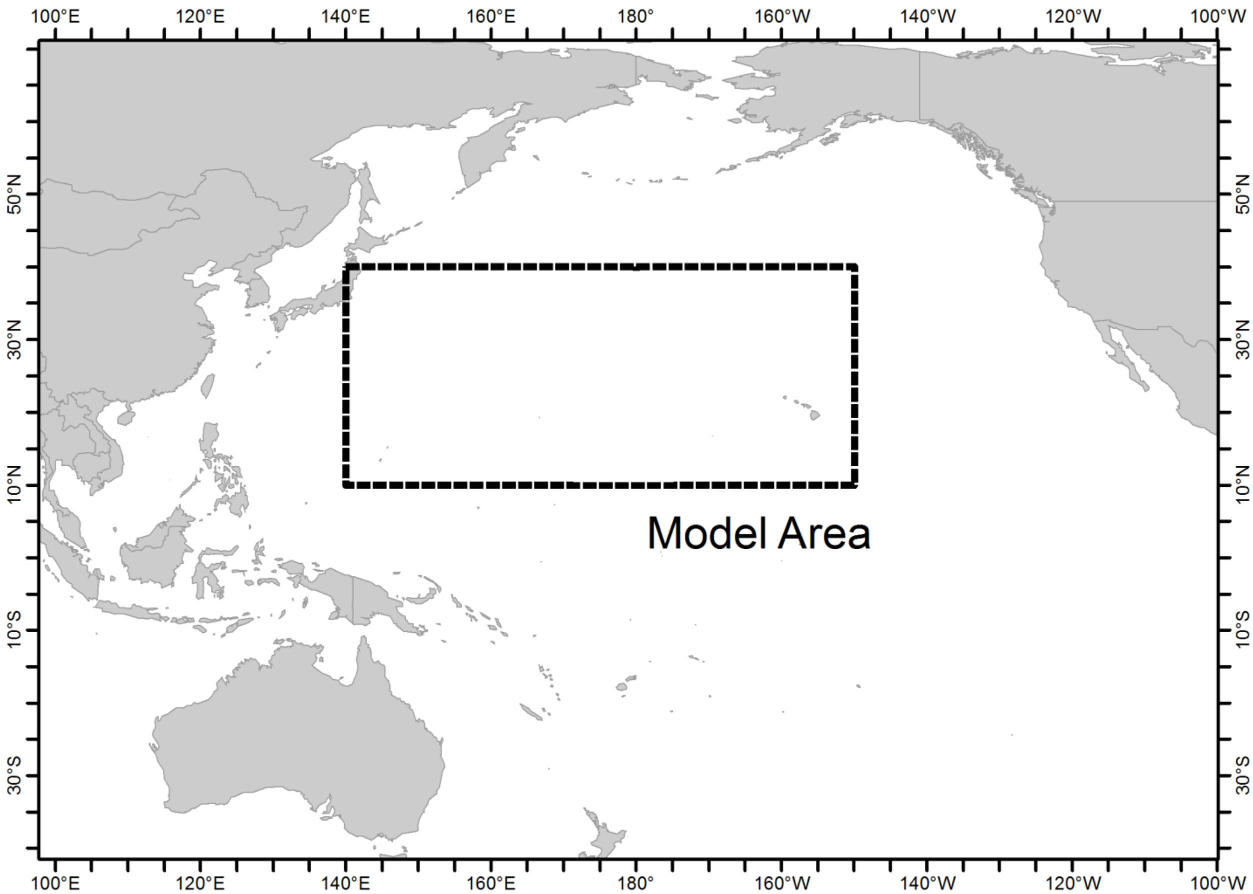


Figure 4. Comparison of biomass estimates for blue shark, swordfish, bigeye tuna, albacore tuna, yellowfin tuna, skipjack tuna, blue marlin and striped marlin from single species stock assessments (open dots) and biomass estimates from the Ecosim model (solid line).

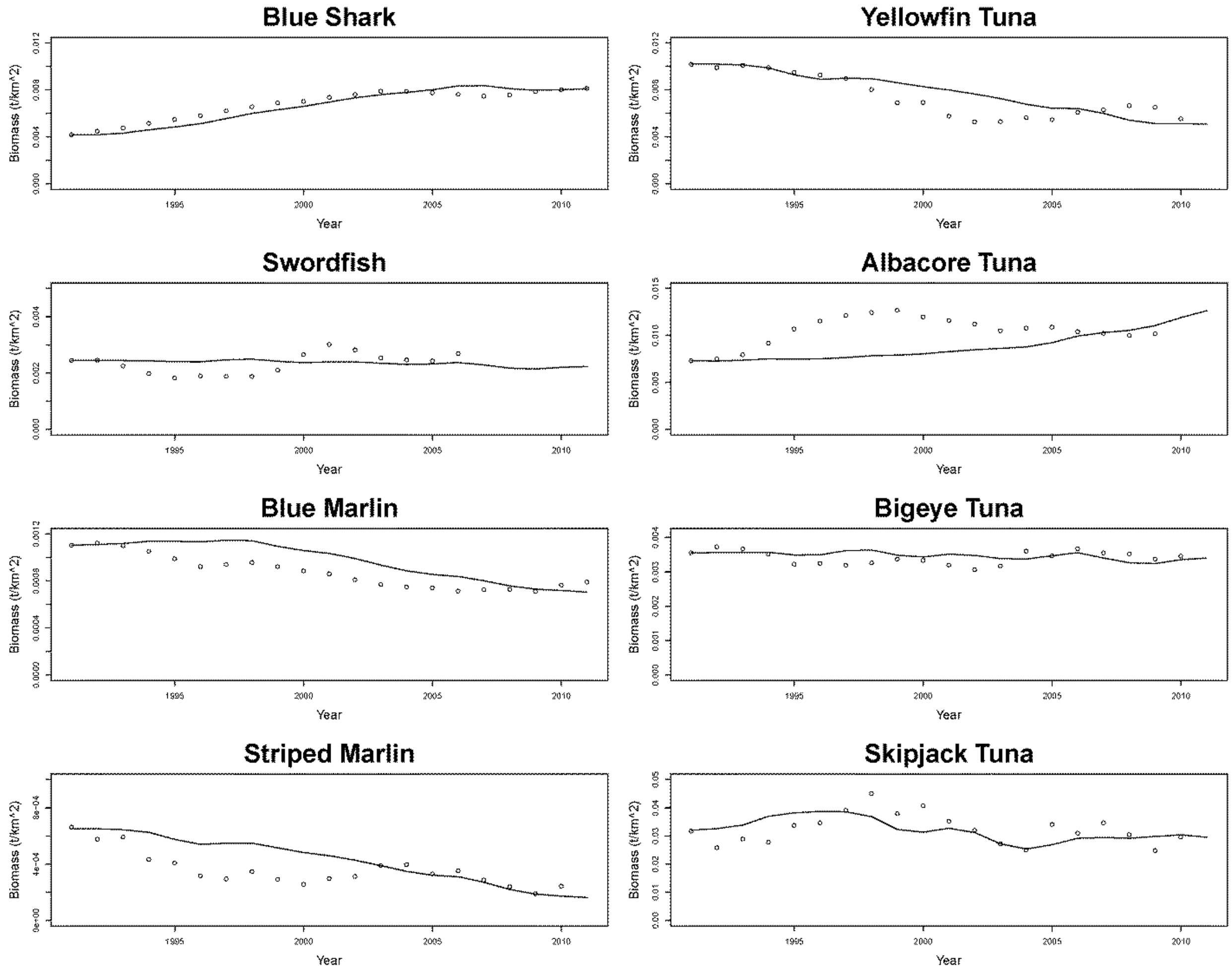


Figure 5. Responses of relative biomass for yellowfin tuna, bigeye tuna, mid-trophic level fish, mahi mahi, invertebrates and mesozooplankton to changes in overall fishing effort. Fishing effort at status quo is represented by the solid line, fishing effort decreased by 50% is represented by the dashed line, and fishing effort increased by 50% is represented by the dashed–and-dotted line.

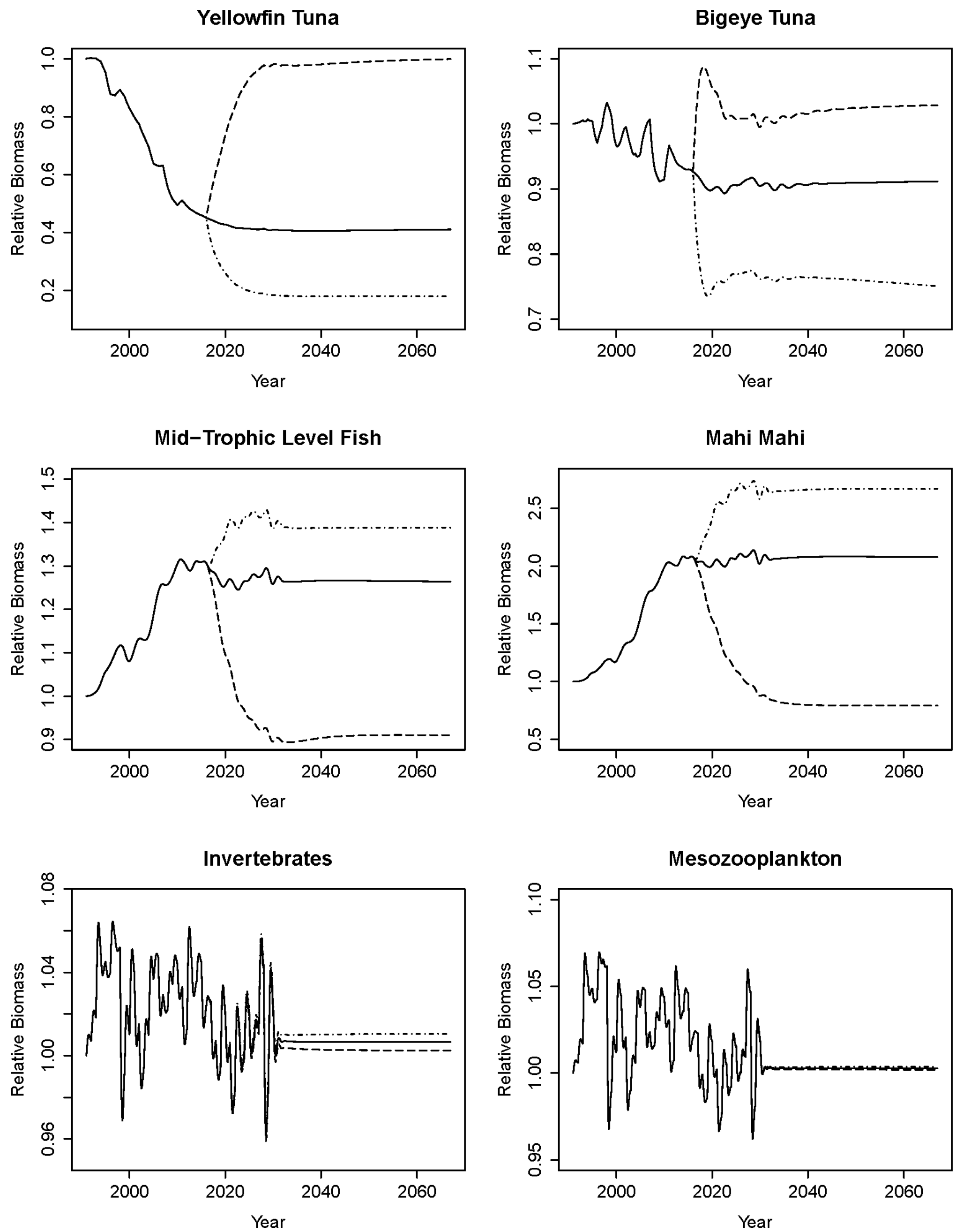


Figure 6. Striped marlin relative biomass under various fishing effort and gear modification scenarios.

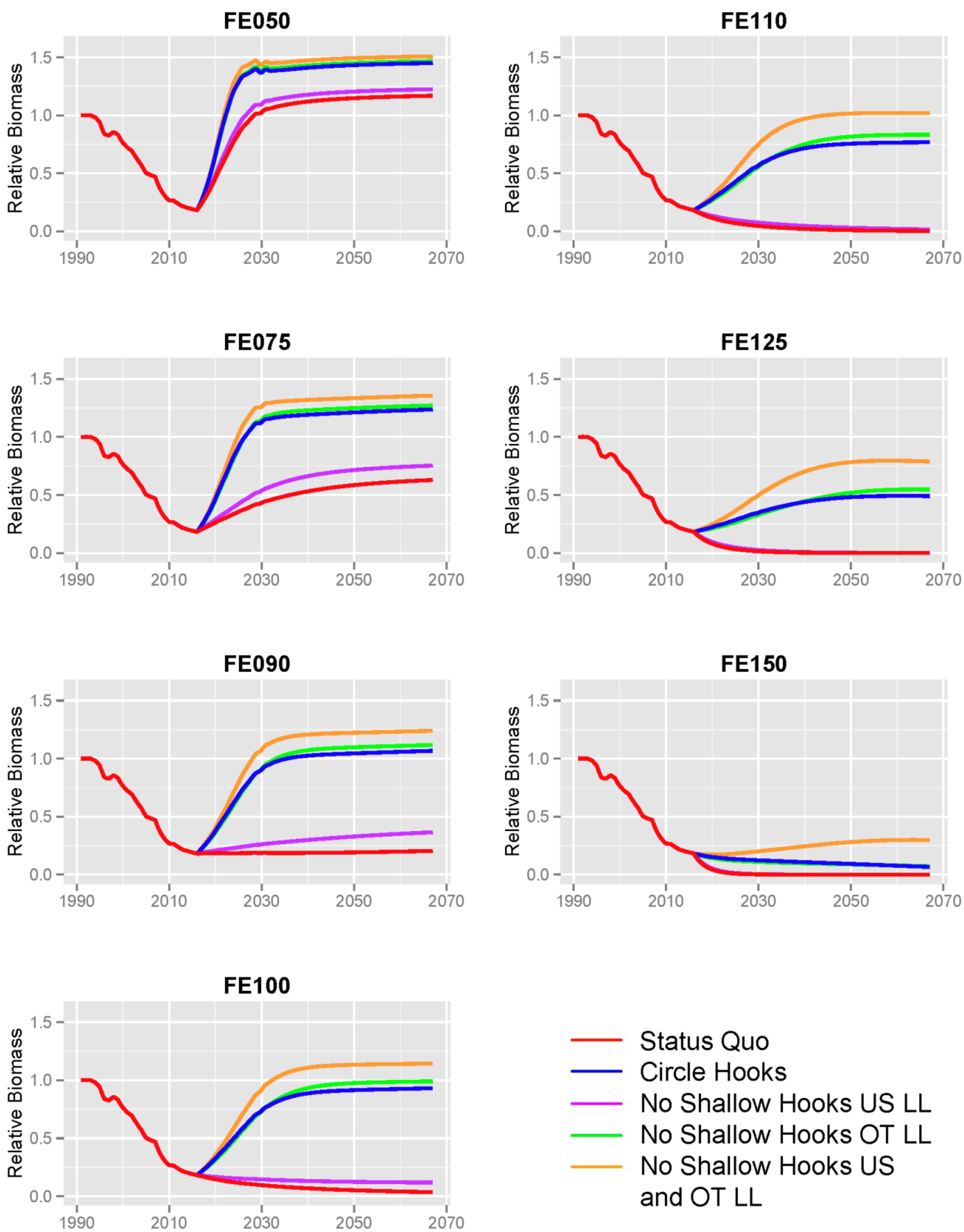


Figure 7. Blue Marlin relative biomass under various fishing effort and gear modification scenarios.

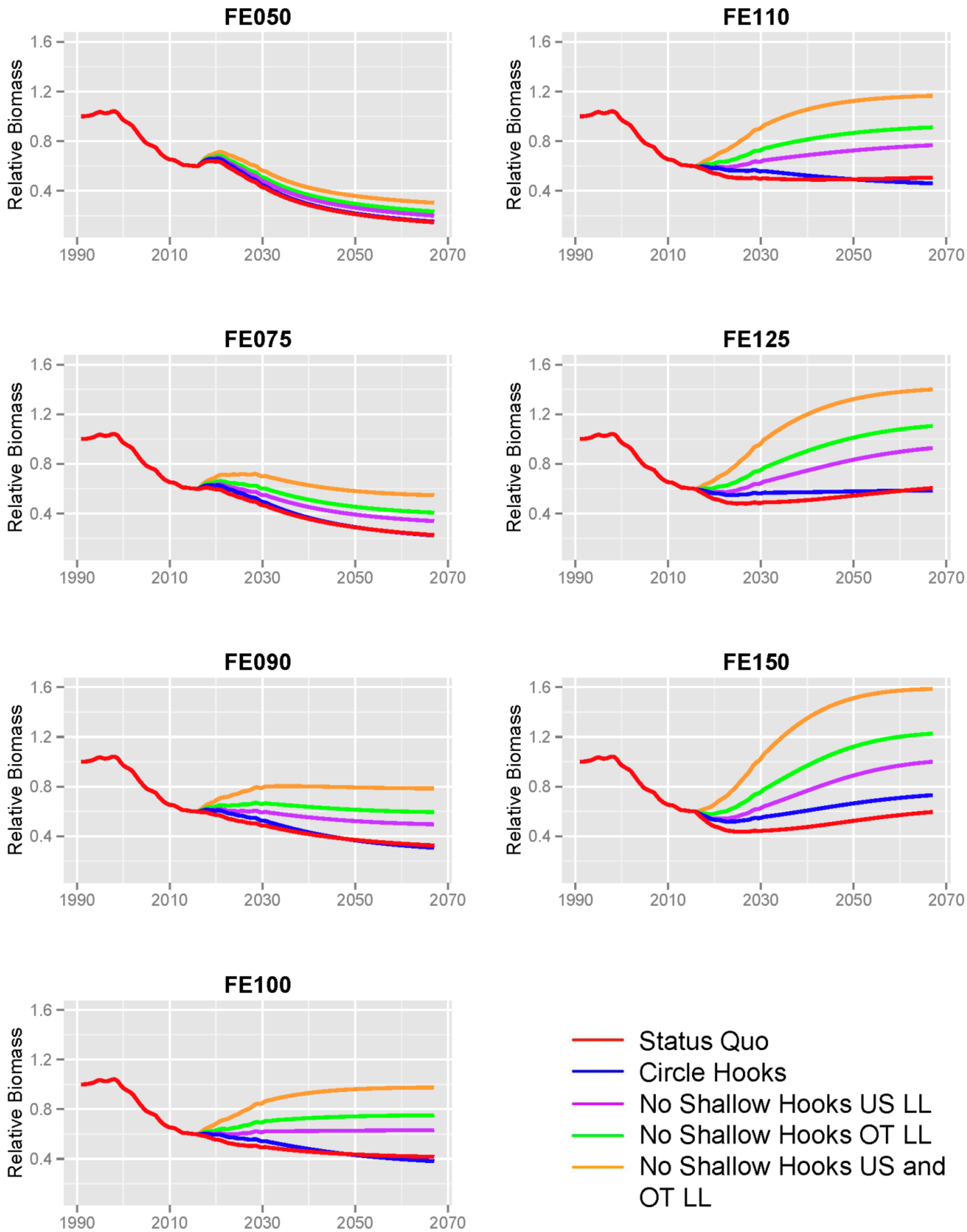


Figure 8. Swordfish relative biomass under various fishing effort and gear modification scenarios.

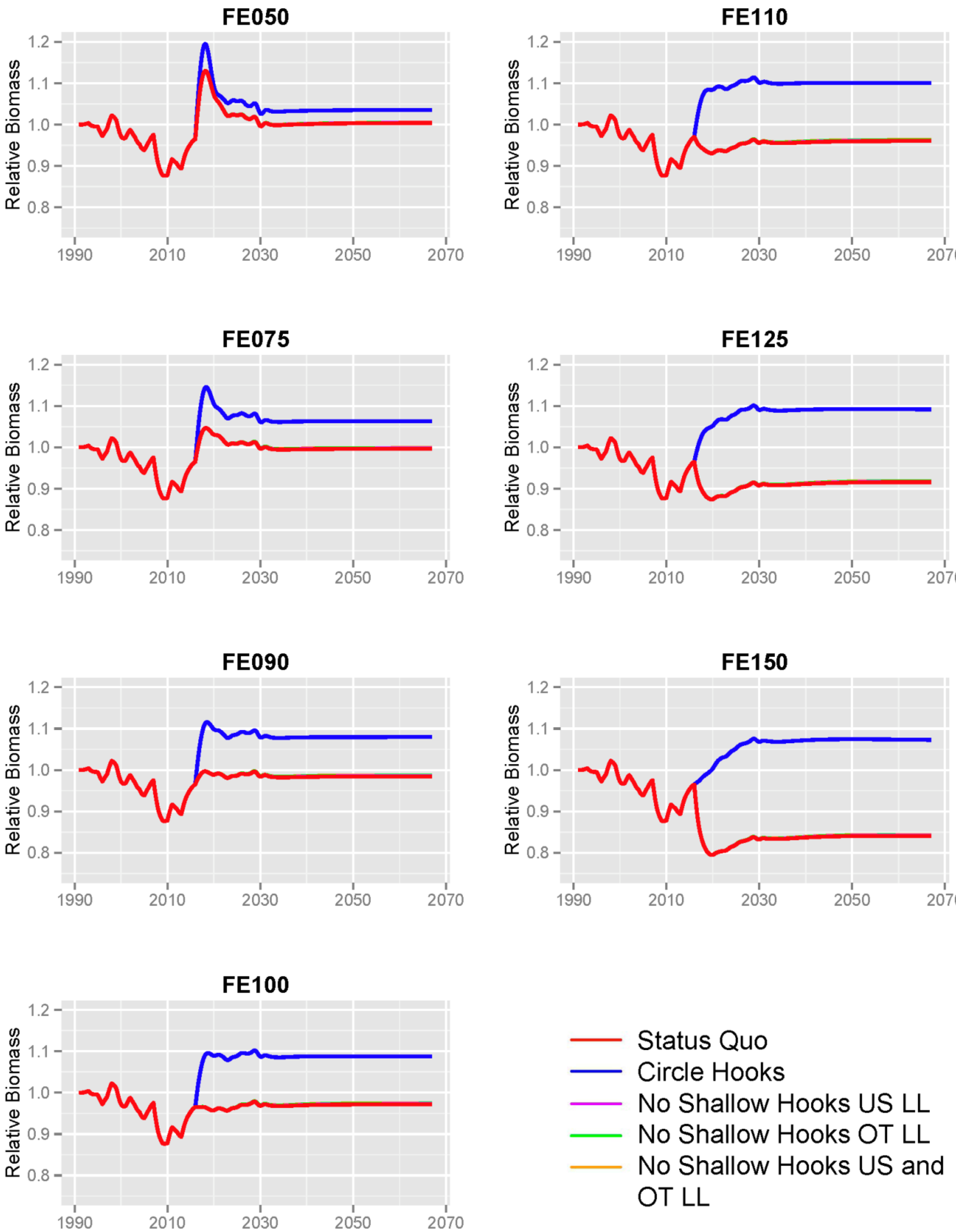


Figure 9. Blue Shark relative biomass under various fishing effort and gear modification scenarios.

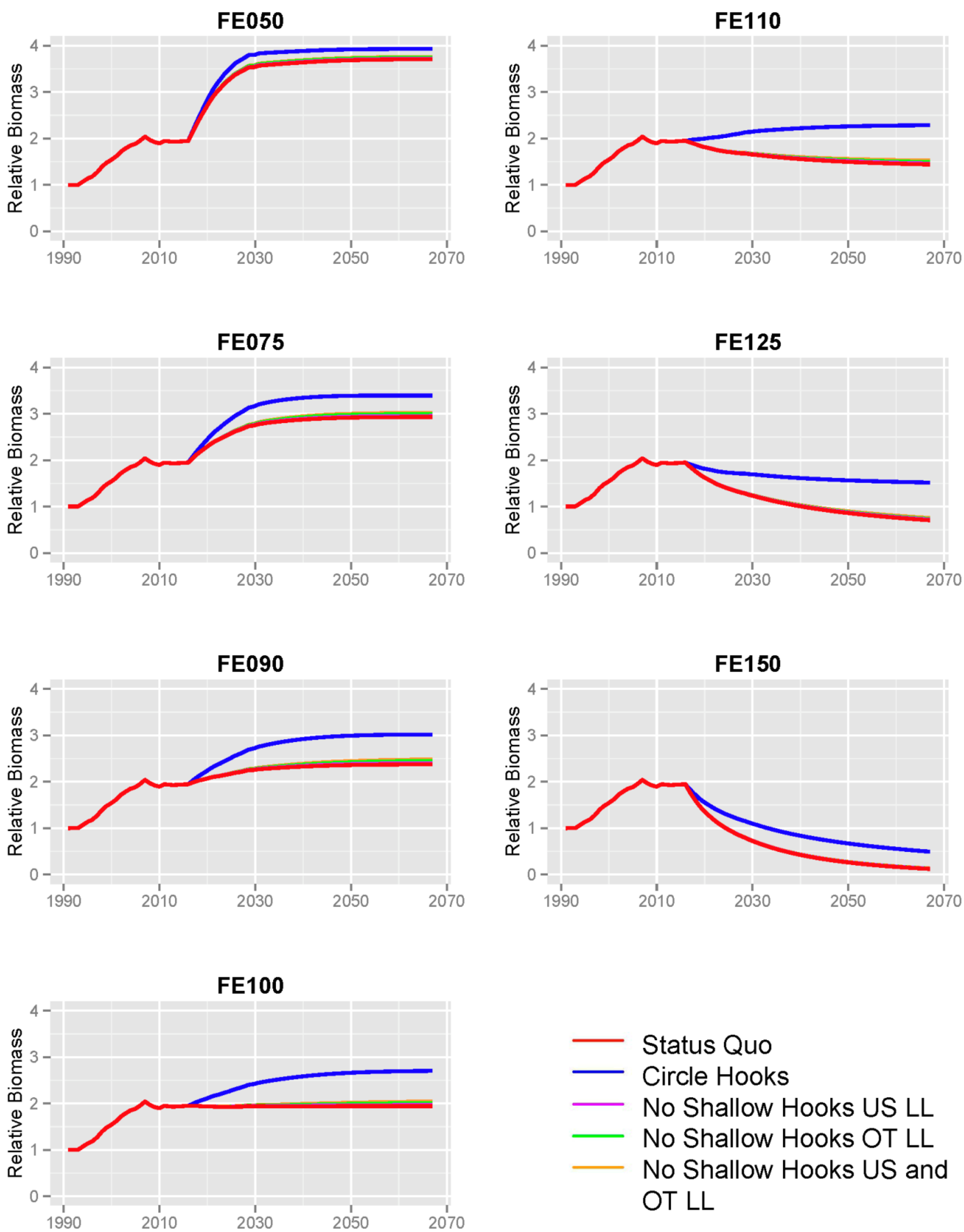


Figure 10. Relative biomass for striped marlin when effort for striped marlin is decreased (0, 20, 40 or 60%) for the US longline fleet (US) and for other fisheries (OT) that catch striped marlin (other longline fleets and Japanese gillnet).

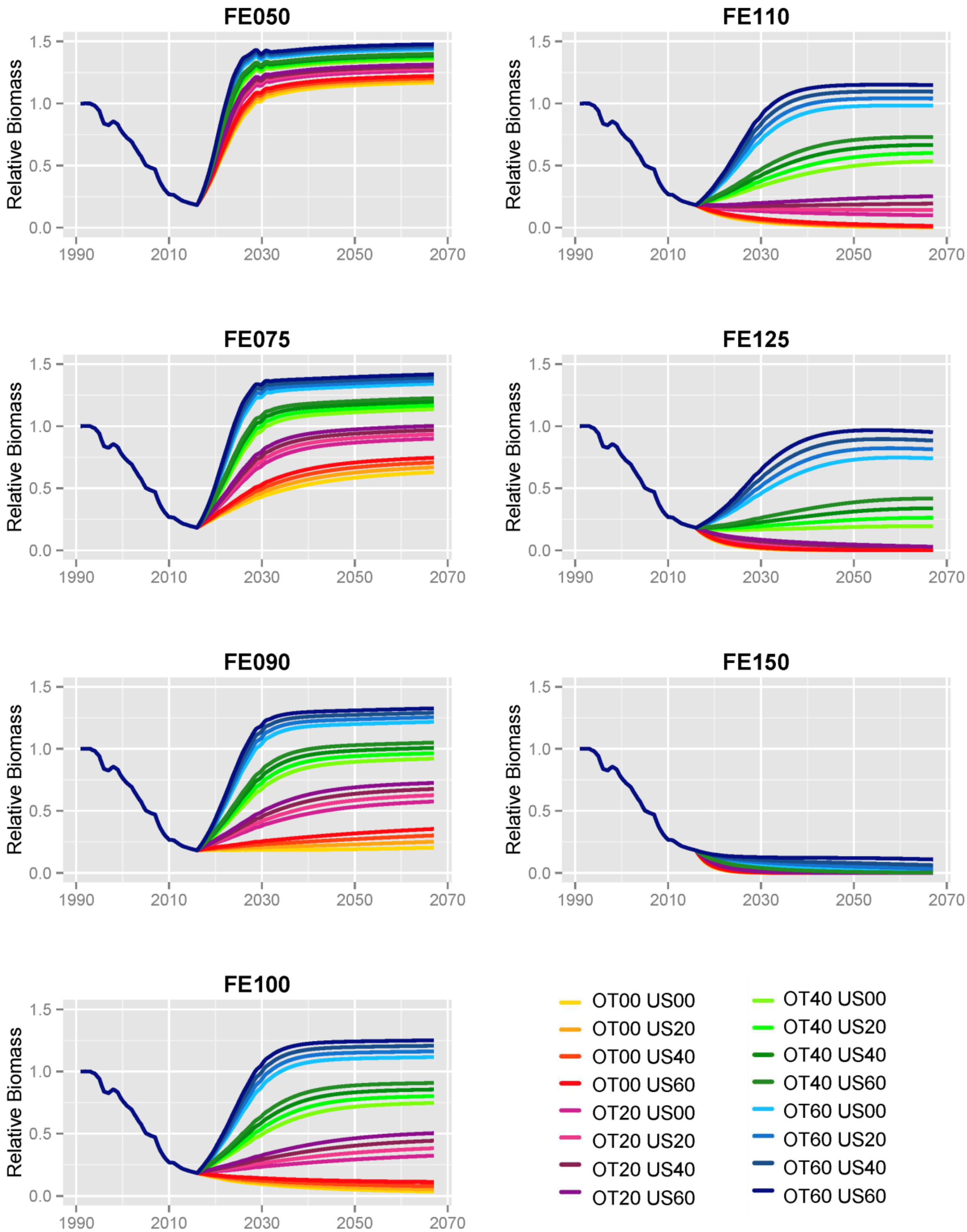


Table 5. Ecopath functional groups and basic input parameters. Numbers in bold indicate that the parameter was estimated as part of the mass balanced calculations of Ecopath. Gray shaded cells indicate where input numbers differ from those used in the HLFG1 model by Howell et al. (2012)

Group name	Trophic level	Biomass (t/km²)	Production / biomass (/year)	Consumption / biomass (/year)	Ecotrophic efficiency
Blue Sharks	4.7	0.0042	0.42	1.5	**0.54**
Other Sharks	4.8	0.0021	0.32	2.82	**0.53**
Swordfish	4.8	0.0024	0.35	3.3	**0.75**
Blue Marlin	4.6	0.0011	0.8	3.8	**0.15**
Striped Marlin	4.5	0.0007	0.7	3.8	**0.81**
Other Billfish	4.5	**0.0007**	0.813	6.07	0.40
Small Billfish	3.8	**0.0019**	1	10	0.60
Yellowfin	4.3	0.0102	0.4	10.60	**0.64**
Juvenile Yellowfin	3.7	0.0007	0.5	24.34	**0.59**
Albacore	4.3	0.0073	0.4	9.6	**0.68**
Juvenile Albacore	3.7	0.0087	0.35	14.92	**0.87**
Bigeye	4.5	0.0036	0.5	8.2	**0.60**
Juvenile Bigeye	3.8	0.0026	0.6	14.70	**0.43**
Skipjack	4.3	0.0320	1.9	32.57	**0.09**
Juvenile Skipjack	3.6	0.0328	5.5	97.66	**0.84**
Mahi mahi	4.1	**0.0139**	1	8.48	0.60
Lancetfish	4.2	**0.0509**	0.47	2.3	0.60
Mid-trophic Level Fish	4.2	**0.0407**	0.6	4.13	0.60
Epipelagic Fish	3.1	2	2	9	**0.58**
Invertebrates	2.4	**7.9471**	8	25	0.80
Epipelagic Molluscs	4.0	0.9	3.5	10	**0.87**
Mesopelagic Fish	3.0	5	2	10	**0.85**
Mesopelagic Molluscs	3.8	1.6	4	10	**0.74**
Bathypelagic Fish	3.6	**3.5**	1.5	7	**0.86**
Mesoscale Zooplankton	2.4	5.81	9.85	25	**0.80**
Microscale Zooplankton	2.0	11.13	25	60	**0.44**
Large phytoplankton	1.0	1.13	120		**0.35**
Small phytoplankton	1.0	10.59	180		**0.36**
Detritus	1.0	100			**0.08**

Table 6. Diet Composition matrix used in the study. Gray shaded cells indicate where values differ from those used in the HLFG model by Howell et al. (2012)

	Predator												
Prey	Blue Sharks	Other Sharks	Swordfish	Blue Marlin	Striped Marlin	Other Billfish	Small Billfish	Yellowfin	Juv Yellowfin	Albacore	Juvenile Albacore	Bigeye	Juvenile Bigeye
Blue Sharks		0.0050											
Other Sharks	0.0200	0.0100				0.0100							
Swordfish	0.0100	0.0100											
Blue Marlin	0.0080	0.0040											
Striped Marlin	0.0050	0.0100											
Other Billfish	0.0100	0.0210											
Small Billfish	0.0150	0.0360		0.0200			0.0020			0.0100			
Yellowfin	0.0100	0.0200		0.0100	0.0100								
Juv Yellowfin	0.0100	0.0100		0.0100	0.0020								
Albacore		0.0500		0.0100						0.0010			
Juv Albacore	0.0100	0.0050		0.0100	0.0100	0.0100		0.0200				0.0100	
Bigeye	0.0020	0.0500											
Juv Bigeye	0.0100	0.0300		0.0300	0.0050						0.0020		
Skipjack	0.0200	0.0200		0.0100	0.0100			0.0200					
Juv Skipjack	0.0100	0.0540		0.1000	0.1000	0.1250	0.0100	0.0200		0.0200	0.0050	0.0050	0.0050
Mahi mahi	0.0250	0.0500	0.0250	0.0100	0.0100	0.0100		0.0500		0.0100		0.0500	
Lancetfish	0.0500	0.0750	0.0350	0.0500	0.0500			0.0500		0.0500		0.1000	
Mid TL	0.0500	0.0500	0.0300	0.0200	0.0100	0.0100		0.1000		0.0200		0.0500	
Epi Fishes	0.1000	0.1800	0.1000	0.3200	0.4000	0.5250	0.3000	0.3000	0.2000	0.2750	0.2800	0.1000	0.3000
Invertebrates	0.0500		0.0400	0.0800	0.0500	0.0100	0.4380	0.2500	0.5500	0.1590	0.5130	0.1000	0.5950
Epi Molluscs	0.3700	0.1700	0.6000	0.3200	0.2930	0.3000	0.0100	0.1500		0.2000		0.1500	
Meso Fishes	0.2000	0.1000	0.0300		0.0500		0.1400	0.0400	0.1000	0.2000	0.0500	0.2250	0.0500
Meso Molluscs	0.0150		0.1100						0.0500	0.0550	0.0500	0.1100	0.0500
Bathy Forage		0.0100	0.0300									0.1000	
Meso ZP							0.1000		0.1000		0.1000		
Micro ZP													
Large PP													
Small PP													
Detritus													
Import		0.0300											

Table 6. continued

	Predator												
Prey	Skipjack	Juvenile Skipjack	Mahi Mahi	Lancetfish	Mid TL	Epi Fishes	Invertebrates	Epi Molluscs	Meso Fishes	Meso Molluscs	Bathy Forage	Meso ZP	Micro ZP
Blue Sharks													
Other													
Swordfish													
Blue Marlin													
Striped													
Other													
Small													
Yellowfin													
Juv													
Albacore													
Juv													
Bigeye													
Juv Bigeye													
Skipjack													
Juv Skipjack			0.0020		0.0500			0.0150					
Mahi mahi													
Lancetfish				0.0100									
Mid TL													
Epi Fishes	0.5000	0.0500	0.8750	0.2250	0.2500	0.0250		0.0650		0.0200			
Invertebrate	0.1500	0.7000	0.0600	0.3000	0.2100	0.4200		0.4000	0.4100	0.5000	0.3500		
Epi	0.3000		0.0200	0.1500	0.1600	0.0500		0.1400		0.0100			
Meso Fishes	0.0500	0.0500	0.0080	0.0075	0.2400	0.0100		0.1500	0.0200	0.2000	0.1000		
Meso		0.0500	0.0300	0.0075	0.0600	0.0100		0.1400	0.0250	0.1000	0.0100		
Bathy		0.0250		0.3000	0.0200	0.0100		0.0300	0.0200	0.0300	0.1000		
Meso ZP		0.0750			0.0100	0.1250	0.1000	0.0600	0.1250	0.1400	0.2900	0.0500	
Micro ZP		0.0500				0.0750	0.3000		0.1000		0.1000	0.3700	
Large PP						0.0250	0.1000		0.1000			0.1500	
Small PP							0.1000						1.0000
Detritus			0.0050			0.2500	0.4000		0.2000			0.4300	
Import											0.0500		

CHAPTER FOUR: FULL RETENTION IN TUNA FISHERIES: BENEFITS, COSTS AND UNINTENDED CONSEQUENCES

Abstract

Several tuna regional fisheries management organizations (t-RFMOs) have adopted retention requirements for skipjack, bigeye and yellowfin tunas caught by purse seine vessels to reduce discards, create disincentives to catch small fish, and incentivize the development and adoption of more selective technologies. Although retention policies in the t-RFMOs have been limited to target tunas in purse seine fisheries, some stakeholders have advocated for an expansion of those policies, and t-RFMOs could consider expanding retention policies to a greater number of species and/or to other gear types. This paper discusses the benefits and costs of broader retention policies for purse seine and longline tuna fisheries in the western and central Pacific Ocean (WCPO). Using bycatch data from observers and logbooks from the U.S. purse seine and longline fleets operating in the WCPO, this paper documents the types and magnitude of fish discarded. For the purse seine fishery, this information was used to estimate direct impacts of having to off-load at the initial point of landing in key Pacific Island ports. For the longline fishery, estimates of direct impacts were limited to Honolulu and Pago Pago, American Samoa, the two primary ports where U.S. catch is landed. Expanding retention policies beyond the target tunas and to other gear types would further reduce discards and possibly provide stronger incentives to develop and use more selective techniques. Beyond impacts to the ecosystem and fisher behavior, adopting broader retention policies may have other implications, and this paper explores those implications on vessels, processors, and communities.

Introduction

Fishery discards occur for a number of reasons including small size, damage that makes the catch unfit for human consumption, and catch of fish that are not the target or are not marketed species (Bailey et al. 1996, Vianna and Almeida 2005). Concerns over discarding have led to the inclusion of statements encouraging the minimization of discards into many international agreements, including the United Nations Fish Stocks Agreement and the FAO Code of Conduct for Responsible Fisheries. In the tuna-regional fishery management organizations (t-RFMO), concerns over waste have resulted in the adoption of agreements requiring purse seine vessels to retain all catches of skipjack (*Katsuwonus pelamis*), bigeye (*Thunnus obesus*), and yellowfin (*T. albacares*) tunas, except when catch is considered unfit for human consumption for reasons other than size, on the last set if a vessel becomes fully loaded, or if there is a serious equipment malfunction. In 2000, the Inter-American Tropical Tuna Commission (IATTC) was the first t-RFMO to adopt a catch retention policy for tuna species in purse seine fisheries, followed by the Western and Central Pacific Fisheries Commission (WCPFC) in 2008, and the Indian Ocean Tuna Commission in 2010.

Recently, some have advocated expanding retention policies to include more than the three principal tuna species in purse seine fisheries. In 2011, the International Sustainable Seafood Foundation (ISSF) announced that one of its "commitments" for its participating members[3] would be to source from vessels retaining all fish, including sharks caught by purse seine vessels, by January 2014. World Wildlife Fund (WWF) issued a similar statement in a position paper released in 2011 encouraging "retention of all bycatch except living and healthy individuals able to survive if thrown back" for tuna fisheries using fish aggregating devices (FADs). Additionally, an early draft of a revised conservation measure for tuna in the WCPFC

[3] Processors who are ISSF members agree to comply with ISSF conservation measures and standards of practice.

circulated in November 2011 contained provisions proposing full retention of all catch by both purse seine and longline fisheries in the WCPFC. Although the full retention provisions were not included in the interim measure that was adopted by the WCPFC in March 2012, full retention policies gained greater attention. Furthermore, the European Union Council recently agreed to revise its Common Fisheries policy to include a phased ban on discarding in its fisheries, and this discarding ban has the potential to impact its vessels operating in the WCPO.

Proponents of full retention argue that this policy is necessary particularly in purse seine fisheries to better understand ecosystem effects of fishing. Full retention of catch may also allow for better estimates of total catch, which can in turn lead to more accurate estimates of fishing mortality in stock assessments (Diamond and Beukers-Stewart 2011). Additionally, broader retention policies in other fisheries provide incentives to develop more selective fishing methods, and a full retention policy could possibly create a similar incentive (Hall and Mainprize 2005).

One of the challenges of full retention to fishing operations is dealing with the catch of nonmarket species, and aside from acknowledging the need to develop markets for such species, few advocates consider and document other implications of a full retention policy in tuna fisheries. The WCPFC draft conservation measure also included longline fisheries, which would have been a major expansion, since the current retain-all policies only apply to purse seine vessels.

This paper considers potential impacts of a full retention policy on tuna purse seine and longline fisheries in the WCPO. Using logbook and observer data from the U.S. purse seine and longline fleets, this paper estimates discards for the U.S. purse seine and longline fleets, and for purse seine fisheries only, extrapolated to estimate discards for the entire WCPO purse seine fishery. This paper also qualitatively -- and where possible quantitatively -- considers the benefits and costs to producers, processors, consumers and the ecosystem. As a significant portion of tuna catch is harvested in waters under the jurisdiction of Pacific Island countries and unloaded/transshipped in Pacific Island ports, this analysis considers implications of retain-all policy on developing nations.

Methods

Overview of Tuna Fishing in the Western and Central Pacific Ocean

The WCPO contains the largest tuna fisheries in the world, with catches in 2011 contributing over 55% of the global tuna catch (Williams and Terawasi 2012). Most catch comes from four gear types, purse seine (75%), longline (11%), pole and line (7%), and troll (<1%) (Williams and Terawasi 2012).

The WCPO purse seine fishery targets schools of skipjack and yellowfin tuna (Williams and Terawasi 2012). Other species often also caught in association with these schools include bigeye, silky shark (*Carcharhinus falciformis*), rainbow runner (*Elagatis bipinnulata*), dolphinfish (*Coryphaena hippurus*) and wahoo (*Acanthocybium solandri*) (Hall 1996, Romanov 2002, Amande et al. 2010). Purse seine vessels in the WCPO historically retained most skipjack, yellowfin and bigeye caught, and beginning in 2010 were required, with limited exceptions, to retain all skipjack, yellowfin and bigeye caught. Most other incidentally caught species are discarded except for those retained for crew consumption (Bailey et al. 1996, Amande et al. 2010).

The longline fishery in the WCPO generally targets tunas and swordfish (*Xiphias gladius*) with hooks typically set deep for sets targeting tuna and shallow for sets targeting swordfish. Other species often caught in the longline fishery include blue marlin (*Makaira mazara*), blue shark (*Prionace glauca*), wahoo and dolphinfish (Bailey et al. 1996). Longline vessels typically retain most tuna and swordfish caught, and unlike purse seine vessels are not required to retain all target tunas caught. Longline vessels do tend to retain other incidentally caught fish, with retention depending on a variety of factors including marketability, timing caught in trip, hold space, availability of ice, etc. (Huang and Liu 2010, Martin 2012).

This paper refers to the catch of other highly migratory species (HMS) as incidentally caught species rather than the more traditional terms of bycatch or non-target species. This study focuses on the incidental catch of those individuals that are discarded as it was interested in the additional tonnage that would be retained; thus estimates are not estimates of total catch of other HMS as the estimates do not include fish retained for crew consumption and/or already retained for commercial use. Furthermore, the analysis was limited to catch of fish, and did not include catches or interactions that vessels may have with sea turtles, seabirds, cetaceans and whale sharks.

Estimating Purse Seine Discards

Since 1988, the South Pacific Tuna Treaty has authorized U.S. purse vessels access to fish in the exclusive economic zones (EEZs) of 16 Pacific Island countries. Participation in the US fleet has varied over time, and in 2012 there were 39 licensed vessels (~13% of WCPO purse seine fleet). As part of the treaty, observers from the Pacific Islands Forum Fisheries Agency (FFA) have been placed on U.S. purse seine vessels. Observer coverage on U.S. purse seine vessels was 20% from 1988-2009 and increased to 100% in January 2010. Annual unpublished summaries of observer data prepared by the Secretariat of the Pacific Community (SPC) were obtained for 2006-2010. These summaries provide information on the catch and discard fate of the main target species as well as incidentally caught species. The total weight of discards and ratio of discards by species (mt)/1,000 mt of landed tuna were estimated from the observed trips.

Landings information was obtained from receipts issued when the catches of tunas from U.S. vessels were unloaded at the cannery. These total landings were multiplied by the discard ratios to derive an estimate of the amount of discards that would have been retained if the U.S. fleet was compelled to retain-all catch during that period. Historically, U.S. purse seine vessels unloaded their catches to the canneries in American Samoa, and more recently have transshipped their catch from various Pacific Island ports. As only four vessels solely offloaded their catch in American Samoa from 2006-2010 and due to limited observer data from 2006-2009, this paper was unable to examine whether operational differences affected discard rates. This paper assumed that if a retain-all policy was implemented, any incidentally caught fish would also be unloaded at the same time in the same port[4], and this paper estimated what the weight of fish would be from the U.S. fleet in that particular port and also extrapolated to the WCPO catch using landings information obtained from SPC for the WCPO for 2007-2010.

Estimating Longline Discards

U.S. longliners fishing in the WCPO primarily operate out of Hawaii and American Samoa, and generally fish within the U.S. EEZ and high seas. In 2012, 129 vessels held Hawaii longline permits and 53 vessels held American Samoa permits with some vessels holding both American Samoa and Hawaii permits. Vessels operating in Hawaii are typically small to midsized vessels that use ice to preserve their catch, and in many ways they may be unique from other longline fleets operating in the region. Most vessels operating out of American Samoa freeze their catch, and characteristics of this fleet may be more similar to other foreign fleets operating in the western Pacific. In Hawaii, longline vessels that set deep target bigeye and yellowfin tuna, while longline vessels that set shallow target swordfish. In American Samoa,

[4] Some vessels reportedly store incidental catch on the vessels for offloading in home ports.

longliners set deep and target albacore. Observers have been placed on longline vessels operating out of Hawaii since 1994 and on longline vessels operating out of American Samoa since 2006. Observer coverage based on number of trips has been maintained at 20% for Hawaii deep-set fishery since 2002. The Hawaii shallow-set fishery was temporarily closed from 2001-2004 due to concerns with turtle interactions, and observer coverage has been 100% since the fishery reopened in 2005. Observer coverage in American Samoa ranged from 6-8% in 2006-2009, and increased to 25% in 2010.

Observer data for 2006-2010 were obtained for all longline trips operating from Hawaii and American Samoa. These data contained information on the date of set, type of set, species, fate of the individual (kept or discarded), and length (when recorded). The average length of each species was determined for all individuals measured (kept and discarded) as well as for individuals measured that were discarded. Length-weight (LW) relationships for most species were obtained from published journal articles, technical memoranda and FishBase (www.fishbase.org). In some instances, LW relationships for closely related species were used. For some species, no length and/or LW relationships were available, and so either the average Honolulu auction weight was used (for marketed species) or an average weight for an individual was assumed using input from observer program staff. Average weights for each species were then calculated using the average length of discarded individuals (where available) and the LW relationships identified. For each species, the average weights were multiplied by the total number of discarded individuals (for the Hawaii shallow set fishery) or the number of estimated discarded individuals (for the Hawaii deep set and the American Samoa fisheries where observer coverage in these fisheries was less than 100%) to estimate discard weight by species (PIFSC, unpublished data). As longline fisheries retain a much larger assemblage of species than purse seiners, the discard ratio calculated for longliners was based on total landed catch (not just skipjack, yellowfin and bigeye). Discards were also considered for the principal target species of the longline fishery, including skipjack, bigeye, yellowfin, albacore (*T. alalunga*) and swordfish (*Xiphias gladius*).

Results

Purse Seine

Estimated discard rates for incidentally caught fish by the U.S. WCPO purse seine fishery by weight averaged 5.1 mt/1,000 mt of landed fish from 2006-2010 (Table 7). Rates were further subdivided into the following groups: billfish, sharks, other tunas and tuna-like species, and other fishes. The largest discard rates by weight came from other fishes (2006-2010 average discard rate = 3.9 mt/1,000 mt), followed by sharks (0.7 mt/1,000 mt), billfish (0.4 mt/1,000 mt) and other tunas (0.1 mt/1,000 mt). Rainbow runner, mackerel scad (*Decapterus macarellus*), silky shark, blue marlin, black marlin (*Makaira indica*), and oceanic triggerfish (*Canthidermis* spp.), were the predominant species discarded and represented between 65-92% of the total discard weight from 2006-2010.

Discards of skipjack, yellowfin and bigeye tunas in the purse seine fleet constituted 2-8% of landed tuna from 2005-2009 to less than 0.5% in 2010 (Table 8) when the catch retention provision of CMM 2008-01 came into effect. Discarded skipjack represented 77-90% of all tunas discarded, followed by yellowfin (7-13%) and bigeye (3-9%).

Between 2007-2010, the U.S. purse seine fleet unloaded nearly all of its catch in seven ports in the Pacific (Honiara, Solomon Islands; Majuro, Republic of Marshall Islands; Pago Pago, American Samoa; Pohnpei, Federated States of Micronesia; Rabaul, Papua New Guinea; Tarawa, Kiribati; and Wewak, Papua New Guinea), with more than 80% of these unloadings occurring in three ports, Majuro, Pago Pago and Pohnpei (Figure 11). Unloadings occurred at some ports every year from 2007-2010, but unloading at other ports such as Tarawa and Wewak only occurred from 2008-2010. Table 9 shows the estimated incidental catch discards that would have been retained and unloaded if a retain-all policy had been in place at each of the seven ports and in total. The total catch discarded for the whole fleet ranged from 624 mt in 2008 to 1,789 mt in 2010. If discard rates from the U.S. fleet were assumed to be representative of all other purse seine fleets in the western Pacific, the total catch discards would have ranged from 5,824 mt in 2008 to 13,118 mt in 2010. The ports that would likely be most impacted by a retain-all policy in the WCPO would be Pohnpei, Majuro, Honiara, Rabaul and Tarawa, which would receive an estimated 1,000-2,000 mt of retained incidental fish each year.

Longline

Total discard rates were highest for the Hawaii deep-set fishery followed by the Hawaii shallow-set fishery and the American Samoa fishery (Table 10). In the Hawaii deep-set fishery, species with the highest numbers of individuals discarded were longnose lancetfish (*Alepisaurus ferox*), blue shark, snake mackerel (*Gempylus serpens*), dolphinfish and bigeye thresher shark (*Alopias superciliosus*). Species with greatest discard tonnages in the Hawaii deep-set fishery were blue shark, longnose lancetfish, bigeye thresher shark, shortfin mako shark (*Isurus oxyrinchus*) and snake mackerel. The Hawaii shallow-set fishery had similar incidental species as the deep-set fishery, and species with the highest numbers of individuals discarded included blue sharks, snake mackerel, longnose lancetfish, dolphinfish, and escolar (*Lepidocybium flavobrunneum*). Species with the greatest discard tonnages in the Hawaii shallow-set fishery were blue shark, swordfish, shortfin mako shark, dolphinfish, and escolar. Incidental species with the highest numbers of individuals discarded in the American Samoa fishery included escolar, longfin escolar (*Promethichthys prometheus)*, slender mola (*Ranzania laevis*), wahoo and lancetfish. Species with the greatest discard tonnages in the American Samoa fishery were blue marlin, escolar, wahoo, blue shark and shortfin mako shark.

Estimated discard rates of target tuna and billfish species in the Hawaii (1-3% discards/landed target catch) and American Samoa (4-8% discards/landed target catch) fleets were generally small (Table 11). In the Hawaii deep-set fishery, bigeye tuna had the largest amount of discards by weight, followed by yellowfin tuna and skipjack tuna. In the Hawaii shallow-set fishery, swordfish were the predominant species discarded. In the American Samoa fishery, skipjack and albacore had the largest amounts of discards by weight, followed by bigeye and yellowfin tunas.

U.S. longline catch in the WCPO was primarily unloaded in two ports, Honolulu for the Hawaii fisheries and Pago Pago for the American Samoa fishery. Table 12 estimates the total tonnage of retained fish that might have been delivered to these ports if a retain-all policy had been in place for the longline fishery from 2006-2010. On average, Honolulu would receive an additional 3,804 mt of fish per year and Pago Pago would receive an additional 684 mt of fish per year.

Discussion

Discard Estimates in Tuna Fisheries

Many studies have attempted to quantify discards in fisheries, and a few have investigated discards from purse seine and longline vessels fishing for HMS (Alverson et al. 1994, Kelleher 2005, Huang and Liu 2010, National Marine Fisheries Service 2011, Pilling et al. 2012). In general, discard rates are higher in longline fisheries than in purse seine fisheries, and our analyses show a similar pattern with U.S. purse seine fisheries discarding on average 0.5% of the total weight of landed fish per year and U.S. longline fisheries discarding between 12-36% of the total weight of landed fish per year (Alverson et al. 1994, Kelleher 2005, National Marine Fisheries Service 2011).

Kelleher (2005) estimated that the discard rate for global tuna purse seine fisheries from 1994-2003 was 5.1% by total weight of catch. This rate includes discards of "target" tunas, and if "target" tuna discards were included in our discard estimates, our estimated discard rates would range from 0.4-8% by weight. Before the catch retention requirement went into effect (2006-2009), discard rates for tuna averaged ~2% of landed weight, and after the catch retention requirement went in effect in 2010, discard rates for the three tuna species declined to 0.4%.

Huang and Liu (2010) examined bycatch and discard rates in the Taiwanese longline fleet in the Indian Ocean and illustrated discard rates to vary between fleets targeting different tuna species. These discard rates were influenced by trip length, proximity of fishing area to ports or unloading areas, cetacean depredation of catch, and quota on bigeye and southern bluefin tuna (*T. maccoyii)* (Huang and Liu 2010). Our study also observed differences in discard rates among the three longline fisheries, with sharks comprising a large component, particularly for the U.S. deep-set fishery targeting tunas

Using discard ratios with information on average numbers of trips and average landings available from published fishery statistics, unloading logsheets, and auction records, rough estimates can be made on the magnitude of additional landings per trip and per year assuming a vessel had space to hold this catch that would otherwise have been discarded (Table 13). For purse seine vessels, this would result in an additional 5 mt of landings/trip. For longline vessels, this would result in an additional 2.2 mt/trip of landings in the Hawaii deep-set fishery, an additional 3.3 mt/trip of landings in the Hawaii shallow-set fishery, and an additional 3 mt/trip of landings in the American Samoa fishery.

Potential Impacts of Adopting a Retain-all Policy

Adopting a "retain-all" policy in longline and purse seine tuna fisheries in the WCPO could have important implications, and would have the potential to affect a range of fishery participants, including individual vessels, processors, consumers/communities and managers as well as ecosystem effects depending on how policies are implemented. Some of these implications may yield positive benefits, while others may result in additional costs or burdens.

Primary producers

For an individual vessel operators and owners, a retain-all policy would directly affect daily operations as well as a vessel's profitability. The impacts of a retain-all policy can be summarized into three general categories: 1) well space and whether species can be stored together or have to be segregated, 2) crew time and safety, and 3) offloading and disposal.

The largest impact to a fishing operation would likely be the use of hold space to retain the incidental catch that would have otherwise been discarded. Generally, vessel operators fill their holds with catch of market species, discarding those fish that have low to no market value. Two general scenarios are possible – Scenario A: where a vessel has adequate hold space to keep this retained fish that would normally be discarded and Scenario B: where a vessel does not have adequate hold space to keep all the retained fish that would normally be discarded. In Scenario A, the vessel gains revenues from any sale of retained fish even if very low. However, in Scenario B, the quantity of additionally retained fish directly impacts whether a vessel would have retained either more "target" tuna or continued to fish. Foregone profits from not retaining more "target" tunas are an opportunity cost of full retention and form an implicit tax on producers.

Vessels in the U.S. purse seine fleet are large with multiple holds, so there may be fewer issues related to hold space for purse seine vessels. Conversations with some vessel owners and operators suggest that purse seine vessels are seldom completely full prior to unloading, and given that the estimated additional tonnage retained per trip is small (~5mt/trip), it may be that any effects on their operations would be manageable. Expanding the existing retention policy for purse seine vessels might result in one fewer set per trip, which would be an economic cost to the vessel in the form of foregone profits, an economic opportunity cost. Still, it's more likely that purse seine vessels would be an example of Scenario A.

In contrast, fish holds on most U.S. longline vessels are much smaller and typically only contain a single storage area or well. The U.S. longline fleets are likely more representative of the Scenario B or a combination of Scenarios A and B. Most longline vessels fishing in American Samoa freeze their catch, and typically end their trips with full holds. Thus, adopting any sort of retention policy for the longline fishery will likely result in Scenario B for the American Samoa fishery, where the additional catch retained that would normally have been discarded could displace catch of higher-valued and marketable fish, leading to an opportunity cost of foregone net revenues as the difference between target and incidentally caught species' net revenues. The longline fleet (both deep and shallow setting vessels) in Hawaii is a fresh fish fishery, and conversations with vessel owners indicate that vessels return to port generally more often due to limitations on ice or deteriorating fish quality rather than full holds. A limitation on ice in the longline fleet could be viewed as akin to limitation on hold space as its use of a resource that could be used for keeping tuna. A longline vessel would need to either carry more ice to chill the incidental catch or return early when the ice has been used up on its catch. If the trip length for a vessel shortens because the vessel is full or its ice has been used up, one potential benefit could be a decrease in fuel consumed. As fuel can account for 40-60% of a fishing trip cost for a longline vessel, decreases in trips costs might help offset losses resulting from retaining less marketable fish (PIFSC Undated). Fish retention is expected to minimally impact trip length or amounts caught when vessels return to port due to deteriorating fish quality.

A second but equally significant issue is whether the incidental catch can be stored in the same hold or would need to be segregated. Sharks in particular contain high concentrations of urea, and if stored in the same hold will contaminate and ruin the quality of other fish kept in the same space (McCoy 2006). Thus, although storage might be more feasible for purse seine vessels, if incidental catch such as sharks had to be segregated, the segregation would decrease the overall amount of space available for storing tuna by the size of the well used, which would likely be much larger than the space needed for the incidental catch (~5 mt). This would result in a significant economic cost to a purse seine vessel.

Even before an incidentally caught fish is stored, additional issues to consider are potential additional crew time to handle the additional retained fish as well as any potential safety impacts. There could be additional time spent for the crew to sort and store incidental catch, which could affect overall fish quality. These form both direct costs and potential economic opportunity costs if fishing opportunities are foregone or quality of target catch deteriorates. For a longline vessel, individual fish that are unwanted are often released as the line is being retrieved, so there would be added time not only for storage, but for bringing the fish in on the deck. Some large species such as sharks and marlins are intentionally not landed because of safety reasons (Martin 2012).

Once a vessel completes a trip there are questions on the fate of incidentally caught species. If there is a market to receive all incidental species, then marketed species can be sold and vessels can receive revenues from the retained individuals that would have normally been discarded, thereby increasing producer benefits (producer surplus), assuming that higher valued target species were not crowded out by the retained incidental catch. A larger issue however, might be what happens to nonmarketable species. Processors can be selective on what they accept and at least in American Samoa, the cannery only accepts tunas and wahoo. All other species landed are exported, sold on the local market or given away. Markets can and have developed for species that were considered less desirable, and developing markets will be discussed in more detail later. However, if there is no market for the species and species are rejected by the cannery or buyers, then the responsibility of its disposal whether the vessels would then have to dispose if in a landfill, in the harbor, or back out at sea. Disposal is not a trivial issue on most islands in the WCPO (Cocklin and Keen 2000) and in addition, direct costs are incurred with disposal.

Wholesalers/Processors/Buyers

Once vessels unload their catch, the responsibility to handle retained catch typically shifts from the vessel to a processor/buyer. For fish processors/buyers, incidental catch is additional fish that can be sold and processed, particularly if they are species that are marketed. Most fish are edible, and there are numerous examples of low-value fish becoming highly valued with effective marketing (Adams 2004, Fahrenthold 2009). For example, in Hawaii, both opah and monchong (*Eumegistus illustris* and *Taractichthys steindachneri*) have become popular to serve in restaurants, and landings and sales of these species have increased by an order of magnitude over the past 20 years (PIFSC, unpublished data). If markets don't exist for some fish, incidentally caught fish can be a source of fishmeal if such facilities are available; however, in the western Pacific they are relatively limited. If the landed incidental catch has not crowded out target species' landings, then the increased revenues less any increased processor/buyers costs increases producer benefits (producer surplus). Conversely, landed incidental catch that has crowded out target species' landings leads to lower processor/buyer net revenues and the impact on their costs can be higher or lower, but are generally expected to reduce producer benefits for processors/buyers. In the short run, costs of developing markets could lead to short-run losses. Increases in processor/buyer spending can potentially lead to small but positive increases in incomes and employment through additional rounds of spending (multiplier effects). Disposal issues associated with nonmarket fish could reduce producer benefits through higher costs.

The additionally landed fish potentially have substitution and complementary effects in processor derived demand, that is, species interact in markets through demand. Landed incidental catch species that are lower priced, whose increased supply lowers their prices, and which are substitutes for currently marketed species, can increase processors' derived demand for the currently marketed species. Conversely, landed incidental catch species that are lower priced, whose increased supply lowers their prices, and which are complements for currently marketed species, can decrease processors' derived demand for that species and even lower the price for the complementary marketed species.

Consumers/Communities

Food security, particularly in developing nations, has been touted as a reason to embrace a retain-all or at least a retain-some policy (Bell et al. 2009, WCPFC 2012b). If fishermen were required to retain additional species or undersized fish, some of this fish could be assumed to be available to local consumers wherever the fish is unloaded. Trade of fish between personnel on board vessels and the local community already occurs to a degree, and is referred to as "leakage."

Potential impacts of leakage include a supply of inexpensive source of seafood, impacts on local fishermen, and disposal issues associated with nonmarket fish (McCoy 2012). The additional quantity of inexpensive seafood can lead to increased consumer benefits (consumer surplus), and any impacts that lower consumer prices also raises consumer benefits (although some of these benefits could come from a transfer of producer benefits, leading to no net benefit, simply a change in distribution). Given that fish form a large proportion of consumer budgets, the impacts upon consumers can be nontrivial. Lower prices from the increased supply of incidental catch can have additional consumer effects depending on whether the other species in the market are complements or substitutes in consumption. Any lower market prices through increased supply of incidental catch could reduce employment, incomes, and producer benefits for local fishermen as discussed in greater detail below.

In the WCPO, little has been formally studied on leakage impacts, but anecdotal evidence suggests that leakage already occurs and creates a source of inexpensive seafood (Itano 1996, Kinsolving 1996, McCoy 2012). For example, in Tarawa, the price of frozen fish from transshipment leakage can be half the price of locally-caught skipjack (McCoy 2012). Some of this may be related to the quality and way that fish is stored. Purse seiners tend to store their fish in a brine (NaCl) solution and unless they add freezers for the incidental catch their incidental catch would be stored in the same manner.

Depending on the quantity of fish offloaded and the size and location of the community where the port was located, there could be large effects. In the purse seine fleet, offloading quantities can vary significantly seasonally as well as from year to year, with some ports receiving a lot of fish and other ports receiving only sporadic visits (McCoy 2012). For example, in Honiara, sales of leakage fish from purse seine vessels were estimated to reach between $15,000-30,000 per month during heavy transshipment months and fall to between $3,000-8,000 per month at other times (McCoy 2012). In Tarawa, sales of leakage fish were estimated to be approximately 200 mt per year, and a retain-all policy could lead to a fivefold increase in the quantity of fish available for sale (McCoy 2012). Influxes of additional fish for sale to local markets would likely be easier to adjust to if ports receive regular unloadings from vessels (e.g., Majuro, Pohnpei). However, there could be greater disruptions if unloading are sporadic and quantities fluctuate wildly (e.g., Honiara, Wewak, Tarawa, Christmas Island) (McCoy 2012).

Some communities view the trade of leakage fish as positive by not only providing inexpensive sources of seafood, but also business opportunities, and may welcome additional quantities of incidental fish (Nunoo et al. 2009, McCoy 2012). In Honiara and Rabaul, middlemen exchange produce and other items with vessel crew for sacks of fish, and in Rabaul, this fish is sold not just within the city, but some is smoked and marketed to other villages (McCoy 2012).

Increased unloadings could hinder development of and/or create conflict with domestic (tuna and other) fisheries. Itano (1996) attributed leakage from American Samoa longline fishery as one factor contributing to the failure of the development of a local bottomfish fishery. Prices for pelagic fish in American Samoa were depressed due to cannery leakage, and local fishermen were only able to obtain higher prices for types of fish such as premium sashimi fish that leakage was not providing (Kinsolving 1996). Additional supplies of landed fish to local markets can thus lower ex-vessel prices received by local fishers, in turn lowering the quantities of their landings and their incomes – crowding out -- and with potentially adverse impacts on the income distribution of what is often a marginal group in society. The quantity of fish involved in leakage is likely rather small compared with the amount that would be involved in directed marketing efforts. It seems likely, therefore, that the unloading and sale of incidental catch in small Pacific Islands, even in relatively low quantities compared to the targeted catch, would have disruptive effect on local fishermen and markets if sold locally, especially given an inelastic price elasticity of derived or consumer demand for a necessity (so prices change more than quantities). Conversely, additional supplies of landed fish to local markets that lower prices to consumers lead to a gain in consumer benefits (increased consumer surplus from increased quantity available and lower prices), as discussed elsewhere in greater detail.

Ecosystem

One reason for adopting a retain-all policy is that retaining catch eliminates waste of individuals that are dead. However, a blanket retain-all policy does not necessarily consider implications of retaining live individuals that may be safely released and survive capture. Post-release survival can depend on many factors including species, size of the individual, hook type, timing of capture and release, and handling (Ward et al. 2009b, Gilman 2011). Some individuals can be released and are able to survive the capture process from longline and purse seine operations (Gilman et al. 2008, Campana et al. 2009, Carruthers et al. 2009, Ward et al. 2009b, Hutchinson et al. 2012). Conversations with purse seine vessel owners suggest that oceanic triggerfish are deliberately discarded because they not only generally survive the brailing process, and swim away if released, but are also believed to be one of the first species to re-colonize FADs. As mentioned previously, large sharks and marlins are often not brought on deck during longline operations due to safety considerations, and it’s possible that some of these individuals, particularly sharks survive after release from the line (Moyes et al. 2006, Gilman et al. 2008, Walsh et al. 2009).

Additional Unintended Consequences

When viable markets for incidental catch are created that increase the value of those species, care must be taken not to increase the economic incentives to increase the incidental catch, a moral hazard problem and unintended consequence (Gjertsen et al. 2010). The question thus arises will utilization of incidental catch create a market for the fish that encourages rather than discourages further capture of similar fish?

The negative economic incentive created by full retention can also induce technological change over a longer time period (Gjertsen et al. 2010). For example, Norway prohibited discarding some commercial fish species in 1990, which was combined with a comprehensive monitoring and surveillance program and a system that opens and closes areas based on bycatch rates (Clucas 1997). Since fishers must bring all their catch to shore, the program appears to have stimulated the further development and acceptance by the fishing industry of selective fishing gears and avoidance of areas and times with high bycatch (i.e., regulatory-induced biased technological change) (Clucas 1997).

Conclusions

Adopting a retain-all policy in WCPO tuna fisheries would minimize waste and discards by increasing landings of incidental species. This study shows that the quantities of incidental fish landings resulting from a retain-all policy vary and depend on whether a broader policy would extend to the longline fishery and whether the policy would extend beyond tunas. Discard rates are much smaller on purse seine vessels than longline vessels, and relative additional tonnage of incidental species that would require retention would be much greater on longline vessels than purse seine vessels.

This study considered both benefits and costs of a retain-all policy to industry (vessels and processors), communities and the ecosystem. Vessels would likely face additional costs associated with retaining incidental fish that would otherwise be discarded, and although vessels may benefit from the sale of incidental species, all vessels, and particularly small vessels with single wells and limited hold space/freezing capacity, would reduce producer benefits if incidental catch displaces catch of more valuable species/individuals. Consumers in communities may benefit from additional consumer surplus through additional quantities of inexpensive fish at potentially lower prices (with impacts depending in part upon price elasticities of demand), and incidental catch may create opportunities to further develop markets for some species, but local fishers may be adversely impacted through lower producer benefits if the landings of incidental catch lower ex-vessel prices and crowd out their catches (also depending upon their price elasticity of supply). There may be multiplier effects from any significant increases in landed incidental catches through additional rounds of spending leading to increased incomes and employment in some communities. Unloading data from the purse seine fishery suggest that unloadings in some Pacific Island ports are irregular, so that quantities of incidental catch available to local markets may vary widely from year to year and may inhibit market formation. Additionally, disposal of non-market species is a potential issue that vessels, processors and communities may need to address, particularly in Pacific Island areas where landfill space is limited. Finally, the potential negative impact on local fishermen and markets from landings of incidental catch in small Pacific islands needs to be considered.

Figure 11. Major ports of unloading for U.S. longline and purse seine vessels in the WCPO

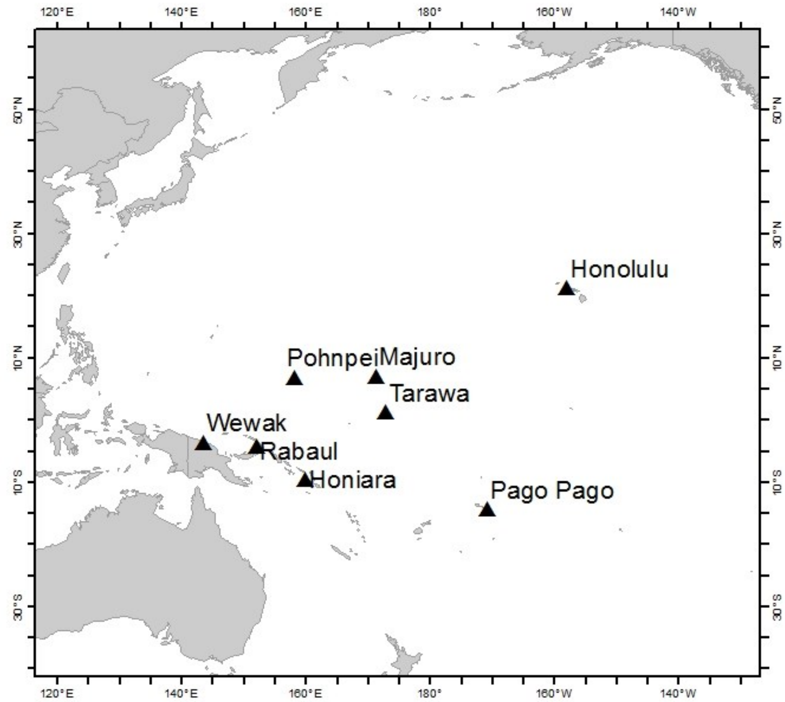


Table 7. Estimated Non-target Fish Discard Rates (mt discard non-target fish/1000 mt landed tunas) for the U.S. purse seine fleet for 2006-2010 in the western and central Pacific Ocean (WCPO). Estimates may not sum to total due to rounding.

Year	Billfish	Sharks	Other Tunas	Other Fishes	Total US Discard Rate
2006	0.3	1.2	<0.1	4.9	6.5
2007	0.3	0.6	0.1	6.7	7.6
2008	0.3	0.6	0.3	1.1	2.4
2009	0.4	0.5	0.1	2.2	3.2
2010	0.5	0.6	0.1	5.1	6.3
Average 2006-2010	0.4	0.7	0.1	4.0	5.2

Table 8. Estimated Principal Target Tuna Discards (mt) for the U.S. purse seine fleet, 2006-2010, in the WCPO.

Year	Skipjack	Yellowfin	Bigeye	Total Tuna Discards	Total Landed
2006	1,129	149	57	1,335	67,545
2007	6,179	622	396	7,198	84,499
2008	5,458	945	672	7,074	196,961
2009	7,096	732	356	8,184	279,357
2010	1,005	76	33	1,115	247,909

Table 9. Estimated Incidental Fish Discards (mt) from the U.S. purse seine fleet and from all purse seine fleets in the WCPO for 2007-2010 by offloading port.

	US Fleet					WCPO				
	2007	2008	2009	2010	Average 2007-10	2007	2008	2009	2010	Average 2007-10
Honiara	31	54	93	156	83.5	1,411	1,060	892	1,963	1,332
Majuro	96	151	312	572	282.75	1,446	897	1,439	2,325	1,527
Pago Pago	416	243	281	422	340.5	842	477	526	682	632
Pohnpei	59	81	326	443	227.25	3,093	652	1,745	2,654	2,036
Rabaul	*	*	27	104	65.5	1,382	752	200	1,705	1,010
Tarawa	-	15	*	58	36.5	1,589	526	1,119	940	1,044
Wewak	-	14	62	*	38	1,186	340	461	270	564
Other Ports	45	67	53	34	49.75	2,660	1,119	1,460	2,580	1,955
Total	647	624	1,153	1,789	1053.25	13,608	5,824	7,841	13,118	10,098

*Data have been combined with other ports for confidentiality purposes.

Table 10. Estimated Incidental Fish Discard Rates (mt discard incidental fish/1000 mt landed fish) and percent marketed and non-marketed species for U.S. longline fleets fishing in the Pacific Ocean.

Fishery	Year	Billfish	Sharks	Other Tunas	Other Fishes	Total Discard Rate
Hawaii Deep Set	2006	5	308	1	65	378
	2007	2	291	1	80	374
	2008	3	206	0	60	269
	2009	4	332	0	78	414
	2010	3	276	1	83	363
	Average	4	283	1	73	356
Hawaii Shallow Set	2006	0	355	0	5	360
	2007	2	355	0	10	367
	2008	3	255	0	9	267
	2009	1	198	0	11	210
	2010	1	396	0	20	417
	Average	1	312	0	11	324
American Samoa	2006	21	53	0	34	109
	2007	38	46	0	55	140
	2008	44	72	0	59	176
	2009	33	41	0	43	116
	2010	24	50	0	45	119
	Average	32	53	0	47	132

Table 11. Estimated principal target tuna and swordfish discards (mt) for the US longline fleet, 2006-2010, fishing in the Pacific Ocean.

	Year	Albacore	Bigeye	Skipjack	Yellowfin	Swordfish	Total Target Species Discards	Total Landings of Target Species	Total Landed All Species
Hawaii Deep Set	2006	2	73	14	18	11	118	5,948	8,769
	2007	3	84	13	17	16	133	7,147	9,605
	2008	2	73	16	39	12	141	7,505	10,269
	2009	-	46	17	5	8	77	5,674	8,317
	2010	15	76	18	4	12	126	6,689	9,219
Hawaii Shallow Set	2006	1	1	0	-	18	20	1,039	1,057
	2007	7	4	0	0	40	51	1,589	1,653
	2008	15	3	0	0	41	59	1,823	1,953
	2009	7	1	0	0	27	35	1,636	1,741
	2010	7	2	0	0	20	29	1,569	1,642
American Samoa	2006	56	27	90	48	4	225	5,143	5,502
	2007	165	94	142	107	2	509	6,213	6,473
	2008	125	36	82	19	3	266	4,202	4,388
	2009	73	22	62	60	1	218	4,614	4,830
	2010	74	52	123	66	2	317	4,687	4,888

Table 12. Estimated incidental fish discards from the US longline fleet fishing in the Pacific Ocean for 2006-2010 by offloading port.

Port	2006	2007	2008	2009	2010	Average
Honolulu – Deep Set	3,314	3,591	2,764	3,445	3,349	3,293
Honolulu – Shallow Set	381	607	522	365	684	512
Pago Pago	601	903	773	562	582	684

Table 13. Average tonnage of incidental fish retained per trip under a retain-all policy.

	Average Landings (mt) /Trip	Average Number of Trips/Year	Average Discard Rate (mt discards/mt landed fish)	Average Discards (mt)/Trip
Purse Seine	880	7	0.006	5.0
Hawaii Deep Set	6	10.4	0.364	2.2
Hawaii Shallow Set	10	3.7	0.324	3.3
American Samoa	23	10.3	0.132	3.0

CHAPTER FIVE: CONCLUSIONS

Issues related to incidental catch in fisheries are slowly being addressed by fisheries managers. While regional fisheries management organizations (RFMOs) such as the Western and Central Pacific Fisheries Commission (WCPFC) have goals to minimize catch and discards of incidental species, conservation and management measures (CMMs) for incidental fish species have been limited thus far to striped marlin and 14 shark species. This study was motivated in part from growing interests in the WCPFC on management issues related to catch of incidental fish, and examined various management options for North Pacific striped marlin through a survey and an ecosystem model, as well as discussed potential impacts of a retain-all policy in the western and central Pacific Ocean (WCPO). This section presents some concluding thoughts, including recommendations for developing a new CMM for N. Pacific striped marlin and suggestions on possible ways to expand the retention policy to minimize waste of fish food while addressing safety and storage concerns.

Management of North Pacific Striped Marlin

A new CMM for N. Pacific striped marlin is warranted because the current CMM contains limits that if members were to fully utilize would result in continued overfishing of this already overfished stock (Lee et al. 2012). Although catches of this stock in 2011 and 2012 were below limits prescribed in the CMM and within levels projected to lead to increases in stock biomass, allowing the CMM to remain in place creates a risk that overfishing could occur in the future despite all members being in compliance with their catch limits. If the WCPFC were to develop a new CMM for N. Pacific striped marlin, the WCPFC should consider revising the

CMM so that limits and/or other management measures adopted reflect current scientific understanding of the stock and of the effectiveness of management measure, overall and/or individual limits to members are transparent and understandable, and annual catches be monitored for compliance, and any non-compliance be addressed and remedied.

The WCPFC should at a minimum consider adopting an overall catch limit that based on best available knowledge would promote stock recovery. Several survey respondents mentioned that they would be more willing to support the need for management or a particular management option if they perceived there was a scientific basis or if effectiveness for a particular management option could be demonstrated. Additional scientific study may be warranted and should be encouraged, particularly for those management options that involve some component of release (i.e., retention ban, live release, minimum size) where post-release mortality is unknown, and for management options where studies have had mixed results (e.g., catch rates and circle hooks). Some scientific information is already available (e.g., effect of elimination of the shallowest hook on catch rates) and educating stakeholders (both fishermen and managers) on existing available information at the WCPFC Scientific Committee meeting or at meetings sponsored by the Western Pacific Fisheries Regional Management Council may be helpful to build support for a new CMM that would encourage more sustainable management for this stock.

One problem with the current CMM for N. Pacific striped marlin is that limits are based on historical catch (2000-2003), but the exact limits are not specifically listed in the measure itself, and the lack of definitive limits has created some confusion in assessing compliance with the measure. Stakeholders in our survey voiced concerns related to a perceived lack of compliance at the Commission level, and some of these concerns could be addressed by including clear limits in a new measure which would eliminate any confusion on what the limit was. Though the current CMM requires members to report on their historical catches, the measure does not define years to include, and members have interpreted the requirement to submit historical data differently, with Chinese Taipei and the United States submitting data from 2000 forward, Korea submitting data for 2000-2003 and from 2010 forward, Japan submitting data from 2007 forward, and Nauru submitting data for 2010. The CMM limits for Chinese Taipei, Korea, and the United States can be easily deduced based on the historical data they submitted, but the limit is less clear for Japan, who has not to date submitted data on historical catch for the relevant time period (WCPFC 2013a). Catch of N. Pacific striped marlin from Japan for the entire North Pacific (including the eastern and western Pacific) are available from the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) and a limit can be derived assuming all of those catches occurred in the WCPO. The current CMM also does not address limits for fleets that have developed since 2000-2003, and data from the WCPFC Tuna Yearbook show a marked increase in catch by fishermen from China (WCPFC 2013b). If the WCPFC wanted to create an overall catch limit or retain catch limits for individual members, these limits or the data underlying them should be explicitly listed in a new measure to avoid confusion when assessing compliance or effectiveness.

The effectiveness of conservation measures and of RFMOs, such as the WCPFC, hinges not only on the ability to develop good measures, but also on the existence of adequate monitoring, compliance and enforcement programs. Though members have largely complied with requirements in this measure for N. Pacific striped marlin based on their catch reports, stakeholders in our survey perceived a lack of monitoring, compliance and enforcement related to requirements from other CMMs. U.S. support for further management action including a new CMM for striped marlin would be strengthened if there were greater trust that measures would be applied to all members and that any non-compliance would be addressed. Our survey only examined opinions from U.S. stakeholders, and many expressed frustration with the perception that the U.S. was the only member enforcing and complying with limits adopted by WCPFC members. Although this study did not evaluate compliance of members in other CMMs, this study did examine how measures taken by the U.S. alone, by foreign fleets excluding the U.S., and by all fleets might affect stock biomass for striped marlin. Gains were also seen when management measures were applied to only to foreign fleets, and minimal changes were seen when management measures were applied to only the U.S. fisheries and U.S. fisheries harvest a small fraction of the total catch of N. Pacific striped marlin in the WCPO. The WCPFC can choose to be as specific or as broad as it would like for its management measures, and this study shows that if management measures are applied unevenly, effects may or may not be as effective depending on how much the catch of a particular fleet or fleet contributes to the overall harvest.

Retain-all policy

Proponents for expanding the retain-all policy in the WCPO or discard bans in other fisheries have posited that these policies could create incentives to develop more selective fishing methods. Although the current retention policy for skipjack, bigeye and yellowfin tuna in the purse seine fishery has lowered the discard rate and quantities of those species discarded, it is not clear that this policy created a disincentive for purse seiners to capture small fish, or encouraged the development of technologies and fishing strategies designed to avoid the capture of small bigeye and yellowfin tuna, the two primary drivers listed in the CMM for adopting the retention policy for the three primary tuna species. For purse seine vessels, our study estimated that the additional amount of fish they would be required to hold under a retain-all policy was small and believed to be generally manageable, but that for some longline vessels, the additional amount of fish that would be required to be retained would be large, and would likely lead to an opportunity cost for foregone net revenues. This suggests that for the longline vessels that freeze their catch, a retain-all policy could be a strong incentive to experiment with more selective fishing methods, but for other longline vessels or purse seine vessels where hold space is less of an issue, a retain-all policy would not likely be a strong incentive for those vessels to develop more selective fishing methods.

We evaluated a retain-all policy for all fishes caught in the WCPO, and sharks had the highest and second highest discard rates of fishes discarded for the longline and purse seine fisheries, respectively. If a broader retention policy were desired, the WCPFC might find greater support for a policy that would exclude retention of sharks. Excluding sharks from a retain-all policy might lessen incentives to develop more selective fishing methods since the quantity of additional fish that vessels would have to retain particularly for longline vessels would drop significantly, but many crew safety and storage concerns by vessels would be alleviated.

One reason there may have been a smooth adoption of a retention policy for the three tropical tunas is that small tunas have commercial value, and vessels can offload them directly to a cannery or transship them to carrier vessels. Disposal or markets for other species are less easy to identify though certain species are considered important food fish, and some are retained when caught by longline and purse seine vessels for crew consumption. If a broader retain-all policy were desired and the focus was on minimizing waste of food fishes, perhaps that WCPFC could adopt a retain-some policy that could require vessels to retain a suite of species of interest like mahi mahi, rainbow runner, marlin, and wahoo. There are already existing markets for these species, and this could potentially supply fish of interest to the community, while not creating a waste problem for species with little to no market value.

Summary

Addressing the management of incidentally caught fish has become of greater interest as the WCPFC works towards developing sustainable fisheries for highly migratory species. For N. Pacific striped marlin, recovery of this stock was projected to occur if reductions on catch are maintained, and the WCPFC should revise its CMM to eliminate the risk of overfishing in the future (Lee et al. 2012). Any new limits should be based on the best available science and should be clearly laid out in the measure to avoid any confusion on what they are and for ease of assessing compliance. Management measures should also apply to all fleets fishing for N. Pacific striped marlin, or at least focus on the gears and fleets responsible for harvesting the majority of striped marlin.

Expanding retention policies in the WCPFC to all species and to purse seine and longline vessels would have major impacts on vessels, consumers and communities in the WCPO, and the WCPFC should weigh all benefits and costs before agreeing to adopt any policy that would expand the current retention policies. Less expansive policies such as ones that that would exclude sharks or ones that focus on fish with market value might be more viable as they would alleviate concerns towards crew safety and storage if sharks did not have to be retained, while promoting retention of important food fishes in the WCPO.

Appendix A. North Pacific Striped Marlin Questionnaire

Survey of Management Options for Sustainably Managing North Pacific Striped Marlin

The following survey is part of a UCLA doctoral dissertation study on management options for North Pacific striped marlin. This survey is interested in understanding views on various management options for sustainably managing striped marlin in the North Pacific.

Demographic Questions

1. Which of the following sectors do you most closely identify with?

   __Government __Fishing Industry __Academia __ENGO __Advisory Council
   __Other

2. If you identify with the government, what organization are you affiliated with?

   __NMFS HQ or Regional Office __NMFS Science Center
   __Other (please specify) _______________

3. If you are a fisherman, what type of gear do you fish with? Please check all that apply.

   __ Deep Set Longline __ Shallow Set Longline __ Troll __ Handline
   __ Other (please specify)_______________ __Not Applicable

4. If you fish with more than one type of gear, what gear do you predominantly fish with?

   __Deep Set Longline __Shallow Set Longline __Troll __Handline
   __Other (please specify)_______________ __Not Applicable

5. If you are a fisherman, do you consider yourself primarily a commercial or a recreational fisherman?

   __Commercial __Recreational __Not Applicable

6. If you identify with an advisory council, which advisory council do you identify with?

   ____

Striped Marlin

7. How would you characterize your knowledge of the North Pacific striped marlin stock in the Western and Central Pacific Ocean?

   __Very Knowledgeable __Knowledgeable __Somewhat Knowledgeable
   __Not at all Knowledgeable __Don’t Know

8. From what you know, is there a need to limit catch of North Pacific striped marlin in the Western and Central Pacific Ocean?

__ Strongly Agree __Somewhat Agree __Undecided __Somewhat Disagree
__Strongly Disagree __ Don't Know

Determining appropriate management tools for sustainably managing North Pacific striped marlin

In December 2010, the Western and Central Pacific Fisheries Commission (WCPFC) adopted a conservation and management measure requiring members to limit their catches of North Pacific striped marlin to 80% of their highest annual catch from 2000-2004 by 2013. This limit is not gear specific and applies to catch from all gear types. For the United States, the highest catch of North Pacific striped marlin was in 2003 and was 571 mt. Under the WCPFC's conservation and management measure, the US is to limit its catch to 514 mt in 2011, 485 mt in 2012, and 457 mt in 2013.

9. Many factors including biological, economic, social and political factors may be considered in determining appropriate management tools for sustainably managing North Pacific striped marlin. For example, biological factors could include the health of the stock and whether the population is experiencing overfishing. Economic factors could be the costs to implement a gear modification or lost revenue if live striped marlin are released. Social factors could be the importance of ensuring the ability to fish for striped marlin for society and/or the local community. Finally political factors could be public acceptance or public resistance to potential management tools. Compare each of the following pairs of factors and using a scale of 1-9 where 1 is not any more important, 3 represents weak importance, 5 represents moderate importance, 7 is strong importance and 9 represents extreme importance indicate by circling the value whether you think the factors should be considered equally in weighing management options or if one factor is more important, how much more important it is to consider. 2, 4, 6 and 8 are intermediate values. If you are not sure or don't know, please circle "not sure." For example, if one believes that biological factors and economic factors are equally important to consider in weighing management options for striped marlin, circle the number 1 (as shown below). As another example, if one felt that social factors were strongly more important to consider in comparison to biological factors, the number 7 would be circled on the side closest to the word social.

Example:

Biological	9	8	7	6	5	4	3	2	(1)	2	3	4	5	6	7	8	9	Economic	Not Sure
Social	9	8	(7)	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biological	Not Sure

Biological	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic	Not Sure
Biological	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social	Not Sure
Biological	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Political	Not Sure
Economic	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social	Not Sure
Economic	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Political	Not Sure
Social	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Political	Not Sure

10. This study identified 6 management options that could be used to manage fisheries that catch of striped marlin. These include catch limits, release of live individuals, minimum size requirements, gear modifications such as requiring circle hooks and/or eliminating shallowest hooks, and a ban on retention. Note the current CMM for striped marlin imposes a catch limit on member countries, and allows member countries discretion on how to achieve those limits. Catch limits for bigeye tuna already exist, and catch limits for striped marlin could be implemented in a similar way where fishers are allowed to fish until the limit is reached. Release of live individuals would allow for the retention of dead marlin, but mandatory release of any live striped marlin. Use of circle hooks and the elimination of the shallowest hook on deep longline sets have been shown to reduce catch of striped marlin on longline vessels. Finally, a retention ban would not allow retention of any caught striped marlin. Compare the following pairs of management options and indicate whether they are equally preferred as a management tool for **biological** reasons (e.g., promoting the health of the stock or reducing overfishing) or if one is preferred over the other.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Minimum	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating	Not

Size Limit																		Shallow Hooks	Sure

11. Keeping in mind the overarching goal of sustainably managing North Pacific striped marlin, consider the following pairs of fisheries and indicate whether **economic impacts** (positive and negative) should be considered equally in selecting management options, or if not which is the more important fishery to focus on.

Deep Set Longline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shallow Set Longline	Not Sure
Deep Set Longline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Handline	Not Sure
Deep Set Longline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Troll	Not Sure
Shallow Set Longline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Handline	Not Sure
Shallow Set Longline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Troll	Not Sure
Handline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Troll	Not Sure

12. Consider the following pairs of management alternatives for the **deep set longline fishery** and indicate whether one would be preferred over the other for **economic** reasons or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure

Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Minimum Size Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure

13. Consider the following pairs of management alternatives for the **shallow set longline fishery** and indicate whether one would be preferred over the other for **economic** reasons or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure

14. Consider the following pairs of management alternatives for the **handline fishery** and indicate whether one would be preferred over the other for **economic reasons** or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size	Not

Limit																		Limit	Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure

15. Consider the following pairs of management alternatives for the **troll fishery** and indicate whether one would be preferred over the other for **economic** reasons or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure

16. Several social factors including community benefits, fisheries access and gear conflicts can be considered in determining appropriate management tools for North Pacific striped marlin. Community benefits describe both benefits to society as a whole as well as to benefits to local communities. Fisheries access can describe the right for commercial and recreational fishery participants to fish for and/or catch or retain a particular species. Finally, gear conflicts describe the importance of separating fisheries to avoid conflicts between

commercial fishing sectors and commercial and recreational fishing sectors. Compare the following **social** factors, and indicate whether they are equally important in considering appropriate management tools for sustainably North Pacific striped marlin or if one is more important from the other.

Community	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access	Not Sure
Gear Conflicts	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Community	Not Sure
Access	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Gear Conflicts	Not Sure

17. Should societal (global) interests be considered equally as important to local interests or is one more important to consider in selecting management options for sustainably managing NP striped marlin?

Society	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Local	Not Sure

18. Consider the following pairs of management alternatives and indicate whether one would be preferred over the other to preserve **societal (global)** interests or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating	Not

Hooks																	Shallow Hooks	Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Minimum Size Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure

19. Consider the following pairs of management alternatives and indicate whether one would be preferred over the other to preserve **local interests** or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Minimum Size Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure

20. Should commercial fisheries access be considered equally as important to recreational fisheries or is one more important to consider in selecting management options for sustainably managing NP striped marlin?

Commercial	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Recreational	Not Sure

21. Consider the following pairs of management alternatives and indicate whether one would be preferred over the other for **commercial fisheries access** reasons or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Minimum Size Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure

22. Consider the following pairs of management alternatives and indicate whether one would be preferred over the other for **recreational access** reasons or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not

Limit																		Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure

23. Consider the following pairs of management alternatives and indicate whether one would be preferred over the other to avoid **gear conflicts** between commercial and recreational fisheries or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating	Not

Hooks																		Shallow Hooks	Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Minimum Size Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure

24. Should public acceptance be considered equally important to public resistance or is one more important to consider in selecting management options for sustainably managing NP striped marlin?

Public Acceptance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Public Resistance	Not Sure

25. Consider the following pairs of management alternatives and indicate whether one would be preferred over the other to for **public acceptance** reasons or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Retention	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size	Not

Ban																		Limit	Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Minimum Size Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure

26. Should **resistance** by different gear types be considered equally important or is resistance by one gear type more important than others to consider in selecting management options for sustainably managing NP striped marlin?

Deep Set Longline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Shallow Set Longline	Not Sure
Deep Set Longline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Handline	Not Sure
Deep Set Longline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Troll	Not Sure
Shallow Set Longline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Handline	Not Sure
Shallow Set Longline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Troll	Not Sure
Handline	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Troll	Not Sure

27. Consider the following pairs of management alternatives for the **deep set longline fishery** and indicate whether one would be preferred over the other if there were **public resistance** or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure

Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure
Minimum Size Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Eliminating Shallow Hooks	Not Sure

28. Consider the following pairs of management alternatives for the **shallow set fishery** and indicate whether one would be preferred over the other if there were **public resistance** or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure

29. Consider the following pairs of management alternatives for the **handline fishery** and indicate whether one would be preferred over the other if there were **public resistance** or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure

30. Consider the following pairs of management alternatives for the **troll fishery** and indicate whether one would be preferred over the other if there were **public resistance** or if the alternatives are equally preferred.

Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Live Release	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Catch Limit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circle Hooks	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Live Release	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Retention Ban	Not Sure
Circle Hooks	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure
Retention Ban	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimum Size Limit	Not Sure

Other Questions

31. Of the six alternatives presented: catch limits, use of circle hooks, eliminating the shallowest hooks in deep longline sets, minimum size limit, live release and a retention ban, which do you think is most feasible, and why?

32. Of the six alternatives presented: catch limits, use of circle hooks, eliminating the shallowest hooks in deep longline sets, minimum size limit, live release and a retention ban, which do you think is the least feasible, and why?

33. Are there alternatives not listed here that should be considered?

34. How familiar are you with the longline catch limits for bigeye tuna in the Western and Central Pacific Ocean?

__Very Familiar __Familiar __Somewhat Familiar __Not at all Familiar __Don't Know

35. In 2009, 2010 and 2011, there were catch limits for bigeye tuna on the longline fishery, and the fishery was closed for the remainder of the calendar year when the catch limit was projected to be reached. Should catch limits for striped marlin be implemented and managed in the same way as they were for bigeye tuna or are there any lessons from implementing the bigeye catch limit that should be considered in implementing a catch limit for striped marlin?

36. Two alternatives involve gear modifications that are specific to the longline fishery. Do you know of any gear modifications that might be applicable for other fisheries that catch striped marlin?

37. Three of the alternatives, catch limits, retention ban and live release are not necessarily gear specific. Should management options for North Pacific striped marlin be applied across all

gear types or should management options be targeted at a specific gear type or types? Why or why not?

38. Striped marlin are sometimes misclassified as blue marlin or shortbilled spearfish. Would you be open to a management measure that covered all marlins and not just striped marlin?

39. If the Western and Central Pacific Fisheries Commission revised its conservation and management measure for North Pacific striped marlin in the future, what change, if any, should be considered?

Appendix B. Sensitivity of model outputs with uniform predator vulnerability and with individual predator-prey vulnerability

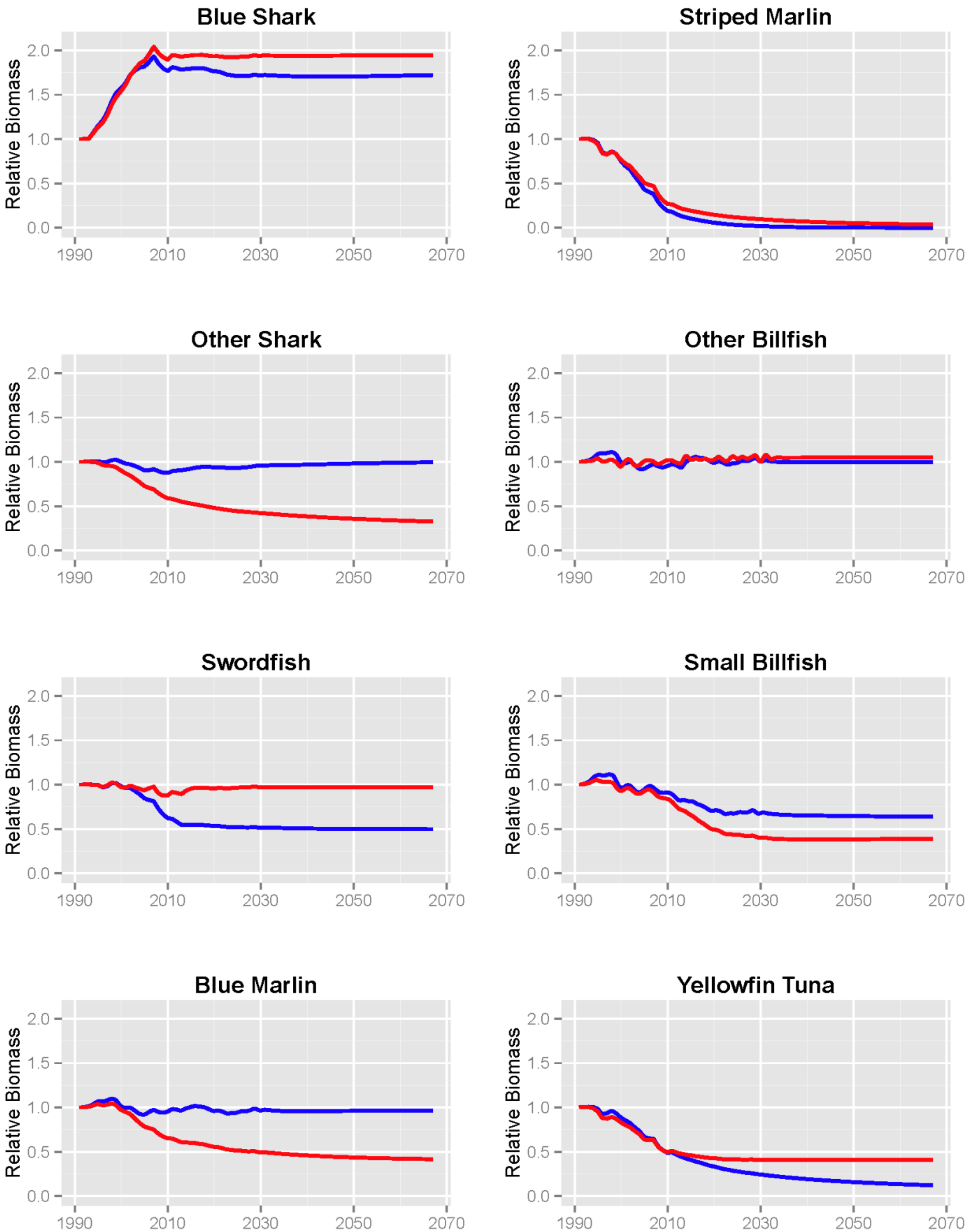
Ecosim uses vulnerabilities to describe the sensitivity of predator/prey relationships with small values implying prey populations are relatively insensitive to fluctuations in predator populations and large values implying prey populations are highly sensitive to fluctuations in predator populations. Vulnerabilities can be input directly into the model or estimated by the model based on fits to empirical data. Vulnerabilities can be estimated for each predator group (uniform vulnerability every prey of a given predator) or estimated for each individual predator-prey relationship. While vulnerabilities likely differ for each predator-prey interaction, choosing to use vulnerabilities for each predator group may avoid over parameterization of the model (Howell et al. 2013).

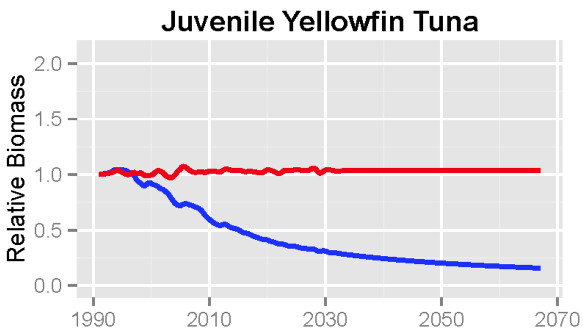
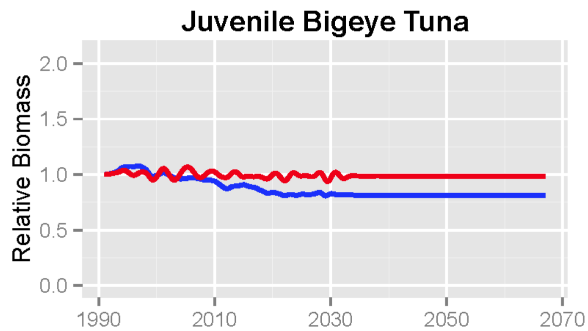
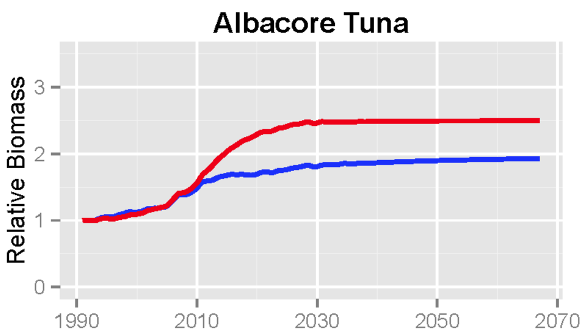
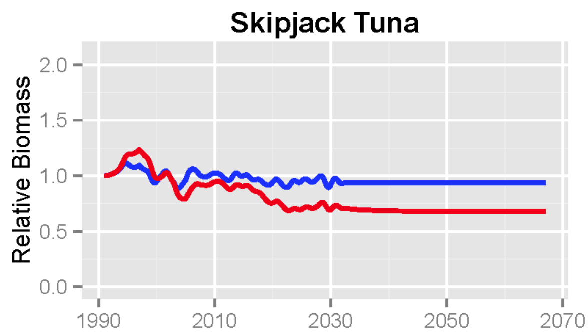
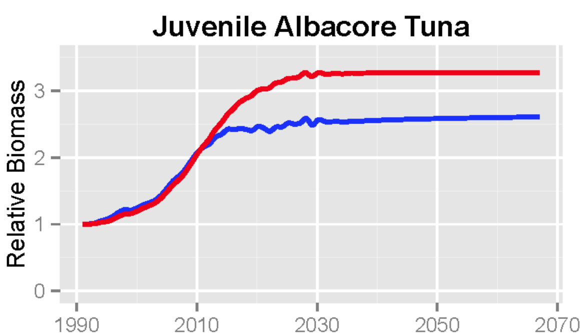
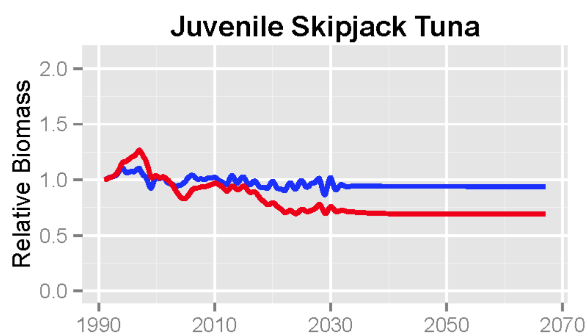
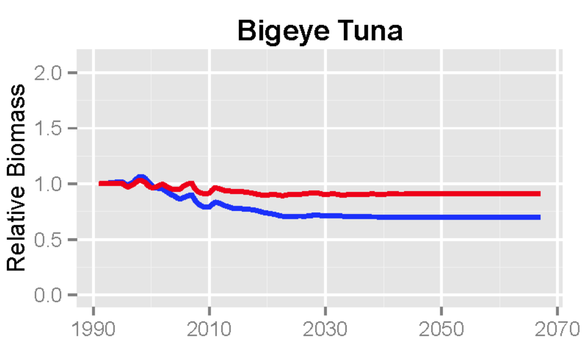
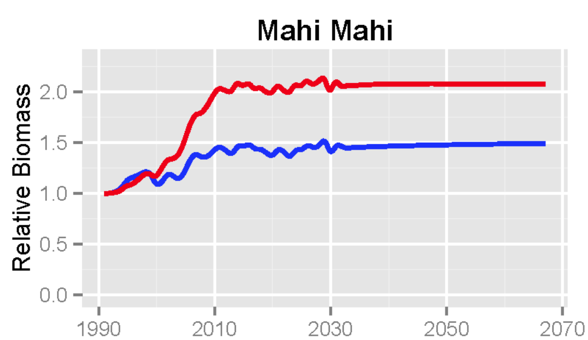
Scenarios were run using vulnerabilities estimated for each predator group (P vulnerability) and for each predator-prey interaction (PP vulnerability). Relative biomass trends for functional groups using P vulnerability (red line) and PP vulnerability (blue line) are shown in Appendix B1. In general, trends were similar such that the direction of change was similar for the functional groups no matter what vulnerability was used. If relative biomass was observed to occur over the simulation when P vulnerabilities were used, relative biomass was observed to occur of the simulation when PP vulnerabilities were used though the magnitude of change differed in some instances. Differences in trends were observed for other sharks, swordfish, blue marlin and juvenile yellowfin. For other sharks and blue marlin, relative biomass levels were maintained over the duration of the simulation when P vulnerabilities were used, but relative biomass levels declined and then level out over the duration of the simulation when PP vulnerabilities were used. For swordfish and juvenile yellowfin, relative biomass levels declined and appeared to level out over the duration of the simulation when P vulnerabilities were used, but relative biomass levels were maintained over the duration of the simulation when PP vulnerabilities were used.

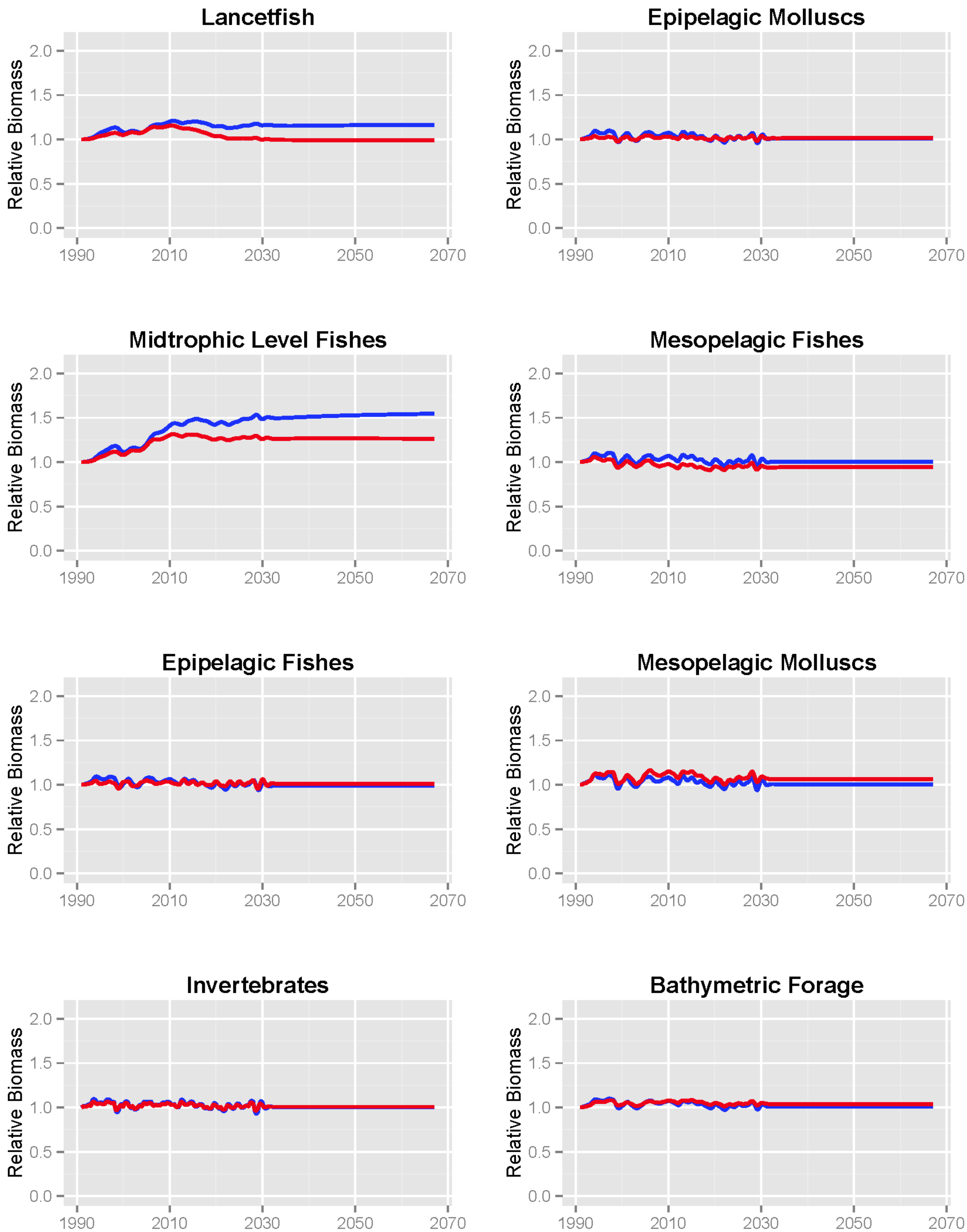
Appendix B2 depicts the relative biomass trends for each functional group under the various fishing effort and gear scenarios using PP vulnerabilities. In comparing these figures to those figures in Figure 6-Figure 9 of the manuscript and figures contained in Appendix C which use P vulnerabilities, the trends and responses to different fishing effort and gear modifications were similar.

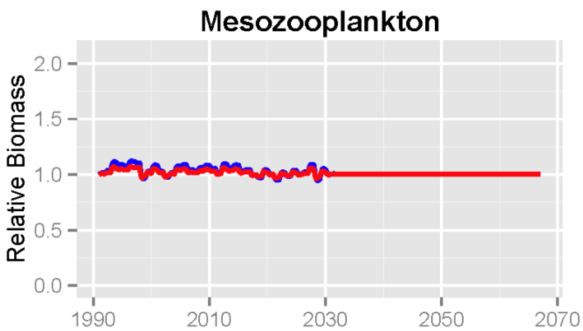
As trends in relative biomass were similar whether P vulnerabilities or PP vulnerabilities were used, and P vulnerabilities were used in the final analysis.

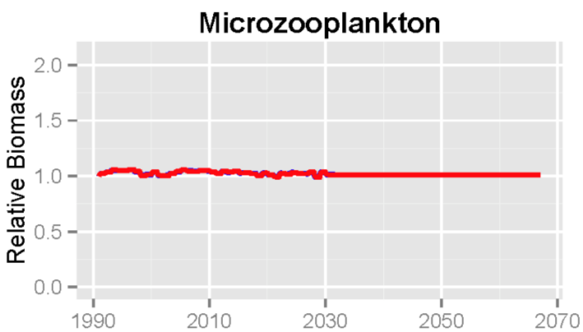
Appendix B1. Relative biomass at status quo for functional groups modeled with P vulnerabilities (red) and PP vulnerabilities (blue)




Juvenile Yellowfin Tuna
Relative Biomass
0.0
0.5
1.0
1.5
2.0
1990
2010
2030
2050
2070

Juvenile Bigeye Tuna
Relative Biomass
0.0
0.5
1.0
1.5
2.0
1990
2010
2030
2050
2070

Albacore Tuna
Relative Biomass
0
1
2
3
1990
2010
2030
2050
2070

Skipjack Tuna
Relative Biomass
0.0
0.5
1.0
1.5
2.0
1990
2010
2030
2050
2070

Juvenile Albacore Tuna
Relative Biomass
0
1
2
3
1990
2010
2030
2050
2070

Juvenile Skipjack Tuna
Relative Biomass
0.0
0.5
1.0
1.5
2.0
1990
2010
2030
2050
2070

Bigeye Tuna
Relative Biomass
0.0
0.5
1.0
1.5
2.0
1990
2010
2030
2050
2070

Mahi Mahi
Relative Biomass
0.0
0.5
1.0
1.5
2.0
1990
2010
2030
2050
2070

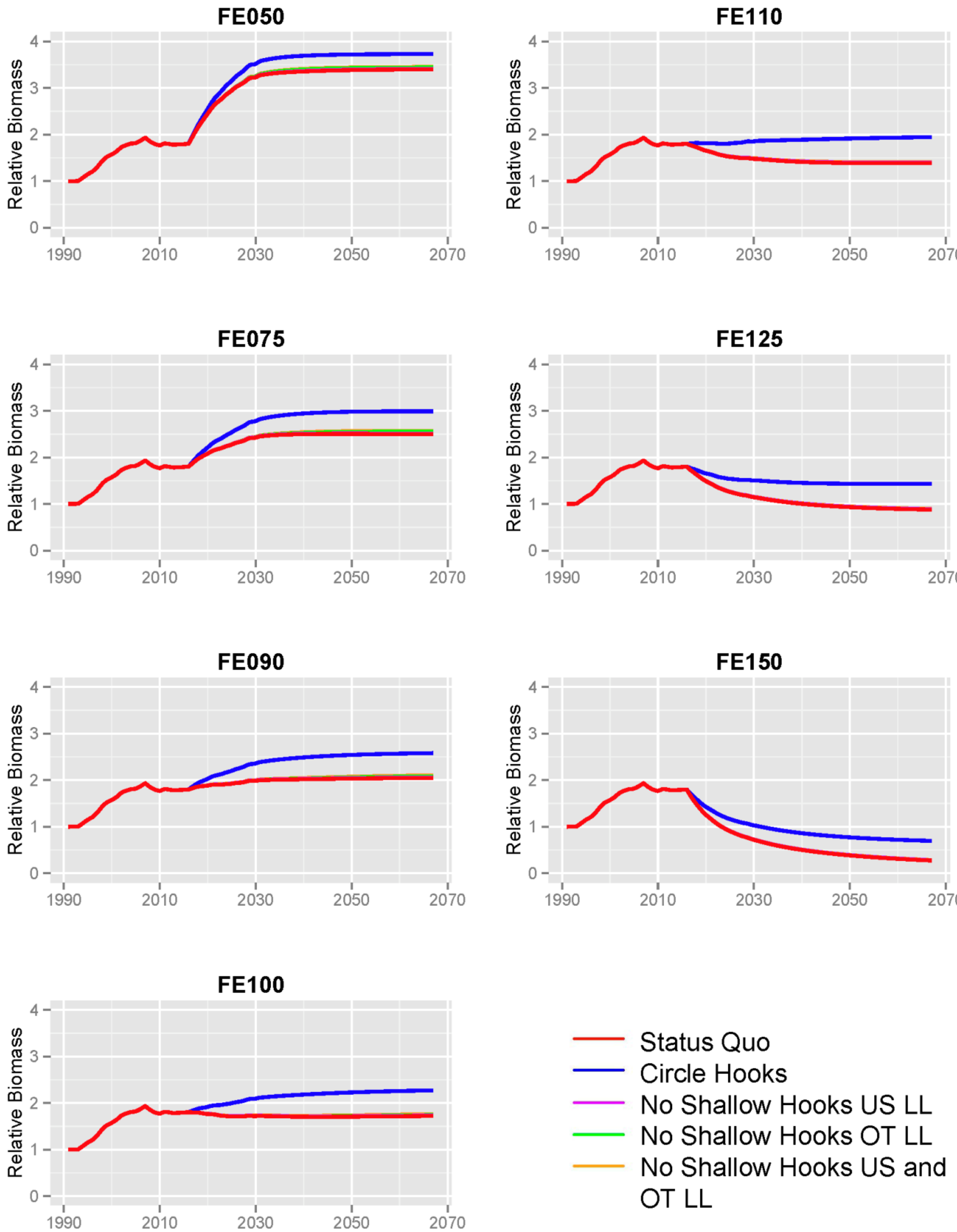

Lancetfish
Epipelagic Molluscs
Midtrophic Level Fishes
Mesopelagic Fishes
Epipelagic Fishes
Mesopelagic Molluscs
Invertebrates
Bathymetric Forage
Relative Biomass
0.0
0.5
1.0
1.5
2.0
1990
2010
2030
2050
2070


Mesozooplankton
Relative Biomass
2.0
1.5
1.0
0.5
0.0
1990
2010
2030
2050
2070

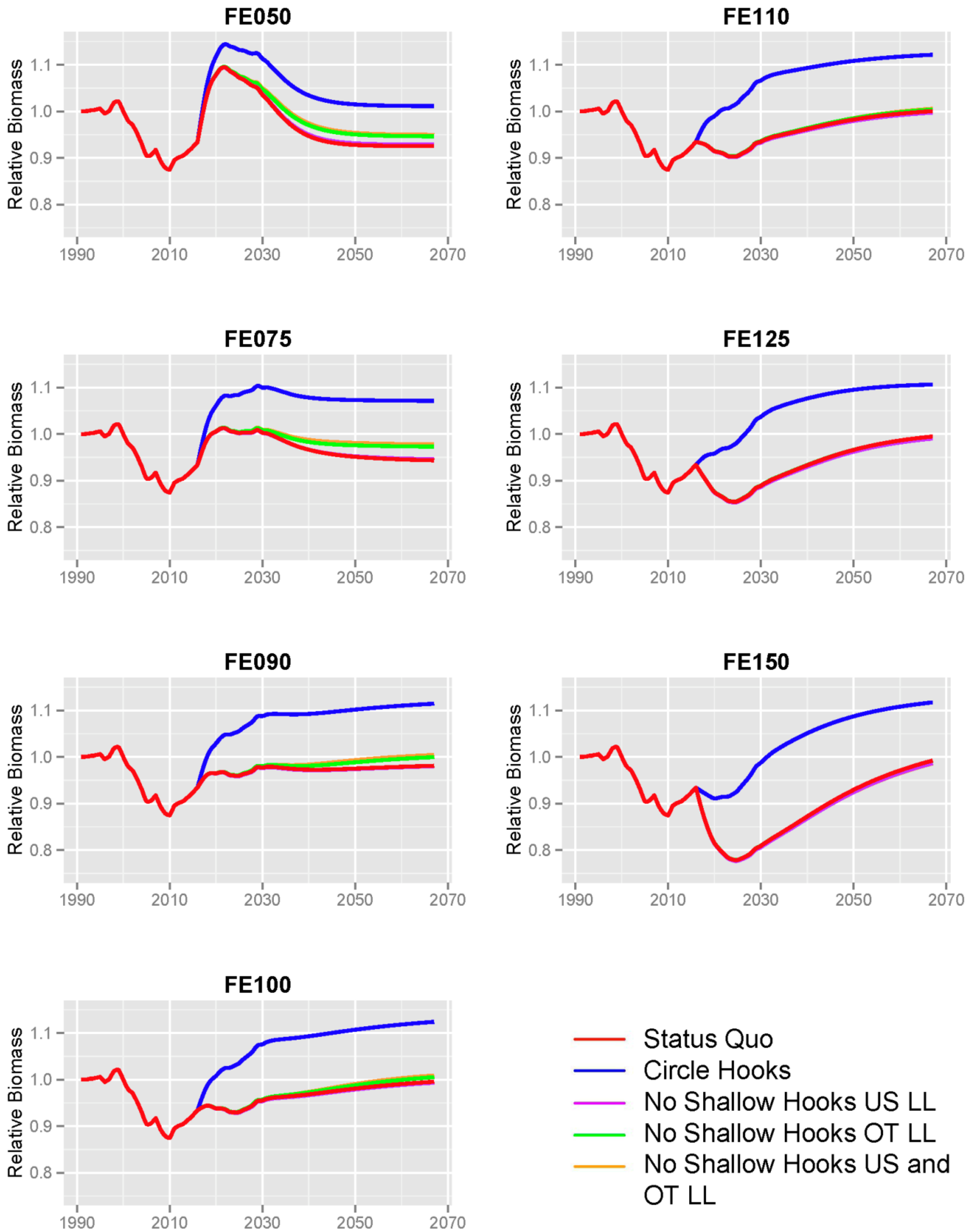

Microzooplankton
Relative Biomass
2.0
1.5
1.0
0.5
0.0
1990
2010
2030
2050
2070

Appendix B2. Relative biomasses for functional groups under various fishing effort and gear modification scenarios using predator-prey vulnerability

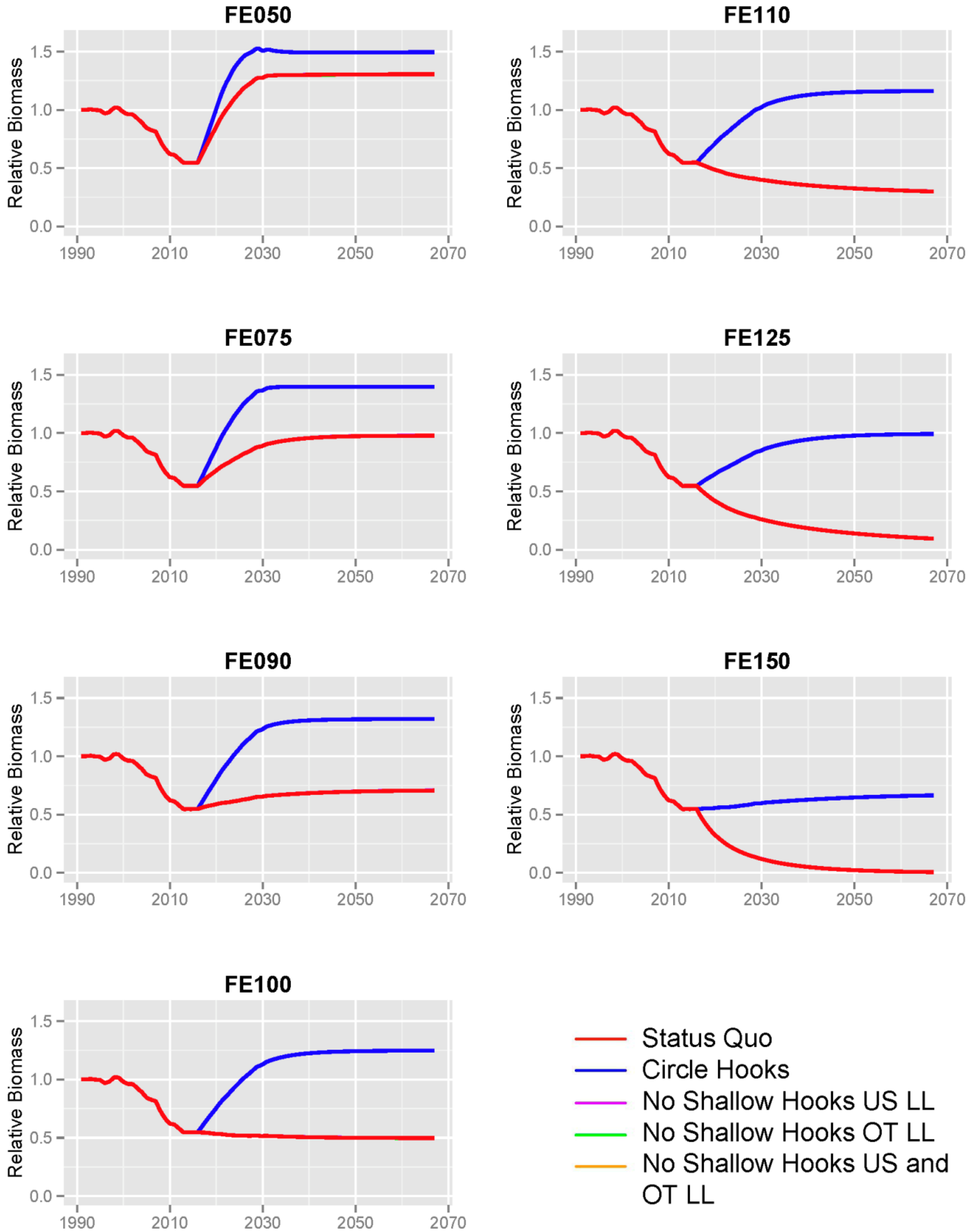
Appendix B2.1. Relative biomasses for blue sharks under various fishing effort and gear modification scenarios



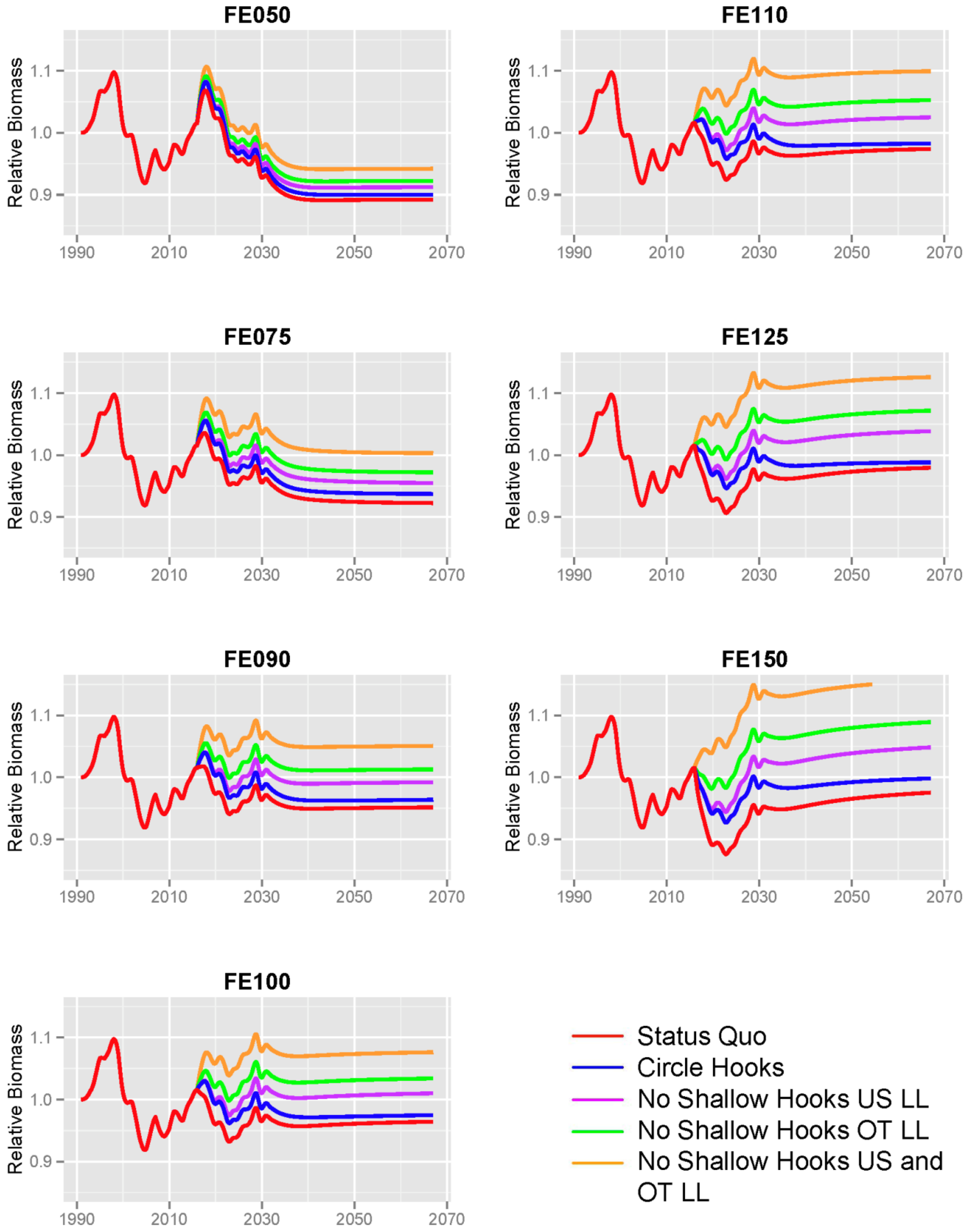
Appendix B2.2. Relative biomasses for other sharks under various fishing effort and gear modification scenarios



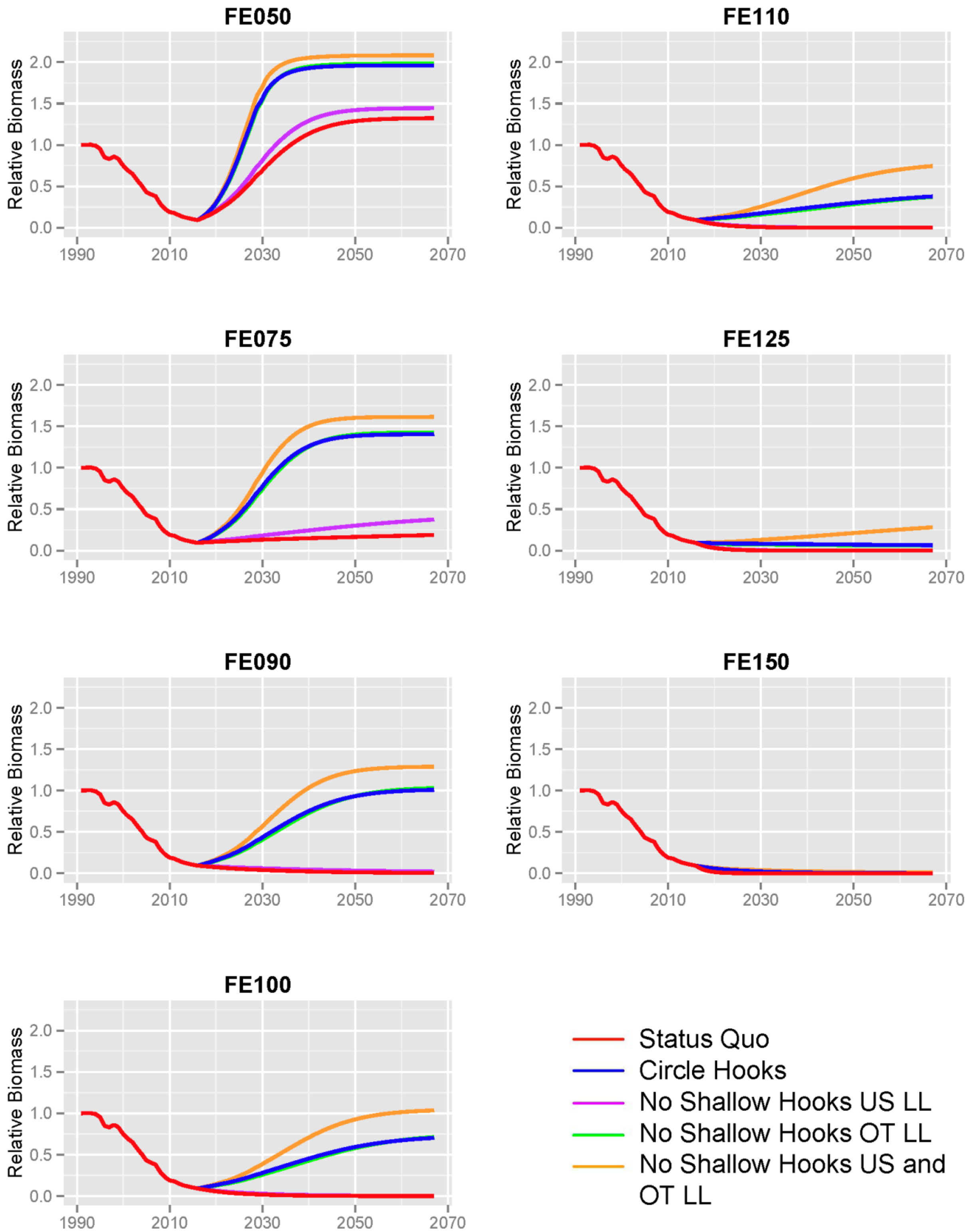
Appendix B2.3. Relative biomasses for swordfish under various fishing effort and gear modification scenarios



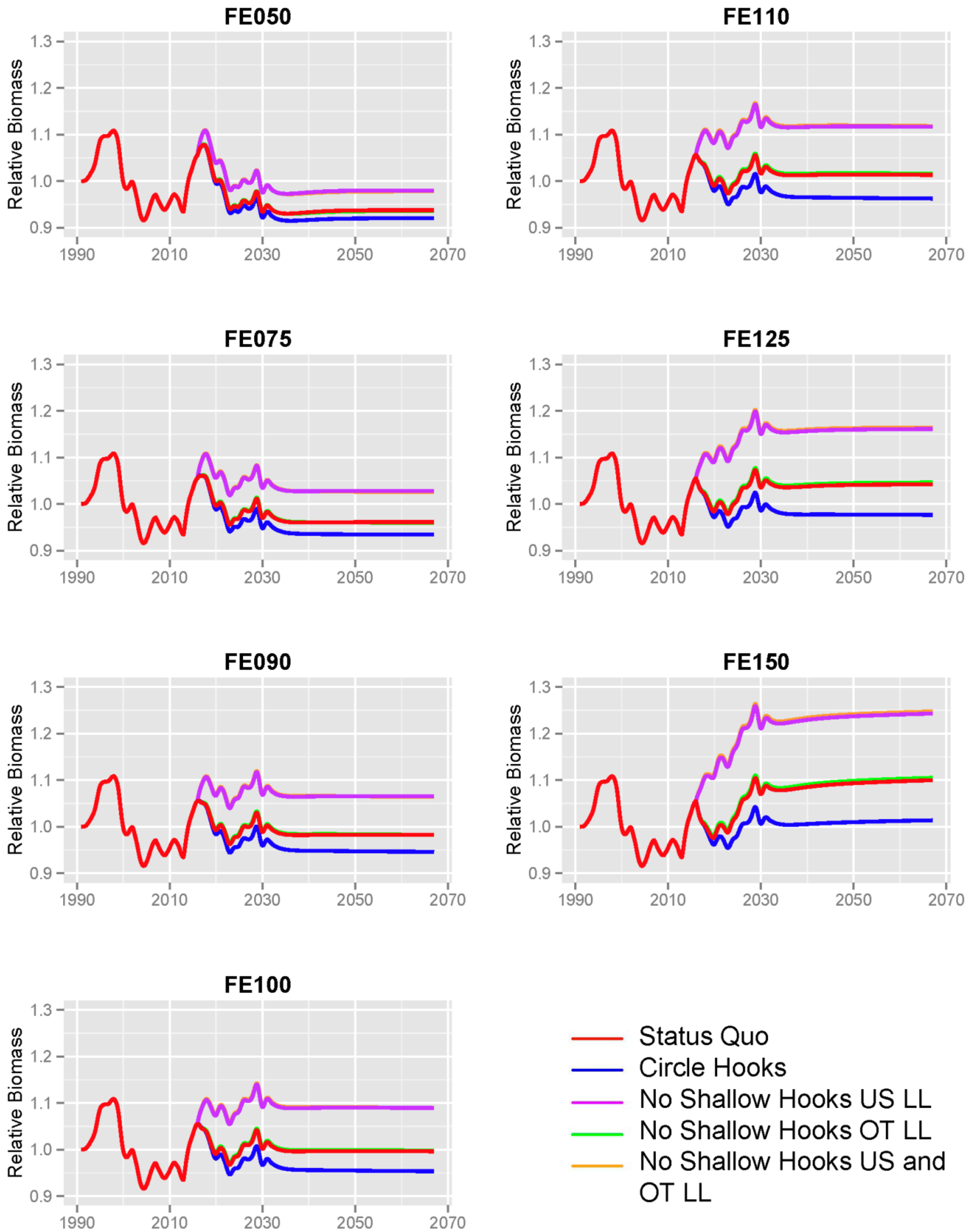
Appendix B2.4. Relative biomasses for blue marlin under various fishing effort and gear modification scenarios



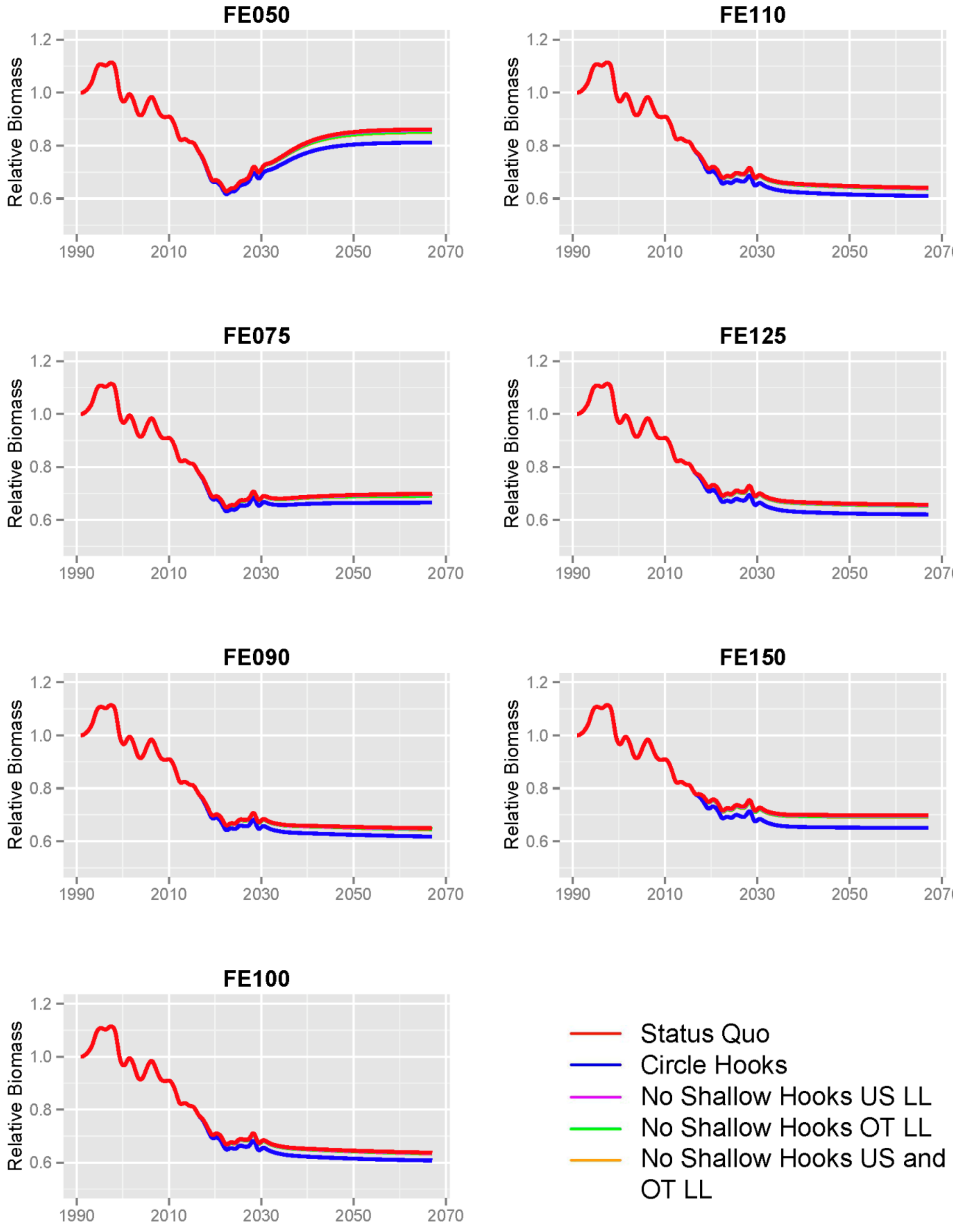
Appendix B2.5. Relative biomasses for striped marlin under various fishing effort and gear modification scenarios



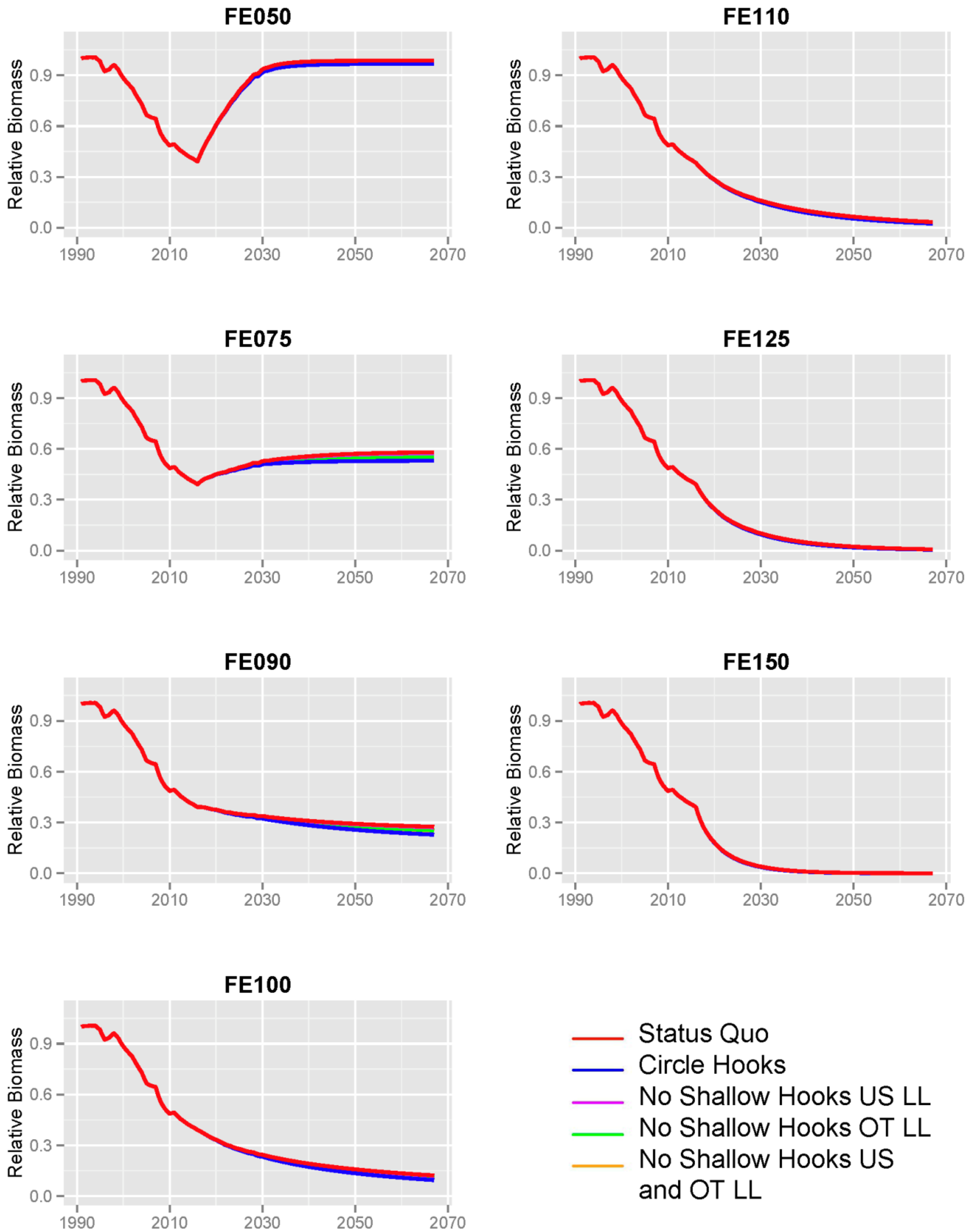
Appendix B2.6. Relative biomasses for other billfish under various fishing effort and gear modification scenarios



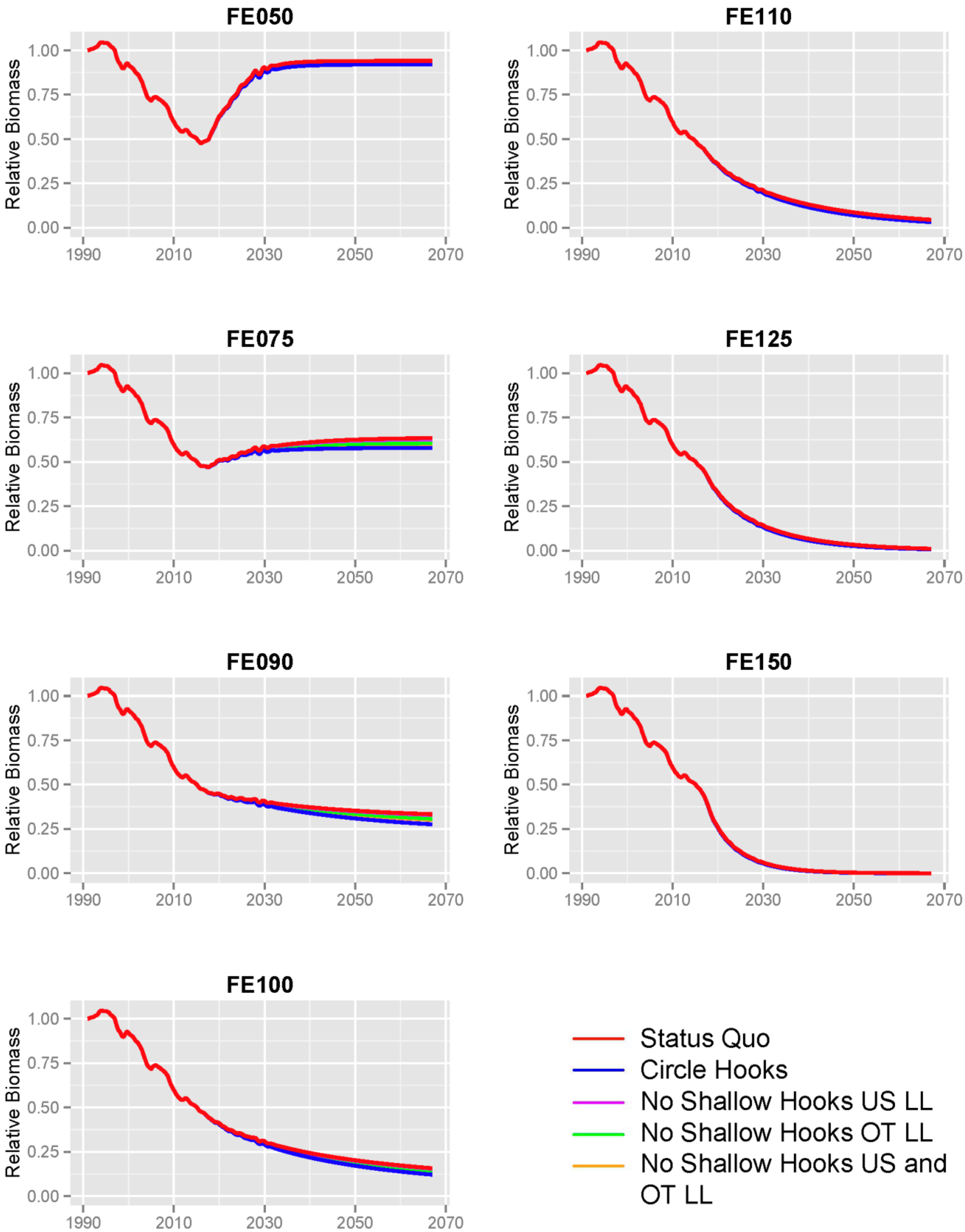
Appendix B2.7. Relative biomasses for small billfish under various fishing effort and gear modification scenarios



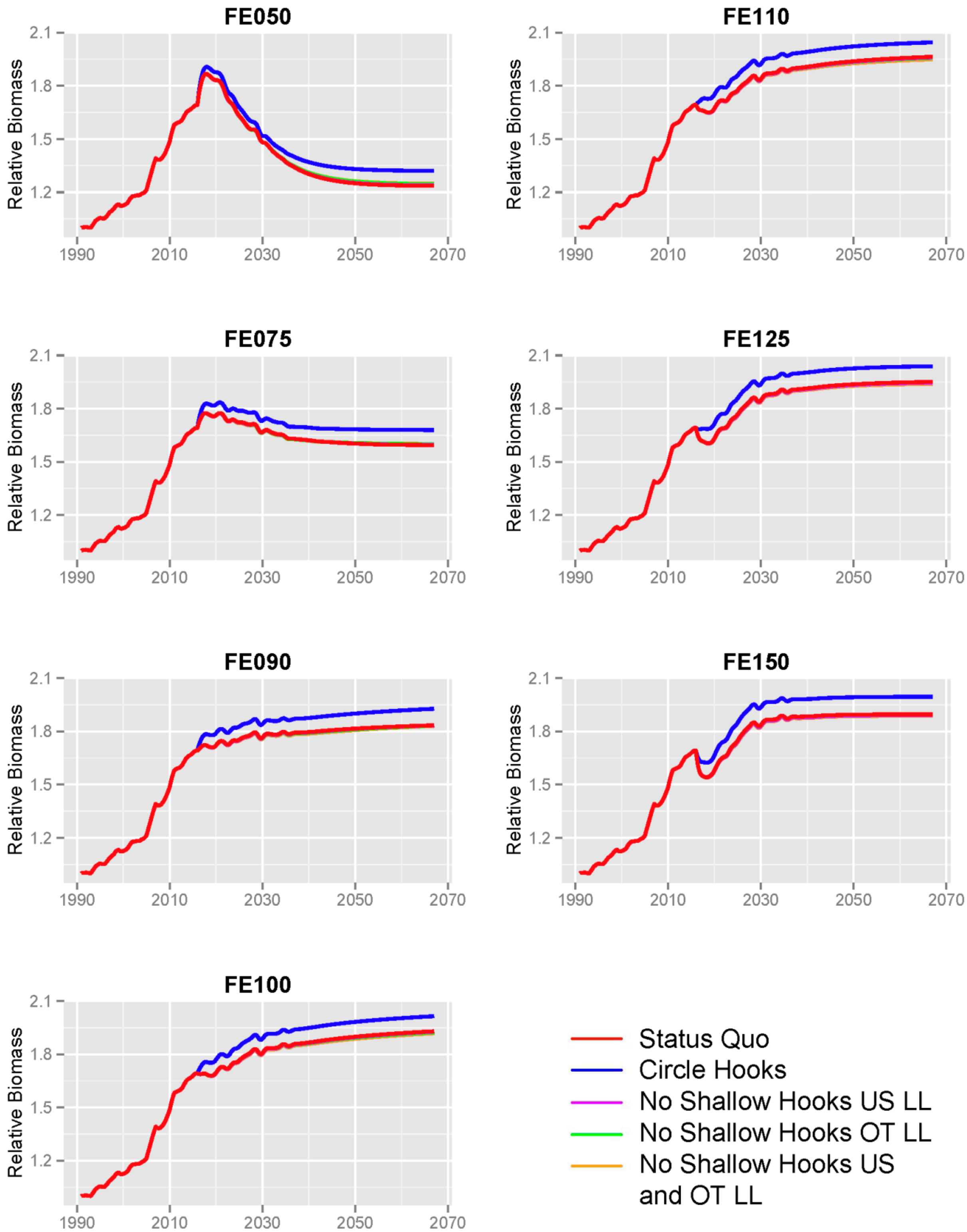
Appendix B2.8. Relative biomasses for yellowfin tuna under various fishing effort and gear modification scenarios



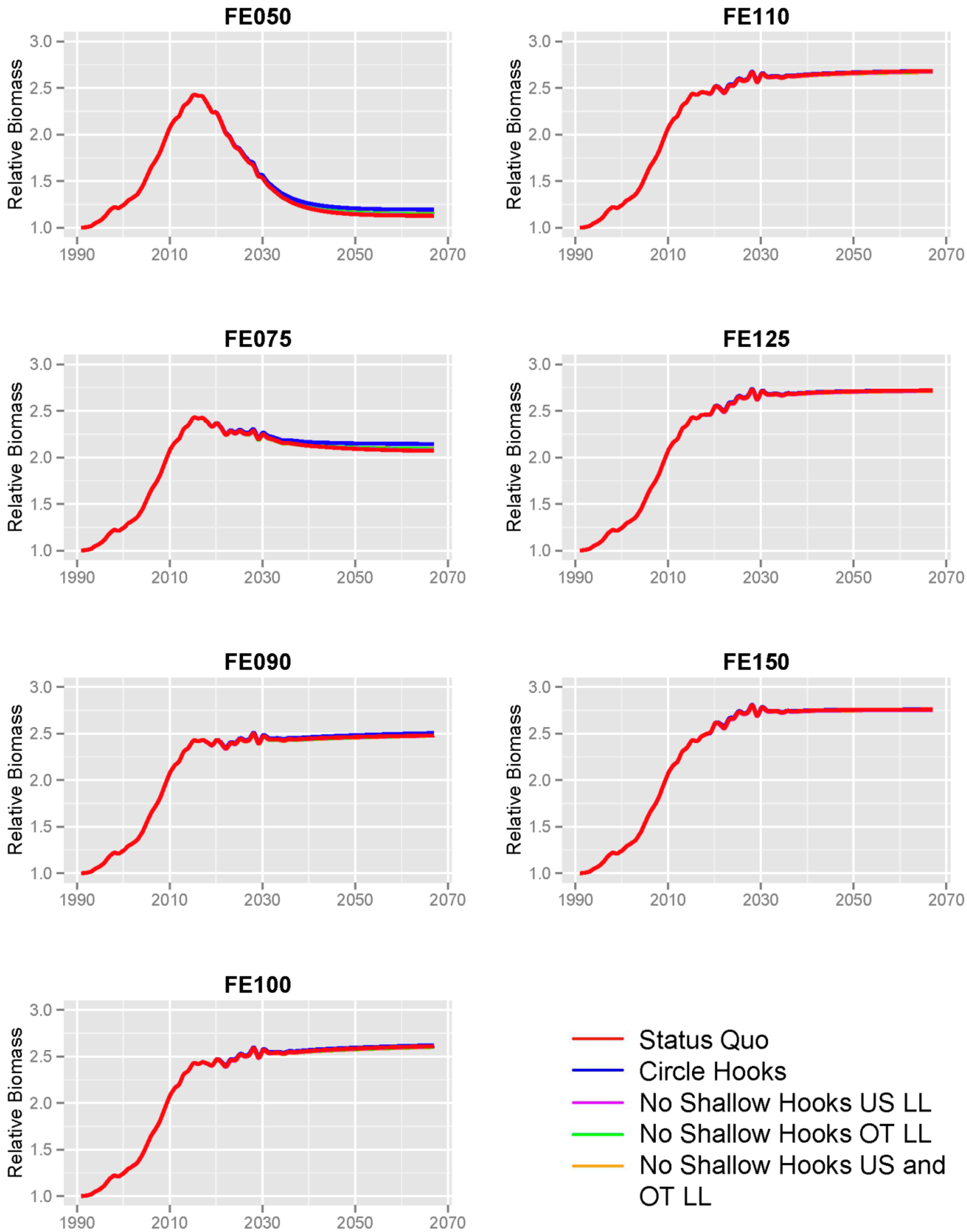
Appendix B2.9. Relative biomasses for juvenile yellowfin tuna under various fishing effort and gear modification scenarios



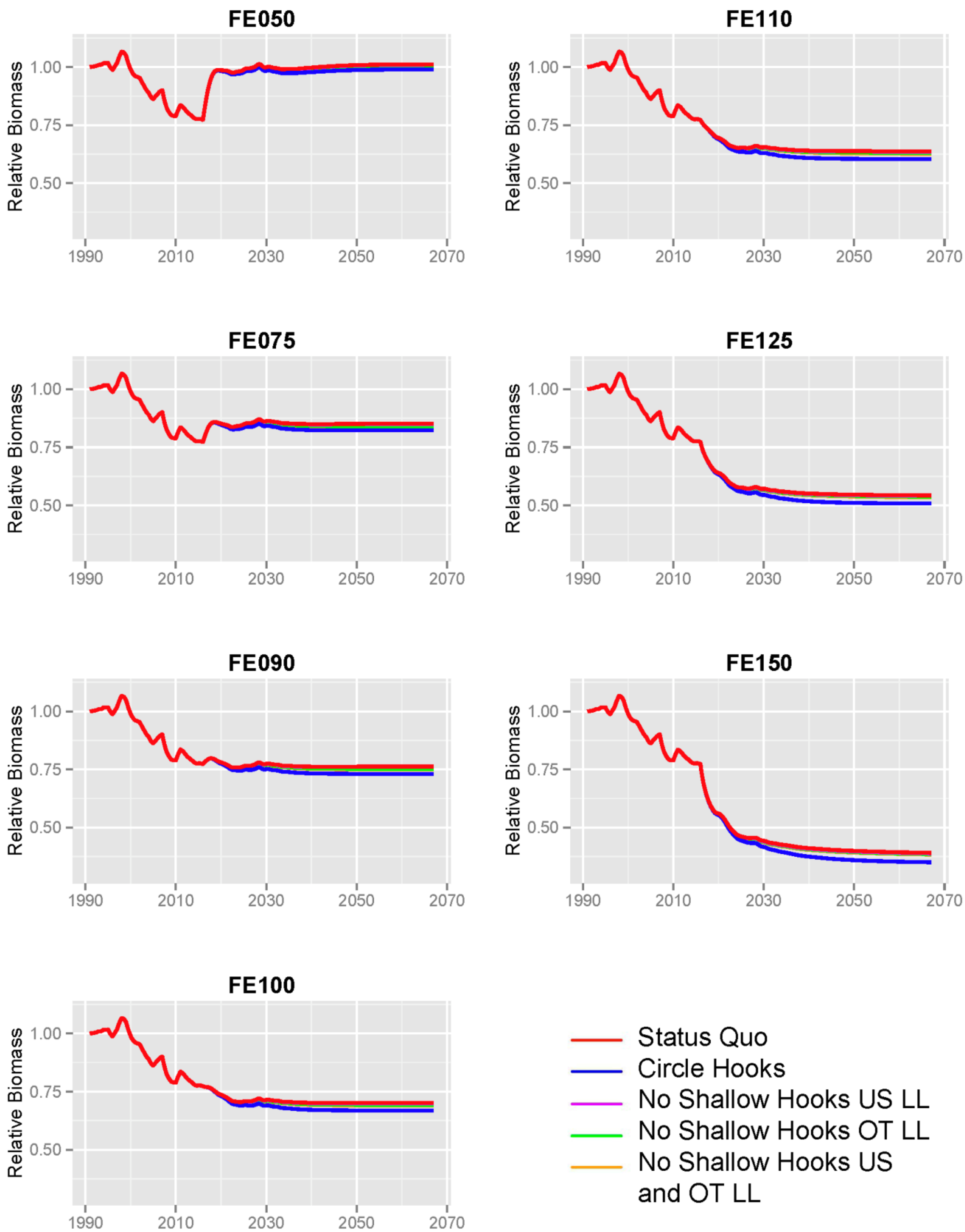
Appendix B2.10. Relative biomasses for albacore tuna under various fishing effort and gear modification scenarios



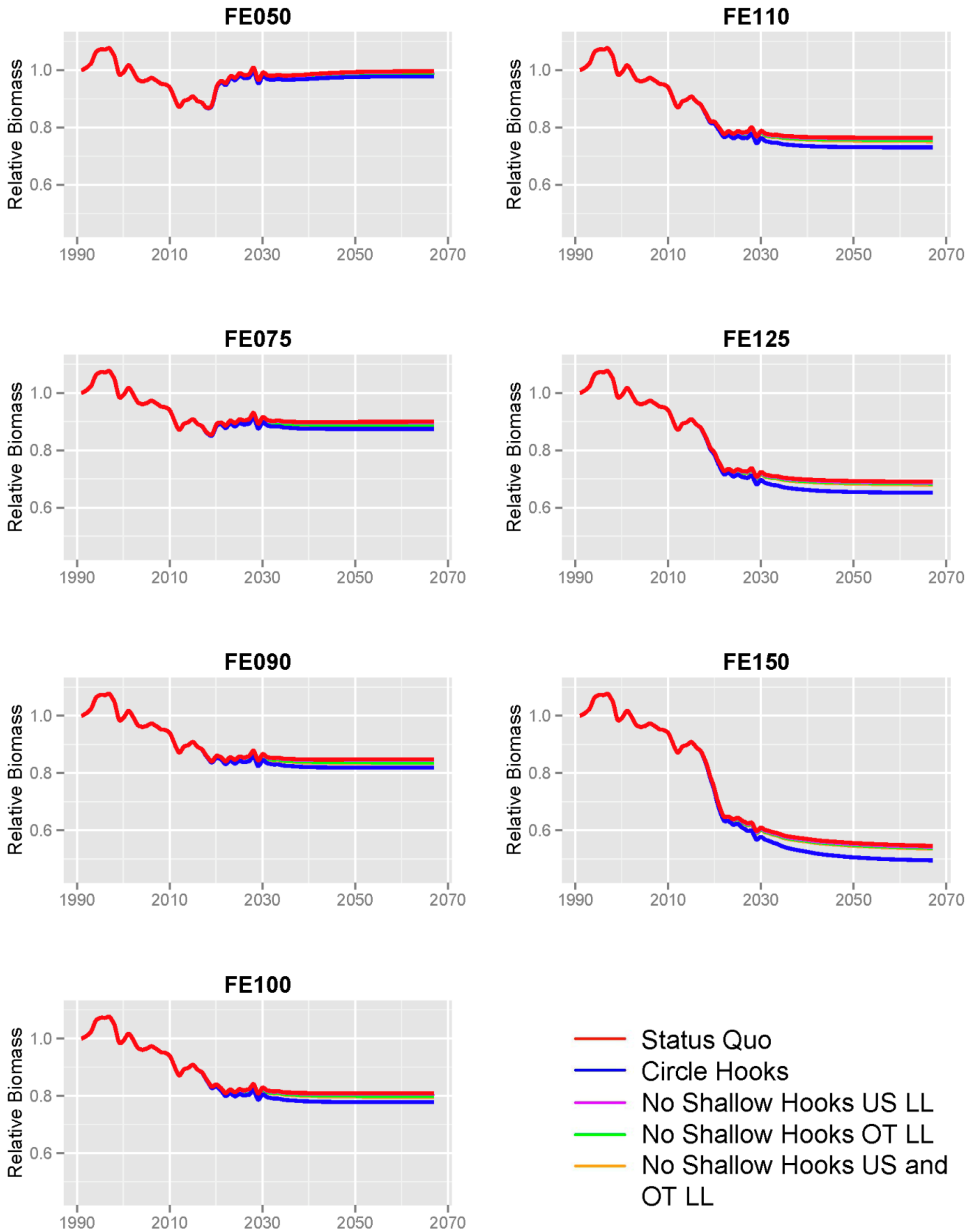
Appendix B2.11. Relative biomasses for juvenile albacore tuna under various fishing effort and gear modification scenarios



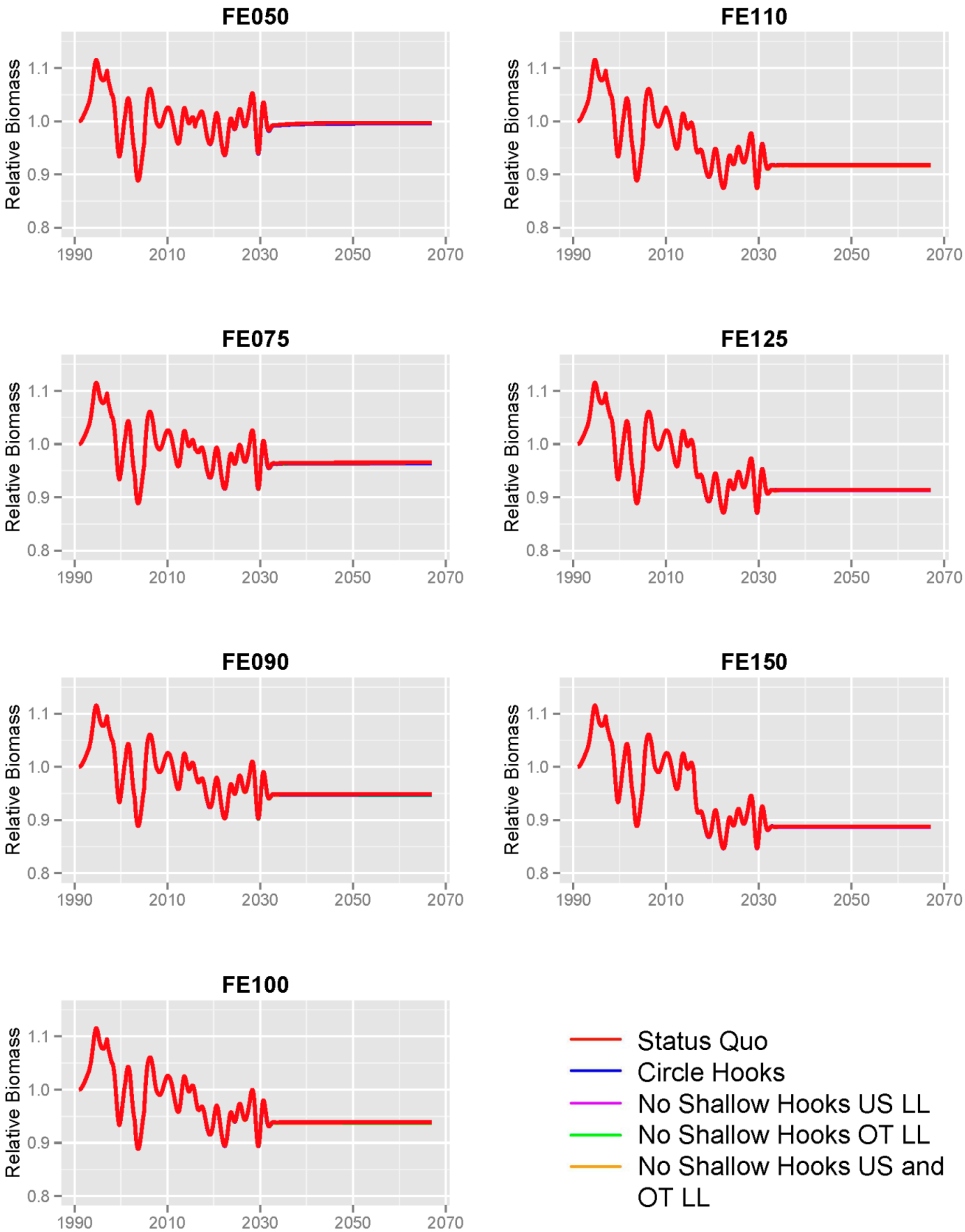
Appendix B2.12. Relative biomasses for bigeye tuna under various fishing effort and gear modification scenarios



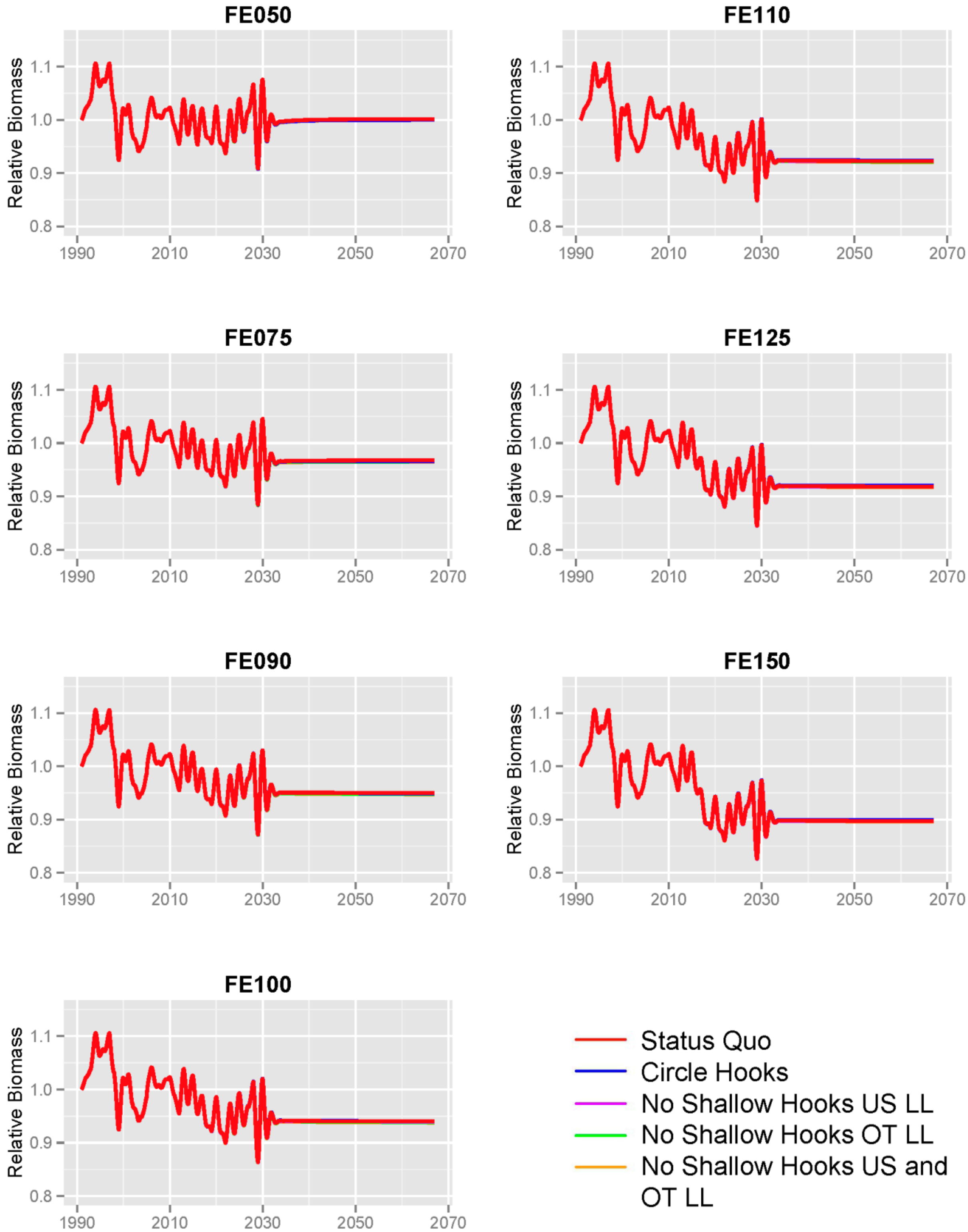
Appendix B2.13. Relative biomasses for juvenile bigeye tuna under various fishing effort and gear modification scenarios



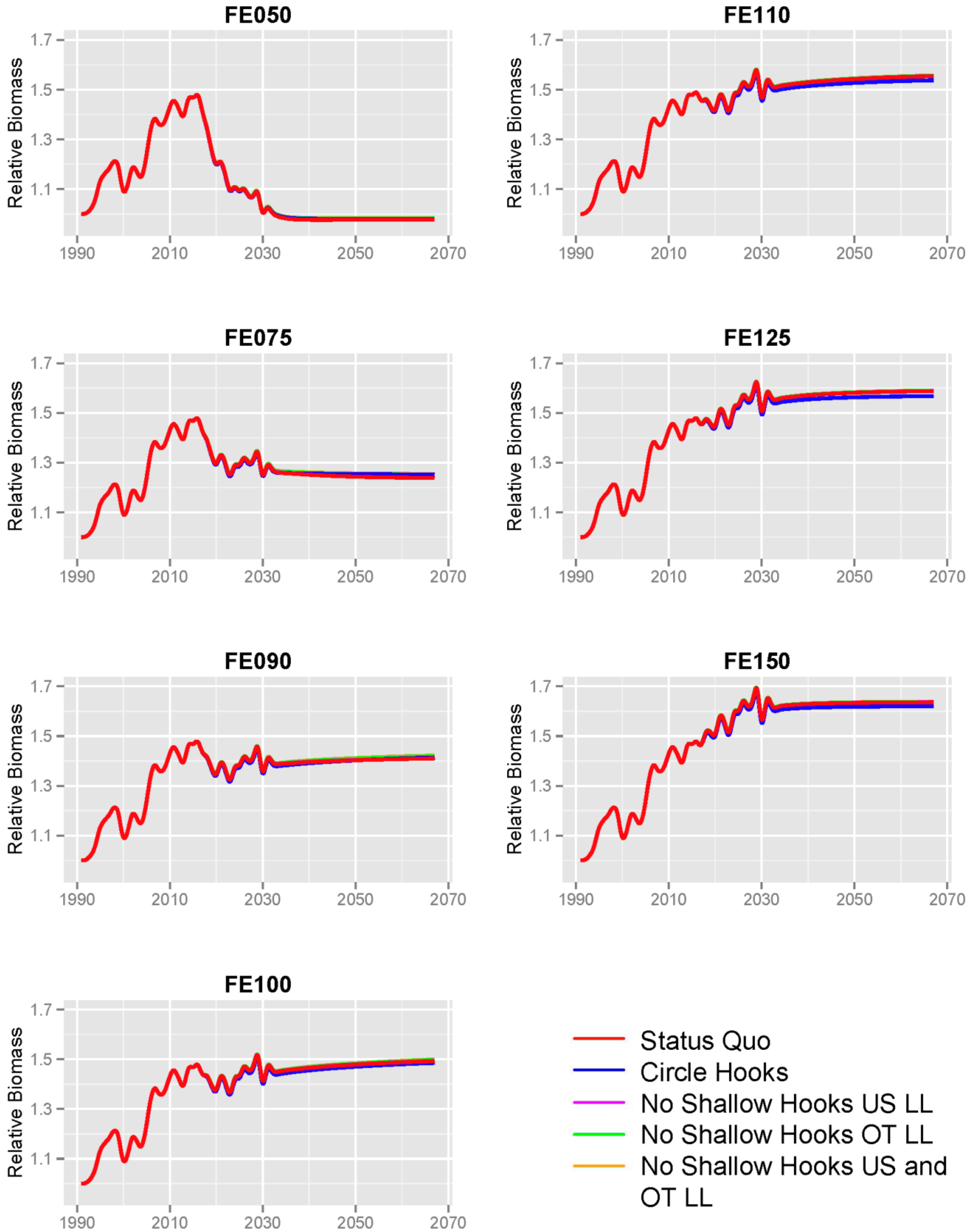
Appendix B2.14. Relative biomasses for skipjack tuna under various fishing effort and gear modification scenarios



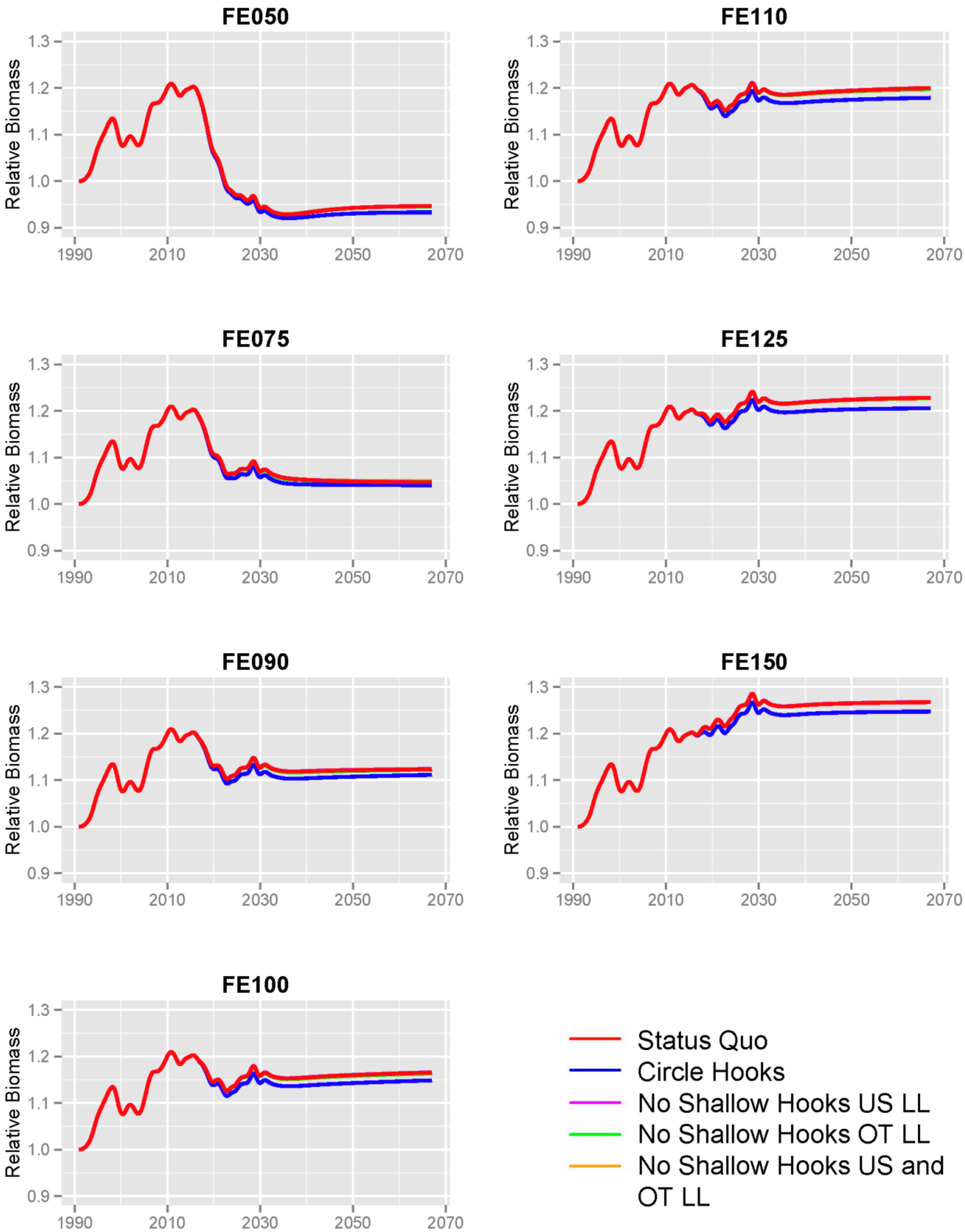
Appendix B2.15. Relative biomasses for juvenile skipjack under various fishing effort and gear modification scenarios



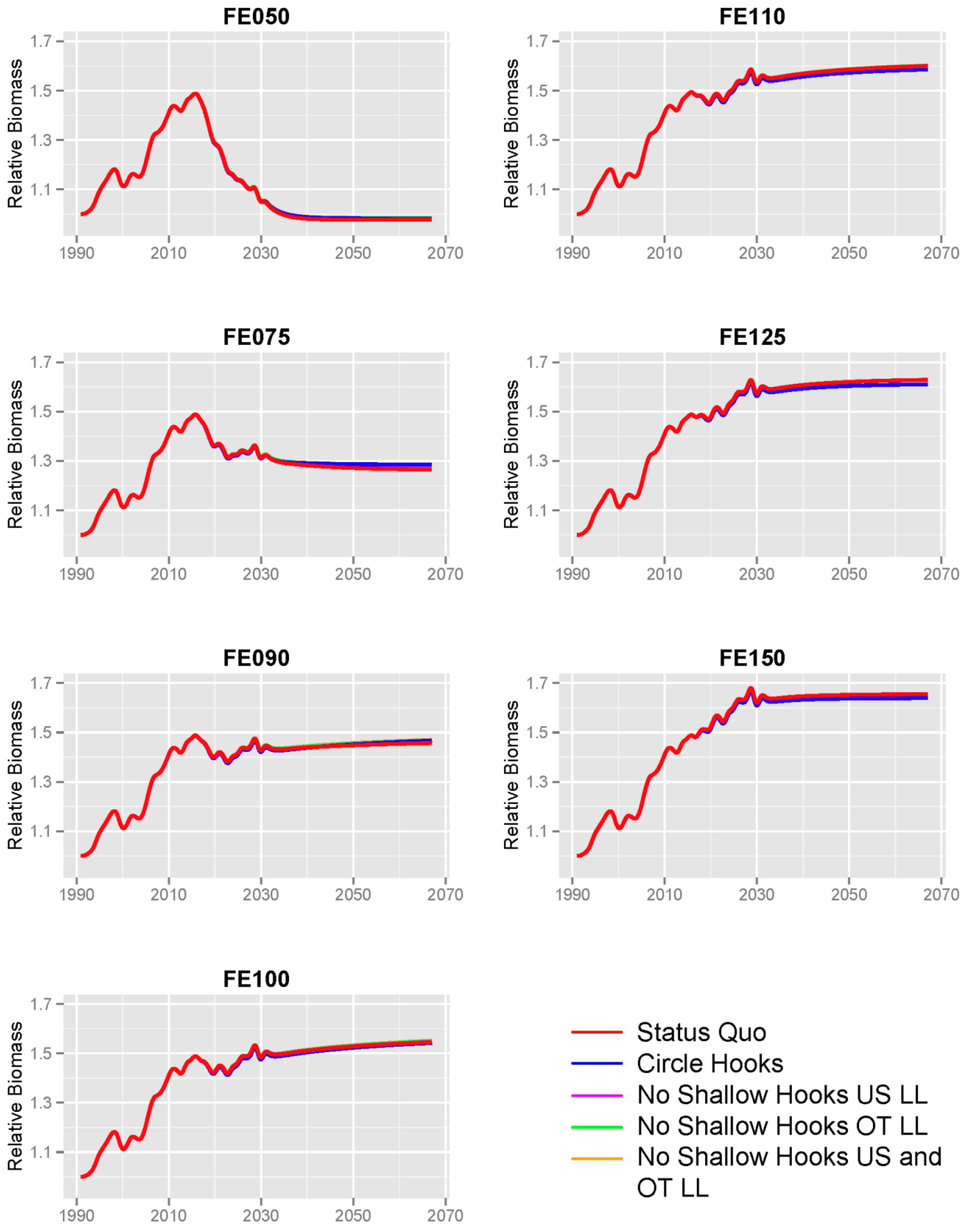
Appendix B2.16. Relative biomasses for mahi mahi under various fishing effort and gear modification scenarios



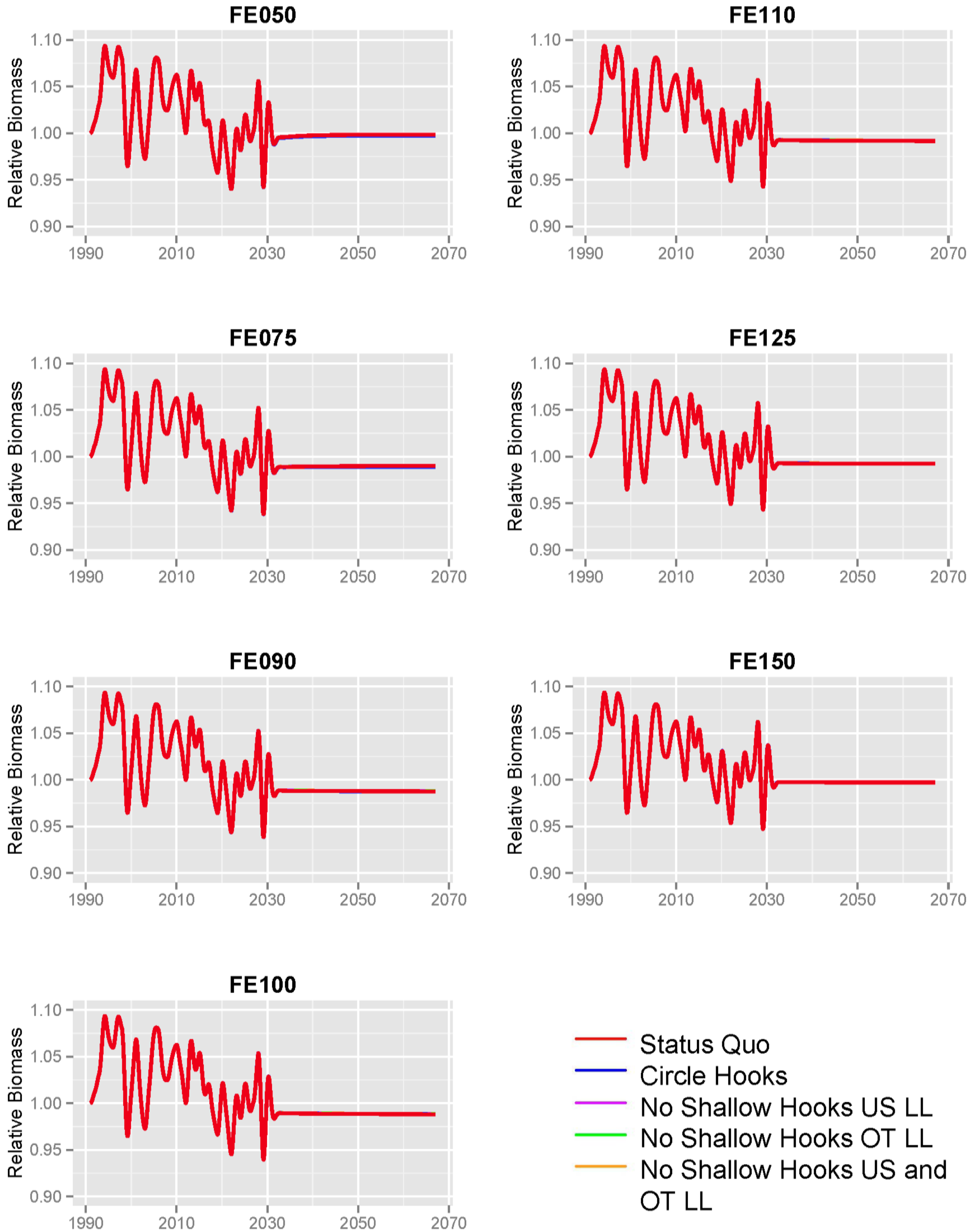
Appendix B2.17. Relative biomasses for lancetfish under various fishing effort and gear modification scenarios



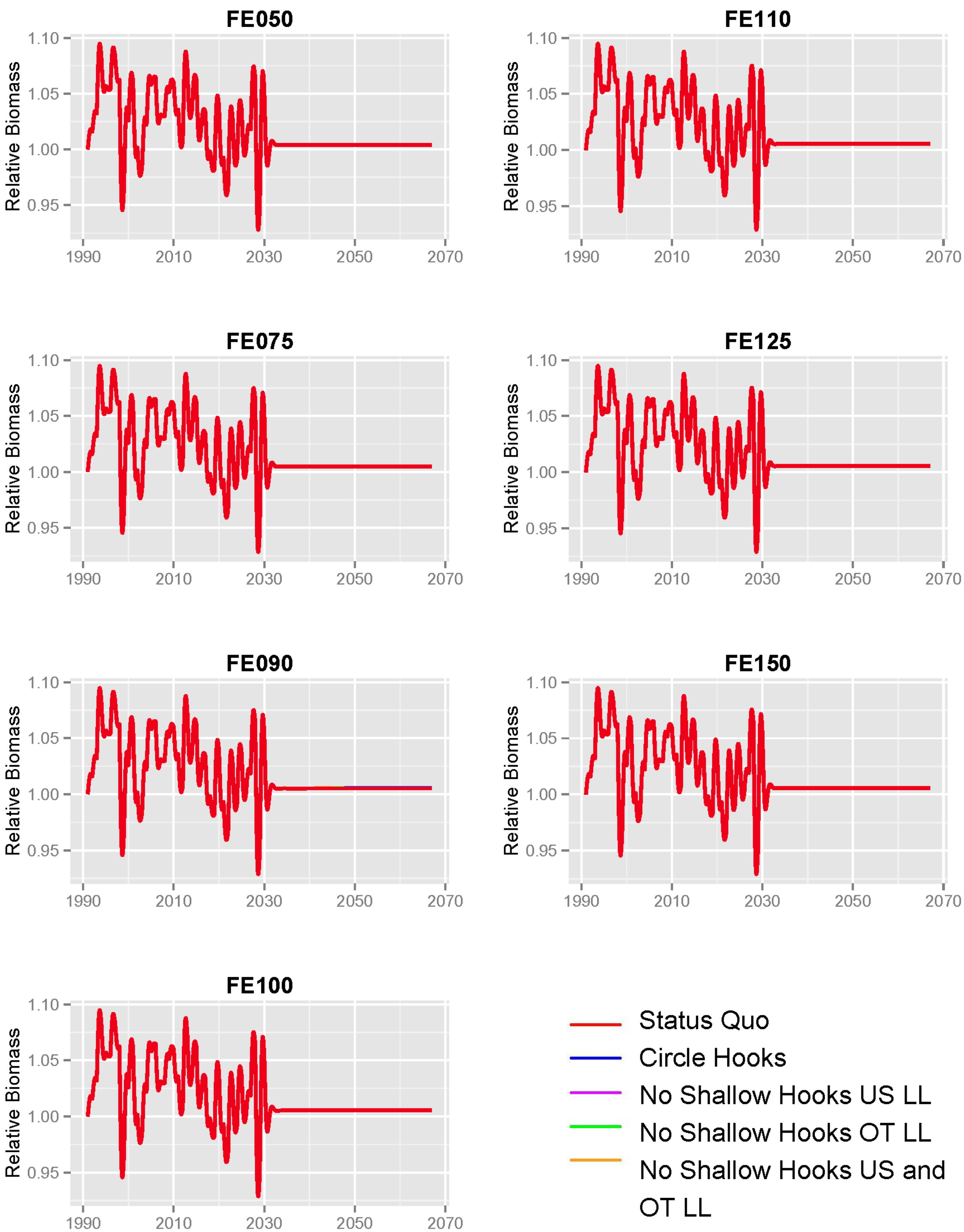
Appendix B2.18. Relative biomasses for mid-level trophic fish under various fishing effort and gear modification scenarios



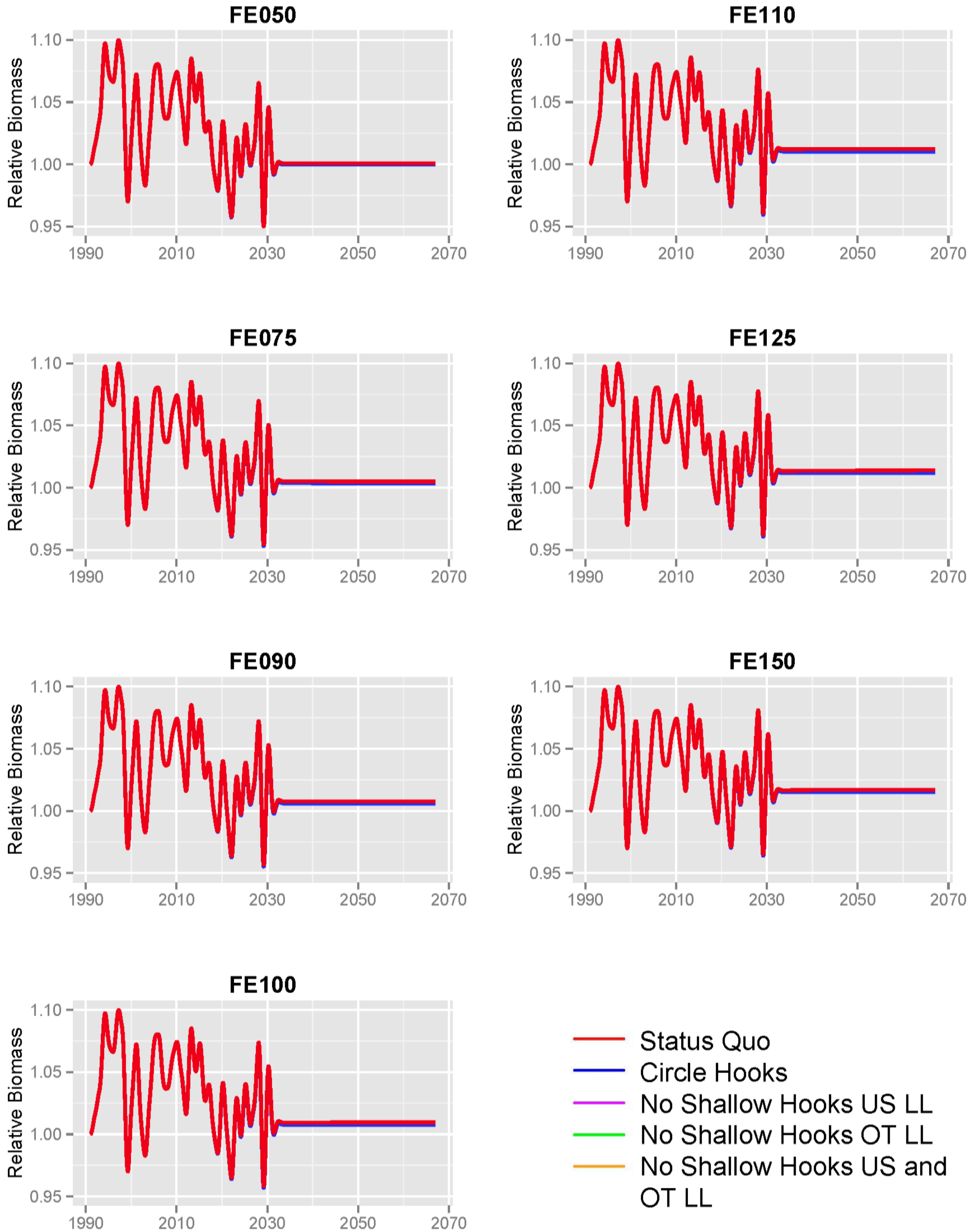
Appendix B2.19. Relative biomasses for epipelagic fishes under various fishing effort and gear modification scenarios



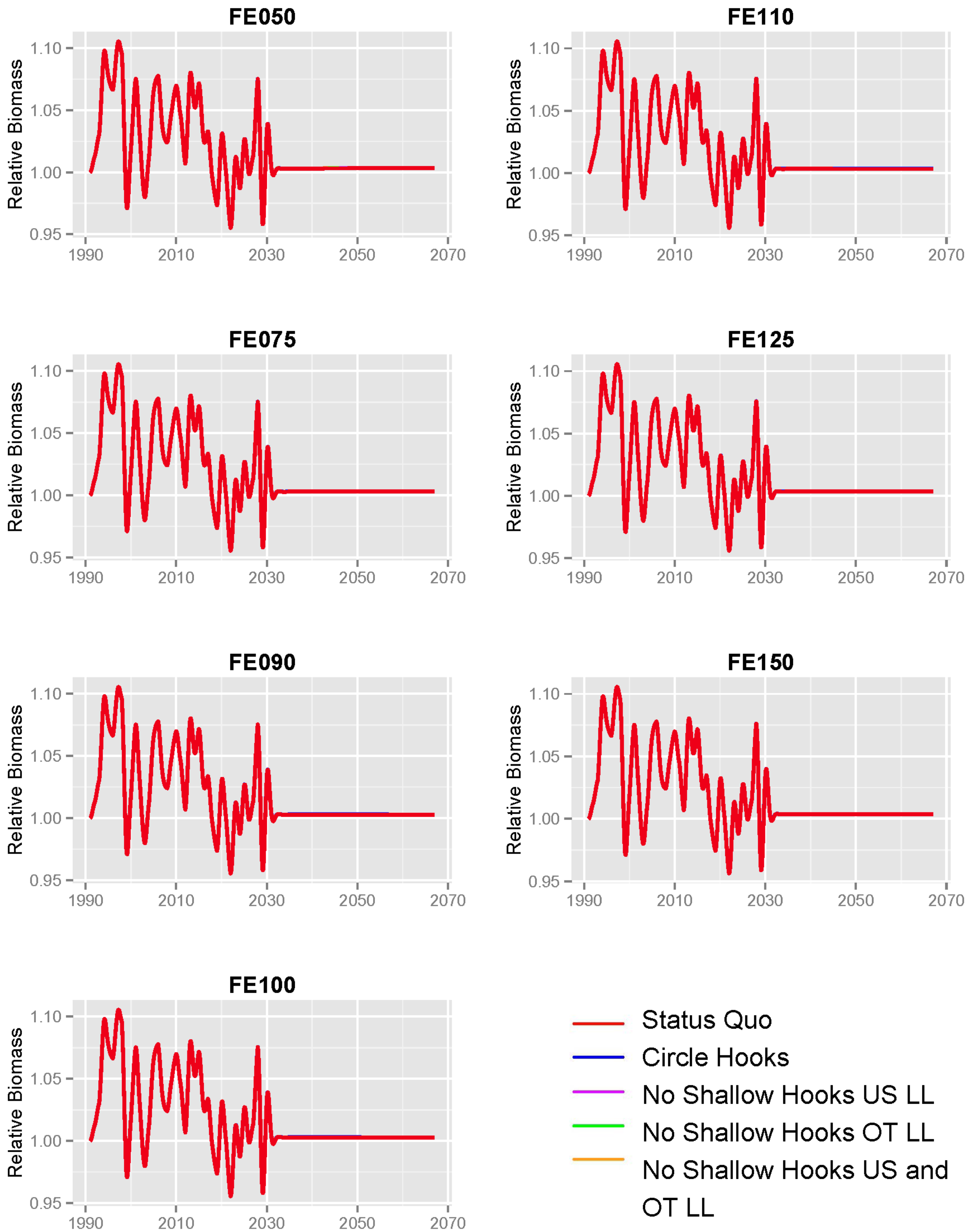
Appendix B2.20. Relative biomasses for invertebrates under various fishing effort and gear modification scenarios



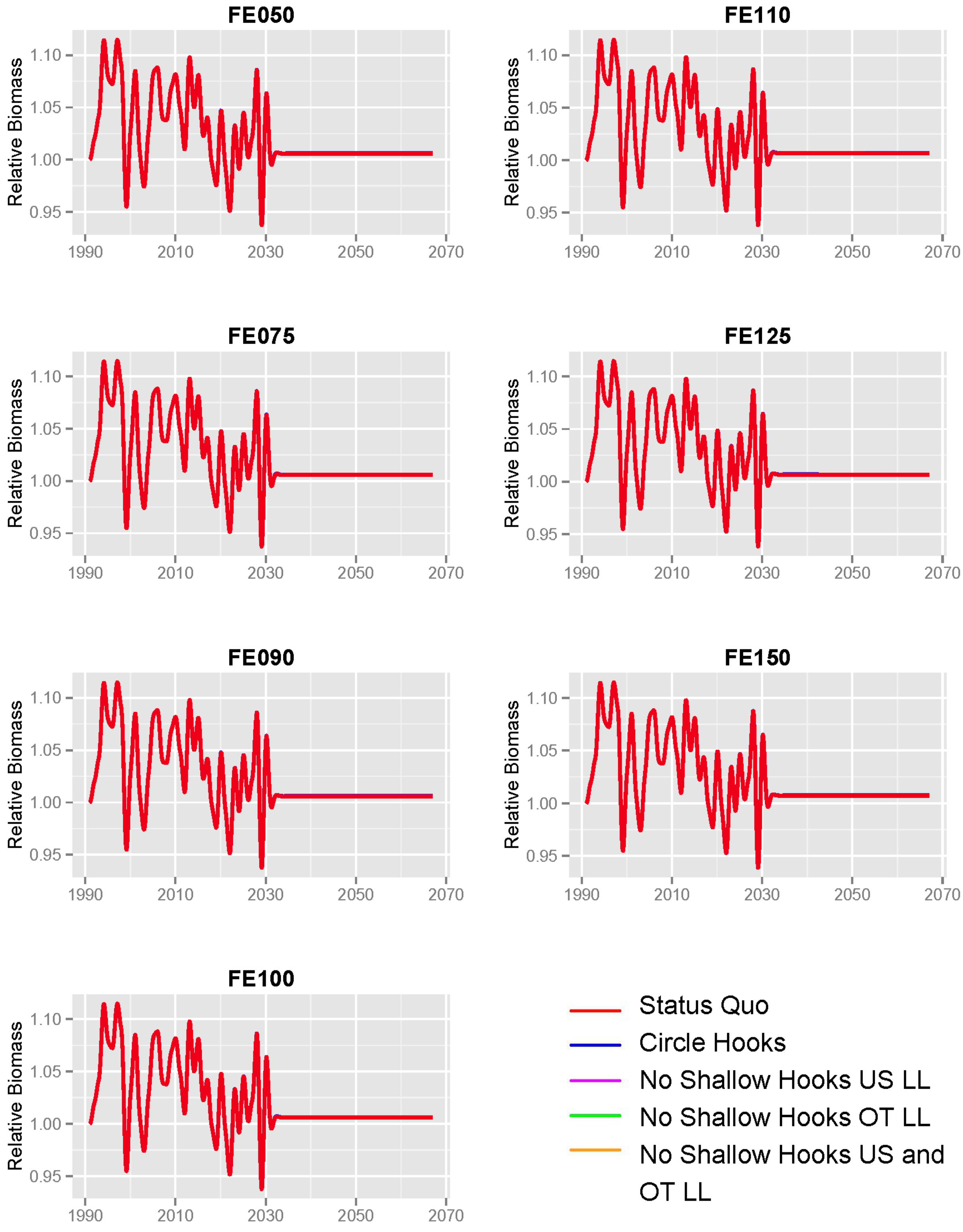
Appendix B2.21. Relative biomasses for epipelagic molluscs under various fishing effort and gear modification scenarios



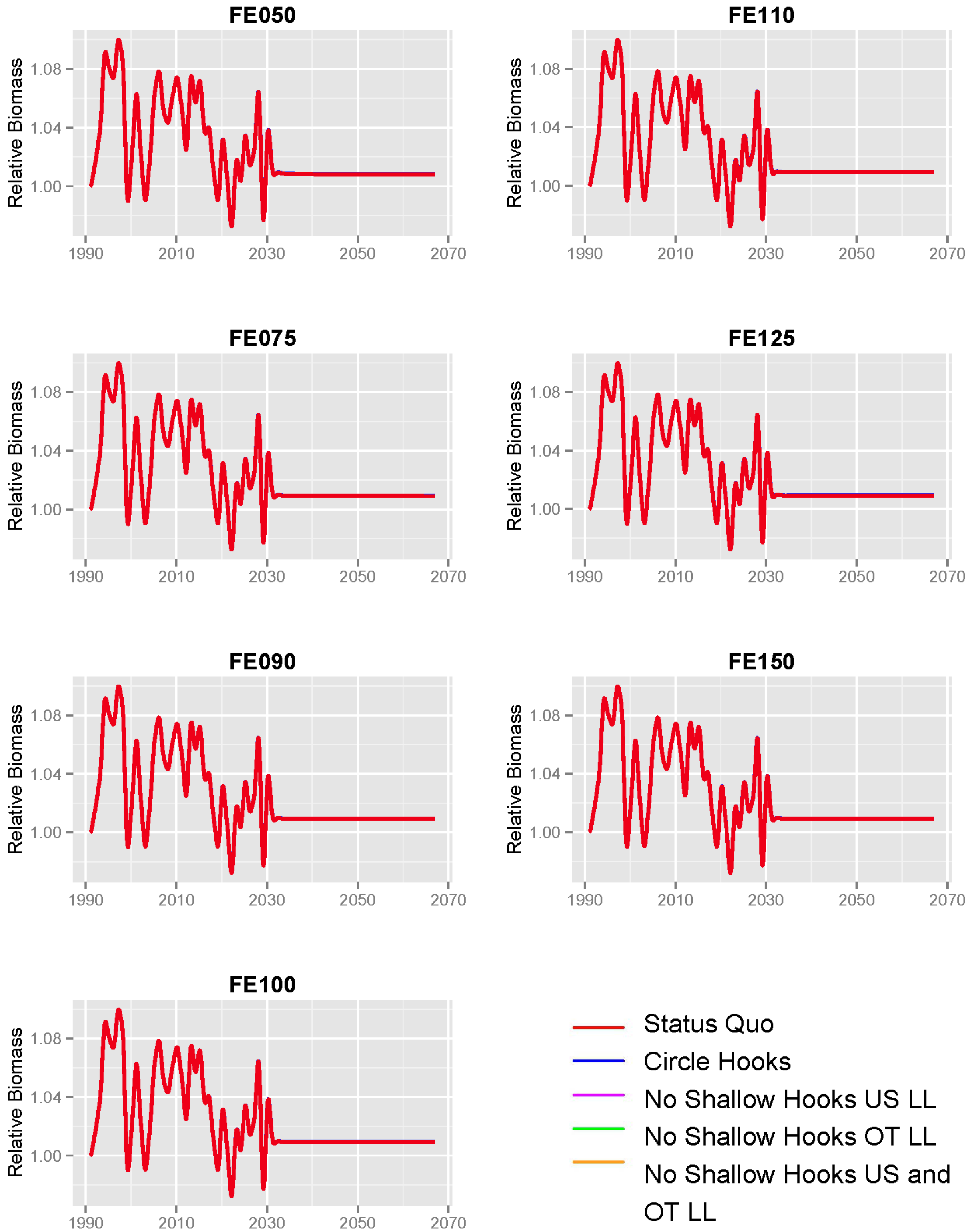
Appendix B2.22. Relative biomasses for mesopelagic fishes under various fishing effort and gear modification scenarios



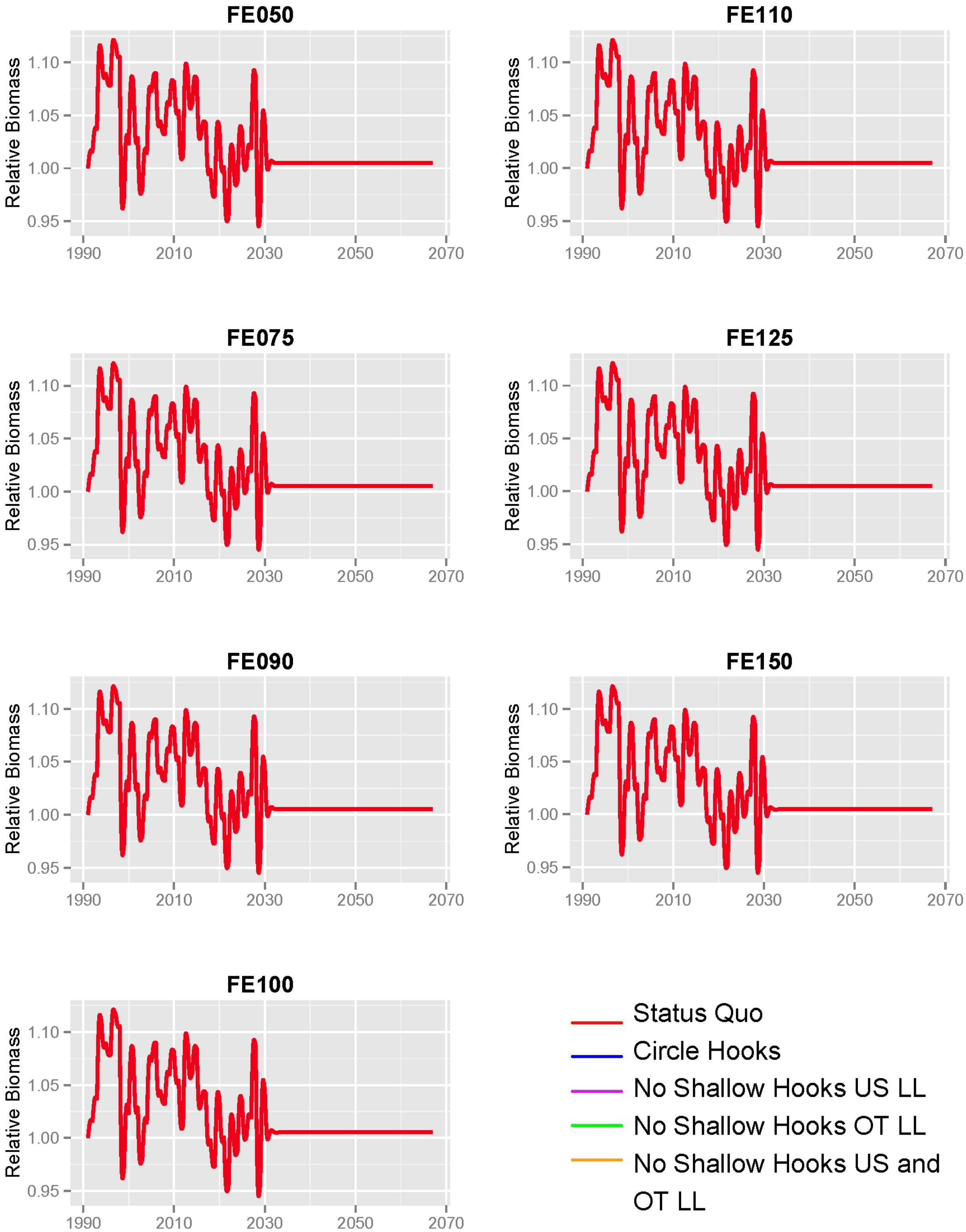
Appendix B2.23. Relative biomasses for mesopelagic molluscs under various fishing effort and gear modification scenarios



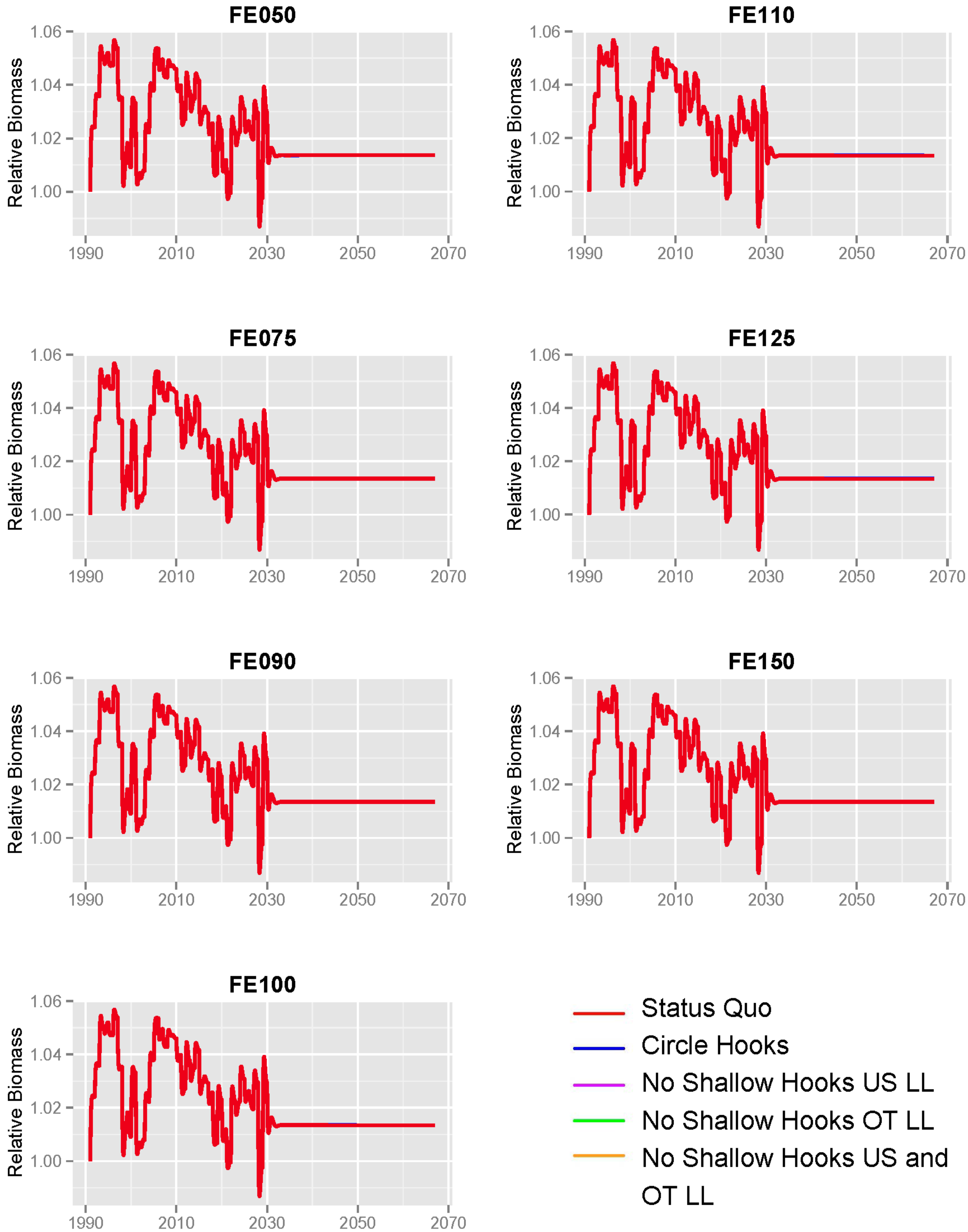
Appendix B2.24. Relative biomasses for bathymetric forage fishes under various fishing effort and gear modification scenarios



Appendix B2.25. Relative biomasses for mesozooplankton under various fishing effort and gear modification scenarios

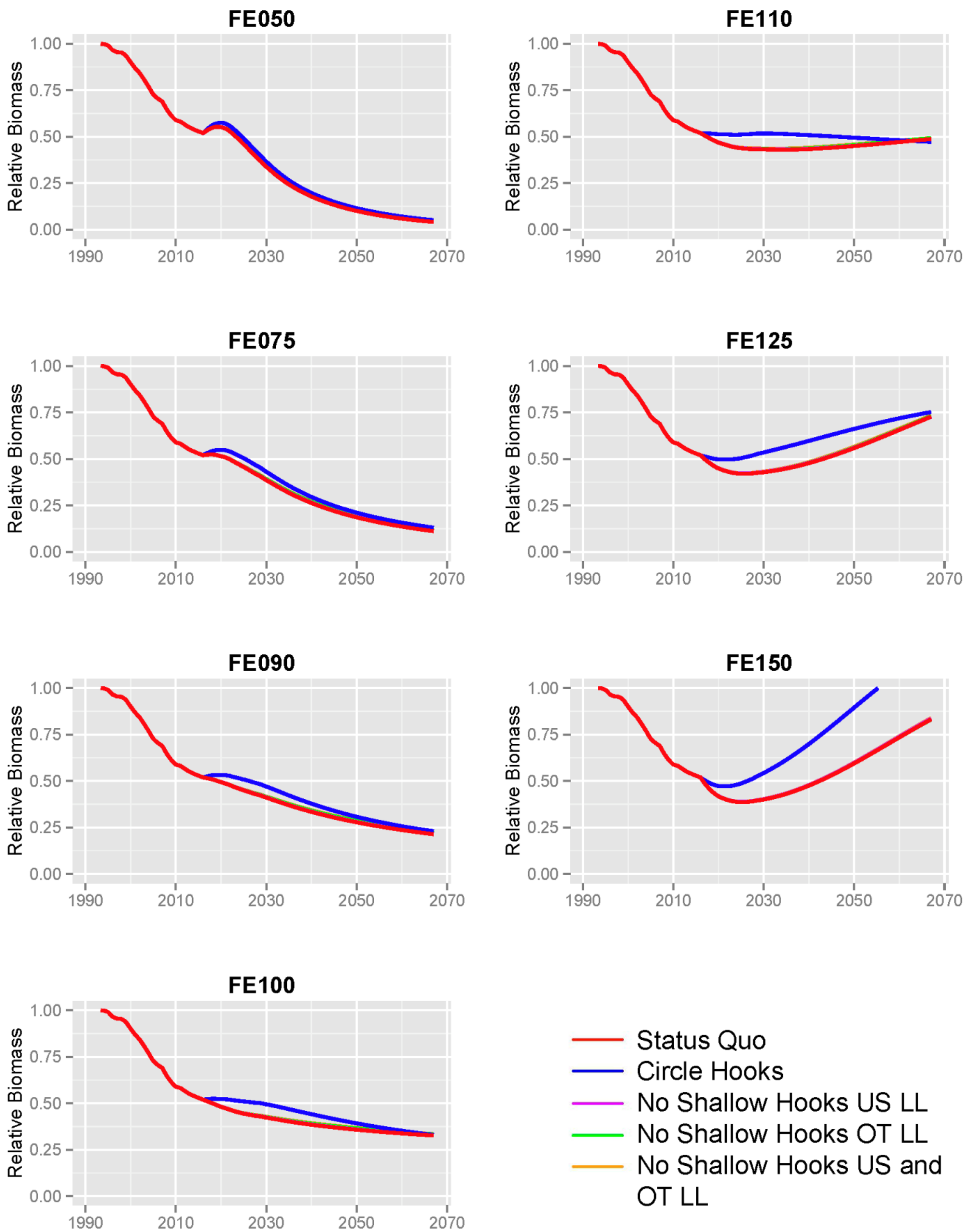


Appendix B2.26. Relative biomasses for microzooplankton under various fishing effort and gear modification scenarios

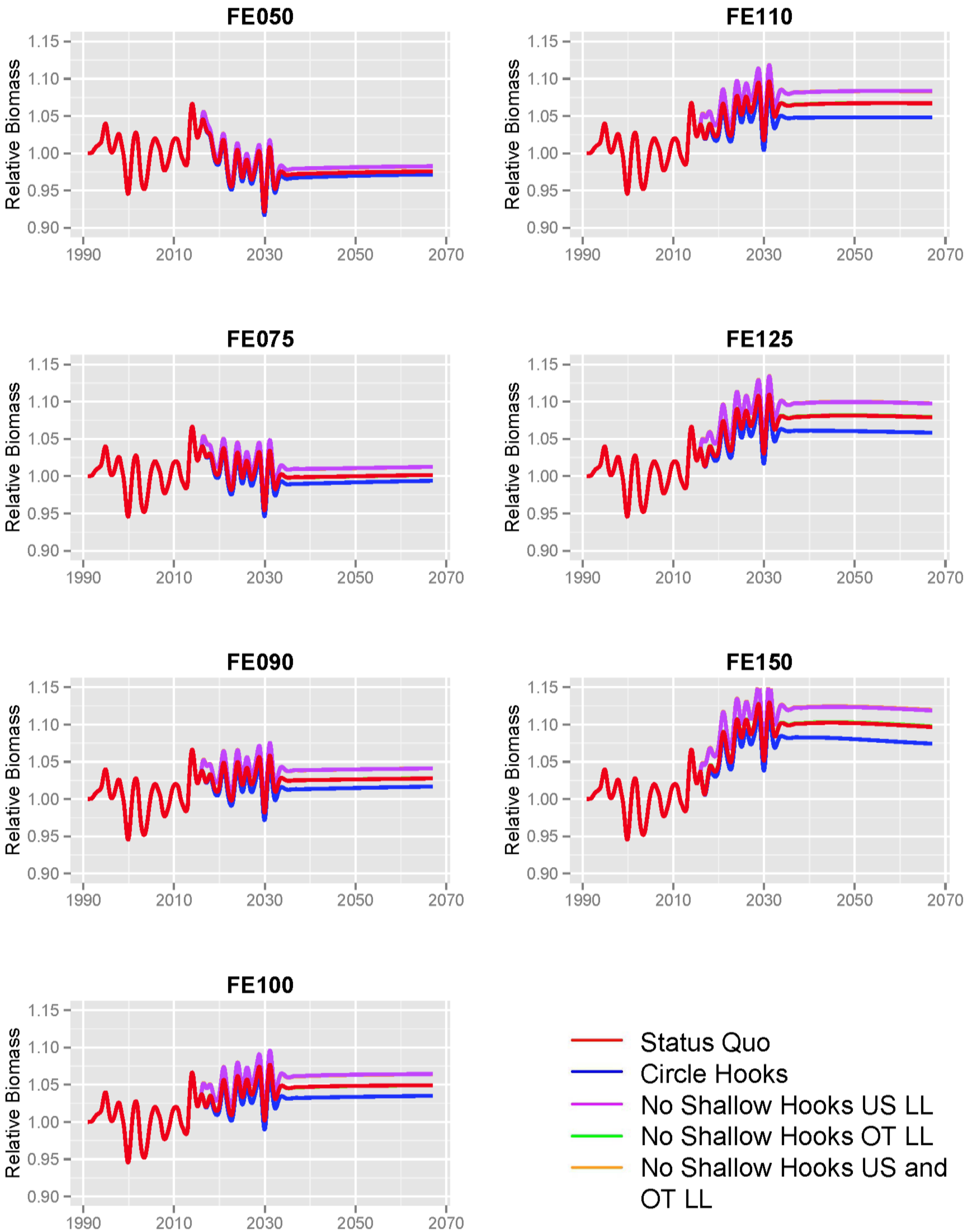


Appendix C. Relative biomasses for other functional groups under various fishing effort and gear modification scenarios

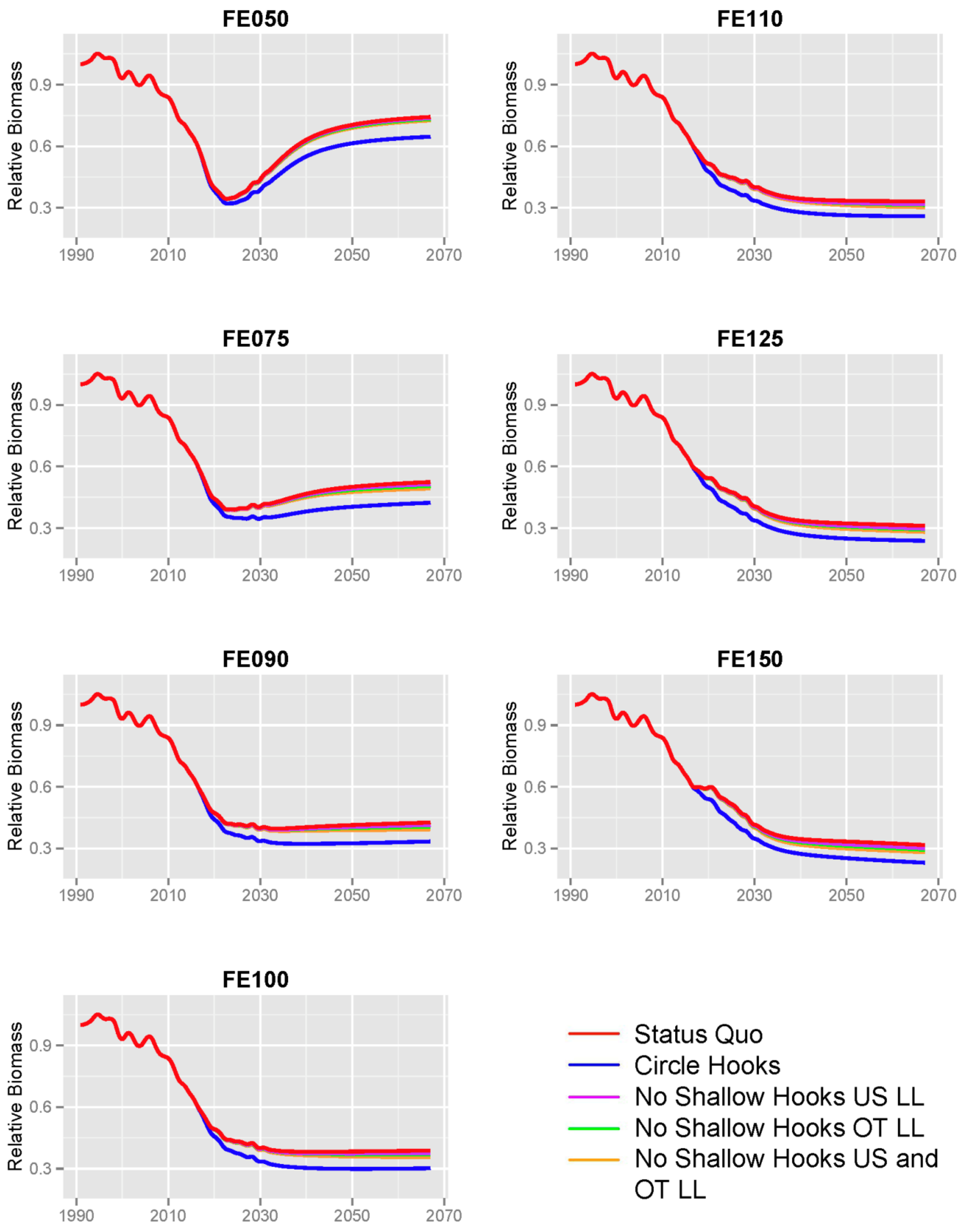
Appendix C1. Relative biomasses for other sharks under various fishing effort and gear modification scenarios



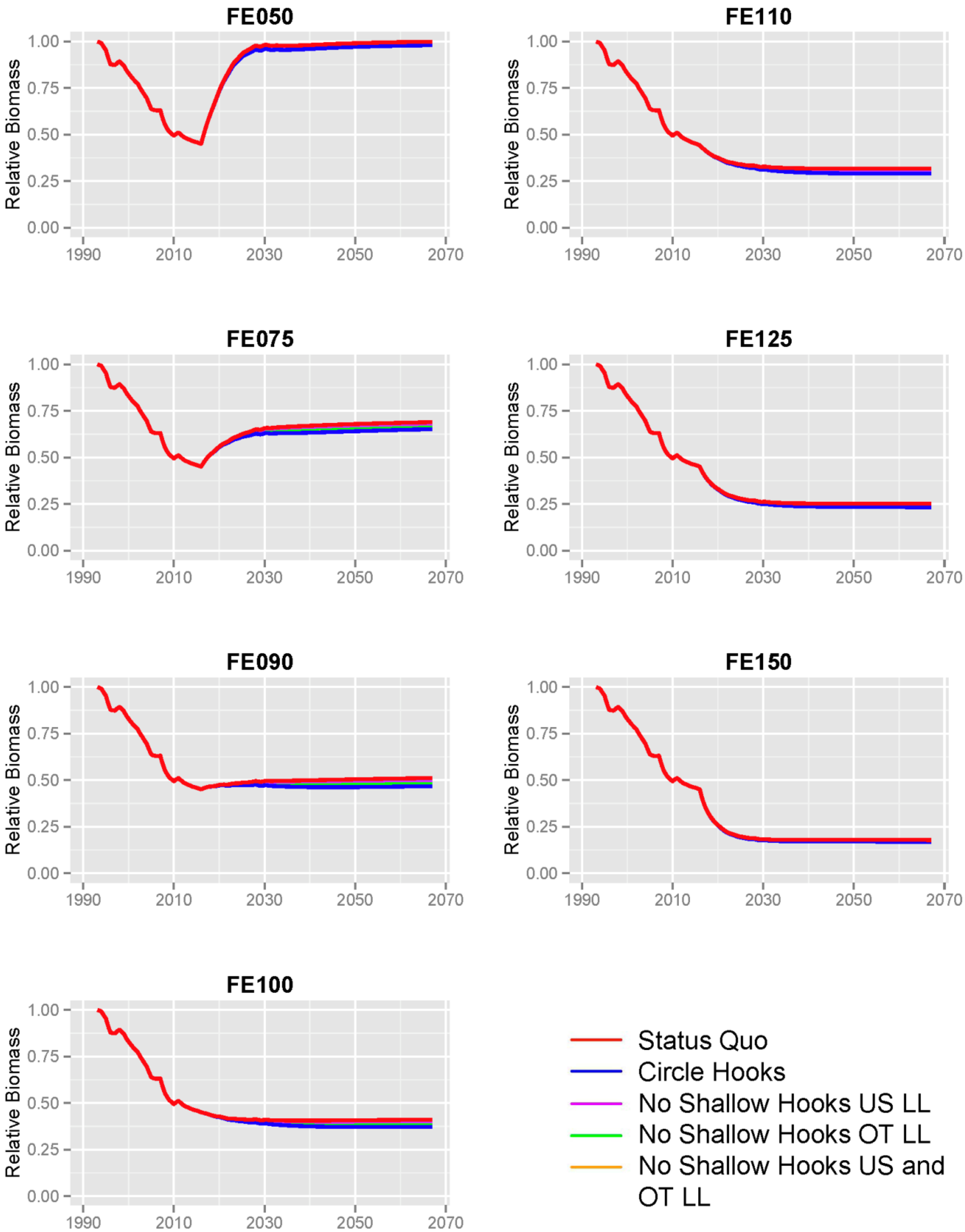
Appendix C2. Relative biomasses for other billfish under various fishing effort and gear modification scenarios



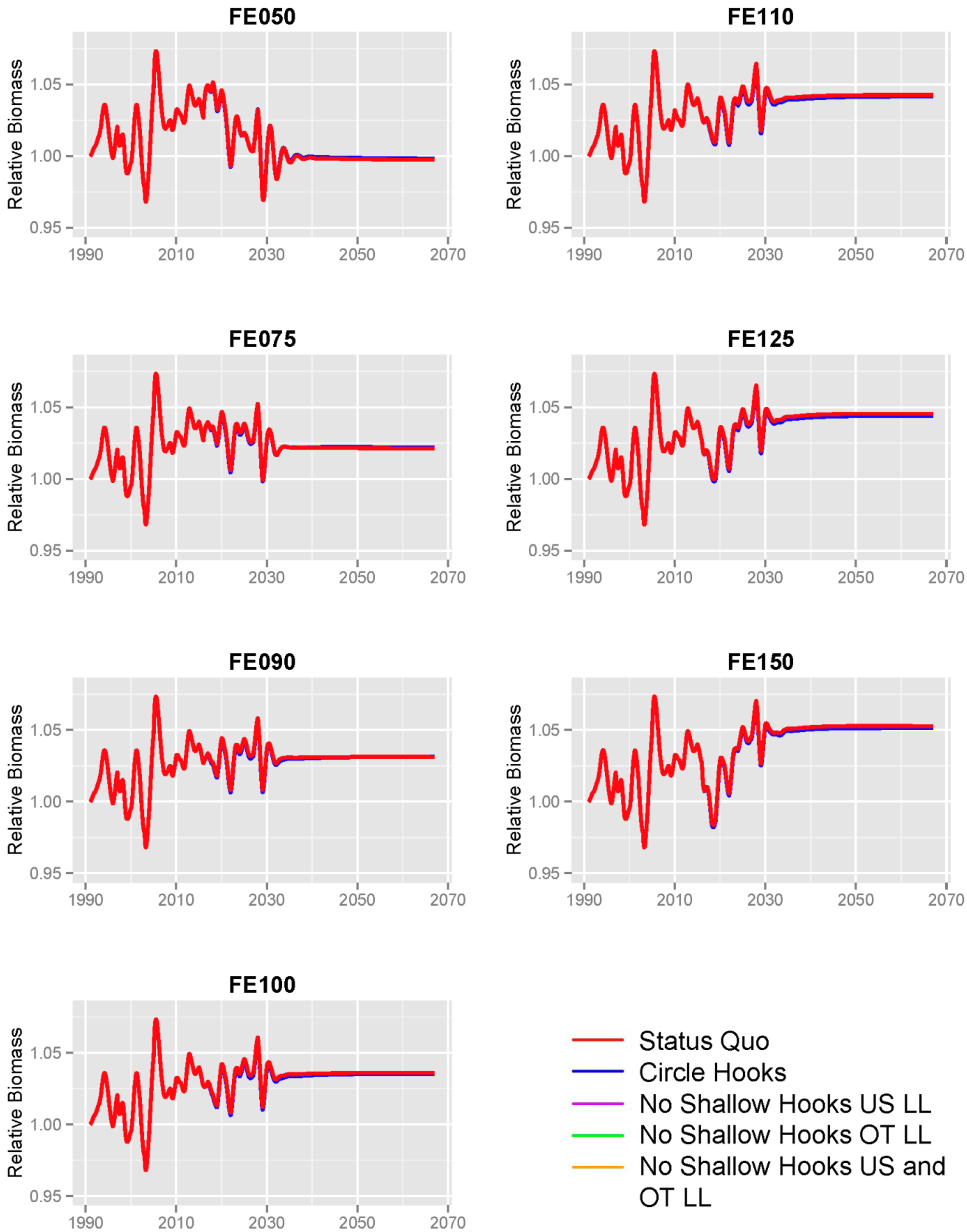
Appendix C3. Relative biomasses for small billfish under various fishing effort and gear modification scenarios



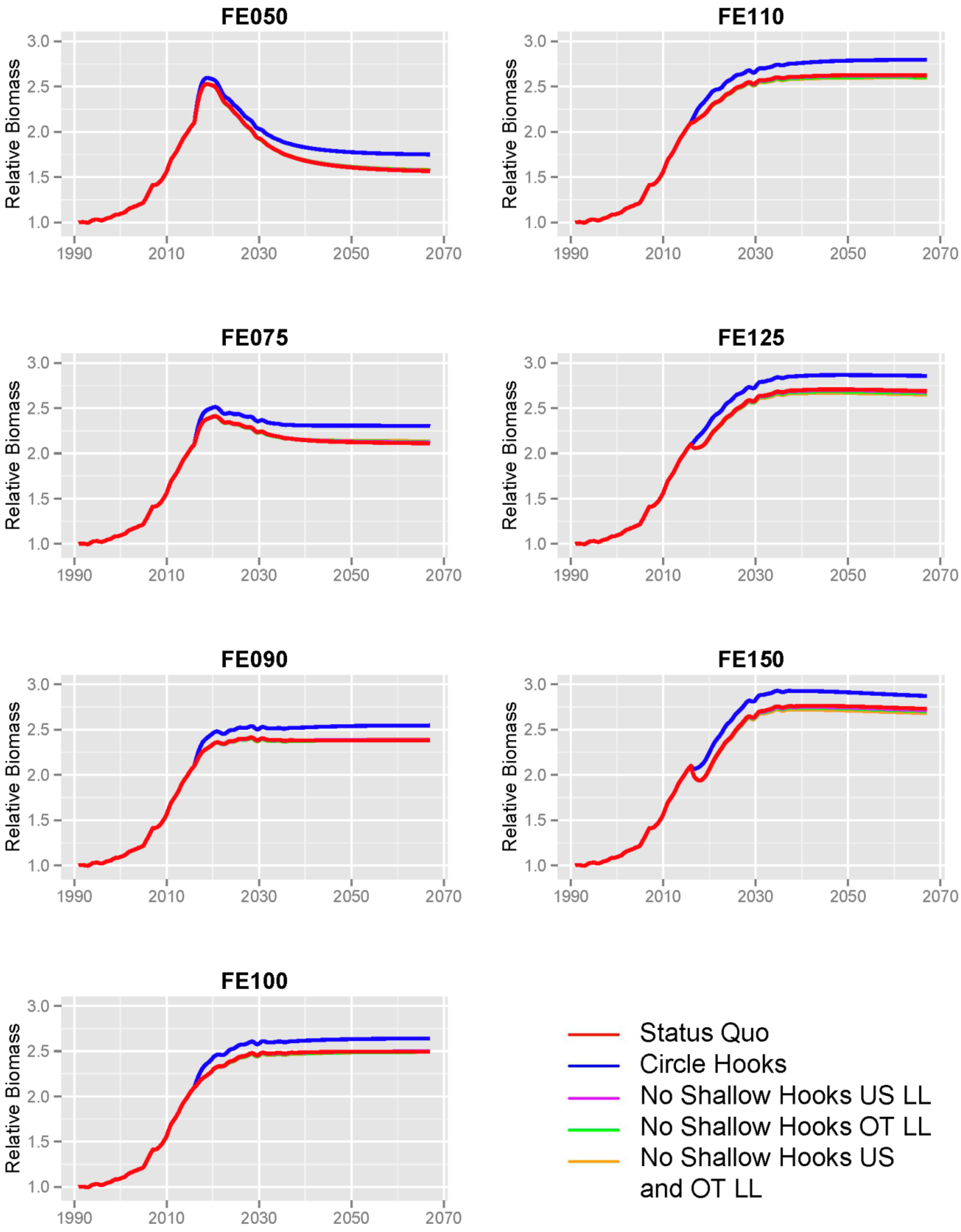
Appendix C4. Relative biomasses for yellowfin tuna under various fishing effort and gear modification scenarios



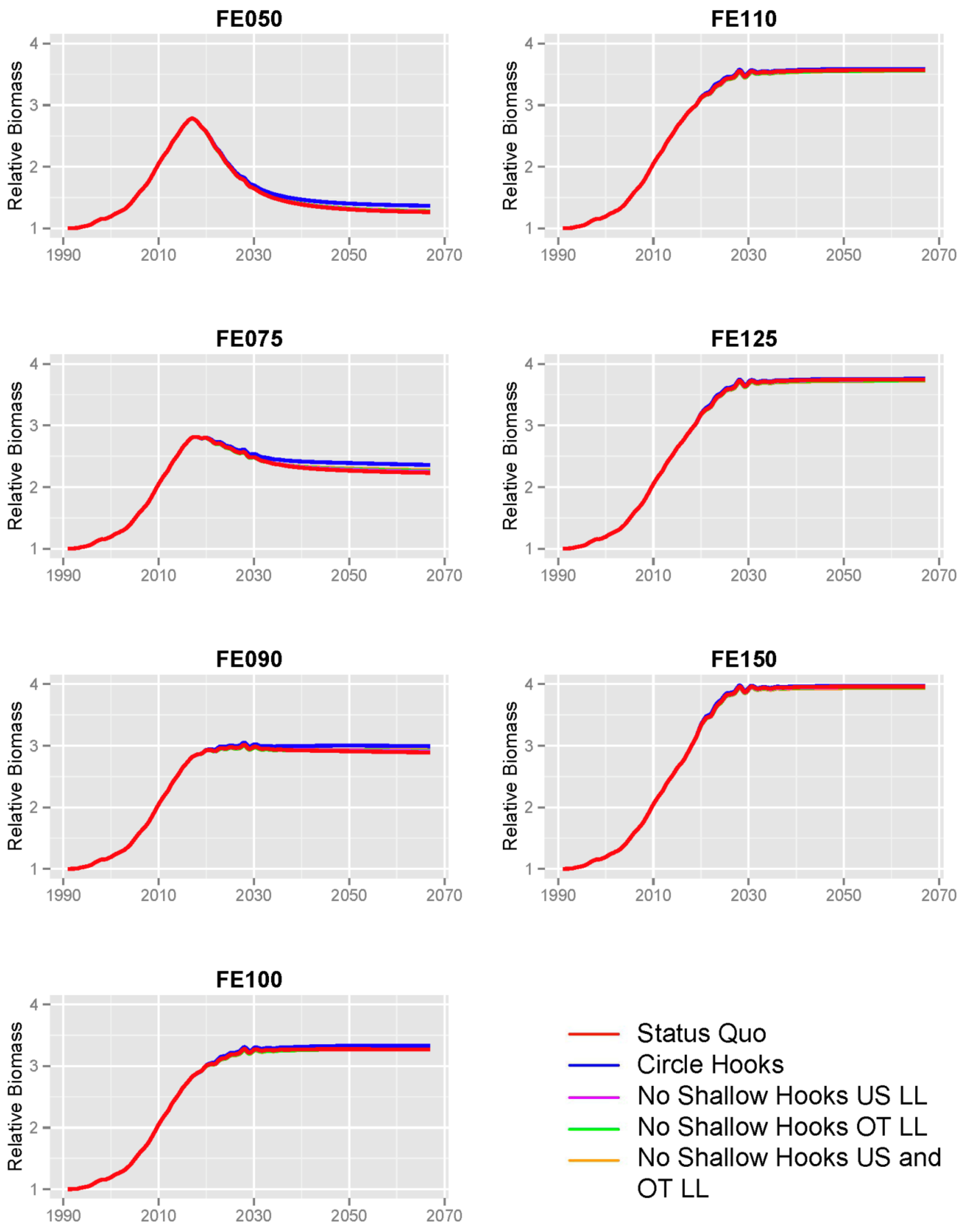
Appendix C5. Relative biomasses for juvenile yellowfin under various fishing effort and gear modification scenarios



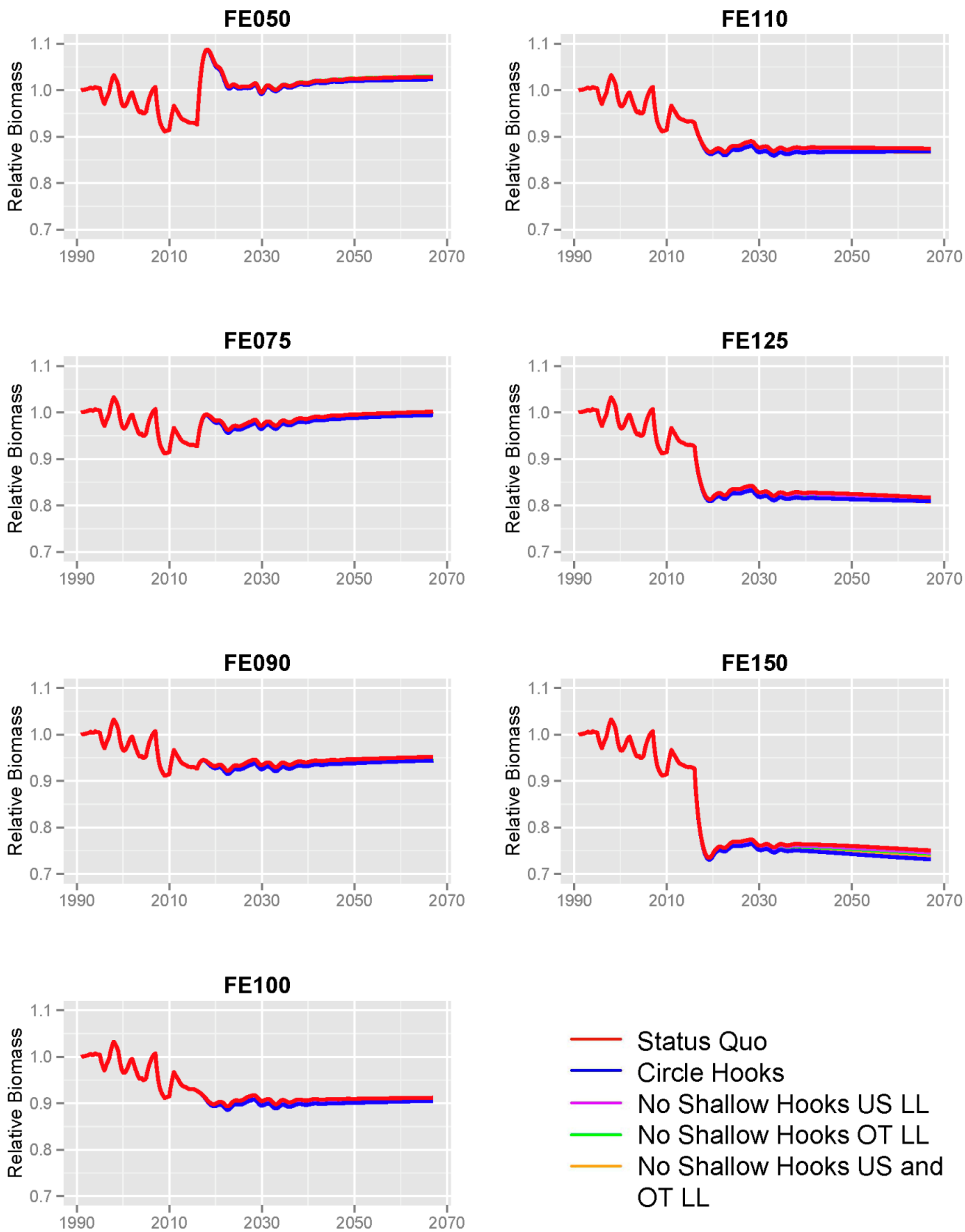
Appendix C6. Relative biomasses for albacore tuna under various fishing effort and gear modification scenarios



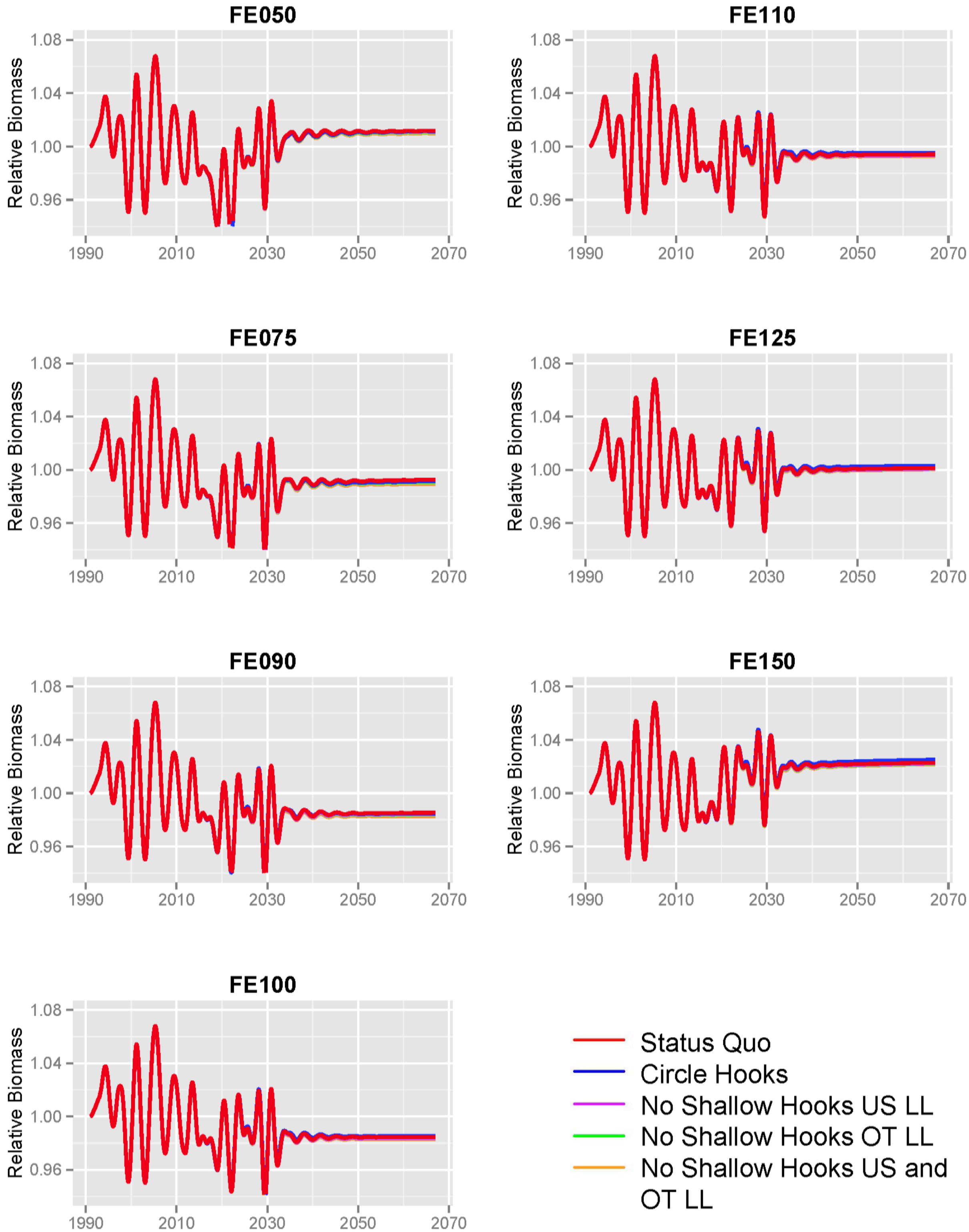
Appendix C7. Relative biomasses for juvenile albacore tuna under various fishing effort and gear modification scenarios



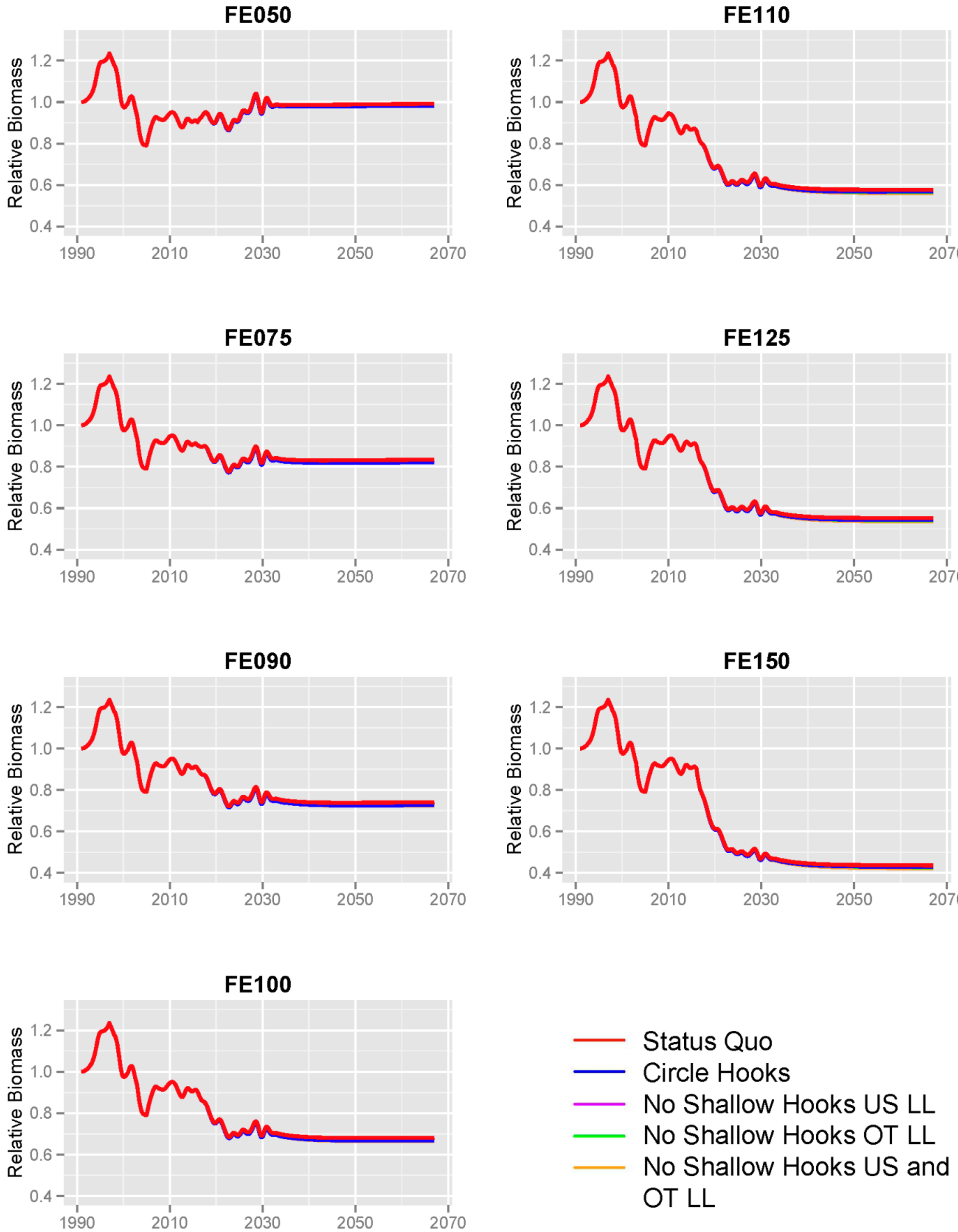
Appendix C8. Relative biomasses for bigeye tuna under various fishing effort and gear modification scenarios



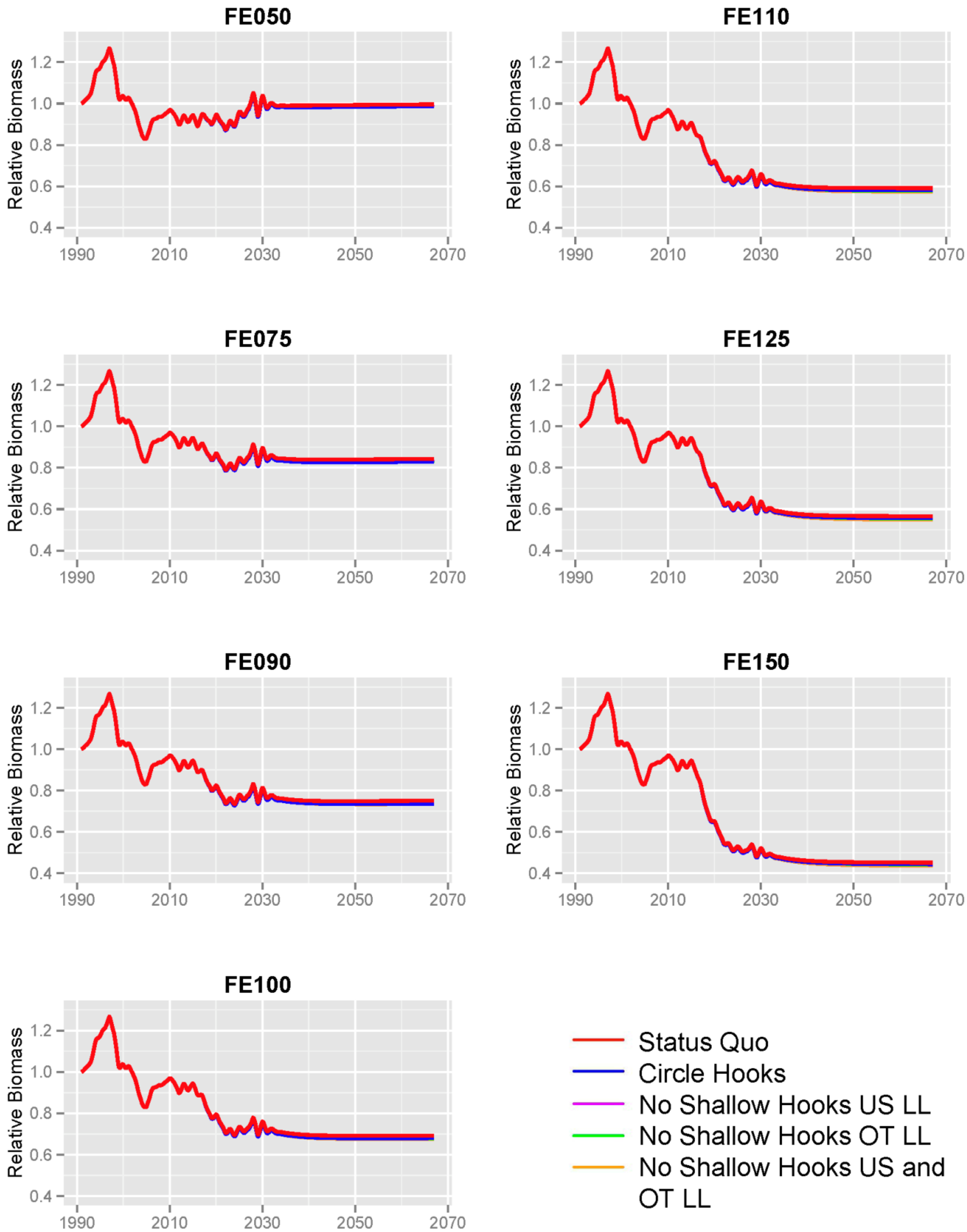
Appendix C9. Relative biomasses for juvenile bigeye tuna under various fishing effort and gear modification scenarios



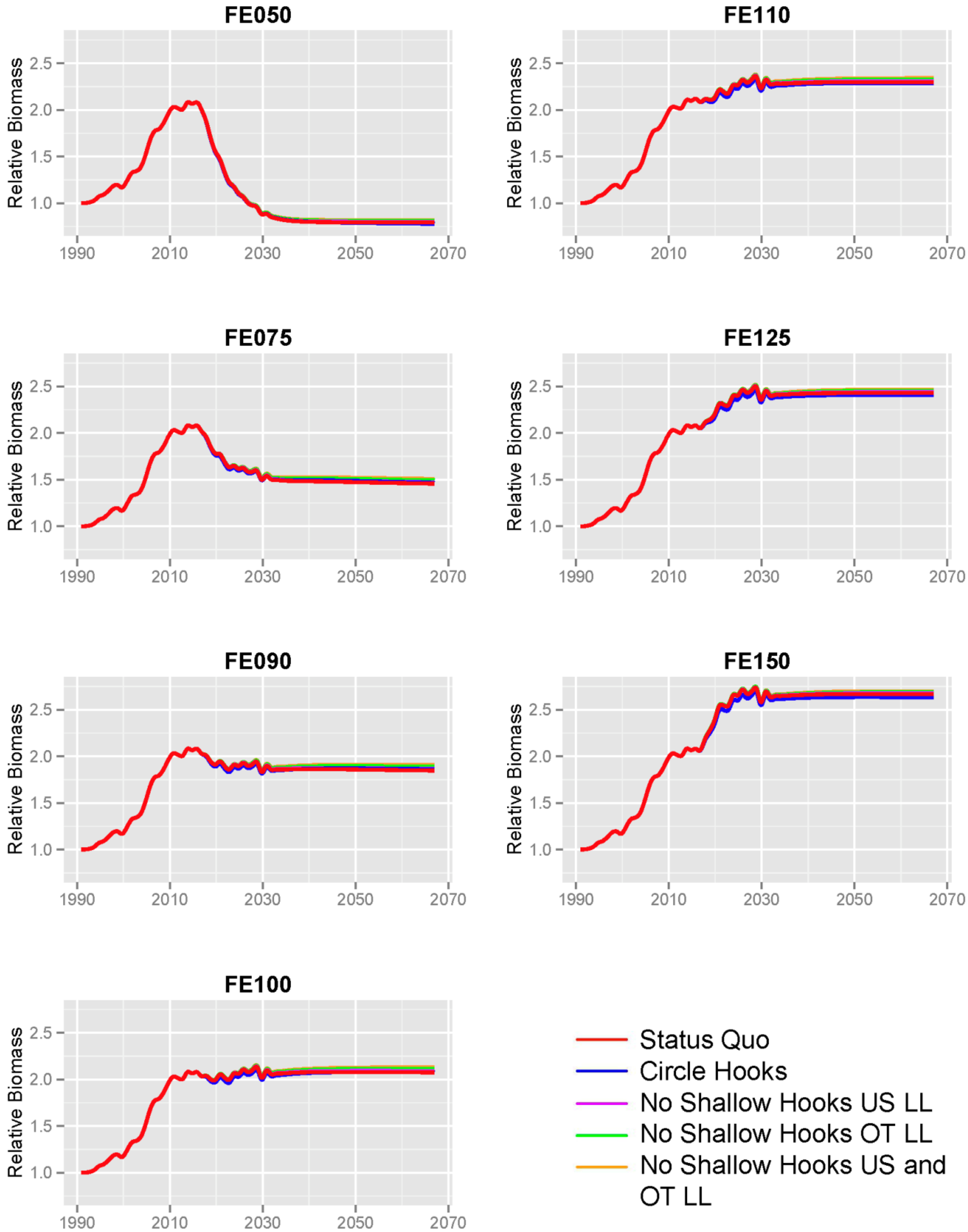
Appendix C10. Relative biomasses for skipjack tuna under various fishing effort and gear modification scenarios



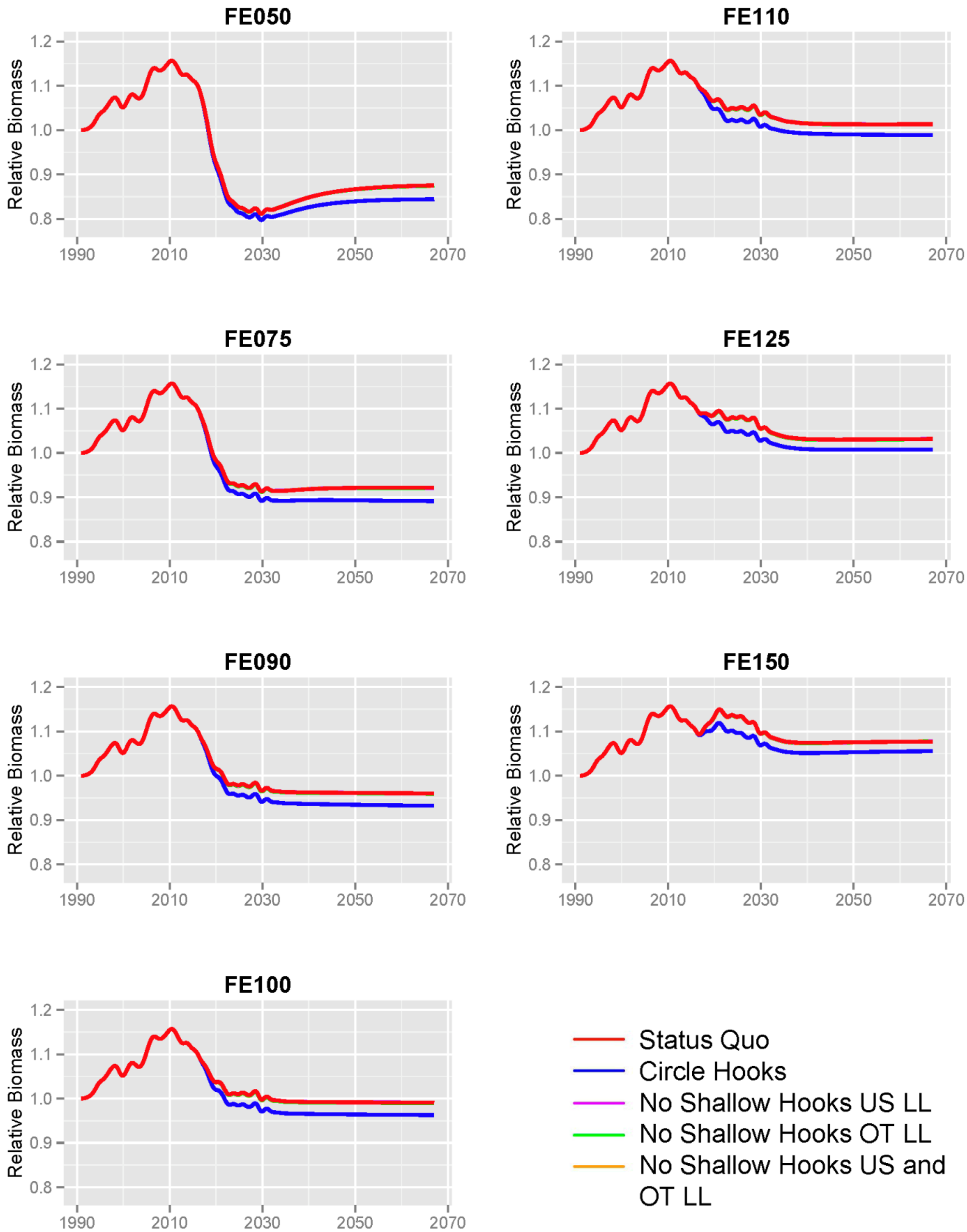
Appendix C11. Relative biomasses for juvenile skipjack under various fishing effort and gear modification scenarios



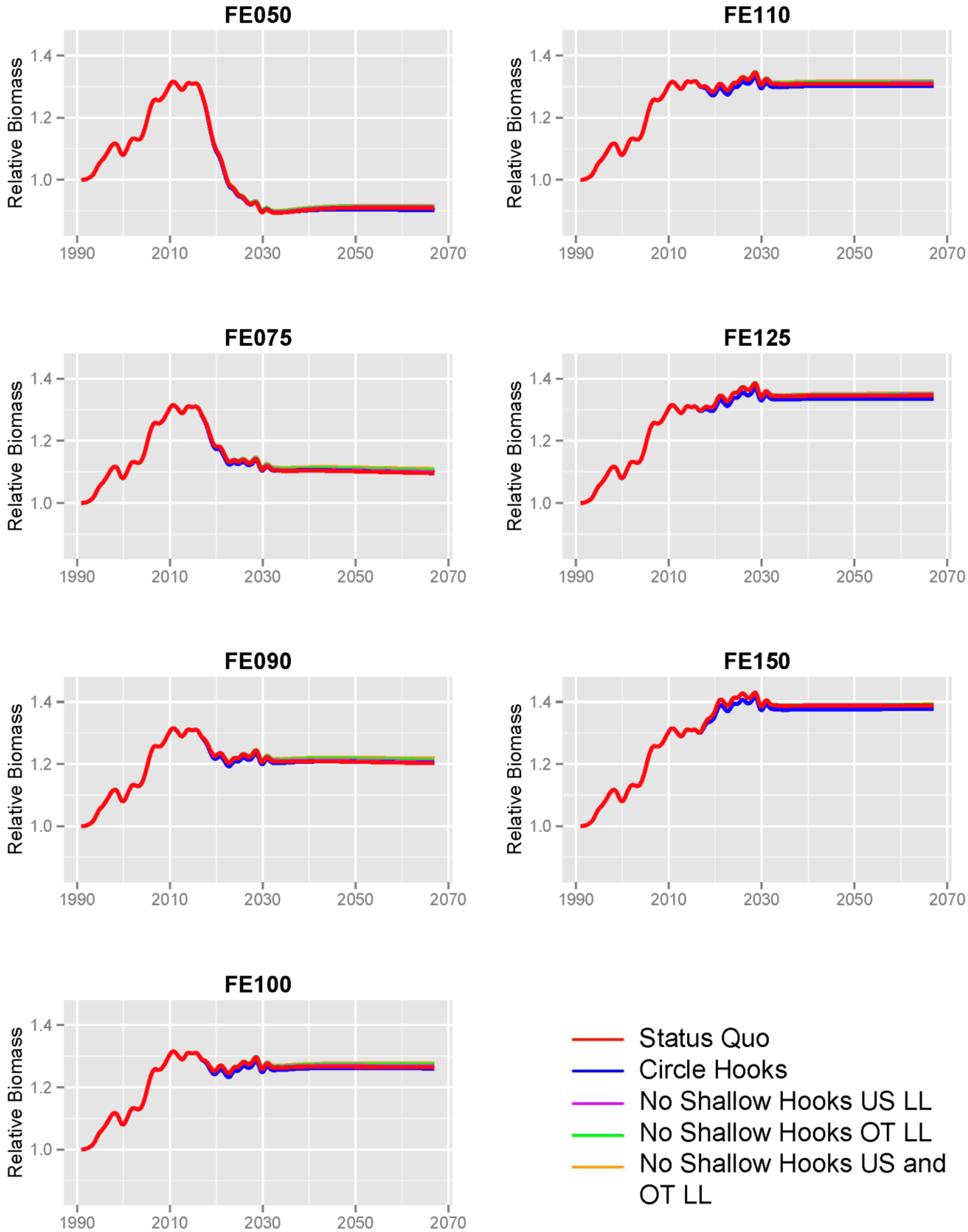
Appendix C12. Relative biomasses for mahi mahi under various fishing effort and gear modification scenarios



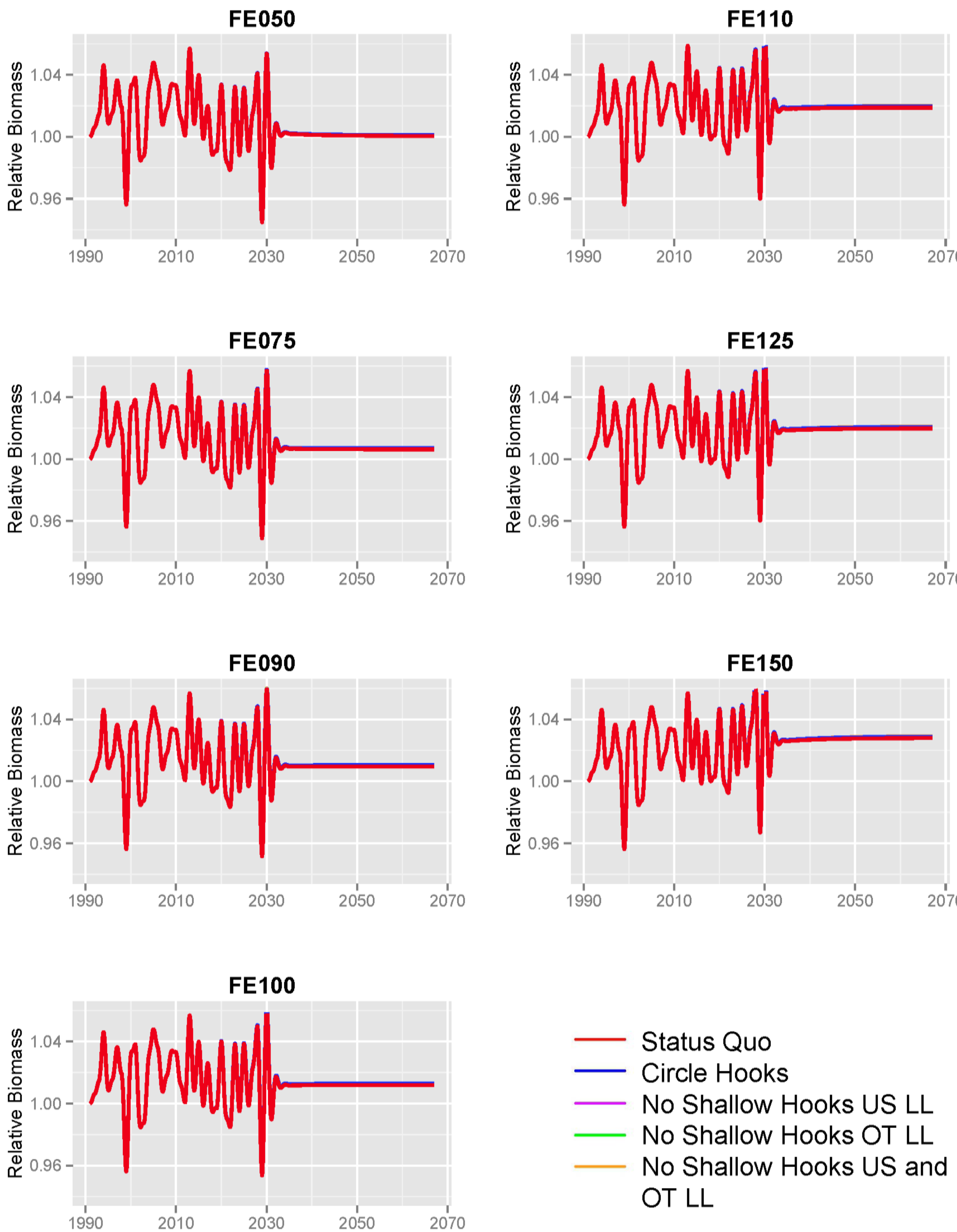
Appendix C13. Relative biomasses for lancetfish under various fishing effort and gear modification scenarios



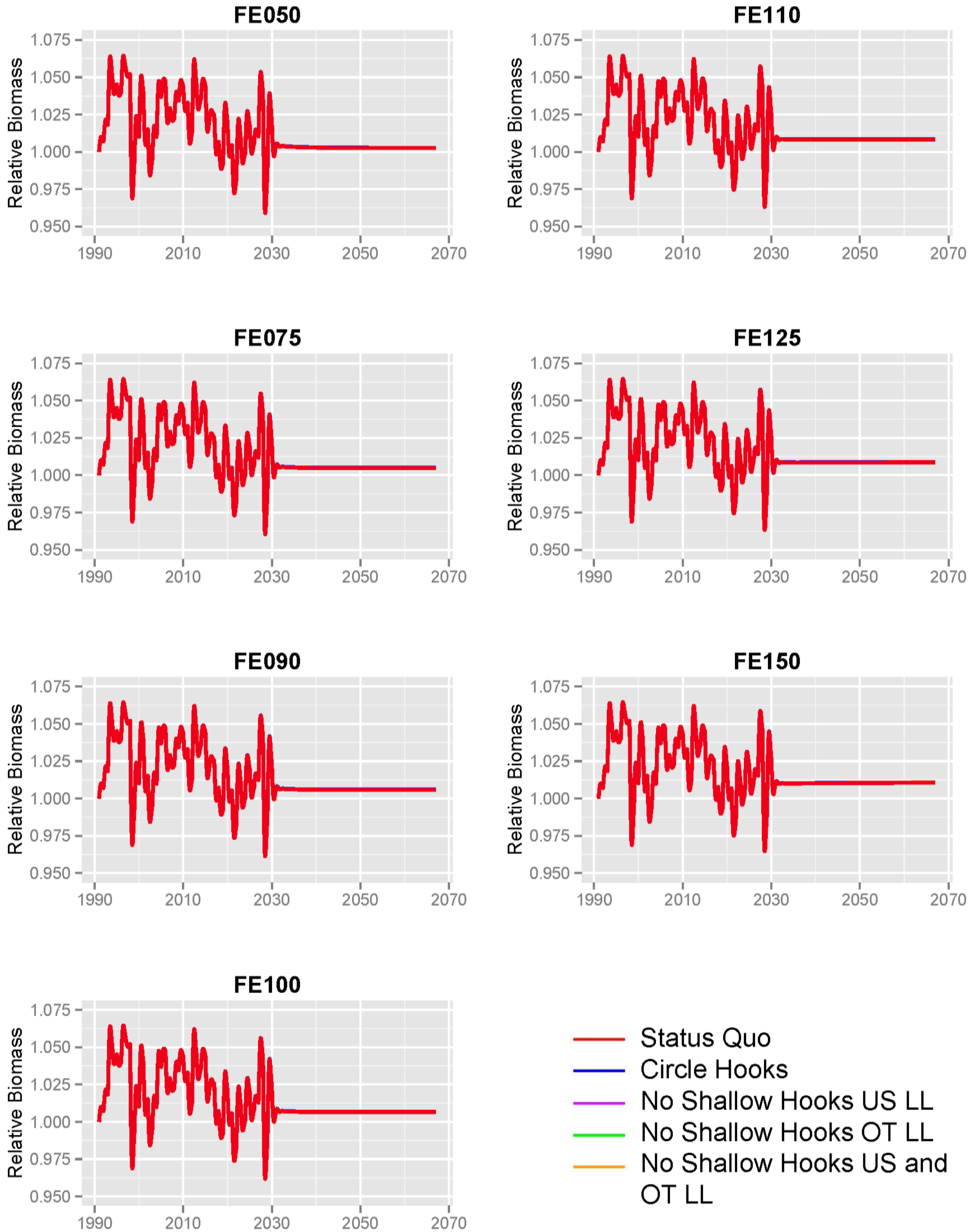
Appendix C14. Relative biomasses for mid-level trophic fish under various fishing effort and gear modification scenarios



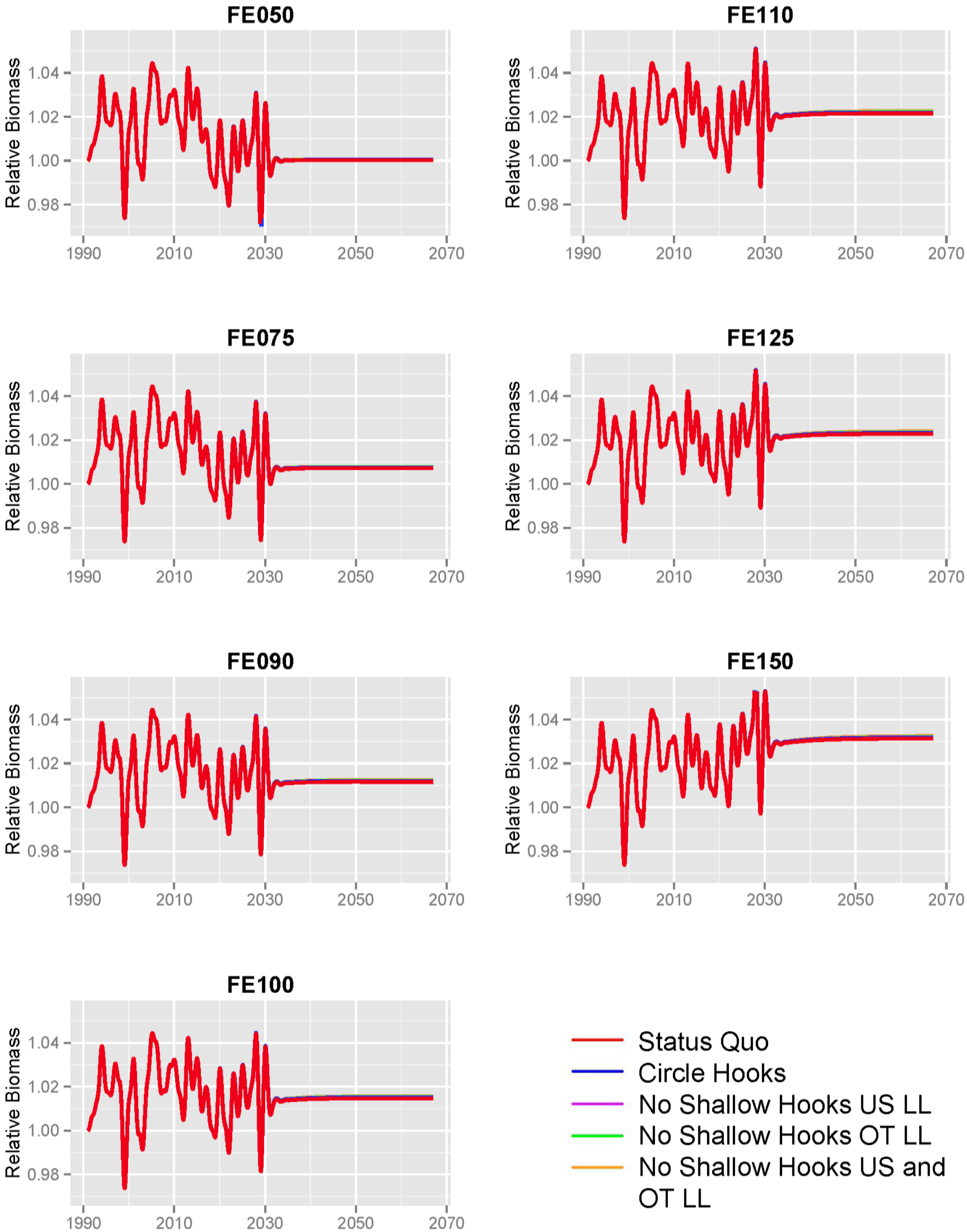
Appendix C15. Relative biomasses for epipelagic fishes under various fishing effort and gear modification scenarios



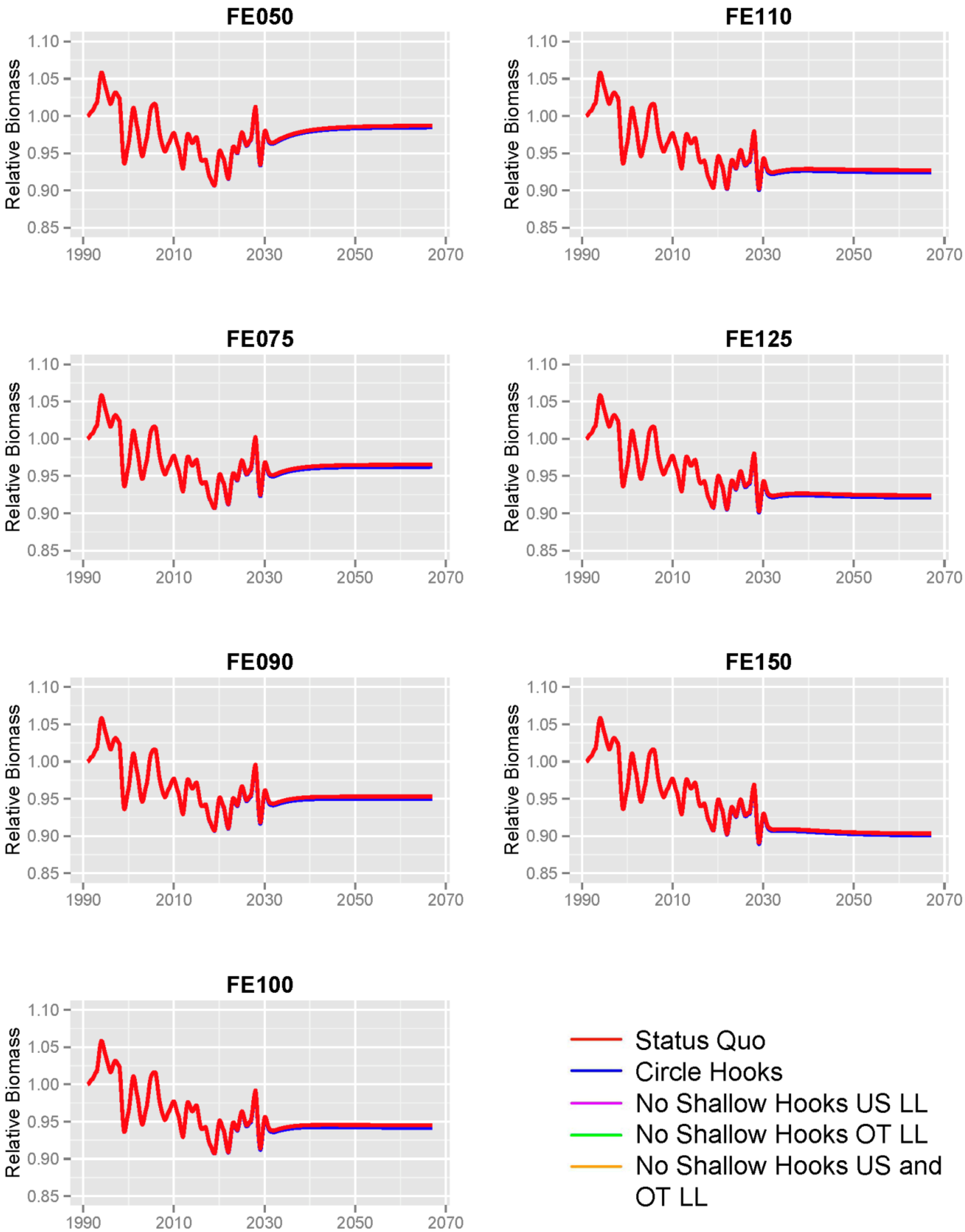
Appendix C16. Relative biomasses for invertebrates under various fishing effort and gear modification scenarios



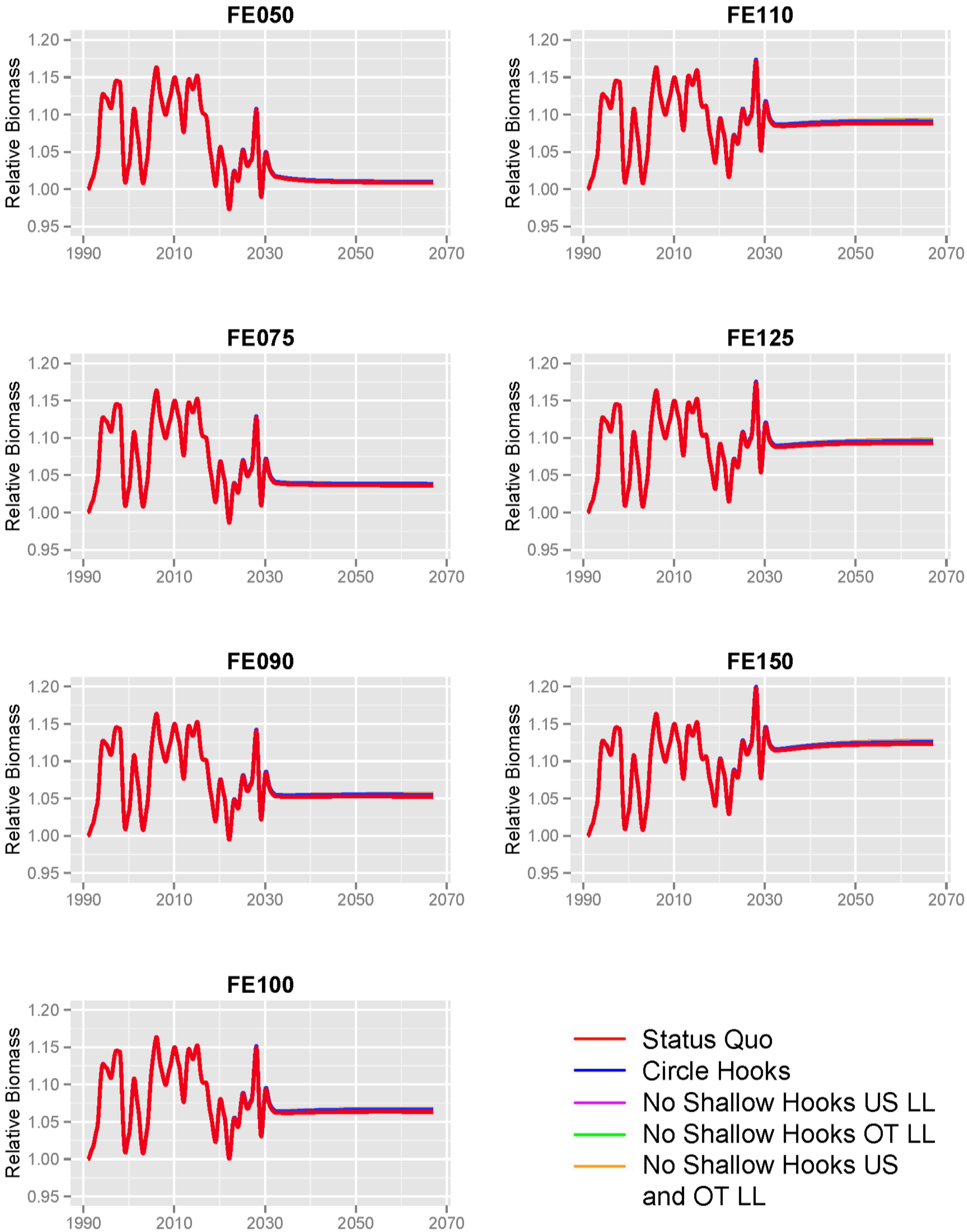
Appendix C17. Relative biomasses for epipelagic molluscs under various fishing effort and gear modification scenarios



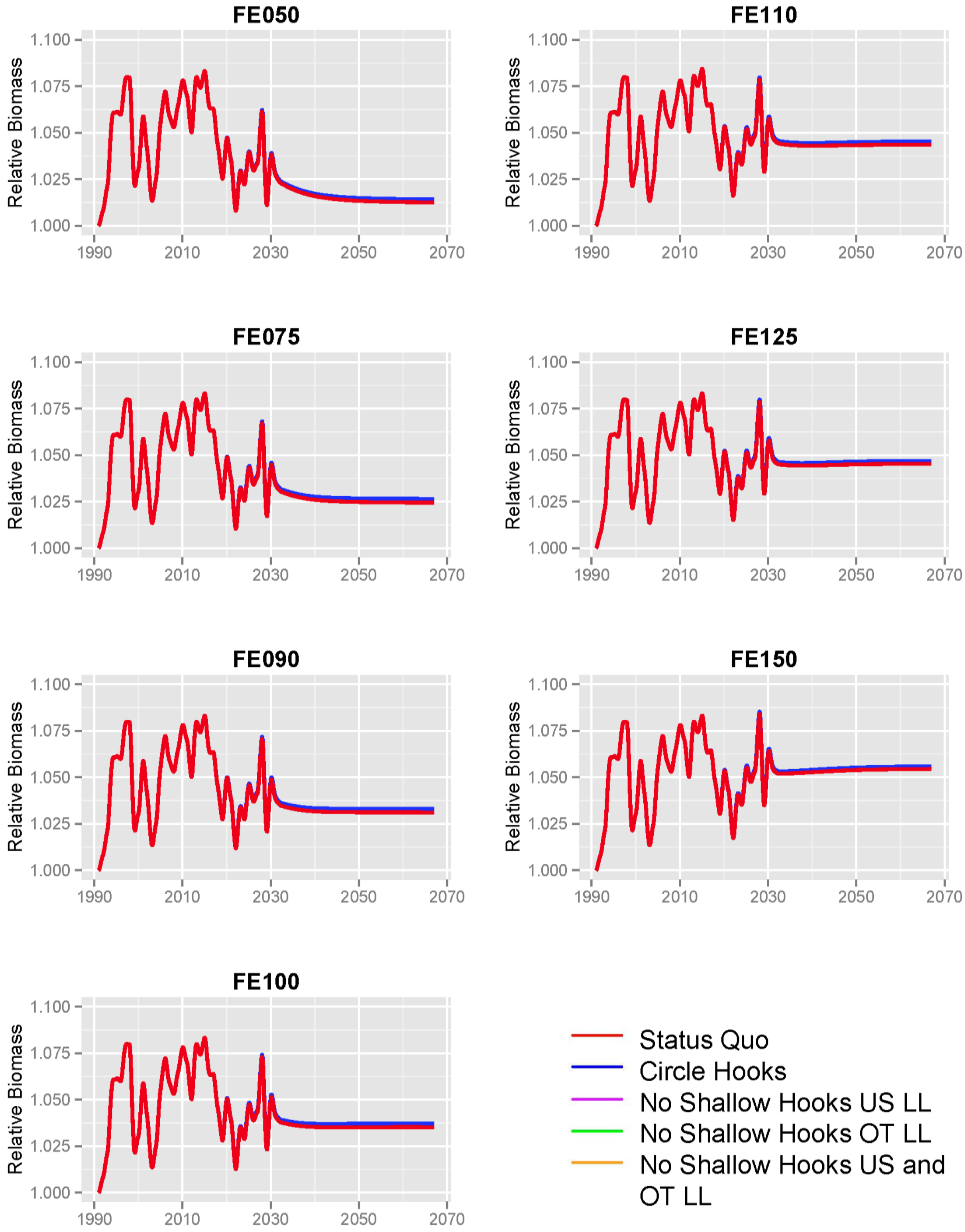
Appendix C18. Relative biomasses for mesopelagic fishes under various fishing effort and gear modification scenarios



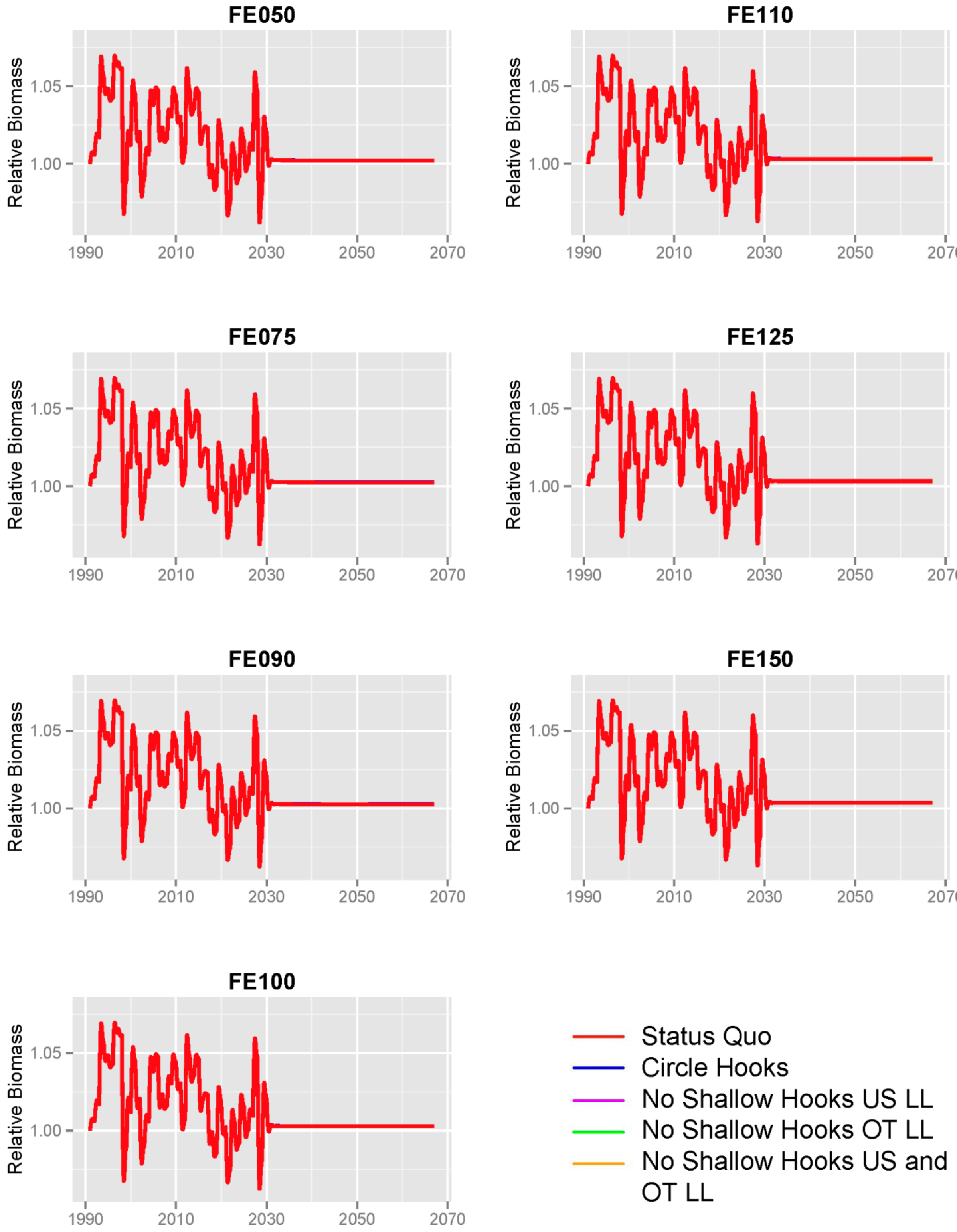
Appendix C19. Relative biomasses for other mesopelagic molluscs under various fishing effort and gear modification scenarios



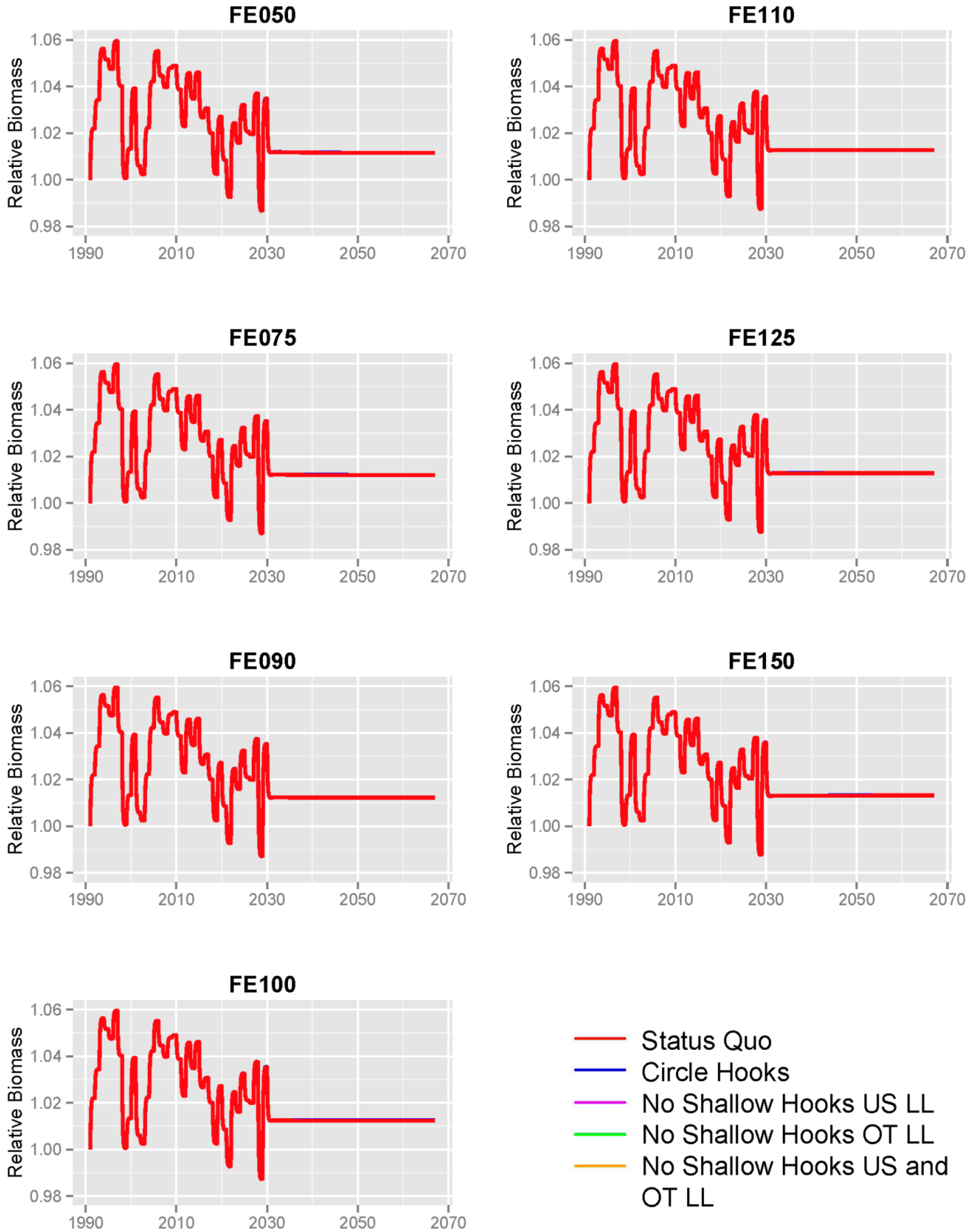
Appendix C20. Relative biomasses for bathymetric forage fish under various fishing effort and gear modification scenarios



Appendix C21. Relative biomasses for mesozooplankton under various fishing effort and gear modification scenarios



Appendix C22. Relative biomasses for microzooplankton under various fishing effort and gear modification scenarios



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