NORTH PACIFIC SWORDFISH (Xiphiaus gladius) STOCK ASSESSMENT IN 2014

REPORT OF THE BILLFISH WORKING GROUP

International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

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EXECUTIVE SUMMARY

Introduction: This Executive Summary updates assessment information for the two North Pacific swordfish stocks. The updated assessments were conducted by the Billfish Working Group of the International Scientific Committee on Tuna and Tuna-Like Species in the North Pacific. The Executive Summary summarizes assessment information on stock status relative to MSY-based reference points, stock projections, and conservation advice, as well as providing current information on stock identification and distribution, fishery catches, data and assessment, biological reference points, and special comments.

Stock Identification and Distribution: Swordfish (*Xiphias gladius*), also known as broadbill swordfish, inhabit a wide region of the Pacific between the latitudes of 50˚N and 50˚S. Swordfish is a highly migratory species with high economic value in both commercial and recreational fisheries. In the North Pacific, the swordfish (*Xiphias gladius*) population is comprised of two stocks, separated by a diagonal boundary extending from Baja, California, to the Equator. These are the Western and Central North Pacific Ocean stock (WCNPO), distributed in the western and central Pacific, and the Eastern Pacific Ocean stock (EPO), distributed in the eastern Pacific (Figure 1).

Catches: For the WCNPO stock, time series of fishery catches by country show variability in swordfish yields over the past six decades (Figure 2.1). During the 1950s, Japanese distant-water and offshore longline fisheries accounted for more than 80% of the annual swordfish harvests. The total reported annual catch of WCNPO swordfish peaked at 22,000 metric tons in 1960 but rapidly decreased during the 1960s coincident with shifts in species targeting by longline fleets. During the 1970s, the average annual reported catch of swordfish in the WCNPO area was about 10,100 metric tons and the historically lowest catch of 6,800 metric tons occurred in 1972. Total annual swordfish catches increased slightly in the 1980s and reached a level of 15,800 metric tons in 1985 due to a few years of high catches by Japanese distant-water and offshore longline fleets and USA fisheries (Figure 2.1). Swordfish catch reached a high level of 19,000 mt in 1993 and declined to a low of 13,000 mt in 1996. During the 2000s, the average annual reported catch of swordfish in the WCNPO was about 13,600 metric tons. After 2007, annual catches decreased substantially to average around 10,000 metric tons in 2011–2012.
In the EPO stock area, swordfish catches were low in the early years of the fishery and steadily increased until 1970, after which catch fluctuated between 2,000 and 7,500 mt through the 1990s (Figure 2.2). In 1998 and 2001-2002, annual catches were above 7,000 mt, and then declined to 3,235 mt in 2006. Since then, catch has risen to an historic peak of 9,910 mt in 2012 (Figure 2.2), averaging about 9,700 mt in 2010-2012. In 2012, Japan, Spain, China, and Taiwan jointly caught 85% of the total swordfish harvest in the EPO.

Data and Assessment: For the WCNPO swordfish stock, catch data was updated for this assessment and this led to an increase of about 10% and 30% in reported catch biomass during 1960-1999 and 2000-2009, respectively. Fishery catch data were taken from all available fishery-dependent data by Japan, Taiwan, Korea, USA, and other countries in the WCNPO stock area (Table 1 and Figure 2.1). Standardized fishery-dependent CPUE swordfish were estimated for Japanese distant water and offshore longline fisheries, Taiwanese distant water longline fisheries, and the shallow-set sector of the Hawaii-based pelagic longline.

Total catches of EPO swordfish from all countries and sources were updated during 1951-2012 (Table 2 and Figure 2.2) and recent catch data from 2007-2012 were recompiled using updated data provided by the IATTC, the WCPFC, and the individual countries of Japan, Taiwan, Korea, Mexico, and Chile (Figure 2.2). Estimates of standardized commercial fishery CPUE for EPO swordfish were provided by Japan and Taiwan through 2012.

Generalized surplus production models used for updating the WCNPO and EPO swordfish assessments had a very similar structure to the previous assessment and were formulated as Bayesian state space models with explicit observation and process error terms. Exploitable biomass time series were estimated from the observed relative CPUE abundance indices and from catches using observation error likelihood function and prior distributions for model parameters. Parameter estimation was based on Markov Chain Monte Carlo simulation using Gibbs sampling was applied to numerically sample the posterior distribution of quantities of interest, e.g. exploitable biomass.

Table 1. Reported annual values of catch (mt) and posterior mean values of exploitable biomass (B, mt), relative biomass (B/B_{MSY}), harvest rate (percent of exploitable biomass), relative harvest rate (H/H_{MSY}), and probability of annual harvest rate exceeding H_{MSY} for the Western and Central North Pacific swordfish stock.

Year	2006	2007	2008	2009	2010	2011	2012	Mean[1]	Min[1]	Max[1]
Reported Catch	15,051	15,799	13,631	12,375	10,670	9,456	9,863	12,962	6,753	21,972
Exploitable Biomass	76,320	72,290	68,620	68,770	68,970	68,560	72,500	81,860	60,200	121,300
Relative Biomass	1.26	1.19	1.13	1.13	1.14	1.13	1.20	1.35	0.99	2.00
Harvest Rate	21%	23%	21%	19%	16%	15%	14%	17%	10%	31%
Relative Harvest Rate	0.84	0.93	0.84	0.76	0.66	0.59	0.58	0.69	0.39	1.23
Pr($H > H_{MSY}$)	0.18	0.34	0.19	0.09	0.02	0.00	0.00	0.12	0.00	0.80

[1] During 1951-2012

Table 2. Reported annual values of catch (mt) and posterior mean values of exploitable biomass (B, mt), relative biomass (B/B_{MSY}), harvest rate (percent of exploitable biomass), relative harvest rate (H/H_{MSY}), and probability of annual harvest rate exceeding H_{MSY} for the Eastern Pacific swordfish stock.

Year	2006	2007	2008	2009	2010	2011	2012	Mean[1]	Min[1]	Max[1]
Reported Catch	3,235	3,701	4,262	7,473	9,631	9,586	9,910	3,561	1	9,910
Exploitable Biomass	43,100	47,980	53,840	60,570	62,120	60,810	58,590	48,875	31,510	67,070
Relative Biomass	1.38	1.54	1.73	1.95	2.00	1.95	1.87	1.58	1.02	2.16
Harvest Rate	8%	9%	9%	14%	17%	18%	19%	8%	<1%	22%
Relative Harvest Rate	0.49	0.50	0.51	0.80	1.00	1.03	1.11	0.49	0.00	1.30
Pr($H > H_{MSY}$)	0.01	0.02	0.02	0.20	0.44	0.47	0.55	0.11	0.00	0.71

[1] During 1951-2012

Status of Stock: Exploitable biomass of WCNPO swordfish fluctuated at or above B_{MSY} throughout the assessment time horizon and has remained high in recent years (Table 1 and Figure 3.1). As expected, there was an inverse pattern between estimated biomass and harvest rate as harvest rate fluctuated at or below H_{MSY}. Trends in exploitable biomass and harvest rate from the current assessment are very similar to those from the 2009 assessment. In recent years, catches and harvest rates of WCNPO swordfish have had a declining trend, with exploitable biomass fluctuating around 70,000 mt, since 2007 (Table 1 and Figure 3.1). The Kobe plot showed that the WCNPO swordfish stock does not appear to have been overfished or to have experienced overfishing throughout most of the assessment time horizon of 1951-2012 (Figure 4.1). For the current status, results indicated it was very unlikely that the WCNPO swordfish population biomass was below B_{MSY} in 2012 ($Pr(B_{2012} < B_{MSY})=14\%$). Similarly, it was extremely unlikely that the swordfish population was being fished in excess of H_{MSY} in 2012 ($Pr(H_{2012} > H_{MSY}) < 1\%$). Retrospective analyses indicated that there was no retrospective pattern in the estimates of exploitable biomass and harvest rate (Figure 5.1).
For the EPO stock, time series of estimates of exploitable biomass and harvest rate over the assessment time horizon differed from the previous assessment in recent years but have remained high in recent years (Table 2 and Figure 3.2). Exploitable biomass had a declining trend during 1969-1995 and has increased from 31,000 mt in 1995 to over 60,000 mt in 2010, generally remaining above B_{MSY}. Harvest rates were initially low, have had a long-term increasing trend, and likely exceeded H_{MSY} in 1998, 2002, 2003, and also the most recent year, 2012 (Figure 3.2). The Kobe plot showed that overfishing likely occurred in only a few years, but may be occurring in recent years (Figure 4.2). In 2012, there was a 55% probability that overfishing was occurring in 2012, but there was a less than 1% probability that the stock was overfished. Retrospective analyses indicated that there was a clear retrospective pattern of underestimating exploitable biomass and overestimating harvest rate (Figure 5.2).

Projections and Risk Analyses: For the WCNPO stock, stochastic projections for eight harvest scenarios were conducted through 2016 (Figure 6.1). Results relative to MSY-based reference points indicated that exploitable biomass would likely remain above B_{MSY} through 2016 under the status quo catch or status quo harvest rate scenarios (Figure 6.1). For the high harvest rate scenarios (i.e., Maximum observed harvest rate, 150% of H_{MSY}, 125% of H_{MSY}), exploitable biomass was projected to decline below B_{MSY} by 2016 (Figure 6.1) with harvest rates exceeding H_{MSY}. In comparison, the stock would not be expected to experience any overfishing during 2014-2016 under the status quo catch and status quo harvest rate scenarios. (Figure 6.1) The risk analyses of harvesting a constant annual catch of WCNPO swordfish during 2014-2016 showed that there would be virtually no chance of the stock being overfished or experiencing overfishing in 2016 (Figure 7) if current annual catches of about 10,000 mt were maintained. Annual catches of WCNPO swordfish would need to increase to roughly 15,000 mt to have a moderate (50% chance) risk of overfishing and would need to increase to over 25,000 mt to exceed a moderate risk of the stock being overfished in 2016 (Figure 7).

For the EPO stock, stochastic projections showed that exploitable biomass will likely have a decreasing trajectory during 2014-2016 under all eight of the harvest scenarios examined (Figure 6.2). Under the high harvest rate scenarios (status quo catch, Maximum observed harvest rate, 150% of H_{MSY}), exploitable biomass was projected to decline to be roughly equal to B_{MSY} in 2016 (Figure 6.2) and maintain harvest rates above H_{MSY}. In comparison, under the status quo harvest rate scenario, exploitable biomass was projected to decline to only 40,000 mt by 2016, well above the B_{MSY} level. Overall, the projections showed that if recent high catch levels persist, exploitable biomass will very likely decrease and a moderate risk of overfishing will likely continue to occur. The risk analyses for harvesting a constant catch of EPO swordfish during 2014-2016 showed that the probabilities of overfishing and becoming overfished increased as projected catch increased in the future (Figure 7). Maintaining the current catch of EPO swordfish of approximately 9,700 mt would lead to a moderate risk of overfishing in 2016 but would lead to less than 1% probability of the stock being overfished in 2016.

Biological Reference Points: Biological reference points based on maximum sustainable yield were calculated from the generalized surplus production model results for the WCNPO and EPO swordfish stocks (Table 3). For WCNPO swordfish (Table 3), the point estimate and coefficient of variation (CV) of maximum sustainable yield, exploitable biomass to produce MSY, and harvest rate to produce MSY were: MSY = 14.92 thousand mt with CV = 12%, B_{MSY} = 60.72 thousand mt with CV =19%, and H_{MSY} = 0.25 with CV = 22%.
For EPO swordfish (Table 3), the point estimate and CV of maximum sustainable yield, exploitable biomass to produce MSY, and harvest rate to produce MSY were: MSY = 5.49 thousand mt with CV = 30%, B_{MSY} = 31.17 thousand mt with CV = 22%, and H_{MSY} = 0.18 with CV = 34%. Overall, the biological reference points indicated that the WCNPO stock was larger and more productive than the EPO stock.

Table 3. Estimates of current levels of exploitable biomass (B_{2012} , thousand mt), average harvest rate ($H_{2010-2012}$, percent of exploitable biomass), and recent average yield ($C_{2010-2012}$, thousand mt) along with estimated MSY-based biological reference points for the WCNPO and EPO swordfish stocks.

Reference Point	WCNPO Stock Estimate	EPO Stock Estimate
B_{2012}	72,500 mt	58,590 mt
$H_{2010-2012}$	15%	18%
$C_{2010-2012}$	9,996 mt	9,709 mt
B_{MSY}	60,720 mt	31,170 mt
H_{MSY}	25%	18%
MSY	14,920 mt	5,490 mt

Conservation Advice: Based on the assessment update, the WCNPO swordfish stock is not currently overfished and is not experiencing overfishing. The WCNPO stock is not fully exploited.

For the EPO swordfish stock, results indicated that overfishing may be occurring in recent years, and the recent average yield of roughly 10,000 mt, or almost two times higher than the estimated

MSY, is not likely to be sustainable in the long term. While biomass of the EPO stock appears to be nearly twice BMSY, any increases in catch above recent[1] levels should consider the uncertainty in stock structure and unreported catch.

Special Comments: The WG recognized unreported catch and stock structure as two potential sources of uncertainty that were not accounted for in the stock assessments and either source would increase the overall uncertainty in the assessment results.

[1] recent is 3-year average for 2010-2012.

Figure 1. Two-stock structure for swordfish (*Xiphias gladius*) in the North Pacific Ocean, indicating separate stocks in the Western and Central Pacific Ocean and in the Eastern Pacific Ocean.

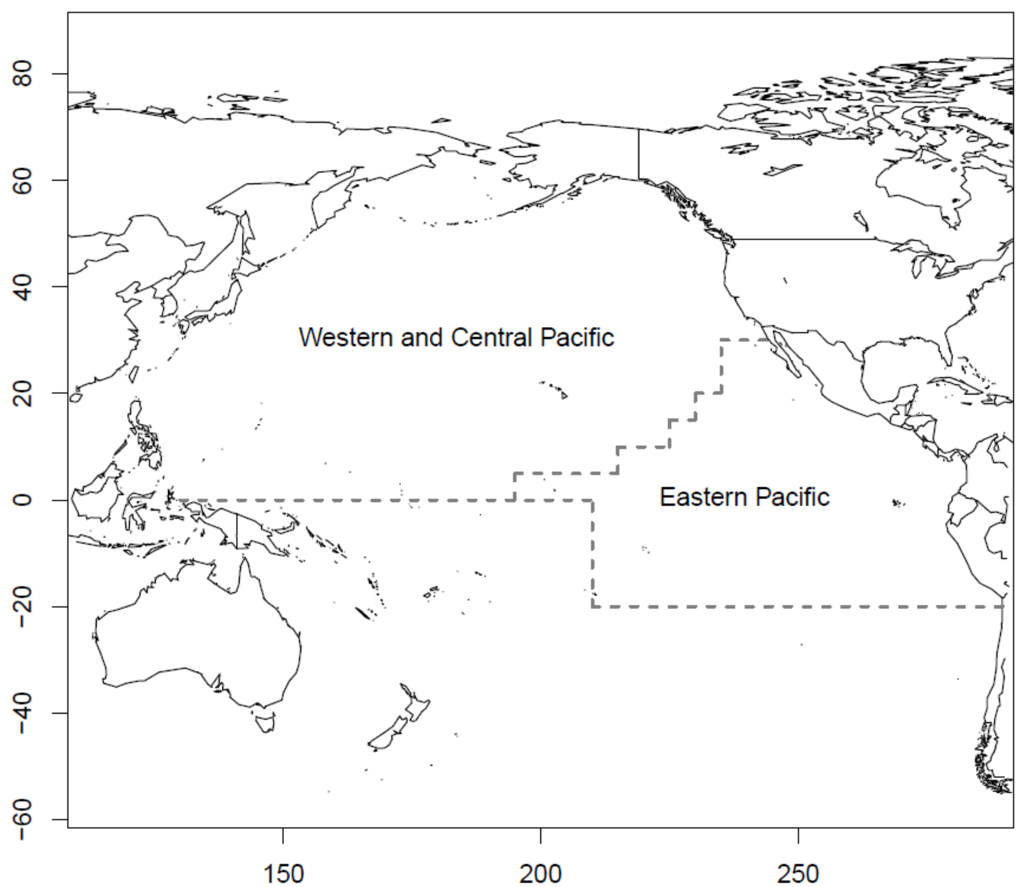


Figure 2.1 Swordfish (*Xiphias gladius*) catch (metric tons) in the Western and Central North Pacific Ocean stock area from 1951-2012 by country. †Other: catch data from Belize, Cook Islands, China, Spain, Fiji, Federated States of Micronesia, Kiribati, Marshall Islands, Papua New Guinea, Senegal, Tuvalu, and Vanuatu.

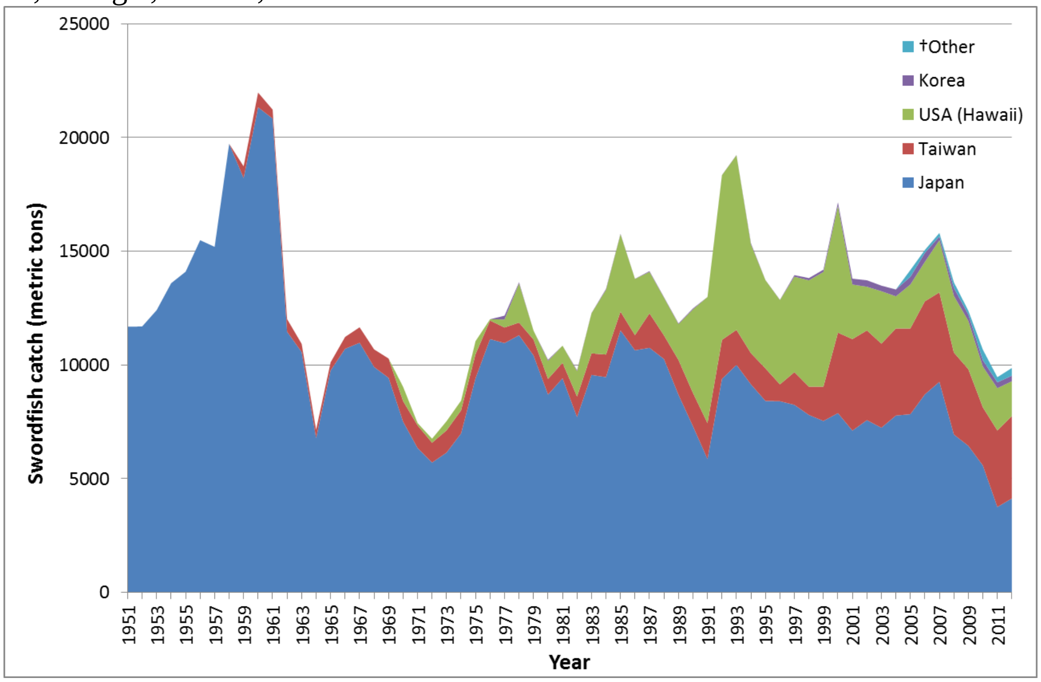


Figure 2.2. Swordfish (*Xiphias gladius*) catch (metric tons) in the Eastern Pacific Ocean stock area from 1951-2012 by country. †Other: catch data from Belize, Cook Islands, China, Spain, Fiji, Federated States of Micronesia, Kiribati, Marshall Islands, Papua New Guinea, Senegal, Tuvalu, and Vanuatu.

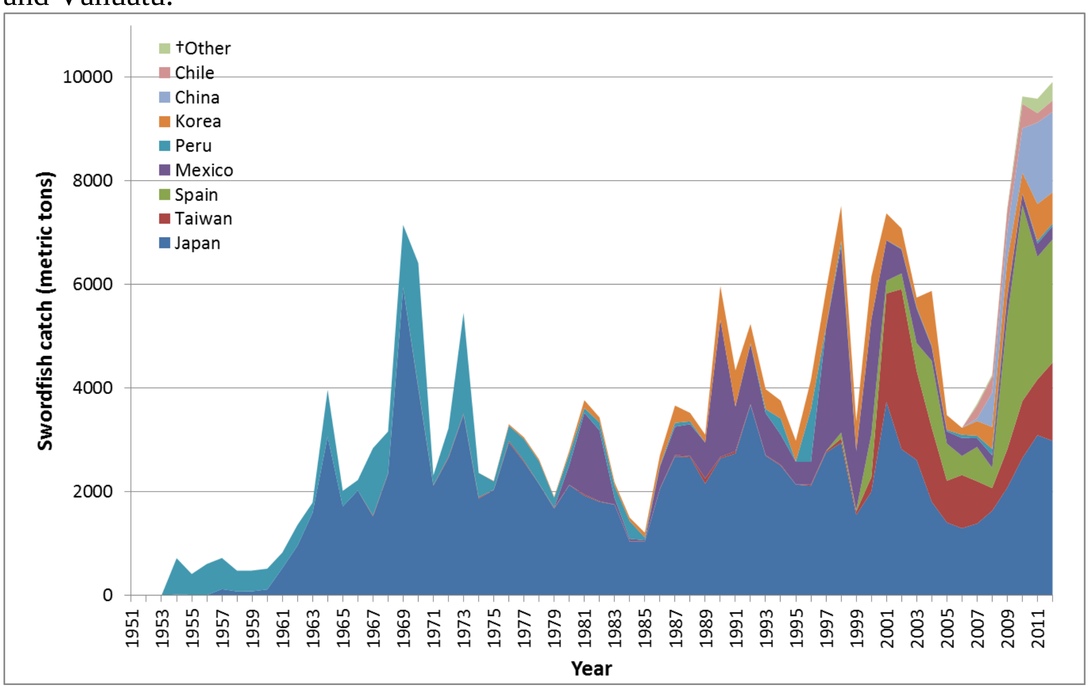


Figure 3.1. Trends in exploitable biomass (top) and harvest rate (bottom) of swordfish (*Xiphias gladius*) in the Western and Central North Pacific Ocean stock area. Estimated mean values from the posterior distribution (black circles and solid line), 95% confidence interval bars (solid vertical lines), and estimated biological reference points (B_{MSY} and H_{MSY}, horizontal dashed lines) are presented.

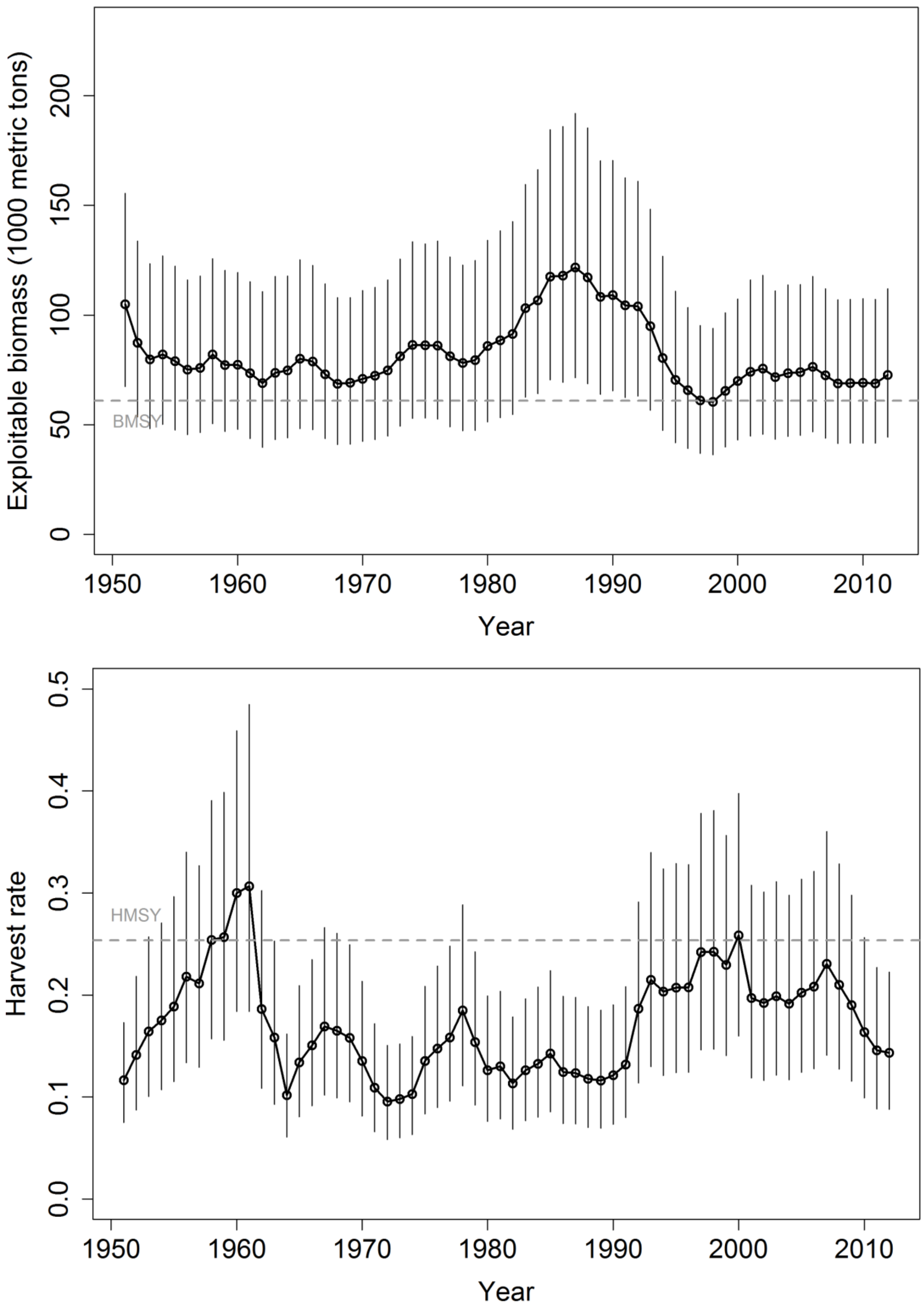


Figure 3.2. Trends in exploitable biomass (top) and harvest rate (bottom) of swordfish (*Xiphias gladius*) in the Eastern Pacific Ocean stock area. Estimated mean values from the posterior distribution (black circles and solid line), 95% confidence interval bars (solid vertical lines), and estimated biological reference points (B_{MSY} and H_{MSY}, horizontal dashed lines) are presented.

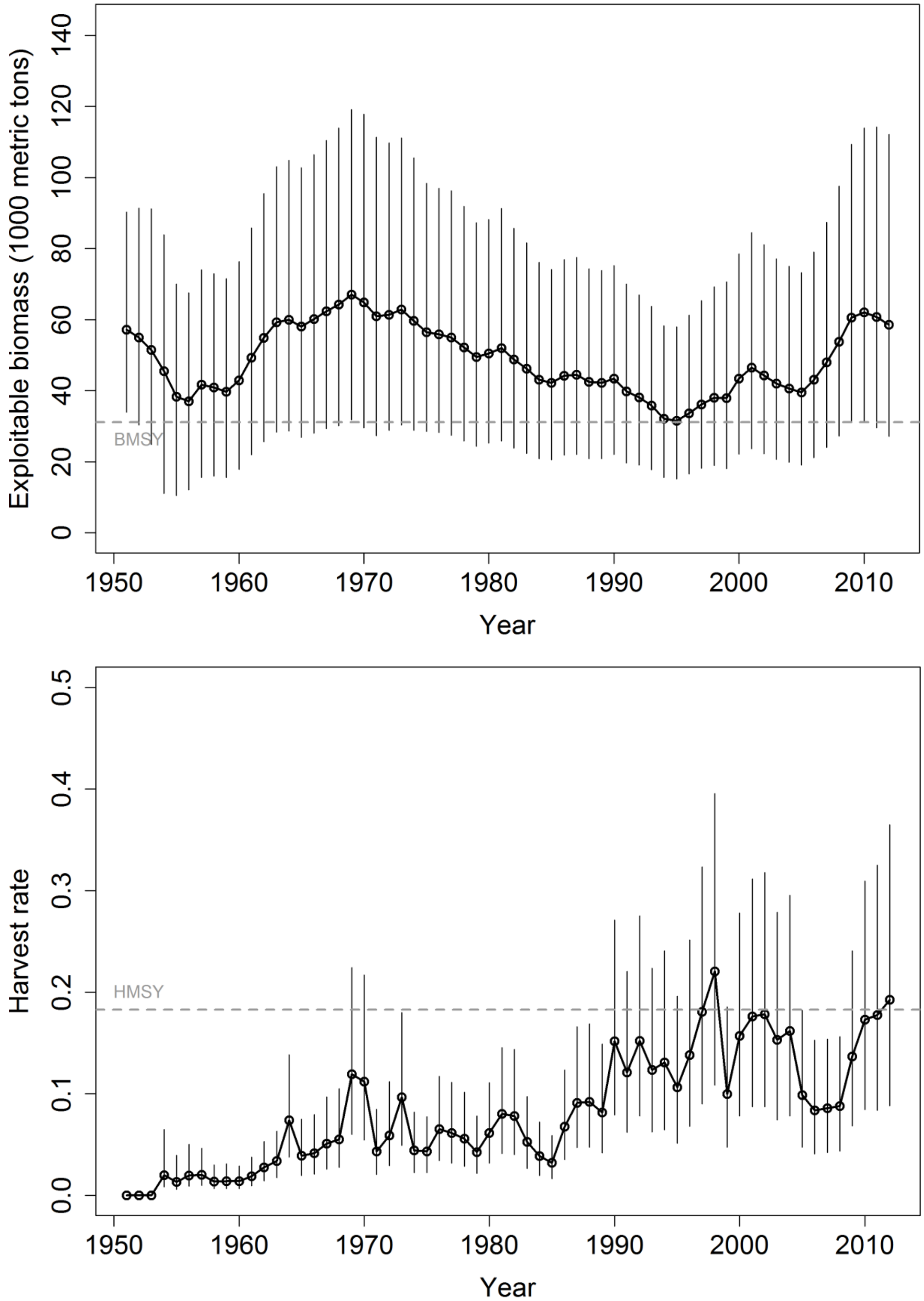


Figure 4.1. Kobe diagram showing the estimated trajectories of relative exploitable biomass (B/B_{MSY}) and relative harvest rate (H/H_{MSY}) for swordfish (*Xiphias gladius*) in the Western and Central North Pacific Ocean stock area during 1951-2012.

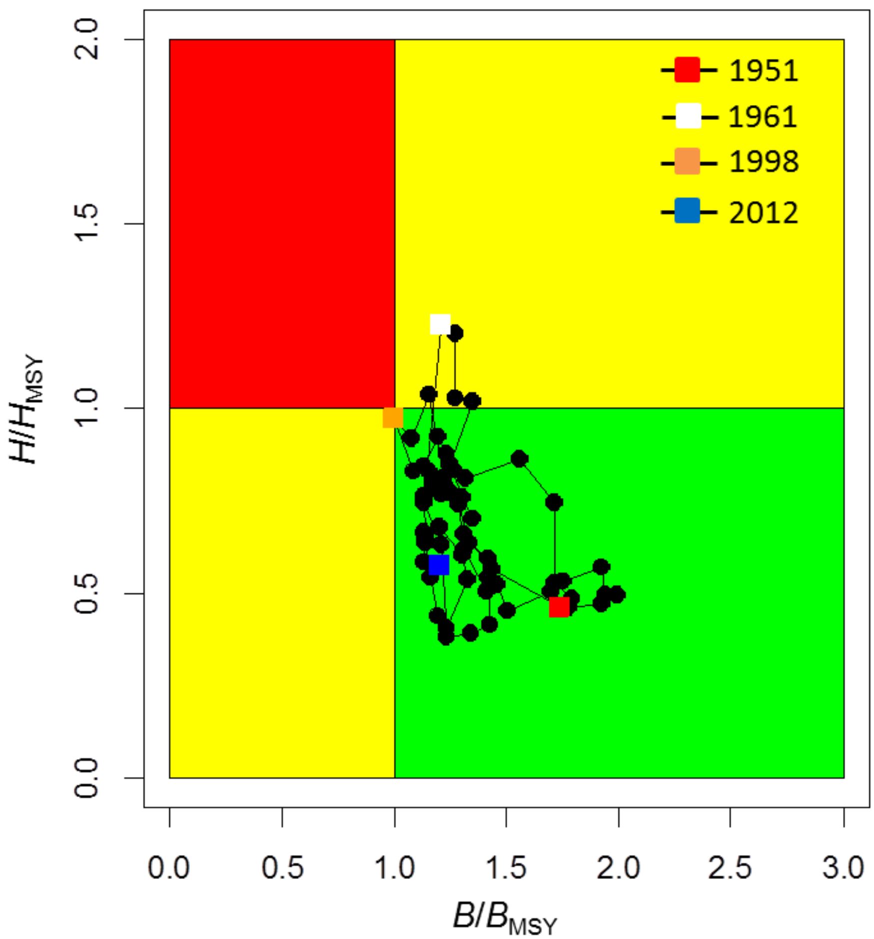


Figure 4.2. Kobe diagram showing the estimated trajectories of relative exploitable biomass (B/B_{MSY}) and relative harvest rate (H/H_{MSY}) for swordfish (*Xiphias gladius*) in the Eastern Pacific Ocean stock area during 1951-2012.

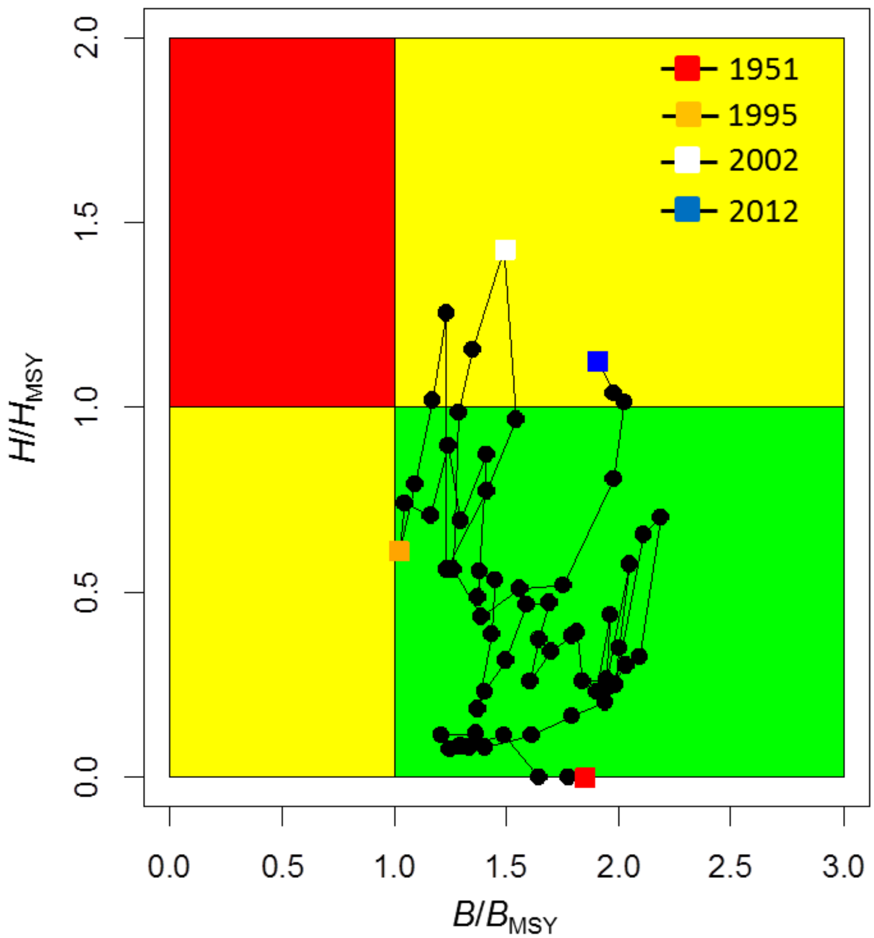


Figure 5.1. Retrospective analyses of the absolute changes in exploitable biomass (a) and harvest rate (b) for swordfish (*Xiphias gladius*) in the Western and Central North Pacific stock area based on successive removals of one-year of assessment data and refits of the baseline production model.

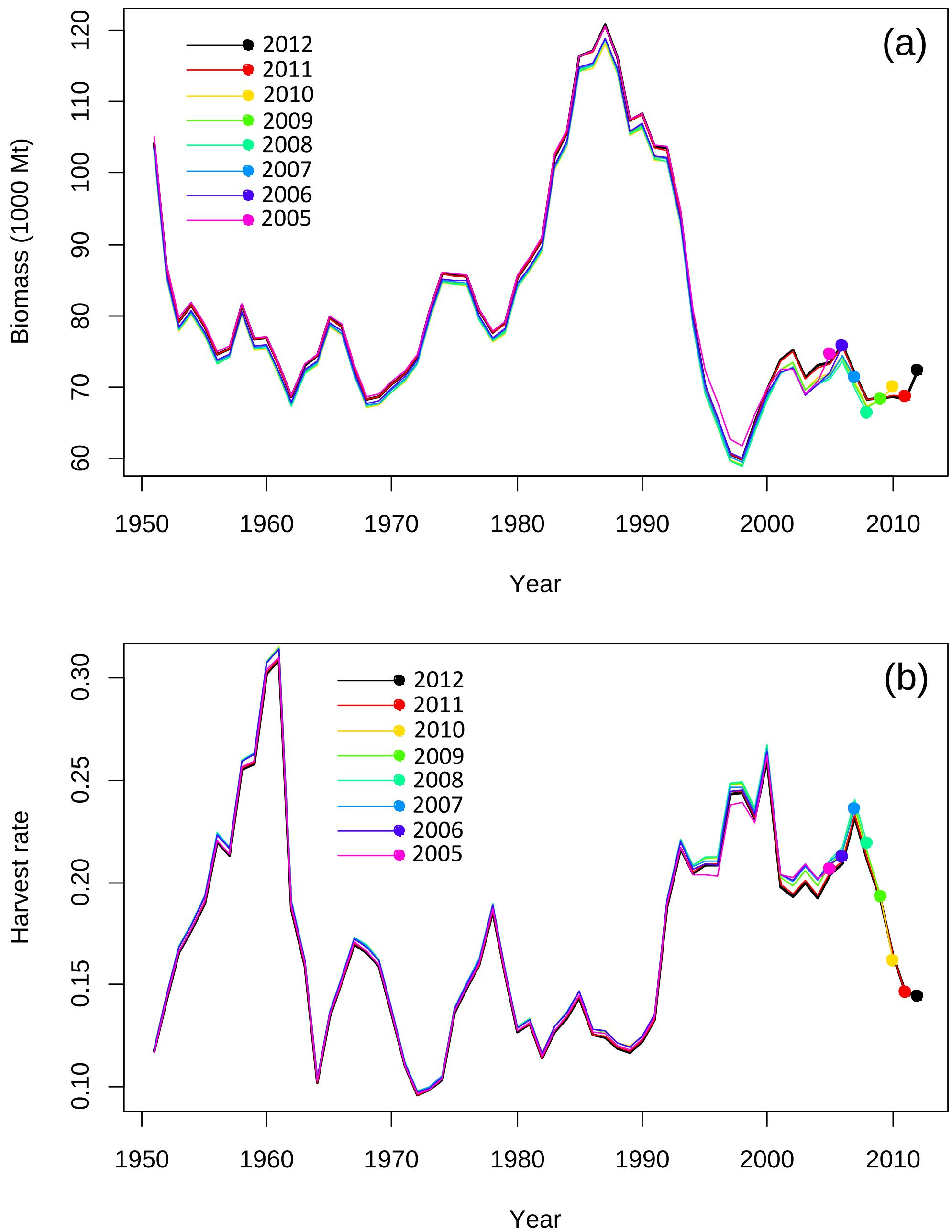


Figure 5.2. Retrospective analyses of the absolute changes in exploitable biomass (a) and harvest rate (b) for swordfish (*Xiphias gladius*) in the Eastern Pacific stock area based on successive removals of one-year of assessment data and refits of the baseline production model.

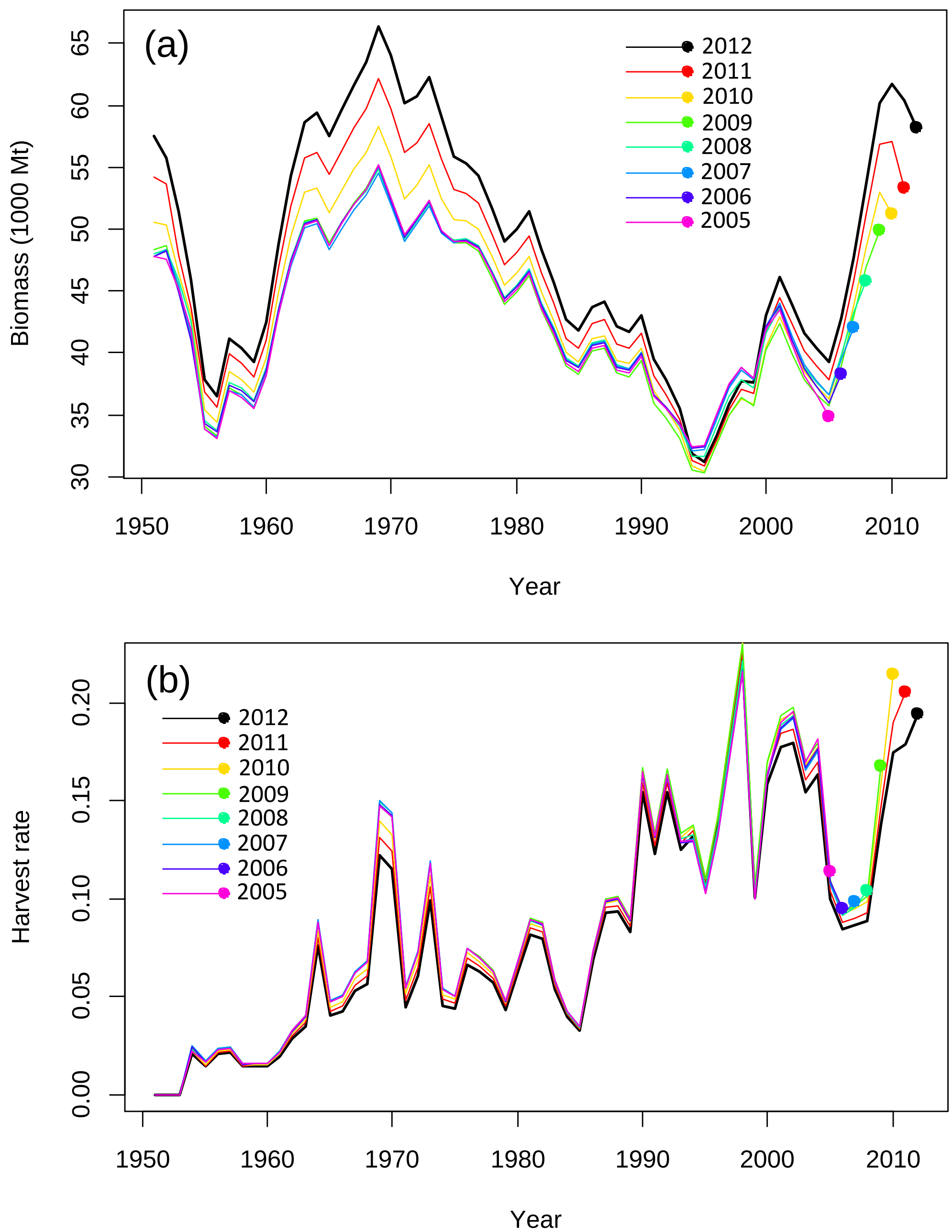


Figure 6.1. Stochastic projections of expected exploitable biomass (1000 metric tons) of swordfish (*Xiphias gladius*) in the Western and Central Pacific Ocean stock area during 2013-2016 under alternative harvest rates. Upper panel shows projection results of applying a harvest rate set to be 50%, 75%, 100%, 125%, and 150% of the value of estimate of H_{MSY} (denoted as F_{MSY} in the Figure). Lower panel shows projection results of applying a status quo harvest rate based on the 2010-2012 average estimates, a status quo catch based on the 2010-2012 average catch, and the maximum observed harvest rate in the 1951-2012 time series.

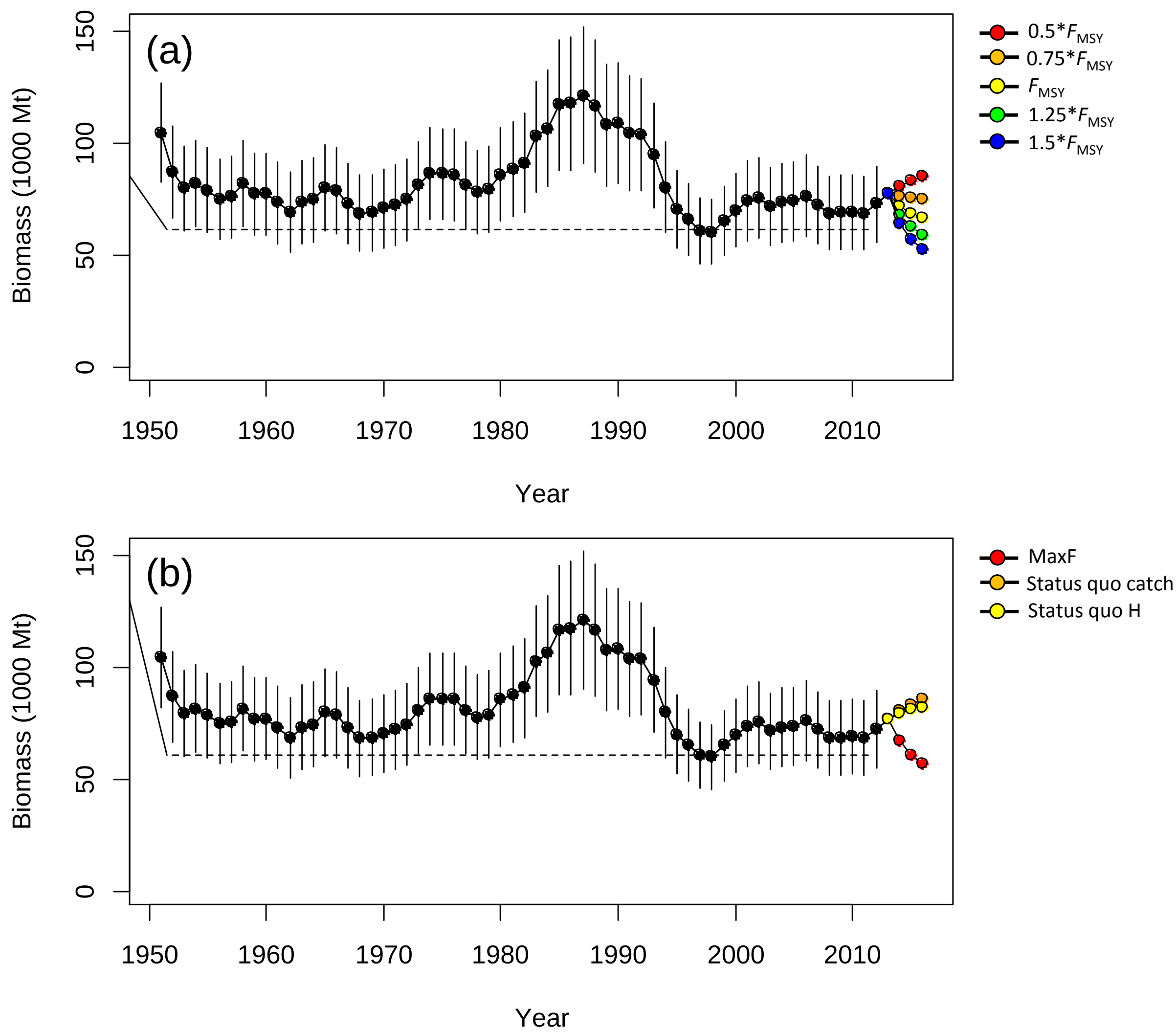


Figure 6.2. Stochastic projections of expected exploitable biomass (1000 metric tons) of swordfish (*Xiphias gladius*) in the Eastern Pacific Ocean stock area during 2013-2016 under alternative harvest rates. Upper panel shows projection results of applying a harvest rate set to be 50%, 75%, 100%, 125%, and 150% of the value of estimate of H_{MSY} (denoted as F_{MSY} in the Figure). Lower panel shows projection results of applying a status quo harvest rate based on the 2010-2012 average estimates, a status quo catch based on the 2010-2012 average catch, and the maximum observed harvest rate in the 1951-2012 time series.

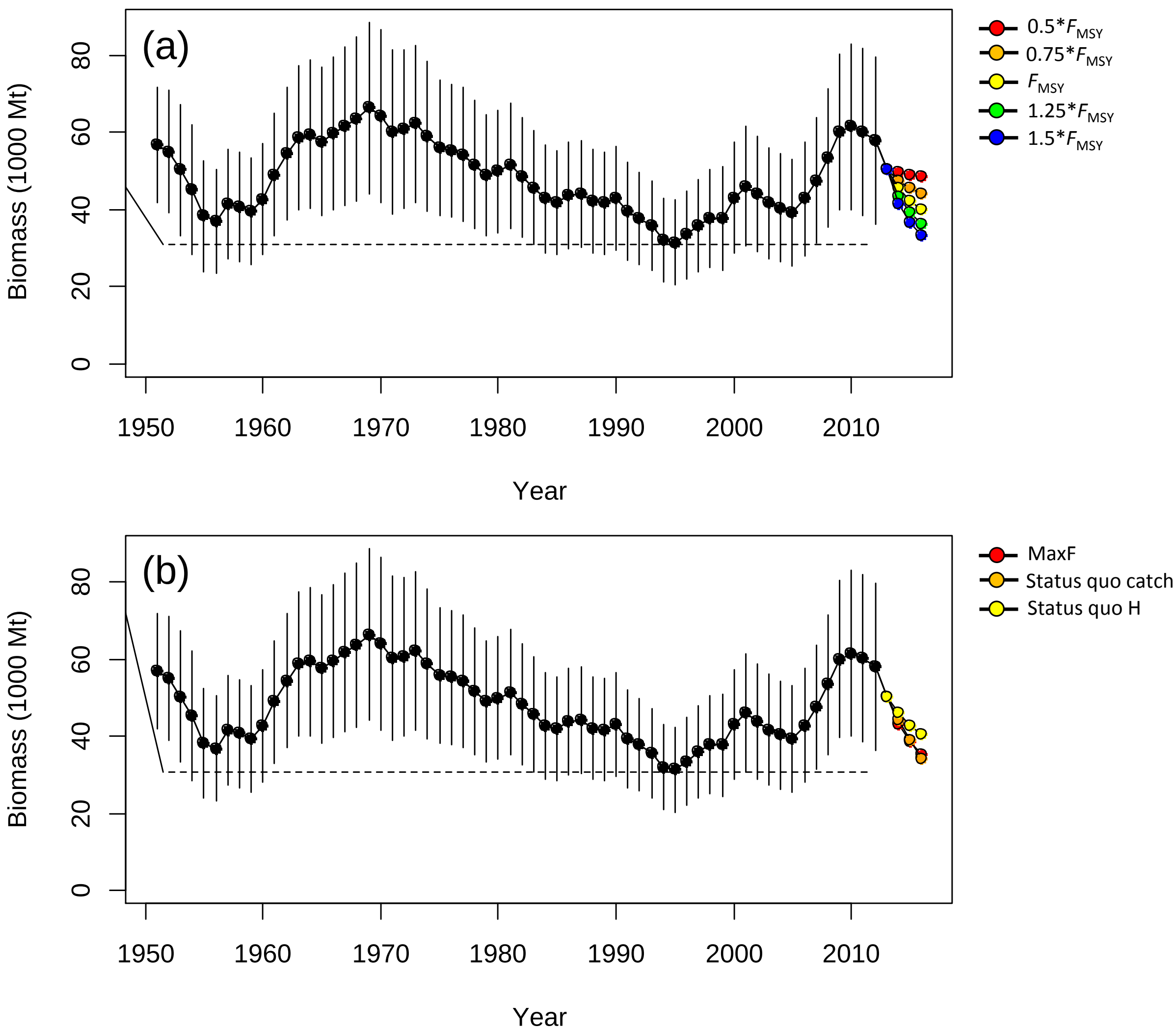
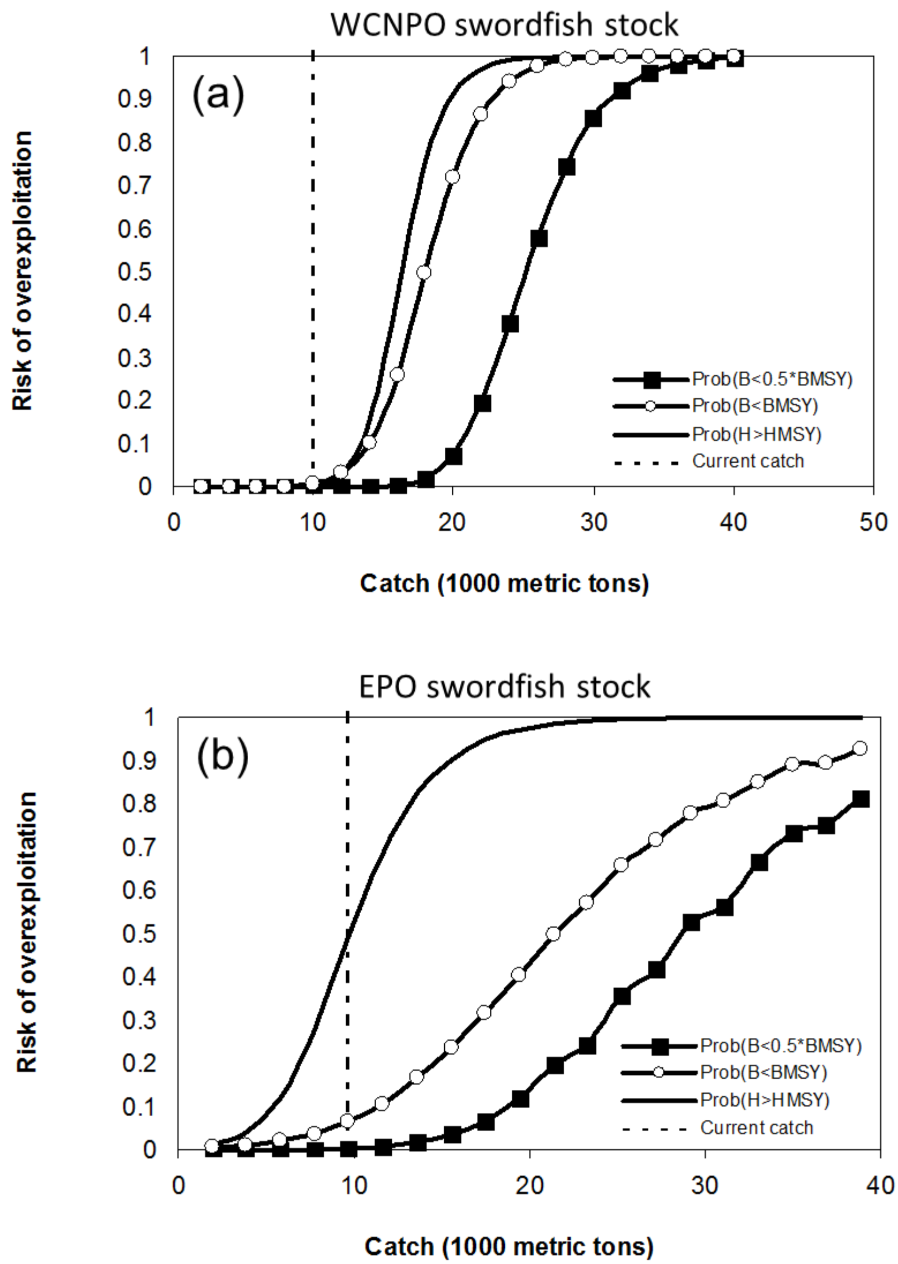


Figure 7. Probabilities of experiencing overfishing (H > HMSY, solid line), of exploitable biomass falling below BMSY (B < 0.5*BMSY, open circles), and of being overfished relative to a reference level of ½BMSY (B < 0.5*BMSY, solid squares) in 2016 for swordfish in the Western and Central Pacific Ocean stock area (a) and Eastern Pacific Ocean stock area (b) based on applying a constant catch biomass (x-axis, thousand mt) in the stock projections.



INTRODUCTION

Swordfish (*Xiphias gladius*), also known as broadbill swordfish, inhabit a wide region of the Pacific between the latitudes of 50˚N and 50˚S (Ward and Elscot, 2000). Swordfish is a highly migratory species with high economic value in both commercial and recreational fisheries. In the North Pacific, the majority of catch has been taken by longline fishing vessels from Japan, Taiwan and the United States, which accounted for 95% of the total harvest in the North Pacific in 2010s, with the remaining catch taken by China, Korea, Mexico, and Spain.

Several stock structures have been proposed for Pacific swordfish (Alvarado Bremer et al., 2006; Ichinokawa and Brodziak, 2008). Stock assessments on swordfish in the North Pacific have been conducted primarily using catch, and abundance indices in the form of catch-per-unit effort, or CPUE. In 2004, Kleiber and Yokawa (2004) used MULTIFAN-CL to assess North Pacific swordfish in a four-region model. It has been suggested that these model fits and parameter estimates were sensitive to model structure. In two subsequent studies, a similar length-structured modeling approach was applied, which included some sex-specific data (Wang et al. 2005, 2007). These previous studies concluded that there was little contrast in the North Pacific swordfish fishery CPUE data to estimate stock status relative to biological reference points. Updated catch and effort data, however, were expected to improve model fits and to help estimate recent trends in swordfish abundance and harvest rates.

In 2009, all swordfish in the North Pacific were assessed as both a single stock north of the Equator and also under a two-stock scenario, with one stock in the Western and Central Pacific Ocean (WCNPO) and another in the Eastern Pacific Ocean (EPO) (ISC 2009), separated by a diagonal boundary extending from Baja, California, to the Equator (
Figure **2**), based on the analysis by Ichinokawa and Brodziak (2008). The EPO swordfish stock assessment was revised in 2010 using updated catch data (Brodziak 2010). The previous assessment results indicated that for both swordfish stocks, current biomasses were above the biomass at which the maximum sustainable yield (MSY), or maximum surplus production would be obtained and harvest rates were below the harvest rate to produce MSY (ISC, 2009).

Based on the scientific consensus that a two-stock scenario is likely, we present here an updated assessment of the WCNPO and EPO swordfish stocks. The WCNPO stock is distributed in the North Pacific Ocean west of a diagonal boundary that extends from 170 ˚W towards Baja California (Figure 1) (Ichinokawa and Brodziak 2008). The EPO swordfish stock is centered on the Equator in the Eastern Pacific, bounded on the south by 20 ˚S and extending northeast diagonally from 170 ˚W towards Baja California (
Figure **2**).

We applied a Bayesian statistical framework to estimate parameters of production models to assess the swordfish population in the WCNPO area using updated catch and effort through 2012. The Bayesian method provided direct estimates of parameter uncertainty that were straightforward to interpret and were appropriate for risk analyses. The production models include both process error for biomass production dynamics and observation errors for fitting the observed CPUE data from multiple fishing fleets. The assessment model estimated biological reference points, biomass, harvest rate, stock status, and associated uncertainties. The objectives of this study are: (i) to update the ISC (2009) stock assessment for the WCNPO and EPO stocks, (ii) to develop Bayesian posterior distributions for quantities of management interest using Markov chain Monte Carlo (MCMC) simulation, (iii) to examine the sensitivity of the results of the assessment to changes to its prior assumptions, (iv) to conduct a retrospective analysis of stock assessment estimates, and (v) to conduct future stock projections accounting for uncertainty in stock size estimates and process error.

MATERIALS AND METHODS

Fishery Data

<u>Catch</u>

For the WCNPO swordfish stock, fishery catch data by country from 1951-2012 for assessing WCNPO swordfish were taken from the most recent summary of available fishery-dependent data (Kimoto and Yokawa, 2014; Ito and Childers, 2014). Commercial catch of swordfish caught by Japan, Taiwan, Korea, USA, and other countries in the WCNPO stock area were updated from the 2009 assessment (Table 1.1, Figures 1 and 2.1). More specifically, Japan, Taiwan, Korea, and the USA directly provided updated catch data, and swordfish catches for all other fishing countries in the WCNPO area were collected from WCPFC 2005-2012 and IATTC 2007-2012 category II data (Tagami et al., 2014, Figure 2.1). Japanese swordfish fishery data included Japanese coastal, offshore, and distant-water longliners and other coastal gears. Taiwanese swordfish fishery data included the distant water longline, offshore longline and costal fisheries while Korean swordfish fishery data included distant water longline fishery. For the IATTC swordfish fishery data, the swordfish catch numbers in WCNPO area were converted to catch biomass by using the annual averaged weight that derived from the size-frequency data and the relationship between body biomass (W, kg) and eye-fork-length (EFL, cm) (DeMartini et al. 2000, DeMartini et al. 2007, Uchiyama and Humphreys, 2007):

$$W = 0.0000137 * L^{3.04} \quad (1)$$

where W is weight in kg and L is eye-fork length in cm. For the WCPFC swordfish fishery data, swordfish catch biomasses were also separated by stock area, and the WCNPO stock included catch data from Belize, Cook Islands, China, Spain, Fiji, Federated States of Micronesia, Kiribati, Marshall Islands, Papua New Guinea, Senegal, Tuvalu, and Vanuatu (Table 1.1).

Swordfish are also mostly caught by longline fisheries in the EPO, some of which target other pelagic species such as tuna. The annual EPO swordfish catch has fluctuated between 3,000 to almost 10,000 metric tons (mt) since 2000. The majority of catch has been taken by longline fishing vessels from Japan, Spain, China, Korea, and Taiwan (Table 1.2, Figures 1 and 2.2), which accounted for 91% of the total harvest in the Eastern Pacific in 2012. The remaining catch was taken by Belize, Mexico, Chile, French Polynesia, Peru, Vanuatu, and the United States.

Fishery catch data for swordfish in the Eastern Pacific Ocean from 1951-2012 were compiled from several sources. Catch data from 1951-2006 were taken from the most recent summary of available fishery-dependent data during the previous assessment (Brodziak 2010). More recent catch data from 2007-2012 were compiled using data provided by the Inter-American Tropical Tuna Commission (IATTC), Western and Central Pacific Fisheries Commission (WCPFC), and individual countries of Japan, Taiwan, Korea, Mexico, and Chile (Table 1.2 and Figure 2.2).

When a country provided catch data directly to the ISC Billfish Working Group, those data were considered more accurate and were used in lieu of data reported to the IATTC and WCPFC. Overall, the catch data were used to model the effects of fishery removals from the EPO swordfish stock during 1951-2012. A description of each dataset follows.

The IATTC provided a catch dataset for 2007-2012 describing total numbers of swordfish caught by longline by year, country, latitude, and longitude. The IATTC also provided a separate smaller dataset on lengths, indicating the total numbers of swordfish caught and their sizes in cm by year, country, latitude, and longitude. Each dataset was separated into data for the EPO stock and for the WCNPO stock. The lengths dataset was used to convert total numbers caught in the catch dataset into biomass. First, the lengths were converted into biomass using the length-weight relationship for swordfish in Eqn (1). From these weights, the average weight of a swordfish caught in each year was calculated, and this average yearly weight was used to convert the numbers of swordfish caught in the catch dataset into swordfish catch biomass. The catch dataset was then aggregated by country and year to calculate the annual swordfish catch biomass.

Based on fishery information from the IATTC, the entire longline swordfish catch of Peru was expected to have been harvested in the EPO. As a result, the entire Peruvian catch time series from 1954-2010 was added to the catch data for swordfish in the EPO. Catch data from Peru came from the most recent assessment of swordfish conducted by the IATTC (Hinton and Maunder 2011). This is the first time that swordfish data from Peru were included in the EPO assessment. The annual EPO swordfish catch from Peru during 2011-2012 was estimated as the average catch from 2007-2010.

Similarly, the WCPFC provided data for 2007-2012 north of the Equator on swordfish numbers and tons caught by year, country, latitude, and longitude. These data were separated by stock area (EPO versus WCNPO) and were aggregated by country and year to calculate the total tons of swordfish caught by each country in each year (Tables 1.1 and 1.2).

Swordfish catches for Japan, Taiwan, Korea, Mexico, and Chile were collected from the individual countries. Japan provided total swordfish catch in mt from their offshore and distant-water longline fleet for 1951-2012, with data from 2011 and 2012 still preliminary (Kimoto and Yokawa 2014). These data were used for 2007-2012, since it was considered more accurate than the reported IATTC and WCPFC data. The updated Japanese catch data for 1951-2006 were considered the best available data to date, and as a result, Japanese catch time series used in the previous assessment was replaced with the updated data and the total catch biomass time series was updated. Taiwan provided total swordfish catch biomass from their offshore and distant water longline fleet from 1964-2012. The updated Taiwanese catch data for 1964-2006 were used in lieu of the Taiwanese time series of catch used in the previous assessment. Taiwan also provided a brand new time series of swordfish catch for their offshore longline and other fisheries. The total catch of swordfish in the EPO was updated using these two catch time series. In particular, the Taiwanese catch data for 2007-2012 were used in place of Taiwanese data reported to IATTC and WCPFC, which included some minor differences. Korea provided total swordfish catch biomass for 2007-2012 from their tuna longline fisheries, by year, latitude, and longitude. These data was separated by stock area (EPO versus WCNPO), and then aggregated by year to calculate the Korean swordfish catch biomass by year during 2007-2012. Again, these country-specific data were used in lieu of catch data for Korean data reported to the IATTC and WCPFC, which included some minor differences.

Swordfish catch biomass data for the Mexican longline fishery during 2007-2010 were taken from the most recent ISC country report submitted by Mexico (Dreyfus et al. 2013). The annual EPO swordfish catch for Mexico during 2011-2012 was estimated as the average annual catch during 2007-2010. Data were not available by latitude and longitude, but catch distribution maps indicated that the vast majority of swordfish were caught in the EPO rather than in the WCNPO. As a result, all swordfish caught by Mexico were assumed to be from the EPO stock. Swordfish catch data from Chile was updated for 2007-2012 using Annual Statistics of Fisheries and Aquaculture reports from the Chilean fisheries agency, Servicio Nacional de Pesca y Acuicultura (SERNAPESCA 2007-2012). At the guidance of the IATCC, it was assumed that swordfish landed in Chile's two northernmost fishery regions (Regions XV and I), which lie north of the southern boundary of the EPO, were likely harvested in the EPO. The total landings of swordfish from these two regions were added to the total EPO catch by year.

Catch-Per-Unit Effort

For WCNPO swordfish, standardized fishery-dependent CPUE swordfish were estimated for Japanese distant water and offshore longline fisheries, Taiwanese distant water longline fisheries, and the shallow-set sector of the Hawaii-based pelagic longline fishery (Table 2.1, Figures 1 and 3.1). In particular, monthly aggregated dataset by 5x5 degree grids from 1952-1974 and those gear configurations from 1975 to 2012 were used in the CPUE standardization for Japanese distant water and offshore longline fisheries (Kimoto et al., 2014). The two standardized CPUE series were combined into a single period from 1952-2012 (n = 61) using the average ratio of the standardized CPUEs for the time period of series overlap between 1975 and 1979 (Table 2.1 and Figure 3.1). Alternative CPUE series without Japanese designated areas 8 and 9 were also provided by Kimoto et al. (2014).

For Taiwanese distant water longline fisheries, aggregated data by 5x5 degree grids, month, and gear configurations were used for CPUE standardization (Sun et al., 2014). Information about gear configuration was only available since 1995. It was noted that there has been a change in target species and fishing grounds in this fishery around 2000. To account for this change, two standardized CPUE series for the separate time periods of 1969-1999 (n = 25) with several missing values and 2000-2012 (n = 13) were developed (Table 2.1 and Figure 3.1).

Operational data in the shallow-set sector of the Hawaii-based pelagic longline fishery in 1995-2012 collected by fishery observers were used for CPUE standardization (Walsh and Brodziak, 2014). Swordfish is the target species in the shallow-set fishery sector, which was closed between 2001 and 2004 due to fishery interactions with protected sea turtles. Because of this temporal gap, the CPUE standardization analyses used data from 1995-2000 (n = 6) and 2005−2012 (n = 8) to estimate standardized shallow-set CPUE (Table 2.1 and Figure 3.1).

For EPO swordfish, estimates of standardized commercial fishery CPUE were provided by Japan (Kimoto et al. 2014) and Taiwan (Sun et al. 2014) through 2012 (Table 2.2, Figures 1 and 3.2). The Japanese longline CPUE time series spanned 58 years (1955–2012), but was divided into three separate series: 1955-1974, 1975-1993, and 1994-2012 (Table 2.2 and Figure 3.2). The

Taiwanese distant water longline CPUE time series spanned 13 years (2000–2012) and included information on hook per float in the CPUE standardization (Table 2.2 and Figure 3.2). A second Taiwanese distant water longline CPUE time series exists for 1968-1999, but ultimately was not used because the inclusion of this CPUE series resulted in a lack of MCMC convergence and a very poor fit to CPUE data. The standardized CPUE series from Japan and Taiwan served as relative abundance indices for swordfish in the EPO, and were used to model changes in the relative abundance of swordfish through time. We calculated the Pearson correlation coefficient for the two CPUE series that overlapped in time: Japanese CPUE from 1994-2012, and Taiwanese CPUE from 2000-2012. The relative CVs of CPUE were all assumed to be a value of 1, that is, annual observation error variances were set to be equal for each CPUE value in a time series (Brodziak 2010).

Bayesian Production Model

Biomass Dynamics

Swordfish production models followed a similar structure to the previous production model used for Pacific swordfish (Meyer and Millar, 1999; Brodziak and Ishimura 2009; Brodziak 2010). Production models were formulated as Bayesian-state space models with explicit observation and process error terms (e.g., Meyer and Millar 1999, Brodziak 2007). We implemented the state-space models in WinBUGS (version 1.4.3, Lunn et al. 2000) via the R2WinBUGS package (Sturtz et al., 2005) in the statistical programming environment R (R Development Core Team 2008). The biomass time series comprised the unobserved state variables which were estimated from the observed relative abundance indices (i.e., CPUE) and from catches using observation error likelihood function and prior distributions for model parameters (θ). In this case, the observation error likelihood measured the discrepancy between observed and predicted CPUE, and the prior distributions represented the relative degree of belief about the possible values of model parameters.

The process dynamics represented the fluctuations in exploitable swordfish biomass due to density-dependent processes and fishery harvests. The biomass dynamics were based on a generalized production model with an annual time step. Under this three-parameter model, biomass in year T (B_T) depends on the previous biomass (B_{T-1}), catch (C_{T-1}), intrinsic growth rate (R), carrying capacity (K), and a production shape parameter (S) for $T = 2, \ldots, N$:

$$B_T = B_{T-1} + R \cdot B_{T-1}\left(1 - \left(\frac{B_{T-1}}{K}\right)^S\right) - C_{T-1} \qquad (2)$$

The production model shape parameter, S, determines where surplus production peaks as biomass varies as a fraction of carrying capacity. If the shape parameter is less than unity ($0 < S < 1$), then surplus production peaks when biomass is below ½ of K (i.e., a left-skewed production curve) and the stock has relatively high productivity. If the shape parameter is greater than unity ($S > 1$), biomass production is highest when biomass is above ½ of K (i.e., a right-skewed production curve), and the stock has relatively low productivity. If the shape parameter is identically unity ($S = 1$), the production model is identical to a discrete-time Schaefer production model where maximum surplus production occurs when biomass is equal to ½ of K. Thus, the shape of the biomass production curve can be symmetric, right-, or left-skewed depending on the estimated value of S.

The generalized production model was re-parameterized using the proportion of carrying capacity ($P = B/K$) to improve the efficiency of the Markov Chain Monte Carlo algorithm used to estimate parameters (i.e., Meyer and Millar 1999). Given this parameterization, the process dynamics are:

$$P_T = P_{T-1} + R \cdot P_{T-1}\left(1 - P_{T-1}^S\right) - \frac{C_{T-1}}{K} \quad (3)$$

<u>Biological Reference Points</u>

The values of biomass and annual harvest rate that maximize biomass production are relevant as biological reference points for maximum sustainable yield (*MSY*). For the generalized production model, the biomass that produced *MSY* (B_{MSY}) is:

$$B_{MSY} = K \cdot (S+1)^{\frac{-1}{S}} \quad (4)$$

The corresponding annual harvest rate that produced *MSY* (H_{MSY}) was:

$$H_{MSY} = R\left(1 - \frac{1}{S+1}\right), \quad (5)$$

and the associated value of maximum sustainable yield (*MSY*) was:

$$MSY = R\left(1 - \frac{1}{S+1}\right) \cdot K\,(S+1)^{\frac{-1}{S}} \quad (6)$$

Note that H_{MSY} can be converted to its instantaneous equivalent, F_{MSY} by the following equation:

$$F_{MSY} = -\log(1 - H_{MSY})\,. \quad (7)$$

As a result, the generalized production model produced estimates of biological reference points for swordfish that can be directly used for determining stock status with respect to MSY-based reference points and this conservation information is provided in the current assessment.

<u>Observation Error Model</u>

The observation error model relates the observed fishery CPUE to the exploitable biomass of the swordfish stock under each scenario. It is assumed that each CPUE index (*I*) is proportional to biomass with catchability coefficient Q_I:

$$I_T = Q_I B_T = Q_I K P_T \quad (8)$$

The observed CPUE values are subject to natural sampling variation which is assumed to be lognormally distributed. The observation errors are distributed as $\nu_T = e^{V_T}$, where the V_T are independent and identically distributed normal random variables with a mean of 0 and variance τ^2_I for CPUE series *I*.

Given the lognormal observation errors, the observation equations for each CPUE series *I* for each year indexed by $T = 1,\ldots, N$ are:

$$I_T = Q_I K P_T \cdot \nu_T \quad (9)$$

This specifies the general form of the observation error likelihood function $p(I_T \mid \theta)$ for each fishing fleet through time.

Process Error Model

The process error model compares the dynamics of exploitable biomass to natural variability in demographic and environmental processes affecting the swordfish stock. The deterministic process dynamics (Eqn. 3) are subject to natural variation as a result of fluctuations in life history parameters, trophic interactions, environmental conditions and other factors. In this case, the process error represents the joint effects of a large number of random multiplicative events which combine to form a multiplicative lognormal process under the Central Limit Theorem. As a result, the process error terms are assumed to be independent and lognormally distributed random variables $\eta_T = e^{U_T}$ where the U_T are normal random variables with mean 0 and variance σ^2.

Given the process errors, the state equations define the stochastic process dynamics by relating the unobserved biomass states to the observed catches and the estimated population dynamics parameters. Assuming multiplicative lognormal process errors, the state equations for the initial time period ($T = 1$) and subsequent periods ($T > 1$) are:

$$P_1 = \eta_1$$

$$P_T = \left(P_{T-1} + R \cdot P_{T-1}\left(1 - P_{T-1}^{S}\right) - \frac{C_{T-1}}{K} \right) \cdot \eta_T \quad for\ T > 1 \qquad (10)$$

These coupled state equations set the conditional prior distribution for the proportion of carrying capacity, $p(P_T)$, in each time period T, conditioned on the proportion in the previous period.

Prior Distributions

Under the Bayesian estimation framework, prior distributions were employed to quantify existing knowledge, or the lack thereof, of the likely value of each model parameter. For the production model, the model parameters consisted of the carrying capacity (K), the intrinsic growth rate (R), the shape parameter (S), the catchability coefficients (Q_I), the process and observation error variances (σ^2 and τ^2_I), and the annual biomasses as a proportion of carrying capacity (P). Auxiliary information was incorporated into the formulation of the prior distributions when it was available. Information about the prior distributions used in the production model analyses were summarized for WCNPO (Table 3.1) and EPO swordfish (Table 3.2) stocks and details of the prior distributions are described below.

Prior for Carrying Capacity

The prior distribution for the carrying capacity $p(K)$ is a lognormal distribution with mean $\left(\mu_K\right)$ and variance $\left(\sigma_K^2\right)$ parameters:

$$p(K) = \frac{1}{\sqrt{2\pi} K \sigma_K} \exp\left(-\frac{\left(\log K - \mu_K\right)^2}{2\sigma_K^2} \right) \qquad (11)$$

The variance parameter is set to achieve a coefficient of variation (CV) for K of 50%, e.g., $CV[K] = \left(\exp\left(\sigma_K^2\right) - 1\right)^{\frac{1}{2}}$ = 0.5. The mean K values for WCNPO and EPO swordfish were set at 150,000 mt and 75,000 mt, respectively. These mean values were taken from the previous assessments and reflect the order of magnitude of exploitable biomass likely needed to support the observed fishery catches.

Prior for Intrinsic Growth Rate

The prior distribution for intrinsic growth rate $p(R)$ is a lognormal distribution with mean (μ_R) and variance $\left(\sigma_R^2\right)$ parameters set to achieve a CV for R of 50%:

$$p(R) \;=\; \frac{1}{\sqrt{2\pi}R\sigma_R}\exp\left(-\frac{\left(\log R-\mu_R\right)^2}{2\sigma_R^2}\right). \qquad (12)$$

The mean R parameter for both WCNPO and EPO stocks was set to be $\mu_R = 0.5$. This mean value is slightly higher than the range of prior means of (0.40, 0.43) estimated for North and South Atlantic swordfish, respectively, based on an analysis of life history parameters (McAllister et al. 2000). A similar analysis using life history parameters for North Pacific swordfish and the mean generation time approach (see McAllister et al. 2001) suggested higher mean values of R of approximately 0.9 to 1.0 were appropriate. This analysis assumed female growth and maturation from DeMartini et al. (2000) and DeMartini et al. (2007) and used five alternative natural mortality rate estimators (Hoenig, Alverson and Carney, Pauly, Beverton-Holt 2nd invariant, and Lorenzen Tropical) from Brodziak (2009) to calculate five alternative estimates of R. The primary difference between the Atlantic and Pacific swordfish life history parameters was the value of natural mortality. McAllister et al. (2000) assumed a constant natural mortality rate of $M = 0.2$ for Atlantic swordfish, while the Pacific swordfish natural mortality rate was estimated to be $M \approx 0.35$, roughly 75% higher than the Atlantic swordfish value. While there is uncertainty about an appropriate prior mean for R, setting the prior mean to be $\mu_R = 0.5$ with a CV of 50% allows sufficient flexibility to estimate the probable value of R given the observed catch and CPUE data.

Prior for Production Shape Parameter

The prior distribution for the production function shape parameter $p(S)$ is a gamma distribution with rate parameter λ and shape parameter k:

$$p(S) \;=\; \frac{\lambda^k S^{k-1}\exp\left(-\lambda S\right)}{\Gamma\left(k\right)}. \qquad (13)$$

For both WCNPO and EPO stocks, the values of the rate and shape parameters are set to $\lambda = k = 2$. This choice of parameters sets the mean of $p(S)$ to be $\mu_S = 1$, which corresponds to the value of S for the Schaefer production model. This choice also implies that the CV of the shape parameter prior is 71%. In effect, the shape parameter prior is centered on the symmetric Schaefer model as the default with sufficient flexibility to estimate a nonsymmetrical production function if needed.

Prior for Catchabilities

The prior for the catchability coefficients $p(Q_I)$ for a given fleet I is chosen to be a diffuse inverse-gamma distribution with scale parameter λ and shape parameter k:

$$p(Q_I) = \frac{\lambda^k Q_I^{-(k+1)}}{\Gamma(k)}\exp\left(\frac{-\lambda}{Q_I}\right). \qquad (14)$$

For both the WCNPO and EPO stocks, the scale and shape parameters are set to be $\lambda = k = 0.01$. This choice of parameters implies that $1/Q_I$ has a mean of 1 and a variance of 100 and produces a relatively uninformative prior. Since $1/Q_I$ is unbounded at $Q_I = 0$, an additional numerical constraint that Q_I be no smaller than 0.0001 is imposed for the Markov Chain Monte Carlo sampling.

Priors for Process and Observation Error Variances

For both swordfish stocks, the priors for the process error variance $p(\sigma^2)$ and observation error variance $p(\tau^2_I)$ for each fleet I are chosen to be inverse-gamma distributions. The choice of an inverse gamma distribution implies that the associated prior for error precision ($\pi = 1/\sigma^2$) was effectively $p(\pi) \propto \pi^{-1}$ which is the Jeffrey's prior for the precision parameter (Congdon 2001). As a result, inferences based on the gamma assumption are scale invariant and are not affected by changing the scale of the variance parameter. For the process error variance prior, the scale parameter is set to $\lambda = 4$ and the shape parameter is $k = 0.1$. This choice of parameters produces an expected value of approximately $E\left[\sigma^2\right] = 0.025$ with a CV of 16%. Similarly, for the observation error variance prior, the scale parameter is set to $\lambda = 2$ and the shape parameter is $k = 0.45$. This choice of parameters produced an expected value of approximately $E\left[\tau_I^2\right] = 0.223$ with a CV of 50%. Given these prior assumptions, the initial observation error variance is roughly threefold greater than the process error variance. Of course, the posterior means of the process and observation errors estimated from the MCMC sampling also depend on the model fits to the observed data.

Priors for Proportions of Carrying Capacity

Prior distributions for the time series of the proportion of biomass to carrying capacity, $p(P_T)$, are lognormal distributions as specified in the process dynamics. For both stocks, the mean proportion of carrying capacity for the initial year of 1951 (P_1) was set to be 0.9. This corresponded to an assumption that the North Pacific swordfish population was lightly exploited and had biomass near its carrying capacity following a period of limited directed fishing during World War II. To be consistent with the previous stock assessment, a CV of 10% was used. However, an alternative model configuration that used a CV of 50% was tested for the WCNPO stock to understand the effect of higher variation.

Posterior Distribution

The joint posterior distribution of the swordfish production model needs to be sampled to make inferences about estimates of the model parameters. Given the catch data and J series of standardized CPUE data to comprise the model data D, the posterior distribution $p(\theta \mid D)$ is proportional to the product of the prior distributions and the CPUE likelihood via Bayes theorem:

$$p(\theta \mid D) \propto p(K)\,p(R)\,p(S)\,p(Q)\,p(\sigma^2)\prod_{t=1}^{N} p(P_t)\prod_{j\in J} p(\tau_j^2)\prod_{T=1}^{N} p(I_{j,T} \mid \theta) \quad (15)$$

Parameter estimation for this nonlinear multi-parameter model is based on generating a large number of independent samples from the posterior distribution. In this case, the Markov Chain Monte Carlo (MCMC) simulation using Gibbs sampling is applied to numerically generate a sequence of samples from the posterior distribution (Gilks et al. 1996). The WINBUGS software (Spiegelhalter et al. 2003) is used to set the initial conditions, perform the MCMC calculations, and summarize the results.

Markov Chain Monte Carlo simulations are conducted by simulating three chains of samples for each model. Each model was run for 800,000 iterations, sampled with a thinning rate of 25 with a burn-in period of 200,000 for three chains for a total of 72,000 samples to generate the posterior distributions.

A key issue in applying MCMC methods is how to determine when random draws have converged to the posterior distribution. Convergence of the MCMC samples to the posterior distribution was checked by monitoring the trace and diagnosing the autocorrelation plot. Convergence of the MCMC simulations to the posterior distribution was also checked using the Geweke diagnostic (Geweke 1992), Gelman and Rubin diagnostic (Gelman and Rubin 1992), and the Heidelberger and Welch stationarity and half-interval test (Heidelberger and Welch 1983), as implemented in the R Language (R Development Core Team 2013) using the CODA software package (Plummer et al. 2006). These convergence diagnostics were monitored for several key model parameters (intrinsic growth rate, carrying capacity, production function shape parameter, and catchability coefficients) to verify convergence of the MCMC chains to the posterior distribution.

Model Diagnostics

Goodness-of-fit to CPUE was measured to compare alternative production models using model residuals, root mean-squared error (RMSE), and the correlation between observed and predicted CPUE. Model residuals for the CPUE series are the log-scale observation errors ε_T:

$$\varepsilon_T = \ln(I_T) - \ln(QKP_T) . \quad (16)$$

A nonrandom pattern in the residuals indicates that the observed CPUE did not conform to one or more model assumptions. The RMSE of the CPUE fit provides another goodness-of-fit diagnostic with lower RMSE indicating a better fit when comparing models with the same number of parameters. Similarly, a higher correlation between observed and predicted CPUE indicates a better model match to observed CPUE trend.

The goodness of fit among different models with same data structure was evaluated by Deviance information criterion (DIC) (Spiegelhalter et al., 2002). The standardized log-residuals from the CPUE fit were visually examined for time trends. The Shapiro-Wilk test (Shapiro and Wilk, 1965) was used to test the normality of the standardized log-residuals. The estimates of production model can be problematic when the data are not informative about whether the population has a high K and a low r or vice versa (Hilborn and Walters, 1992). The posterior correlation between model parameters was examined for the base-case model.

Sensitivity Analyses

The sensitivity of model outputs to priors was tested by varying the initial prior means of four key parameters: *R*, intrinsic growth rate; *K*, carrying capacity; *S*, shape parameter; and P_1, initial proportion of biomass to carrying capacity. For each of these prior means, we varied the prior mean by 25% higher and 25% lower, and compared resulting model outputs. These were considered to be useful high and low bounds for understanding which parameter was most important for estimating outputs, and more importantly, whether assessment results were robust to a 25% change in an input prior.

Retrospective Analyses

We tested for any possible retrospective pattern (systematic inconsistencies among our model estimates of biomass and harvest rate based on increasing periods of data) by sequentially removing the most recent year of data going back 7 years, re-analyzing the model, and comparing estimated biomass and harvest rates. The within-model retrospective analyses were used to examine changes in the estimates of exploitable biomass. Mohn's (1999) rho statistic (rho) was calculated as:

$$rho = \sum_{y=1}^{npeels} \frac{B_{Y-y,tip} - B_{Y-y,ref}}{B_{Y-y,ref}} \qquad (3)$$

where B denotes exploitable biomass, y denotes year, *npeels* denotes the number of years that are dropped in successive fashion and the assessment rerun, Y is the last year in the full time series, *tip* denotes the terminal estimate from an assessment with a reduced time series, and *ref* denotes the assessment using the full time series.

Projections

Stochastic projections were conducted to show the probable changes in exploitable biomass and catch under various harvest scenarios, including scenarios requested by the Western and Central Pacific Fisheries Commission's 9th session of the Northern Committee. The following harvest scenarios were projected 4 years forward from 2012, the most recent year included in the assessment, to 2016:

a) Status quo harvest rate from the most recent 3 years
b) Status quo catch from the most recent 3 years
c) The maximum observed annual harvest rate
d) Harvest rate set at multiples of 0.5, 0.75, 1.0, 1.25, and 1.5 of F_{MSY}

Projected harvest rates were sampled from a normal distribution with a mean corresponding to each scenario harvest value, and the standard deviation of harvest or catch values for the most recent 3 years (scenarios a and b) or a standard deviation assumed to be 5% of the mean value (scenarios c and d). Projections included process error and uncertainty in parameter estimation. The initial conditions for the projections are based on the MCMC samples from the estimated posterior distribution of exploitable swordfish biomass in the most recent year.

Risk Analyses

Risk analyses to show the odds of depletion and overfishing were conducted. In these analyses, we calculated the probability of becoming overfished ($B<0.5*B_{MSY}$) and overfishing ($H>H_{MSY}$) given a range of different projected future total catch levels for each stock. We projected 5 years forward from 2012, the most recent year of full data available to be included in the assessment, using catch levels at fixed intervals from 0 mt to a maximum of 40,000 mt, which is approximately four times the most recent average catch. Projected catch was sampled from a normal distribution centered at the projected catch level with a standard deviation of the most recent 3 years of catch. The initial conditions for the projections were based on the MCMC samples from the estimated joint posterior distribution of exploitable swordfish biomass and all other parameters in the most recent year. As a result, each projection harvest scenario included parameter estimation uncertainty, which, in turn, was incorporated into the estimated probabilities of overfishing or becoming overfished.

RESULTS

Fishery Data

Catch

For the WCNPO swordfish stock, the updated catch led to an increase of about 10% and 30% in the 1960-2000 and 2000-2009 reported swordfish catch biomass, respectively, compared to the 2009 assessment. Time-series of fishery catches by country showed variability in swordfish yields over the past six decades (Table 1.1 and Figure 2.1). During the 1950s, Japanese distant-water and offshore longline fisheries accounted for more than 80% of the annual swordfish harvests. The total reported annual catch of WCNPO swordfish peaked at 22,000 metric tons in 1960. In the following decade, however, these fleets rapidly expanded for targeting tunas, and swordfish catches rapidly decreased during the 1960s. During the 1970s, the average annual reported catch of swordfish in the WCNPO area was about 10,100 metric tons and the historical lowest catch of 6,800 metric tons occurred in 1972. The total swordfish catch slightly increased in the 1980s and reached a level of 15,800 metric tons in 1985 resulting from a few years of higher catch of Japanese distant-water and offshore longline fleets and other USA fisheries (Figure 2.1). The swordfish catches by Japanese distant-water and offshore longline fleets showed a declining trend since 1990. However, there was a steep increase in Hawaii-based longline catches during the early 1990s and total swordfish catch reached a high level of 19,200 metric tons, then declined to a level of 13,700 metric tons in 1996-1999 (Figure 2.1). During the 2000s, the average annual reported catch of swordfish in the WCNPO was about 13,600 metric tons. After 2007, the total catches decreased significantly to around 10,000 metric tons and maintained at that level in 2011−2012. It should be noted a large fraction (25%) of the swordfish catch has been taken by the Taiwanese offshore longline and other fisheries during this period.

Total catches of EPO swordfish were tabulated from all countries and sources (Table 1.2 and Figure 2.2) from 1951-2012. Swordfish catches were low in the early years of the fishery and steadily increased until 1970, after which catch fluctuated between 2,000 and 7,500 mt through the 1990s (Figure 2.2). In 1998 and 2001-2002, annual catches were above 7,000 mt, and then declined to 3,235 mt in 2006. Since then, catch has risen to an historic peak of 9,910 mt in 2012 (Figure 2.2).

For the EPO swordfish stock, Japan and Spain had the highest swordfish catch in recent years (2007-2012), each catching over 2,000 mt in 2012 (Table 2.1 and Figure 2.2). China and Taiwan also caught large amounts of swordfish, over 1,500 mt in 2012. These four countries (Japan, Spain, China, and Taiwan) jointly caught 85% of the total swordfish harvest in the EPO in 2012. Korea, Belize, Mexico, and Chile caught moderate amounts of swordfish. French Polynesia, Peru, the United States, and Vanuatu caught nominal amounts of swordfish.

Catch-Per-Unit Effort

For the WCNPO stock, time-series of abundance indices available for this assessment showed some similarities in trends (Figure 3.1). Visual examination of the four CPUE indices suggested a similar trend of low CPUE in the 1970s, high CPUE in the early 1990s, and declining CPUE in the recent years among the indices used. Outliers in 1976, 1990, and 1995 were found in the Taiwanese distant water longline CPUE. The relative CV for Japanese distant water and offshore longline CPUE during 1952-1974 was larger than the CPUE values during 1975-2012. Higher relative CPUE was also observed in the earlier period of Taiwanese distant water longline (1969-1999) and the Hawaii longline during 1995-1999 (Table 2.1 and Figure 3.1). There were no strong correlations ($|\rho| \geq 0.5$) between CPUE time series. All pairs of CPUE indices were weakly or moderately positively correlated and had Pearson correlations ranging from 0.17 to 0.3, with the exception of the correlation between the Japanese distant water and offshore longline CPUE during 1952-2012 and the Taiwanese distant water longline CPUE during 2000-2012 (ρ = -0.06) and the correlation between the Hawaii longline CPUE during 1995-2012 and the Taiwan DW longline CPUE during 1969-1999 (ρ = -0.22).

For the EPO stock, the two early standardized CPUE time series for Japan are each relatively stable, fluctuating around an average value (Table 2.2 and Figure 3.2). The third and most recent CPUE series for Japan shows a sharp threefold increase in the most recent years, 2006-2012. The single CPUE series for Taiwan for 2000-2010 fluctuated around an average value. The most recent Japanese CPUE during 1994-2012 and the Taiwanese CPUE during 2000-2012 were moderately positively correlated with a Pearson correlation coefficient of $\rho = 0.50$.

Bayesian Production Model

<u>Posterior Distribution Convergence</u>
For the WCNPO swordfish stock, a plot of the autocorrelation function indicated a thinning interval of 25 which was large enough to address potential autocorrelation in the MCMC runs. Visual inspection of trace plots for the major parameters showed good mixing of the three MCMC chains (i.e., fully-sampling the parameter space), and also indicated convergence of the MCMC chains. For all parameters, the Gelman and Rubin statistic, including the variance terms, equaled 1, which indicated convergence of the MCMC chains. Similarly, the Heidelberger and Welch test did not reject the hypothesis that the MCMC chains were stationary at the 95% confidence level for any of the parameters. Overall, these diagnostics indicated that the posterior distribution of the model parameters was adequately sampled with the MCMC simulations.

For the EPO swordfish stock, all key model parameters (intrinsic growth rate, carrying capacity, production function shape parameter, and catchability coefficients) and biological reference points converged according to the Geweke diagnostic (Geweke 1992), Gelman and Rubin diagnostic (Gelman and Rubin 1992), and the Heidelberger and Welch stationarity and half-interval tests. A visual inspection of model parameter posterior distribution density plots indicated that these densities were smooth and unimodal for all parameters as expected for a convergent sequence of MCMC samples. Overall, the convergence diagnostics that were examined indicated that the MCMC samples generated from the generalized production model had numerically converged to the posterior distribution.

<u>Production Model Fits to CPUE</u>
For the WCNPO stock, the predicted CPUE indices were compared to the observed CPUE for each model to determine the adequacy of model fit (Figure 4.1). Plots of standardized residual diagnostics by fishery for the base-case model indicated a good fit to the long-term Japanese longline CPUE and more variable fits to the shorter CPUE time series (Figure 4.1). Fits of other candidate runs were also examined and were summarized in Chang et al. (2014) but are not

presented here. A summary table of residual patterns, normality test results, RMSE values and DIC values showed that several patterns were immediately apparent (Table 4.1 and Figure 4.1):

1) Models which included Taiwanese longline CPUE during 1969-1999 had residuals which showed non-random temporal patterns for both the two Taiwanese longline CPUE indices (1969-1999 and 2000-2012) and the Hawaii longline CPUE. The Taiwanese longline CPUE during 2000-2012 also failed the Shapiro-Wilk normality test ($W = 0.82$, $P < 0.05$).

2) The model fit using the alternative Japanese longline CPUE that did not include data from areas 8 and 9 showed a poorer fit (RMSE = 2.716) and appeared to have a non-random residual pattern for the Hawaii CPUE in comparison to model fits which included Japanese data from areas 8 and 9 (RMSE = 2.273).

3) Assuming a higher CV for the prior distribution of P1 (CV=50%) did not produce an overall improvement to model fit to the CPUE indices and also had a poorer fit and residual pattern for the Hawaii CPUE series (RMSE = 2.758).

4) DIC values were compared among models with the same data structure. Results indicated that the minimum value of DIC (DIC=-185.49) was achieved by model selected as the base case model. DIC values for the other two viable candidate models were 8.48 and 2.90 units higher than for the base case model (Chang et al. 2014), respectively. Based on all this information, the base case model for stock status determination was agreed upon by the ISC Billfish Working Group.

For the base case model fit to Japanese CPUE, predicted CPUE values fluctuated about the observed CPUE time series and the standardized residuals had no time trend and were normally distributed (Figure 4.1). However, the Taiwanese longline CPUE fit had a pattern of consecutive negative residuals in the late-2000s and the standardized residuals failed the normality test at significance level of 0.05 ($W = 0.81$, $P = 0.001$). Fits to the Hawaii longline CPUE appeared to have no trend in residuals and the standardized residuals were normally distributed. Overall, the base case model fits to the WCNPO Pacific swordfish CPUE indicated that there was a good fit to the Japanese longline CPUE and a minor lack of fit to the Taiwanese longline CPUE.

For the EPO stock, the base case model fit the standardized CPUE series adequately (Figure 4.2). Standardized residuals for the first and second Japanese CPUE series appeared to be random and predicted CPUE fluctuated randomly about the observed CPUE. Standardized residuals for the third Japanese CPUE series did not appear random and the predicted CPUE was an underestimate of the observed Japanese CPUE during 2006-2012 when the CPUE series exhibited a twofold increase (Figure 4.2). During 2006-2012, the residuals for the Taiwanese CPUE also did not appear to have a flat trend although the magnitude of those residuals was relatively small. However, the Shapiro-Wilks normality test indicated that standardized residuals from each CPUE series were normally distributed ($P>0.05$). Standardized residuals of the first Japanese CPUE, third Japanese CPUE, and Taiwanese CPUE exhibited some time trend ($P\leq0.01$) according to a regression of standardized residuals against time. Bartlett's test showed that the variances of standardized residuals for the first and third Japanese CPUE were not homogeneous ($P<0.05$), but variance was homogeneous for the Taiwanese CPUE ($P>0.05$). Standardized residuals for the second Japanese CPUE series showed no time trend ($P>0.05$) and had homogeneous variance ($P>0.05$). Overall, the CPUE fits were judged to be adequate, albeit variable.

Based on RMSE values, model fits were best for the first two Japanese CPUE series (1952-1974, 1975-1993), followed by the Taiwanese series (2000-2012) (Table 4.2). The poorest fit (highest RMSE value) came from the model fit to the third Japanese CPUE series from 1994-2012, which reflected the difficulty of fitting the model to the high values of CPUE in recent years. The correlation coefficients for all Japanese CPUE series were greater than one-half ($\rho>0.50$) and indicated a generally good model fit to CPUE trend. The correlation coefficient for the Taiwan CPUE series was a moderately good fit to CPUE trend with a value of $\rho=0.43$. Overall, the base case model fit was judged to provide an adequate fit to the CPUE series with some exceptions for the most recent years of high observed CPUE for the Japanese longline fishery.

Estimated Parameters, Quantities of Interest, and Reference Points

For the WCNPO stock, estimates of the mean and standard deviation of model parameters, quantities of interest, and MSY-based reference points were tabulated (Table 5.1). Estimates of posterior densities of the parameters r, K, M, σ^2, τ^2, and P1 were smooth and unimodal. Summaries of posterior quantiles of parameters and quantities of interest were provided and showed that the marginal posteriors generally were right-skewed. The marginal posterior for r had a median of r=0.54 (0.28-1.11 95% C.I.), similar to the prior mean. Although both the posterior and prior for K had a peak around 120,000 metric tons, the posterior was much less dispersed than the prior. The marginal posteriors for M and P_1 had median values of 0.89 (0.36-2.08 95% C.I.) and 0.84 (0.69-1.03 95% C.I.), respectively, and these values were slightly different from the prior means. Although diffuse priors were assigned to the process error and observation error variances, the posterior error variances were less dispersed than the priors, which indicated the data reduced uncertainty for the error variances. Furthermore, the observation error variances were greater than the process error variance. The marginal posteriors for MSY, HMSY, and BMSY were slightly right-skewed and were centered at median values of MSY=14,730 metric tons, HMSY=0.25, and BMSY=59,520 metric tons, respectively.

Parameter estimates from this 2014 update were generally similar to those from the 2009 assessment (Table 5.1). The estimate of K scaled with exploitable biomass and was slightly higher in the current assessment (median 121,000 mt) compared to the 2009 assessment (113,000 mt). The estimates of r and M in the current assessment also did not differ substantially from the estimated values in 2009. As a result, estimates of exploitable biomass to maximize surplus production, BMSY, and the maximum surplus production, MSY, from the 2014 assessment were all slightly higher than those values from the 2009 assessment.

Exploitable biomass of WCNPO swordfish fluctuated at or above BMSY throughout the assessment time horizon (Table 6.1 and Figure 5.1). As expected, there was an inverse pattern between estimated biomass and harvest rate as harvest rate fluctuated at or below HMSY. Trends in exploitable biomass and harvest rate from the current assessment are very similar to those from the 2009 assessment (Figure 5.1). After several years of high catches, harvest rates increased to fluctuate around HMSY during 1956-1961. As a result, exploitable biomass decreased to 69,000 mt in 1962, and then fluctuated around 70,000 mt for a decade. Harvest rates fluctuated around 50% of HMSY from the mid-1960s to the late-1980s. Concurrently, exploitable biomass increased to a peak of 121,000 mt in 1987, or roughly two-fold higher than BMSY. Due to increased swordfish catches during the 1990s, harvest rates increased to fluctuate about HMSY and the exploitable biomass gradually declined to roughly BMSY in 1996. The

WCNPO swordfish catch has had a declining trend since 2007, with harvest rates fluctuating around 50% of HMSY (Figures 2.1 and 5.1). For the recent 10 years, exploitable biomass has been relatively stable and fluctuated above BMSY (around 70,000 mt). The probabilities of exploitable biomass being below BMSY and harvest rate exceeding HMSY in 2012 were estimated to be 0.14 and 0, respectively. The Kobe plot showed that the WCNPO swordfish stock does not appear to have been depleted or to have experienced overfishing throughout most of the assessment time horizon of 1951-2012 (Figure 6.1).

For the EPO stock, estimates of the mean and standard deviation of model parameters, quantities of interest, and MSY-based reference points were tabulated (Table 5.2). The intrinsic growth rate was estimated to be r=0.46 and the carrying capacity was K=65,000 mt with an maximum sustainable yield of MSY=5,490 mt. Biomass to produce maximum sustainable yield was estimated to be about 50% of the carrying capacity at BMSY=31,200 mt, and harvest rate to produce maximum sustainable yield was estimated to be HMSY=0.18. The initial proportion of biomass to carrying capacity was P_1=0.88, close to the initially assumed value of 0.90. The production shape parameter was estimated as M=0.93, close to a symmetric Schaefer curve, but was imprecisely estimates with a standard deviation of 0.71 (CV=76%).

Time series of model estimates of exploitable biomass and harvest rate over the assessment time horizon were also summarized (Table 6.2 and Figure 5.2). Exploitable biomass was initially near carrying capacity in the early-1950s and since then, has fluctuated and ranged from 30,000 to 60,000 mt, generally remaining above B_{MSY} throughout the assessment time horizon. It is notable that the estimated 95% confidence intervals for exploitable biomass are wide and large enough that the lower 95% confidence limit falls below B_{MSY} over much of the time period (Figure 5.2). Harvest rates were initially low and steadily increased through time, and likely exceeded H_{MSY} in 1998, 2002, 2003, and also the most recent year, 2012. Trends of exploitable biomass and harvest rate in relation to MSY-based biological reference points were presented as a Kobe plot (Figure 6.2). This plot illustrated that overfishing has likely occurred in a few years in the history of the fishery, and is likely to be occurring in some recent years. In 2012, swordfish in the EPO were experiencing overfishing with a 55% probability.

<u>Sensitivity Analyses</u>

For the WCNPO swordfish stock, the sensitivity analyses for the input prior means of the four parameters showed that the model results were robust to changes in the prior assumptions (Table 7.1 and Figures 7.1.1 and 7.1.2). The trends of relative biomass B/BMSY were almost the same except for the model runs with high or low P1 prior mean (Table 7.1 and Figures 7.1.1 and 7.1.2). However, the status of relative biomass in 1997 and 1998 appeared to depend on the sensitivity scenario. The impact of using lower r and P1 prior means was to produce more pessimistic estimates of stock status. A similar inverse pattern was found in the results for relative harvest rate H/HMSY. Overall, the sensitivity analyses suggested that prior assumptions were not driving the results of the base case WCNPO swordfish production model.

For the EPO swordfish stock, the sensitivity analysis using high (+25%) and low (-25%) values of input prior means for the parameters R, K, S, and P_1 generally indicated that the model results were robust to changes in the prior assumptions (Table 7.2 and Figures 7.2.1 and 7.2.2). The trend and scale of exploitable biomass and harvest rate estimates were also robust to the high and low alternative prior means (Table 7.2 and Figures 7.2.1 and 7.2.2). Overall, this suggested that the priors were not unduly influential for the base case EPO swordfish production model results.

Retrospective Analyses

For the WCNPO stock, retrospective analyses showed that the time series of exploitable biomass estimates produced with the removal of annual assessment data in successive model runs matched very well with the base case model (Figure 8.1). For WCNPO swordfish the value of Mohn's (1999) DR statistic was DR=-0.06 for exploitable biomass, which supported the fact that there was no retrospective pattern for the estimates of exploitable biomass.

For the EPO stock, the retrospective analyses revealed a clear and consistent pattern. Terminal year estimates of biomass and harvest rate appeared to be biased with an underestimation of exploitable biomass and an overestimation of harvest rate (Figure 8.2). The cause of the retrospective pattern in the data has not yet been determined. Any management decisions based on the results of this assessment should consider the fact that there is a clear retrospective pattern in estimates of quantities of interest.

Projections

For the WCNPO stock, projections results were summarized for each of the eight harvest scenarios (Table 8.1 and Figures 9.1.1 and 9.1.2). Stochastic projections indicated there exploitable biomass would likely remain above BMSY through 2016 under the status quo catch or status quo harvest rate scenarios (Table 8.1 and Figure 9.1.1). For the high harvest rate scenarios MaxF, 1.5*FMSY, 1.25*FMSY), exploitable biomass would be projected to decline below BMSY by 2016 (Table 8.1 and Figures 9.1.1 and 9.1.2). Projected harvest rates would exceed the MSY-based overfishing threshold for the high harvest rate scenarios, and in particular, the stock would not be experiencing overfishing during 2014-2016 under the status quo catch or harvest rate scenarios.

For the EPO stock, stochastic projections revealed that exploitable biomass will likely have a decreasing trajectory in the near future under all of the harvest scenarios examined (Table 8.2and Figures 9.2.1 and 9.2.2). Under the high harvest scenarios (status quo catch, MaxF, and 1.5*F_{MSY}), exploitable biomasses were projected to decline to be roughly equal to B_{MSY} in 2016 (Table 8.2and Figures 9.2.1 and 9.2.2). These high relative harvest rate scenarios, including 1.25*F_{MSY}, also resulted in harvest rates above H_{MSY} (Table 8.2). Under the status quo harvest rate scenario, exploitable biomass was projected to decline to about 40,000 mt by 2016, well above the BMSY level. The lowest future harvest scenario of 0.50*F_{MSY} resulted in the smallest decline of exploitable biomass, which was projected to decline from 50,300 mt in 2013 to 48,400 mt in 2016. Overall, the projections showed that if recent high catch levels persist, exploitable biomass will very likely decrease and a moderate risk of overfishing will likely continue to occur.

Risk Analyses

For the WCNPO stock, the risk analyses showed that there was virtually no chance of the stock being overfished or experiencing overfishing in 2016 (Table 9.1 and Figure 10) if current catch levels of about 10,000 mt are maintained. Catches would need to increase to average roughly 15,000 mt to have a moderate (50% chance) risk of overfishing and would need to increase to about 25,000 mt to have a moderate risk of the stock being overfished in 2016 (Figure 10).

For the EPO stock, the risk analyses showed that the probabilities of overfishing and becoming overfished increased as projected catch increased in the future (Table 9.2 and Figure 10). Maintaining the current EPO swordfish catch level would lead to a moderate risk of overfishing in 2016 but would lead to virtually no chance of the stock being overfished in 2016. In particular, future catch levels would need to be reduced to average approximately 9,700 mt, or slightly below the recent average catch, for the probability of overfishing to be below a moderate risk threshold of 50%. In contrast, at the 9,700 mt catch level there would a roughly 0% chance of becoming overfished by 2016 (Figure 10). In comparison, a reduced catch level of 5,800 mt, or slightly above MSY, would result in a reduced probability of overfishing of only about 12% in 2016 in comparison to the status quo harvest rate scenario. Overall, the EPO swordfish stock is perceived to be at a high abundance level above BMSY. However, any increases in catch to fish down the stock should be considered in light of the observed retrospective pattern of biomass estimation in recent years.

DISCUSSION

For the WCNPO stock, the Bayesian estimation framework provided conservation information that accounted for uncertainty in estimates of stock status relative to biological reference points. This is important for effectively conveying stock assessment results to fisheries managers and stakeholders. The probabilistic interpretation of stock status showed that it was very unlikely that the WCNPO swordfish population biomass was below BMSY in 2012 (Pr(B2012 < BMSY)=0.14). Similarly, it was extremely unlikely that the swordfish population was being fished in excess of HMSY in 2012 (Pr(H2012 > HMSY) < 0.005).

For the EPO stock, the generalized production model produced estimates and associated uncertainty of parameters, biological reference points, stock status, and future stock status given different harvest scenarios. Results indicated that overfishing may be occurring in the swordfish longline fishery in the Eastern Pacific Ocean. This result reflects changes to the production model fits to the revised catch and CPUE time series, including the fit to the increased catches and increased Japanese CPUE in recent years. The high increase exhibited by Japanese CPUE in recent years, however, was not matched by an increase in the Taiwanese CPUE. There is a 55% probability that overfishing was occurring in 2012, while there is a 0% chance that the stock was overfished in 2012. If the 2012 high catch levels persist, the moderate risk of overfishing will also persist. Therefore, while the exploitable biomass of the EPO swordfish stock is likely at a healthy level, the most recent catch levels of 10,000 mt, or roughly two times higher than the estimated MSY, are not likely to sustainable in the long term.

During the model selection process and prior to settling on the base case model for EPO swordfish, it was observed that model runs that included the early Taiwanese CPUE series (1968-1999) (Sun et al. 2014) failed to converge. As a result, the early Taiwanese CPUE series was excluded from the final base case model. Future assessments should explore the inclusion of this CPUE series using updated catch and CPUE data, and perhaps alternative standardization models.

We caution that our analysis revealed a clear retrospective pattern in the EPO assessment results, with underestimation of exploitable biomass and overestimation of harvest rate. Any management decisions should take this pattern into account. We recommend that further assessment work on North Pacific swordfish should be conducted to determine whether the retrospective pattern can be accounted for, and further work should also investigate using more detailed biological data with age- or length-structured models.

Applying a Bayesian estimation framework allowed us to make clear statements about the degree of confidence in estimated quantities (Ellison 2004), including biological reference points and the effect of various future harvest scenarios on the stock. By providing probabilities of overfishing and becoming overfished for future harvest scenarios, it is hoped that this information would enable managers to implement a precautionary approach to swordfish fishery management in which acceptable risk levels for undesirable outcomes are selected and decision tables are applied to judge the efficacy of alternative management options (Hilborn and Peterman 1996, McAllister and Kirkwood 1998). A notable result from the use of the Bayesian estimation framework is the large 95% confidence intervals for biomass estimates indicating moderately high uncertainty over the time series of the fishery (1951-2012) and also in the projections and risk analyses.

Although a single stock has generally been assumed for assessment purposes, fisheries stock assessment scientists recognized that not all exploited species fit easily into a unit stock definition. In 2009, the ISC (2009) swordfish assessment indicated that the North Pacific swordfish population was be estimated to be a smaller- (lower K) and more productive stock (higher r) under the single-stock scenario than as a combination of two stocks under the two-stock scenario. While an update the stock assessment for the swordfish in WCNPO area based on the two stocks scenario has been provided, we suggest that alternative swordfish stock structure hypotheses may need to be included in future assessments to address the uncertainty associated with stock structure.

Using a Bayesian estimation approach allowed us to make clear statements about the degree of confidence and uncertainty in estimated quantities. However, it is important to note that the choice of prior distributions can alter posterior estimates of stock status, especially when data quality is questionable (Booth and Quinn, 2006). Although the sensitivity analyses suggested that the prior mean were not driving the results of the base case, we suggest that it is important in future work to explore the robustness of our stock assessment models to different prior distribution functions (e.g., uniform). We also suggest the development and refinement of informative priors based on demographic analyses to reduce the estimation uncertainty (McAllister et al., 2001).

Swordfish are known to be sexually dimorphic. For example, swordfish females mature later than males and the sex-ratio varies with length (DeMartini et al., 2000). These phenomena have implications for fishery selectivity and hence fishing-induced mortality. Therefore, we also recommend that further assessment work on WCNPO swordfish consider more detailed biological data with sex-specific and age- or length-structured models to better approximate the population dynamics.

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Table 1.1. Swordfish (*Xiphias gladius*) catches (metric tons) in the Western and Central Pacific Ocean by fisheries, 1951-2012. A "-" indicates no effort or data not available, and "0" indicates less than 1 metric ton.

Year	Japan		Taiwan		USA		Korea	†Other	TOTAL
	Deepwater & offshore longline	Other	Deepwater longline	Offshore longline & other	Longline (Hawaii)	Other	Longline		
1951	7245	4432	-	-	-	-	-	-	11677
1952	8888	2801	-	-	-	-	-	-	11689
1953	10794	1612	-	-	-	-	-	-	12405
1954	12543	1047	-	-	-	-	-	-	13591
1955	13050	1047	-	-	-	-	-	-	14097
1956	14590	890	-	-	-	-	-	-	15480
1957	14207	983	-	-	-	-	-	-	15190
1958	18510	1209	-	-	-	-	-	-	19719
1959	17181	1031	-	518	-	-	-	-	18731
1960	19983	1342	-	647	-	-	-	-	21972
1961	19398	1432	-	391	-	-	-	-	21221
1962	9950	1508	-	556	-	-	-	-	12014
1963	9644	922	-	361	-	-	-	-	10926
1964	5594	1183	0	368	-	-	-	-	7145
1965	7506	2249	0	358	-	-	-	-	10113
1966	8809	1897	0	520	-	-	-	-	11226
1967	9845	1125	0	681	-	-	-	-	11651
1968	8067	1839	0	775	-	-	-	-	10681
1969	7508	1920	0	850	-	-	-	-	10278
1970	5280	2223	0	909	5	622	-	-	9039
1971	5437	909	0	995	1	102	0	-	7444
1972	4814	891	0	873	0	175	0	-	6753
1973	4833	1307	0	979	0	403	0	-	7522
1974	4791	2193	0	1016	0	428	0	-	8428
1975	5835	3575	11	1052	0	570	0	-	11043
1976	6386	4747	10	807	0	55	0	-	12005
1977	7452	3505	3	683	17	337	165	-	12162
1978	7532	3769	0	558	9	1712	53	-	13633
1979	8168	2246	7	694	7	386	-	-	11508
1980	5655	3038	11	679	5	788	47	-	10223
1981	6638	2774	1	681	3	746	-	-	10843
1982	5312	2392	1	904	5	1111	39	-	9764
1983	7318	2239	0	949	5	1758	9	-	12278
1984	7001	2458	0	997	3	2838	42	-	13339
1985	9114	2402	0	825	2	3399	22	-	15764
1986	8160	2480	0	667	2	2469	7	-	13785

1987	8695	2054	1	1518	24	1795	35	-	14122
1988	8144	2112	0	1040	24	1638	21	-	12979
1989	5942	2741	4	1529	218	1361	30	-	11825
1990	5390	1909	5	1463	2436	1238	41	-	12482
1991	4377	1483	10	1570	4508	1035	3	-	12986
1992	6911	2471	2	1716	5700	1540	5	-	18345
1993	7955	2043	58	1484	5909	1768	11	-	19228
1994	7015	2127	0	1374	3176	1604	49	-	15345
1995	6005	2412	71	1360	2713	1165	7	-	13733
1996	6260	2141	10	733	2502	1203	11	-	12860
1997	6250	1992	20	1419	2881	1315	69	-	13946
1998	5590	2207	22	1219	3263	1416	100	-	13817
1999	5292	2241	63	1446	3100	1943	102	-	14187
2000	5398	2480	64	3476	2949	2630	147	-	17144
2001	5194	1915	121	3903	220	2181	255	-	13789
2002	5199	2370	155	3793	204	1715	284	-	13720
2003	4794	2442	144	3554	147	2156	247	-	13484
2004	4939	2834	502	3327	213	1200	300	-	13315
2005	5054	2777	269	3505	1622	307	339	297	14170
2006	5805	2897	203	3891	1211	523	389	133	15051
2007	5916	3337	191	3744	1735	555	170	151	15799
2008	3979	2960	162	3443	2014	478	351	244	13631
2009	3729	2710	147	3222	1817	306	280	163	12375
2010	3660	1918	231	2324	1676	119	278	463	10670
2011	2430	1320	366	2999	1623	237	256	226	9456
2012	2446	1680	576	3049	1418	110	245	338	9863

†catch data from Belize, Cook Islands, China, Spain, Fiji, Federated States of Micronesia, Kiribati, Marshall Islands, Papua New Guinea, Senegal, Tuvalu, and Vanuatu

Table 1.2. Swordfish (*Xiphias gladius*) catches (metric tons) in the Eastern Pacific Ocean by fisheries, 1951-2012. A '-' indicates no effort or data is not available, and "0" indicates catch of less than 1 metric ton. Japanese catch in 2011 and 2012 is provisional.

Year	Japan	Taiwan		Spain	Mexico	Peru	Korea	China	Chile	†Other	TOTAL
	Offshore & distant water longline	Distant water longline	Offshore longline	Longline	All gears	Longline	Longline				
1951	1	-	-	0	-	-	0	-	-	-	1
1952	1	-	-	0	-	-	0	-	-	-	1
1953	3	-	-	0	-	-	0	-	-	-	3
1954	20	-	-	0	-	700	0	-	-	-	720
1955	14	-	-	0	-	400	0	-	-	-	414
1956	9	-	-	0	-	600	0	-	-	-	609
1957	124	-	-	0	-	600	0	-	-	-	724
1958	80	-	-	0	-	400	0	-	-	-	480
1959	81	-	-	0	-	400	0	-	-	-	481
1960	118	-	-	0	-	400	0	-	-	-	518
1961	527	-	-	0	-	300	0	-	-	-	827
1962	961	-	-	0	-	400	0	-	-	-	1361
1963	1592	-	-	0	-	200	0	-	-	-	1792
1964	3066	0	-	0	-	900	0	-	-	-	3966
1965	1718	0	-	0	-	300	0	-	-	-	2018
1966	2029	0	-	0	-	200	0	-	-	-	2229
1967	1523	21	-	0	-	1300	0	-	-	-	2844
1968	2350	15	-	0	-	800	0	-	-	-	3165
1969	5944	6	-	0	-	1200	0	-	-	-	7150
1970	3995	24	-	0	-	2396	0	-	-	-	6415
1971	2118	14	-	0	-	185	0	-	-	-	2317
1972	2653	22	-	0	2	550	0	-	-	-	3227
1973	3491	19	-	0	4	1941	0	-	-	-	5455
1974	1869	22	-	0	6	470	0	-	-	-	2367
1975	2037	8	-	0	-	158	9	-	-	-	2212
1976	2951	31	-	0	-	295	29	-	-	-	3306
1977	2573	27	-	0	-	420	33	-	-	-	3053
1978	2149	6	-	0	-	436	35	-	-	-	2626
1979	1674	16	-	0	7	188	18	-	-	-	1903
1980	2131	7	-	0	380	216	62	-	-	-	2796
1981	1926	25	-	0	1575	91	153	-	-	-	3770
1982	1806	14	-	0	1365	154	97	-	-	-	3436
1983	1752	5	-	0	120	238	65	-	-	-	2180
1984	1039	9	-	0	47	343	65	-	-	-	1503
1985	1039	8	-	0	18	55	91	-	-	-	1211

1986	2054	11	-	0	422	21	198	-	-	-	2706
1987	2683	25	-	0	550	73	334	-	-	-	3665
1988	2670	23	-	0	613	54	163	-	-	-	3523
1989	2158	103	-	0	690	3	151	-	-	-	3105
1990	2645	29	-	0	2650	1	645	-	-	-	5970
1991	2739	44	-	0	861	3	696	-	-	-	4343
1992	3676	16	-	0	1160	16	372	-	-	-	5240
1993	2696	13	-	0	812	76	385	-	-	-	3982
1994	2507	18	-	0	581	310	344	-	-	-	3760
1995	2140	2	-	0	437	7	399	-	-	-	2985
1996	2116	24	-	0	439	1013	568	-	-	-	4160
1997	2755	26	-	6	2365	24	707	-	-	-	5884
1998	2949	80	-	115	3603	98	675	-	-	-	7520
1999	1551	69	-	29	1136	15	561	-	-	-	3361
2000	2001	283	-	831	2216	2	817	-	-	-	6150
2001	3735	2095	-	245	780	2	517	-	-	-	7374
2002	2824	3088	-	303	465	14	391	-	-	-	7085
2003	2615	1648	72	534	671	26	182	-	-	-	5748
2004	1809	1375	54	1292	270	19	1060	-	-	-	5878
2005	1408	713	93	717	235	28	287	-	-	-	3480
2006	1297	915	114	366	347	63	132	-	-	-	3235
2007	1386	783	36	661	172	46	284	50	246	38	3701
2008	1634	427	12	390	242	124	424	660	312	37	4262
2009	2079	663	76	2546	394	25	687	573	391	38	7473
2010	2653	994	107	3780	222	5	398	858	472	143	9631
2011	3094	790	286	2364	257	50	715	1571	182	278	9586
2012	2986	815	694	2377	257	50	601	1552	221	357	9910

†catch data from Belize, French Polynesia, United States, and Vanuatu

Table 2.1. Catch per unit effort (CPUE, # of swordfish/1000 hooks) used for assessment of swordfish (*Xiphias gladius*) in the Western and Central North Pacific Ocean. A '-' indicates no effort or data available. Calculated relative CVs are reported here, but model runs assumed a relative CV of 1 for all values of all CPUE series.

	Japan Deepwater & offshore longline		Taiwan Deepwater longline		Hawaii Longline	
Year	CPUE	Relative CV	CPUE	Relative CV	CPUE	Relative CV
1951	-	-	-	-	-	-
1952	0.20	1.79	-	-	-	-
1953	0.17	1.78	-	-	-	-
1954	0.24	1.78	-	-	-	-
1955	0.21	1.76	-	-	-	-
1956	0.17	1.75	-	-	-	-
1957	0.18	1.75	-	-	-	-
1958	0.25	1.75	-	-	-	-
1959	0.19	1.74	-	-	-	-
1960	0.21	1.74	-	-	-	-
1961	0.20	1.74	-	-	-	-
1962	0.19	1.73	-	-	-	-
1963	0.22	1.73	-	-	-	-
1964	0.20	1.73	-	-	-	-
1965	0.22	1.72	-	-	-	-
1966	0.22	1.72	-	-	-	-
1967	0.19	1.71	-	-	-	-
1968	0.16	1.72	-	-	-	-
1969	0.18	1.72	-	-	-	-
1970	0.19	1.71	-	-	-	-
1971	0.19	1.72	-	-	-	-
1972	0.18	1.73	-	-	-	-
1973	0.21	1.73	-	-	-	-
1974	0.24	1.72	-	-	-	-
1975	0.21	1.05	-	-	-	-
1976	0.24	1.02	-	-	-	-
1977	0.21	1.01	-	-	-	-
1978	0.18	1.00	-	-	-	-
1979	0.20	1.00	-	-	-	-
1980	0.25	1.01	-	-	-	-
1981	0.23	1.00	-	-	-	-
1982	0.22	1.01	-	-	-	-
1983	0.30	1.01	-	-	-	-
1984	0.27	1.00	-	-	-	-

1985	0.37	1.02	-	-	-	-
1986	0.35	1.01	-	-	-	-
1987	0.39	1.01	-	-	-	-
1988	0.36	1.00	-	-	-	-
1989	0.28	1.01	-	-	-	-
1990	0.32	1.02	-	-	-	-
1991	0.27	1.01	-	-	-	-
1992	0.30	1.02	-	-	-	-
1993	0.29	1.02	-	-	-	-
1994	0.23	1.01	-	-	-	-
1995	0.20	1.01	-	-	8.33	2.12
1996	0.20	1.01	-	-	8.54	2.31
1997	0.14	1.02	-	-	9.18	2.05
1998	0.14	1.02	-	-	8.20	2.11
1999	0.17	1.01	-	-	11.20	1.46
2000	0.20	1.02	0.14	1.21	10.61	2.93
2001	0.24	1.04	0.17	1.15	-	-
2002	0.21	1.03	0.24	1.18	-	-
2003	0.16	1.01	0.19	1.11	-	-
2004	0.17	1.04	0.27	1.00	-	-
2005	0.18	1.04	0.17	1.00	13.33	1.14
2006	0.22	1.03	0.17	1.01	16.32	1.02
2007	0.18	1.05	0.16	1.03	13.83	1.18
2008	0.17	1.05	0.16	1.03	13.53	1.09
2009	0.20	1.07	0.16	1.06	10.90	1.23
2010	0.21	1.10	0.18	1.07	9.23	1.23
2011	0.17	1.08	0.16	1.04	11.70	1.00
2012	0.20	1.16	0.17	1.10	11.18	1.09

Table 2.2. Catch per unit effort (CPUE, # of swordfish/1000 hooks) used for assessment of swordfish (*Xiphias gladius*) in the Eastern Pacific Ocean. A '-' indicates no effort or data available. Calculated relative CVs are reported here, but model runs assumed a relative CV of 1 for all values of all CPUE series.

Year	Japan 1 Deepwater & offshore longline		Japan 2 Deepwater & offshore longline		Japan 3 Deepwater & offshore longline		Taiwan Deepwater longline	
	CPUE	Relative CV	CPUE	Relative CV	CPUE	Relative CV	CPUE	Relative CV
1951	-	-	-	-	-	-	-	-
1952	-	-	-	-	-	-	-	-
1953	-	-	-	-	-	-	-	-
1954	-	-	-	-	-	-	-	-
1955	0.07	1.29	-	-	-	-	-	-
1956	0.05	1.45	-	-	-	-	-	-
1957	0.20	1.08	-	-	-	-	-	-
1958	0.12	1.05	-	-	-	-	-	-
1959	0.07	1.05	-	-	-	-	-	-
1960	0.09	1.05	-	-	-	-	-	-
1961	0.16	1.02	-	-	-	-	-	-
1962	0.18	1.01	-	-	-	-	-	-
1963	0.23	1.00	-	-	-	-	-	-
1964	0.20	1.00	-	-	-	-	-	-
1965	0.17	1.00	-	-	-	-	-	-
1966	0.19	1.01	-	-	-	-	-	-
1967	0.20	1.01	-	-	-	-	-	-
1968	0.20	1.01	-	-	-	-	-	-
1969	0.24	1.01	-	-	-	-	-	-
1970	0.28	1.01	-	-	-	-	-	-
1971	0.22	1.01	-	-	-	-	-	-
1972	0.18	1.01	-	-	-	-	-	-
1973	0.25	1.01	-	-	-	-	-	-
1974	0.26	1.00	-	-	-	-	-	-
1975	-	-	0.35	2.01	-	-	-	-
1976	-	-	0.36	1.33	-	-	-	-
1977	-	-	0.39	2.65	-	-	-	-
1978	-	-	0.35	1.50	-	-	-	-
1979	-	-	0.29	1.12	-	-	-	-
1980	-	-	0.31	1.88	-	-	-	-
1981	-	-	0.38	3.10	-	-	-	-
1982	-	-	0.32	1.91	-	-	-	-
1983	-	-	0.32	1.76	-	-	-	-
1984	-	-	0.26	1.66	-	-	-	-

1985	-	-	0.24	1.15	-	-	-	-
1986	-	-	0.28	1.27	-	-	-	-
1987	-	-	0.30	1.41	-	-	-	-
1988	-	-	0.26	1.20	-	-	-	-
1989	-	-	0.26	1.14	-	-	-	-
1990	-	-	0.30	1.19	-	-	-	-
1991	-	-	0.26	1.00	-	-	-	-
1992	-	-	0.24	1.07	-	-	-	-
1993	-	-	0.27	1.14	-	-	-	-
1994	-	-	-	-	0.26	1.00	-	-
1995	-	-	-	-	0.27	1.01	-	-
1996	-	-	-	-	0.30	1.12	-	-
1997	-	-	-	-	0.35	1.39	-	-
1998	-	-	-	-	0.41	1.49	-	-
1999	-	-	-	-	0.39	1.46	-	-
2000	-	-	-	-	0.48	1.81	0.44	1.56
2001	-	-	-	-	0.55	2.08	0.57	1.00
2002	-	-	-	-	0.44	1.60	0.53	1.00
2003	-	-	-	-	0.41	1.50	0.50	1.01
2004	-	-	-	-	0.35	1.35	0.51	1.03
2005	-	-	-	-	0.35	1.41	0.43	1.04
2006	-	-	-	-	0.44	1.79	0.45	1.04
2007	-	-	-	-	0.52	2.01	0.48	1.14
2008	-	-	-	-	0.68	2.67	0.49	1.26
2009	-	-	-	-	0.85	3.34	0.57	1.29
2010	-	-	-	-	1.01	3.73	0.50	1.14
2011	-	-	-	-	1.00	3.86	0.51	1.23
2012	-	-	-	-	1.02	3.91	0.57	1.64

Table 3.1. Parameters and assumed prior distributions for a Bayesian generalized production model of swordfish (*Xiphias gladius*) in the Western and Central North Pacific Ocean.

Parameter	Description	Assumed Distribution	Assumed Mean	Assumed CV
R	Intrinsic growth rate (yr^{-1})	$R \sim \log N(\log(0.5) - \frac{\sigma_R^2}{2}, \sigma_R^2)$	0.5	50%
K	Carrying capacity (1000 mt)	$K \sim \log N(\log(150) - \frac{\sigma_K^2}{2}, \sigma_K^2)$	150,000 mt	50%
S	Production shape parameter	$S \sim Gamma(2,2)$	1.0	71%
Q	Catchability coefficient	$1/Q \sim Gamma(0.01, 0.01)$	$1/Q = 1.0$	Variance = 1000
P_1	Initial proportion of biomass to carrying capacity	$P_1 \sim \log N(\log(0.9) - \frac{\sigma_{P_1}^2}{2}, \sigma_{P_1}^2)$	0.90	10%
τ^2	Observation error variance	$1/\tau^2 \sim Gamma(2, 0.45)$	0.223	50%
σ^2	Process error variance	$1/\sigma^2 \sim Gamma(4, 0.1)$	0.025	16%

$CV_\theta = \left(\exp\left(\sigma_\theta^2\right) - 1\right)^{1/2}$

Table 3.2. Parameters and assumed prior distributions for a Bayesian generalized production model of swordfish (*Xiphias gladius*) in the Eastern Pacific Ocean.

Paramete r	**Description**	**Assumed Distribution**	**Assumed Mean**	**Assumed CV**
R	Intrinsic growth rate (yr^{-1})	$R \sim \log N(\log(0.5) - \frac{\sigma_R^2}{2}, \sigma_R^2)$	0.5	50%
K	Carrying capacity (1000 mt)	$K \sim \log N(\log(75) - \frac{\sigma_K^2}{2}, \sigma_K^2)$	75,000 mt	50%
S	Production shape parameter	$S \sim Gamma(2,2)$	1.0	71%
Q	Catchability coefficient	$1/Q \sim Gamma(0.01, 0.01)$	$1/Q = 1.0$	Variance = 1000
P_1	Initial proportion of biomass to carrying capacity	$P_1 \sim \log N(\log(0.9) - \frac{\sigma_{P_1}^2}{2}, \sigma_{P_1}^2)$	0.90	10%
τ^2	Observation error variance	$1/\tau^2 \sim Gamma(2, 0.45)$	0.223	50%
σ^2	Process error variance	$1/\sigma^2 \sim Gamma(4, 0.1)$	0.025	16%

$CV_\theta = \left(\exp\left(\sigma_\theta^2\right) - 1\right)^{1/2}$

Table 4.1. Summary of model diagnostics for a Bayesian state-space model of swordfish in the Western and Central North Pacific Ocean. DIC is the deviance information criterion (a model fit statistic used to compare models that use the same datasets), RMSE is root mean-squared error from fitted versus observed CPUE, and ρ is the correlation coefficient between observed and predicted CPUE.

Diagnostic	**Index**	**Mean**
DIC	Model	-185.49
RMSE	Japan CPUE (1952-2012)	0.033
RMSE	Taiwan CPUE (2000-2012)	0.038
RMSE	Hawaii CPUE (1995-2012)	2.273
ρ	Japan CPUE (1952-2012)	0.80
ρ	Taiwan CPUE (2000-2012)	0.18
ρ	Hawaii CPUE (1995-2012)	0.41

Table 4.2. Summary of model diagnostics for a Bayesian state-space model of swordfish in the Eastern Pacific Ocean. DIC is the deviance information criterion (a model fit statistic used to compare models that use the same datasets), RMSE is root mean-squared error from fitted versus observed CPUE, and ρ is the correlation coefficient between observed and predicted CPUE.

Diagnostic	**Index**	**Mean**
DIC	Model	-112.54
RMSE	Japan CPUE 1 (1952-1974)	0.054
RMSE	Japan CPUE 2 (1975-1993)	0.052
RMSE	Japan CPUE 3 (1994-2012)	0.169
RMSE	Taiwan CPUE (2000-2012)	0.107
ρ	Japan CPUE 1 (1952-1974)	0.61
ρ	Japan CPUE 2 (1975-1993)	0.58
ρ	Japan CPUE 3 (1994-2012)	0.79
ρ	Taiwan CPUE (2000-2012)	0.41

Table 5.1. Estimated mean and standard deviation model parameter values for a Bayesian state-space production model for swordfish in the Western and Central North Pacific Ocean.

Parameter	Mean	SD
Intrinsic rate of pop. growth (r)	0.578	0.217
Carrying capacity (K; 1000 mt)	123.700	24.630
Production shape parameter (M)	0.978	0.453
Process error variance (σ^2)	0.017	0.005
JPN longline CPUE obs. error variance (τ^2_{JPN})	0.035	0.008
TWN longline CPUE obs. error variance (τ^2_{TWN})	0.094	0.040
HW longline CPUE obs. error variance (τ^2_{HW})	0.093	0.038
P_1 (B_{1951}/K)	0.848	0.086
JPN longline CPUE catchability (q_{JPN})	2.82×10^{-3}	6.18×10^{-4}
TWN longline CPUE catchability (q_{TWN})	2.67×10^{-3}	6.21×10^{-4}
HW longline CPUE catchability (q_{HW})	0.169	0.040
Max surplus production (MSY; 1000 tons)	14.920	1.816
Biomass giving MSY (B_{MSY}; 1000 tons)	60.720	11.790
Harvest rate giving MSY (H_{MSY})	0.255	0.057

Table 5.2. Estimated mean and standard deviation model parameter values for a Bayesian state-space production model for swordfish in the Eastern Pacific Ocean.

Parameter	Mean	SD
Intrinsic rate of pop. growth (*r*)	0.458	0.195
Carrying capacity (*K*; 1000 mt)	65.19	15.71
Production shape parameter (*M*)	0.927	0.712
Process error variance (σ^2)	0.030	0.011
JPN longline CPUE I obs. error variance (τ^2_{JPN1})	0.174	0.077
JPN longline CPUE II obs. error variance (τ^2_{JPN2})	0.069	0.026
JPN longline CPUE III obs. error variance (τ^2_{JPN3})	0.115	0.053
TWN longline CPUE obs. error variance (τ^2_{TWN})	0.097	0.045
P_1 (B_{1951}/K)	0.880	0.089
JPN longline CPUE I catchability (q_{JPN1})	3.48x10^{-3}	1.31x10^{-3}
JPN longline CPUE II catchability (q_{JPN2})	7.17x10^{-3}	2.23x10^{-3}
JPN longline CPUE III catchability (q_{JPN3})	0.012	3.81x10^{-3}
TWN longline CPUE III catchability (q_{JPN3})	0.011	3.69x10^{-3}
Max surplus production (*MSY*; 1000 tons)	5.49	1.63
Biomass giving MSY (B_{MSY}; 1000 tons)	31.17	6.99
Harvest rate giving MSY (H_{MSY})	0.183	0.063

Table 6.1. Estimated mean values of exploitable biomass and harvest rate for swordfish in the Western and Central North Pacific Ocean.

Year	Exploitable biomass (1000 mt)		Harvest rate	
	Mean	SD	Mean	SD
1951	104.60	22.56	0.12	0.03
1952	87.01	20.48	0.14	0.03
1953	79.61	19.29	0.16	0.04
1954	81.83	19.85	0.18	0.04
1955	78.77	19.21	0.19	0.05
1956	74.86	18.18	0.22	0.05
1957	75.76	18.34	0.21	0.05
1958	81.88	19.45	0.25	0.06
1959	76.98	18.60	0.26	0.06
1960	77.21	18.51	0.30	0.07
1961	73.29	18.40	0.31	0.08
1962	68.93	18.20	0.19	0.05
1963	73.50	19.01	0.16	0.04
1964	74.68	19.10	0.10	0.03
1965	80.05	19.78	0.13	0.03
1966	78.82	19.31	0.15	0.04
1967	72.97	18.07	0.17	0.04
1968	68.54	17.12	0.17	0.04
1969	68.85	17.29	0.16	0.04
1970	70.63	17.82	0.14	0.03
1971	72.23	18.00	0.11	0.03
1972	74.62	18.45	0.10	0.02
1973	81.01	19.57	0.10	0.02
1974	86.16	20.67	0.10	0.02
1975	85.99	20.55	0.14	0.03
1976	85.85	20.82	0.15	0.04
1977	81.04	20.04	0.16	0.04
1978	77.99	19.31	0.19	0.05
1979	79.28	19.82	0.15	0.04
1980	85.73	21.33	0.13	0.03
1981	88.18	21.89	0.13	0.03
1982	91.10	22.48	0.11	0.03
1983	102.70	25.03	0.13	0.03
1984	106.30	26.40	0.13	0.03
1985	116.90	29.34	0.14	0.04

1986	117.70	30.05	0.12	0.03
1987	121.30	30.90	0.12	0.03
1988	116.70	29.96	0.12	0.03
1989	108.00	27.52	0.12	0.03
1990	108.70	27.16	0.12	0.03
1991	104.10	25.81	0.13	0.03
1992	103.80	25.30	0.19	0.05
1993	94.69	23.49	0.22	0.05
1994	80.19	20.43	0.20	0.05
1995	70.20	17.78	0.21	0.05
1996	65.65	16.37	0.21	0.05
1997	60.86	14.98	0.24	0.06
1998	60.20	14.81	0.24	0.06
1999	65.18	15.77	0.23	0.06
2000	69.82	16.65	0.26	0.06
2001	74.02	18.24	0.20	0.05
2002	75.47	18.48	0.19	0.05
2003	71.61	17.41	0.20	0.05
2004	73.37	17.81	0.19	0.05
2005	73.86	17.69	0.20	0.05
2006	76.32	18.32	0.21	0.05
2007	72.29	17.50	0.23	0.06
2008	68.62	16.85	0.21	0.05
2009	68.77	16.80	0.19	0.05
2010	68.97	16.95	0.16	0.04
2011	68.56	16.77	0.15	0.04
2012	72.50	17.50	0.14	0.03

Table 6.2. Estimated mean values of exploitable biomass and harvest rate for swordfish in the Eastern Pacific Ocean.

Year	Exploitable biomass (1000 mt)		Harvest rate	
	Mean	SD	Mean	SD
1951	57.21	14.46	0.00	0.00
1952	55.01	15.68	0.00	0.00
1953	51.47	16.98	0.00	0.00
1954	45.55	17.06	0.02	0.02
1955	38.36	14.45	0.01	0.01
1956	37.03	13.82	0.02	0.01
1957	41.69	14.47	0.02	0.01
1958	40.89	14.29	0.01	0.01
1959	39.68	14.15	0.01	0.01
1960	42.92	14.85	0.01	0.01
1961	49.29	16.16	0.02	0.01
1962	54.92	17.73	0.03	0.01
1963	59.32	19.06	0.03	0.01
1964	60.01	19.45	0.07	0.03
1965	58.08	19.45	0.04	0.02
1966	60.16	20.00	0.04	0.02
1967	62.37	20.70	0.05	0.02
1968	64.25	21.37	0.06	0.02
1969	67.07	22.31	0.12	0.04
1970	64.85	22.52	0.11	0.04
1971	60.99	21.47	0.04	0.02
1972	61.35	20.65	0.06	0.02
1973	62.89	20.72	0.10	0.04
1974	59.70	19.69	0.04	0.02
1975	56.52	17.91	0.04	0.01
1976	55.92	17.68	0.07	0.02
1977	54.95	17.63	0.06	0.02
1978	52.23	16.91	0.06	0.02
1979	49.50	16.15	0.04	0.01
1980	50.49	16.22	0.06	0.02
1981	51.96	16.69	0.08	0.03
1982	48.78	15.87	0.08	0.03
1983	46.16	15.19	0.05	0.02
1984	43.11	14.19	0.04	0.01
1985	42.18	13.84	0.03	0.01

1986	44.18	14.19	0.07	0.02
1987	44.52	14.26	0.09	0.03
1988	42.48	13.74	0.09	0.03
1989	42.19	13.63	0.08	0.03
1990	43.41	13.72	0.15	0.05
1991	39.84	12.97	0.12	0.04
1992	38.14	12.32	0.15	0.05
1993	35.86	11.82	0.12	0.04
1994	32.16	11.05	0.13	0.05
1995	31.51	11.07	0.11	0.04
1996	33.62	11.52	0.14	0.05
1997	36.17	12.18	0.18	0.06
1998	37.98	12.91	0.22	0.07
1999	37.90	13.49	0.10	0.04
2000	43.42	14.47	0.16	0.05
2001	46.46	15.61	0.18	0.06
2002	44.32	15.18	0.18	0.06
2003	41.98	14.62	0.15	0.05
2004	40.66	14.17	0.16	0.06
2005	39.55	13.94	0.10	0.03
2006	43.10	14.89	0.08	0.03
2007	47.98	16.29	0.09	0.03
2008	53.84	18.08	0.09	0.03
2009	60.57	20.29	0.14	0.04
2010	62.12	21.44	0.17	0.06
2011	60.81	21.83	0.18	0.06
2012	58.59	21.95	0.19	0.07

Table 7.1. Effects of high (+25%) and low (-25%) changes in prior means on model parameters including maximum sustainable yield, exploitable biomass to produce *MSY*, and harvest rate to produce *MSY* for swordfish in the Western and Central North Pacific Ocean.

Parameter	Base case		1.25*r		0.75*r		1.25*K		0.75*K		1.25*P_1		0.75*P_1		1.25*M		0.75*M	
	Mean	SD	% change	CV	% change	CV	% change	CV	% change	CV	% change	CV	% change	CV	% change	CV	% change	CV
r	0.58	0.22	13.79%	0.39	-15.52%	0.37	-1.72%	0.37	1.72%	0.37	0.00%	0.38	-3.45%	0.38	-5.17%	0.38	6.90%	0.37
K	123.66	24.63	-1.91%	0.20	2.77%	0.20	3.52%	0.20	-5.75%	0.20	-8.18%	0.21	4.33%	0.20	-1.16%	0.20	1.08%	0.20
M	0.98	0.45	-11.22%	0.48	15.31%	0.44	-1.02%	0.47	3.06%	0.46	17.35%	0.50	-4.08%	0.48	9.18%	0.48	-11.22%	0.44
P_1	0.85	0.09	0.00%	0.11	0.00%	0.11	0.00%	0.11	0.00%	0.11	28.24%	0.12	-23.53%	0.09	0.00%	0.11	0.00%	0.09
B_{MSY}	60.72	11.79	-4.05%	0.20	5.67%	0.20	3.28%	0.20	-5.07%	0.19	-5.57%	0.20	3.56%	0.20	0.41%	0.20	-0.99%	0.19
B_{1951}	104.60	22.37	-1.72%	0.22	2.68%	0.22	3.35%	0.22	-5.47%	0.21	17.69%	0.21	-20.49%	0.22	-0.96%	0.22	0.86%	0.21
B_{1951}/B_{MSY}	1.73	0.22	2.31%	0.12	-2.89%	0.13	0.00%	0.13	-0.58%	0.13	24.86%	0.13	-23.12%	0.12	-1.16%	0.13	1.73%	0.13
B_{2012}	72.50	17.47	-1.39%	0.25	2.33%	0.24	3.48%	0.24	-5.41%	0.24	-4.50%	0.25	-2.22%	0.24	-0.86%	0.24	0.58%	0.24
B_{2012}/B_{MSY}	1.20	0.19	2.50%	0.15	-3.33%	0.16	0.00%	0.16	-0.83%	0.16	0.83%	0.17	-5.83%	0.16	-1.67%	0.16	1.67%	0.16
H_{MSY}	0.25	0.06	8.00%	0.22	-4.00%	0.21	0.00%	0.24	8.00%	0.22	12.00%	0.21	-4.00%	0.21	0.00%	0.24	4.00%	0.23
H_{1951}	0.12	0.02	0.00%	0.25	-8.33%	0.18	-8.33%	0.18	0.00%	0.25	-16.67%	0.20	25.00%	0.20	0.00%	0.25	0.00%	0.17
H_{1951}/H_{MSY}	0.47	0.08	-4.26%	0.18	4.26%	0.18	0.00%	0.17	0.00%	0.17	-23.40%	0.19	31.91%	0.16	0.00%	0.19	-2.13%	0.17
H_{2012}	0.14	0.03	7.14%	0.27	0.00%	0.21	0.00%	0.21	7.14%	0.27	7.14%	0.27	7.14%	0.20	7.14%	0.20	0.00%	0.21
H_{2012}/H_{MSY}	0.58	0.13	-3.45%	0.23	5.17%	0.23	0.00%	0.22	0.00%	0.22	-3.45%	0.23	8.62%	0.22	1.72%	0.22	-1.72%	0.23
MSY	14.92	1.82	1.41%	0.12	-1.68%	0.12	0.07%	0.12	-0.20%	0.12	2.68%	0.12	-2.61%	0.11	-0.07%	0.12	-0.07%	0.12

Table 7.2. Effects of high (+25%) and low (-25%) changes in prior means on model parameters including maximum sustainable yield, exploitable biomass to produce *MSY*, and harvest rate to produce *MSY* for swordfish in the Eastern Pacific Ocean.

Parameter	Base case		1.25*r		0.75*r		1.25*K		0.75*K		1.25*P_1		0.75*P_1		1.25*M		0.75*M	
	Mean	SD	% change	CV	% change	CV	% change	CV	% change	CV	% change	CV	% change	CV	% change	CV	% change	CV
r	0.46	0.20	17.91%	0.44	-19.31%	0.41	-1.51%	0.43	2.29%	0.42	0.74%	0.43	-3.86%	0.43	-6.90%	0.44	7.05%	0.42
K	65.19	15.71	-1.87%	0.24	2.91%	0.24	6.06%	0.24	-7.49%	0.24	-5.92%	0.25	7.79%	0.23	-3.60%	0.25	2.84%	0.24
M	0.93	0.71	-13.58%	0.77	19.62%	0.74	-9.98%	0.68	7.02%	0.72	22.21%	0.78	-15.87%	0.62	37.96%	0.85	-21.83%	0.61
P_1	0.88	0.09	0.08%	0.10	-0.27%	0.10	-0.33%	0.10	0.27%	0.10	26.07%	0.10	-25.71%	0.10	0.40%	0.10	-0.32%	0.10
B_{MSY}	31.17	6.99	-4.20%	0.22	6.26%	0.23	4.65%	0.23	-6.45%	0.22	-2.82%	0.24	4.17%	0.22	0.80%	0.24	-0.48%	0.22
B_{1951}	57.21	14.46	-1.78%	0.25	2.66%	0.26	5.73%	0.26	-7.22%	0.25	18.65%	0.26	-20.89%	0.25	-3.25%	0.27	2.53%	0.25
$B_{1951}/B_{\mathrm{MSY}}$	1.84	0.26	2.44%	0.14	-3.26%	0.14	0.98%	0.14	-0.92%	0.14	22.27%	0.15	-24.06%	0.13	-3.86%	0.16	2.93%	0.13
B_{2012}	58.59	21.95	-2.92%	0.37	3.67%	0.38	6.57%	0.37	-8.55%	0.38	-7.63%	0.37	6.49%	0.37	-4.92%	0.38	2.12%	0.37
$B_{2012}/B_{\mathrm{MSY}}$	1.87	0.53	1.12%	0.28	-1.87%	0.33	1.82%	0.28	-2.51%	0.29	-4.86%	0.28	2.46%	0.29	-5.50%	0.29	2.72%	0.29
H_{MSY}	0.18	0.06	8.20%	0.36	-10.22%	0.35	-5.19%	0.35	7.00%	0.35	9.95%	0.33	-10.11%	0.35	4.16%	0.35	-2.90%	0.35
H_{1951}	0.00	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00
$H_{1951}/H_{\mathrm{MSY}}$	0.00	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00
H_{2012}	0.19	0.07	3.17%	0.38	-3.37%	0.37	-6.13%	0.37	9.61%	0.37	8.15%	0.37	-6.28%	0.37	5.66%	0.38	-2.18%	0.37
$H_{2012}/H_{\mathrm{MSY}}$	1.11	0.42	-4.49%	0.37	8.62%	0.48	-0.63%	0.39	2.06%	0.37	-2.15%	0.37	4.67%	0.42	0.90%	0.36	1.35%	0.39
MSY	5.49	1.63	3.53%	0.31	-4.57%	0.31	-0.86%	0.30	-0.09%	0.29	6.92%	0.30	-6.60%	0.29	4.90%	0.31	-3.59%	0.29

Table 8.1. Projected exploitable biomasses (1000 mt) and harvest rates under eight different harvest scenarios during 2012-2016 for swordfish in the Western and Central North Pacific Ocean.

	Recent harvest rate				Recent catch				Max obs harvest rate				FMSY			
Year	Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2012	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07
2013	50.40	21.69	0.18	0.07	50.37	21.56	0.23	0.10	50.35	21.76	0.24	0.08	50.40	21.73	0.19	0.07
2014	45.96	20.73	0.18	0.07	44.40	21.17	0.27	0.14	43.11	19.73	0.24	0.08	45.39	19.88	0.19	0.07
2015	42.89	19.85	0.18	0.07	39.09	20.98	0.33	0.19	38.51	18.32	0.24	0.08	42.27	18.69	0.19	0.07
2016	40.58	19.10	0.18	0.07	34.14	21.12	0.40	0.25	35.26	17.23	0.24	0.08	40.08	17.79	0.19	0.07

	0.5*FMSY				0.75*FMSY				1.25*FMSY				1.5*FMSY			
Year	Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2012	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07
2013	50.32	21.62	0.10	0.04	50.35	21.66	0.14	0.06	50.32	21.58	0.23	0.08	50.34	21.68	0.27	0.09
2014	49.48	20.76	0.10	0.04	47.35	20.20	0.14	0.06	43.32	19.17	0.23	0.08	41.59	18.89	0.27	0.09
2015	48.96	20.30	0.10	0.04	45.40	19.42	0.14	0.06	39.22	17.72	0.23	0.08	36.67	17.19	0.27	0.09
2016	48.44	19.83	0.10	0.04	44.01	18.72	0.14	0.06	36.35	16.59	0.23	0.08	33.25	15.88	0.27	0.09

	Recent harvest rate				Recent catch				Max obs harvest rate				FMSY			
Year	Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2012	72.51	17.27	0.14	0.03	72.51	17.27	0.14	0.03	72.51	17.27	0.14	0.03	72.51	17.27	0.14	0.03
2013	77.09	20.06	0.15	0.04	77.17	20.05	0.14	0.04	77.27	20.17	0.32	0.08	77.16	20.1	0.25	0.06
2014	79.58	21.56	0.15	0.04	80.82	22.17	0.13	0.04	67.05	20.11	0.32	0.08	71.59	19.17	0.25	0.06
2015	81.19	22.24	0.15	0.04	83.68	23.66	0.13	0.04	61.18	19.86	0.32	0.08	68.4	18.75	0.25	0.06
2016	82.32	22.82	0.15	0.04	85.79	24.58	0.13	0.04	57.34	19.76	0.32	0.08	66.36	18.42	0.25	0.06

Year	0.5*FMSY				0.75*FMSY				1.25*FMSY				1.5*FMSY			
	Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2012	72.51	17.27	0.14	0.03	72.51	17.27	0.14	0.03	72.51	17.27	0.14	0.03	72.51	17.27	0.14	0.03
2013	77.14	20.05	0.14	0.03	77.13	20.09	0.2	0.05	77.14	20.15	0.3	0.07	77.11	19.99	0.35	0.07
2014	80.45	20.74	0.14	0.03	75.96	20	0.2	0.05	67.66	18.49	0.3	0.07	63.88	17.76	0.35	0.07
2015	83.04	21.36	0.14	0.03	75.32	19.97	0.2	0.05	62.38	17.61	0.3	0.07	56.94	16.52	0.35	0.07
2016	84.79	21.78	0.14	0.03	74.95	20.06	0.2	0.05	58.98	17.08	0.3	0.07	52.39	15.66	0.35	0.07

Table 8.2. Projected exploitable biomasses (1000 mt) and harvest rates under eight different harvest scenarios during 2012-2016 for swordfish in the Eastern Pacific Ocean.

	Recent harvest rate				Recent catch				Max obs harvest rate				FMSY			
Year	Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2012	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07
2013	50.40	21.69	0.18	0.07	50.37	21.56	0.23	0.10	50.35	21.76	0.24	0.08	50.40	21.73	0.19	0.07
2014	45.96	20.73	0.18	0.07	44.40	21.17	0.27	0.14	43.11	19.73	0.24	0.08	45.39	19.88	0.19	0.07
2015	42.89	19.85	0.18	0.07	39.09	20.98	0.33	0.19	38.51	18.32	0.24	0.08	42.27	18.69	0.19	0.07
2016	40.58	19.10	0.18	0.07	34.14	21.12	0.40	0.25	35.26	17.23	0.24	0.08	40.08	17.79	0.19	0.07

	0.5*FMSY				0.75*FMSY				1.25*FMSY				1.5*FMSY			
Year	Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate		Biomass		Harvest rate	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2012	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07	58.59	21.95	0.19	0.07
2013	50.32	21.62	0.10	0.04	50.35	21.66	0.14	0.06	50.32	21.58	0.23	0.08	50.34	21.68	0.27	0.09
2014	49.48	20.76	0.10	0.04	47.35	20.20	0.14	0.06	43.32	19.17	0.23	0.08	41.59	18.89	0.27	0.09
2015	48.96	20.30	0.10	0.04	45.40	19.42	0.14	0.06	39.22	17.72	0.23	0.08	36.67	17.19	0.27	0.09
2016	48.44	19.83	0.10	0.04	44.01	18.72	0.14	0.06	36.35	16.59	0.23	0.08	33.25	15.88	0.27	0.09

Table 9.1. Results from the final projected year of the risk analysis, 2016, for swordfish in the Western and Central North Pacific Ocean. Projected catch levels, probability of becoming overfished, and probability of overfishing are presented.

Catch (1000 mt)	Prob(B<0.5*BMSY)	Prob(H>HMSY)
1.99	0.000	0.000
3.99	0.000	0.000
5.99	0.000	0.000
7.99	0.000	0.000
9.99	0.000	0.002
11.99	0.000	0.025
13.99	0.001	0.155
15.99	0.004	0.454
17.99	0.019	0.753
19.98	0.073	0.912
21.99	0.197	0.972
23.99	0.381	0.992
25.98	0.581	0.998
27.98	0.744	0.999
29.98	0.858	1.000
31.98	0.925	1.000
33.98	0.963	1.000
35.98	0.982	1.000
37.98	0.991	1.000
39.98	0.996	1.000

Table 9.2. Results from the final projected year of the risk analysis, 2016, for swordfish in the Eastern Pacific Ocean. Projected catch levels, probability of becoming overfished, and probability of overfishing are presented.

Catch (1000 mt)	Prob(B<0.5*BMSY)	Prob(H>HMSY)
1.94	0.000	0.011
3.88	0.000	0.039
5.83	0.000	0.121
7.77	0.001	0.280
9.71	0.002	0.493
11.65	0.008	0.682
13.59	0.017	0.824
15.53	0.036	0.903
17.48	0.066	0.949
19.42	0.120	0.972
21.36	0.196	0.986
23.30	0.245	0.993
25.24	0.356	0.996
27.18	0.419	0.998
29.13	0.529	0.999
31.07	0.564	0.999
33.01	0.665	1.000
34.95	0.733	1.000
36.89	0.753	1.000
38.84	0.814	1.000

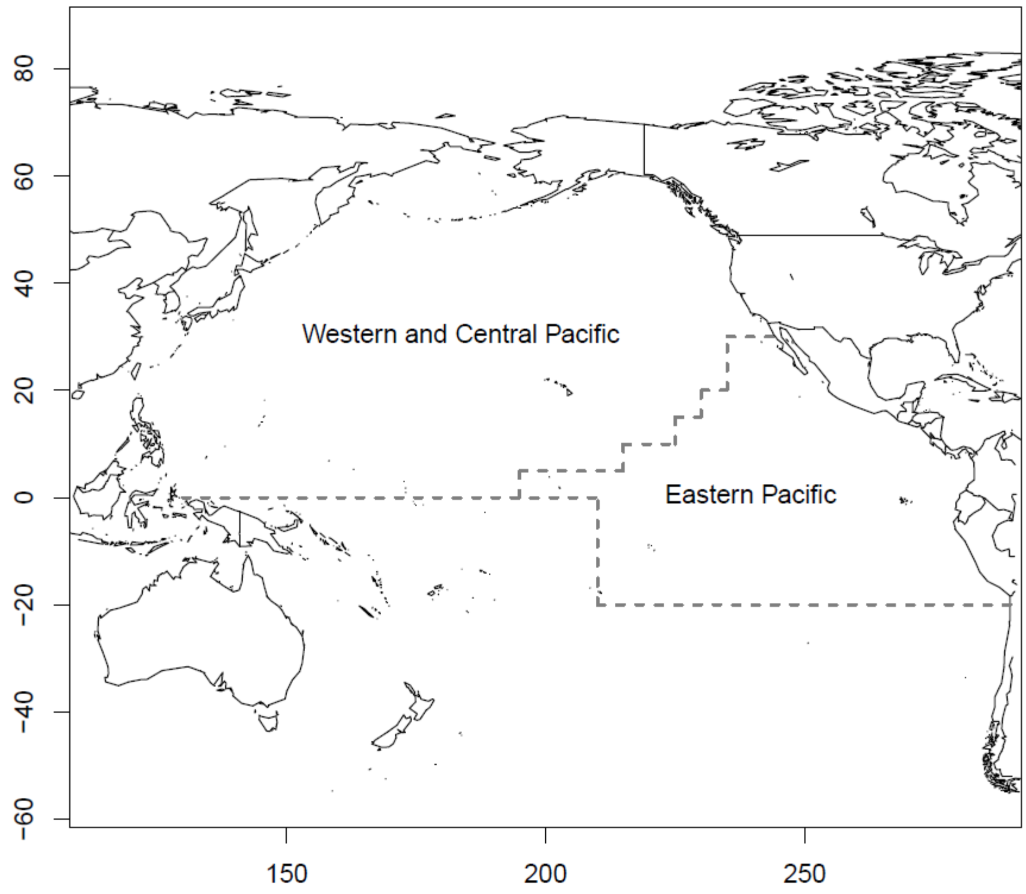
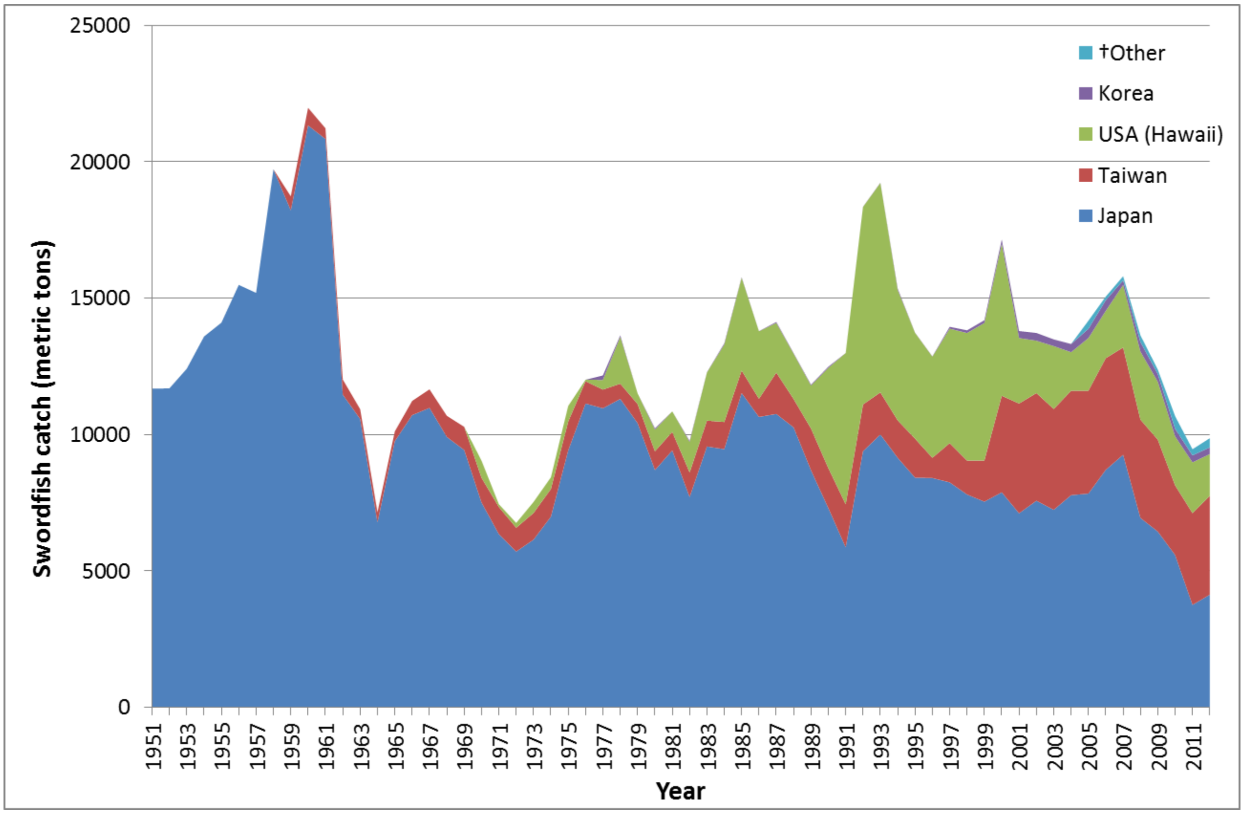


Figure 2. Two-stock structure for swordfish (*Xiphias gladius*) in the North Pacific Ocean, indicating separate stocks in the Western and Central Pacific Ocean and in the Eastern Pacific Ocean. This paper assesses swordfish in the Eastern Pacific Ocean.



fsFigure 2.1. Swordfish (*Xiphias gladius*) catch (metric tons) in the Western and Central North Pacific Ocean from 1951-2012 by country. †Other: catch data from Belize, Cook Islands, China, Spain, Fiji, Federated States of Micronesia, Kiribati, Marshall Islands, Papua New Guinea, Senegal, Tuvalu, and Vanuatu.

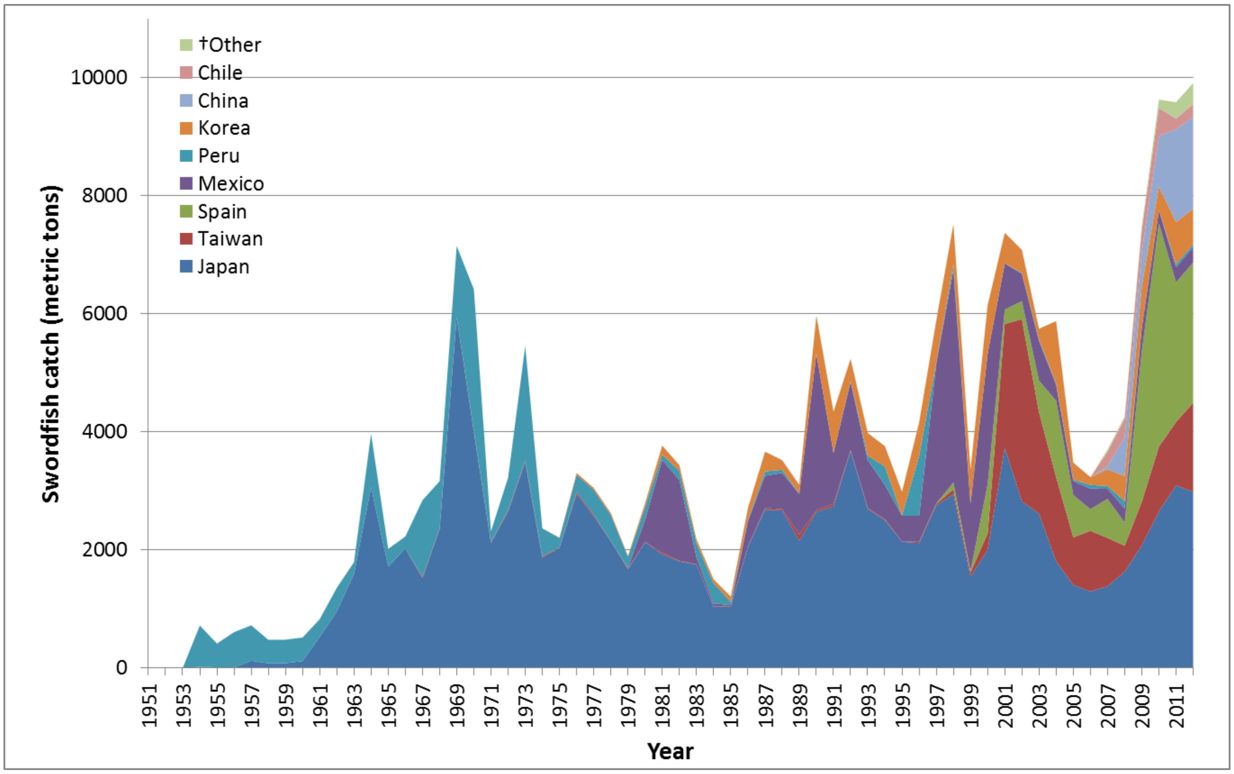


Figure 2.2. Swordfish (*Xiphias gladius*) catch (metric tons) in the Eastern Pacific Ocean from 1951-2012 by country. †Other: catch data from Belize, French Polynesia, United States, and Vanuatu.

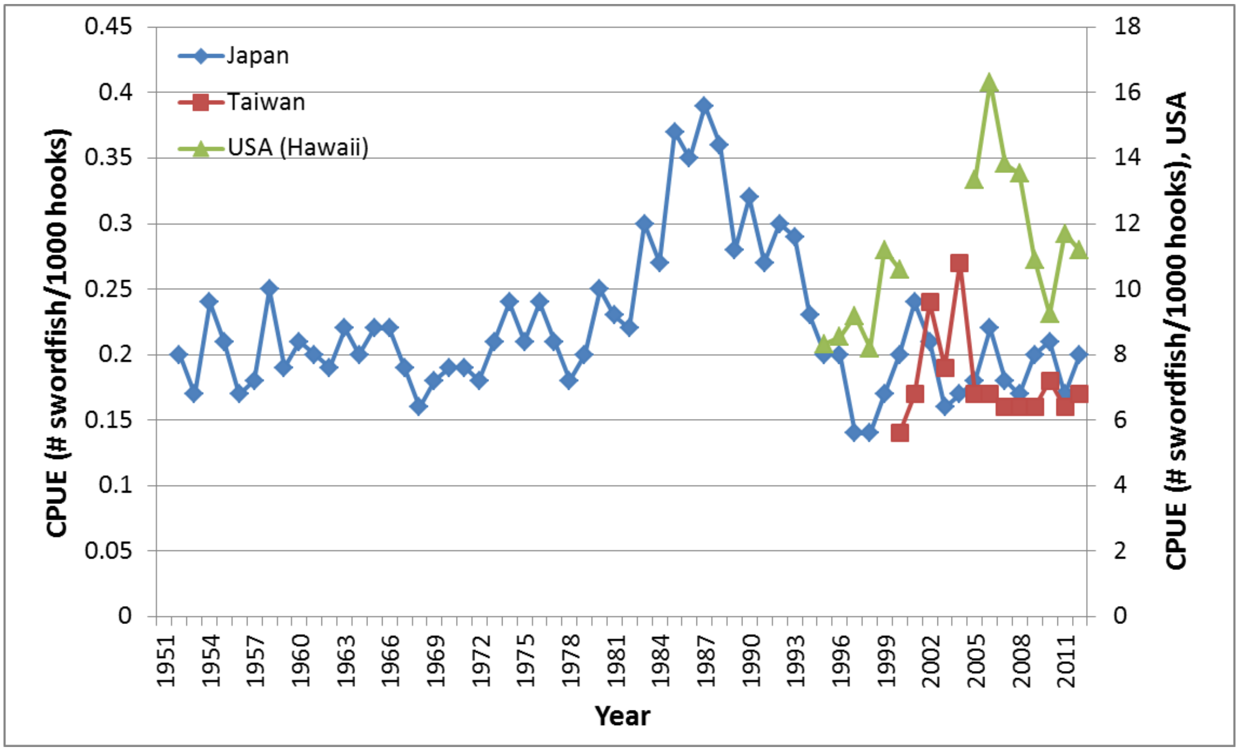


Figure 3.1. Catch-per-unit-effort (CPUE) time series calculated from longline fisheries for swordfish (*Xiphias gladius*) in the Western and Central Pacific Ocean. The scale of CPUE for the Hawaii longline fishery is higher than the scales of the Japanese and Taiwanese CPUE series.

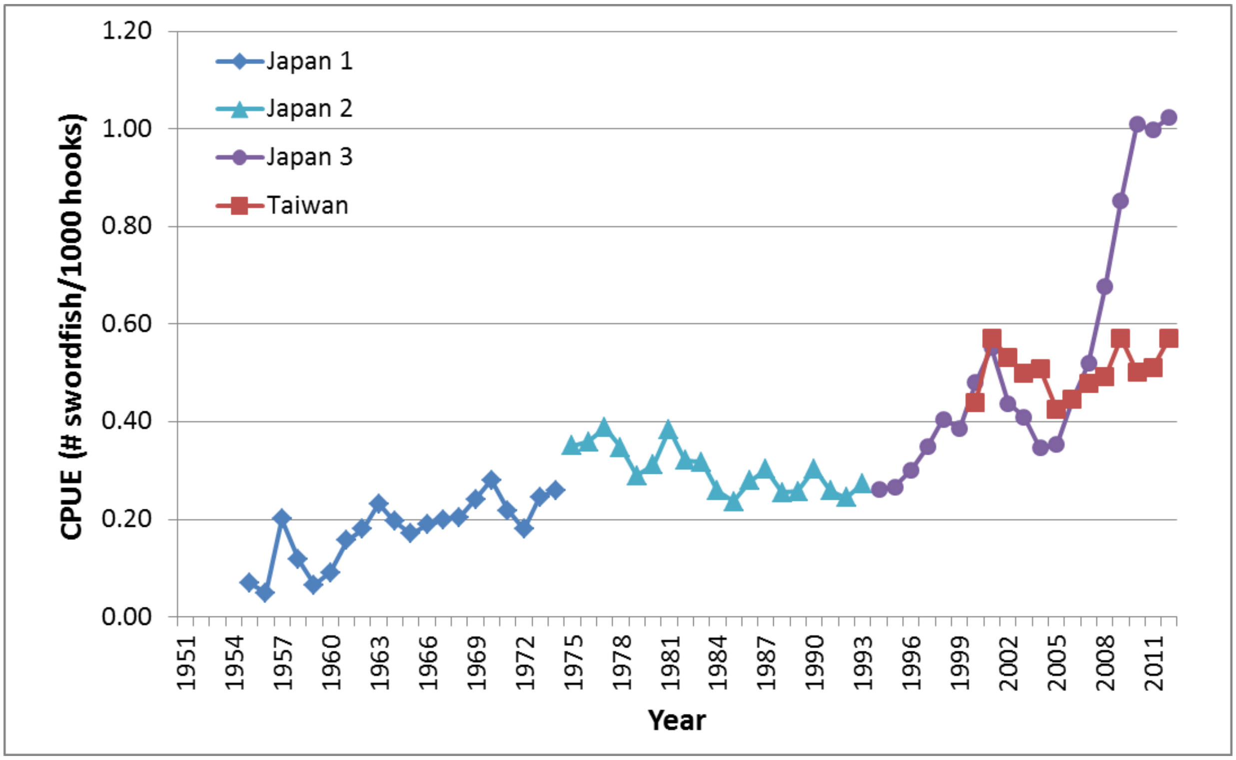


Figure 3.2. Catch-per-unit-effort (CPUE) time series calculated from longline fisheries for swordfish (*Xiphias gladius*) in the Eastern Pacific Ocean.

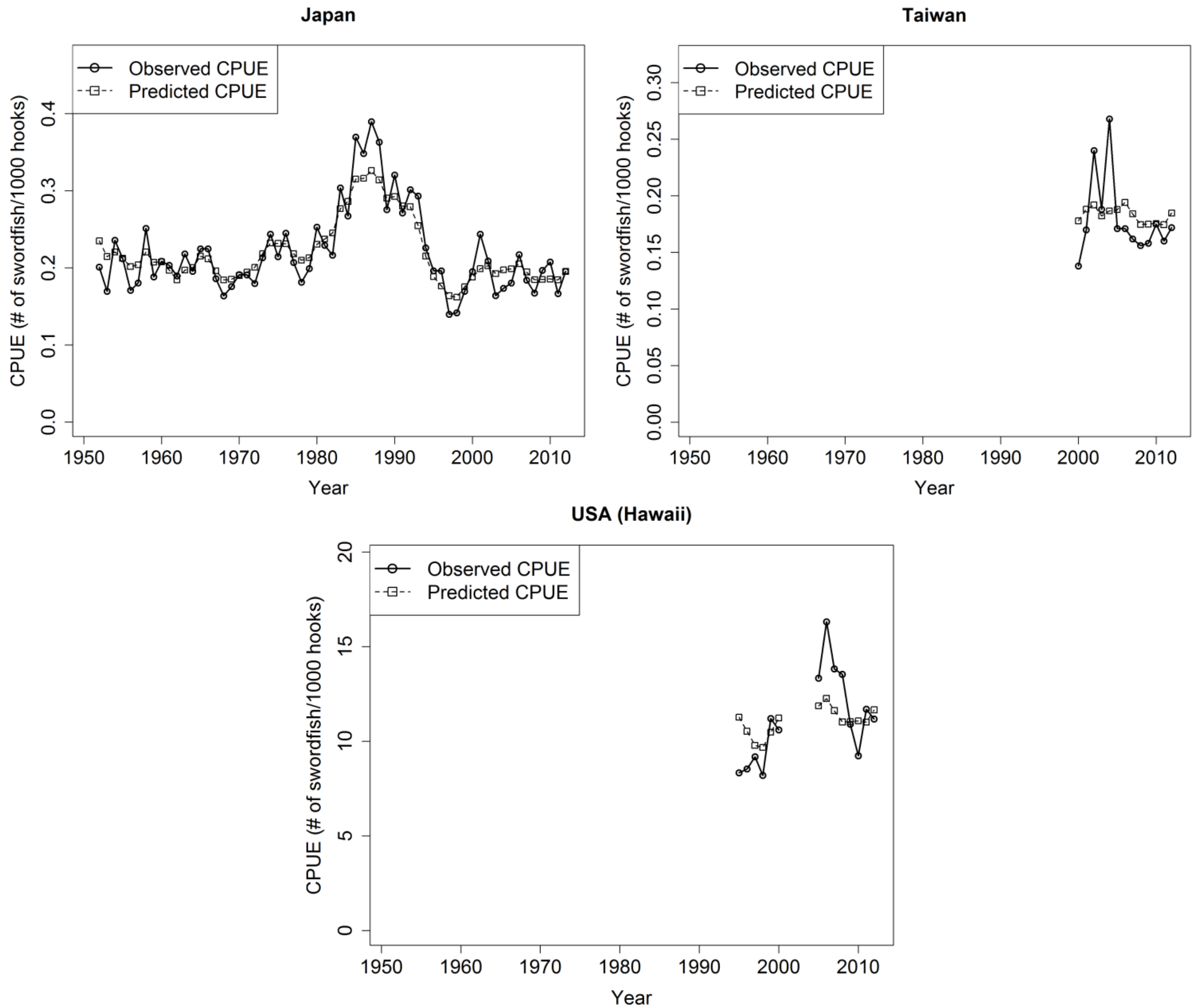


Figure 4.1. Bayesian state-space surplus production model predicted catch-per-unit-effort (CPUE) (dotted line, squares) and observed standardized CPUE (solid line, circles) for swordfish (*Xiphias gladius*) in the Western and Central North Pacific Ocean.

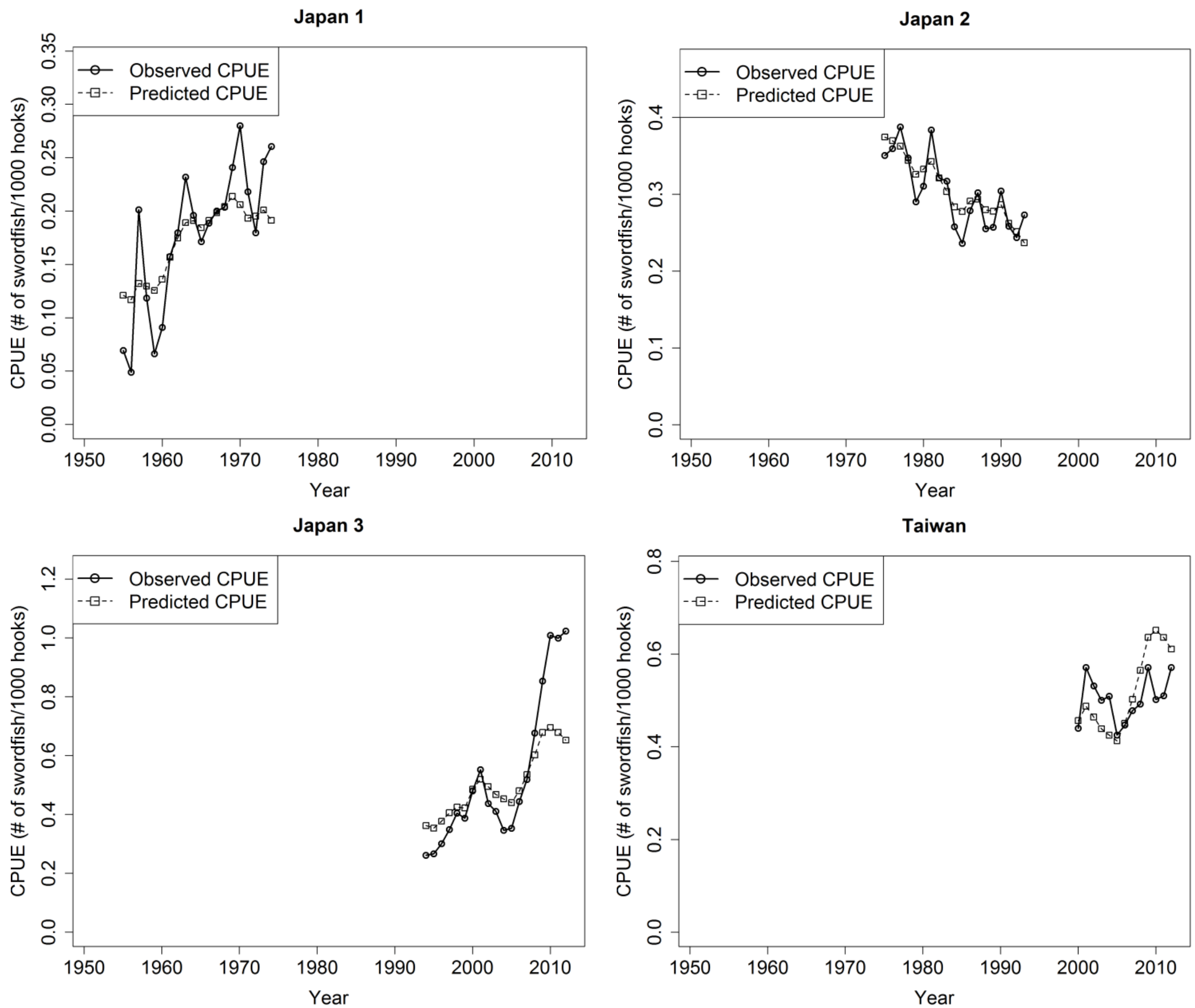


Figure 4.2. Bayesian state-space surplus production model predicted catch-per-unit-effort (CPUE) (dotted line, squares) and observed standardized CPUE (solid line, circles) for swordfish (*Xiphias gladius*) in the Eastern Pacific Ocean.

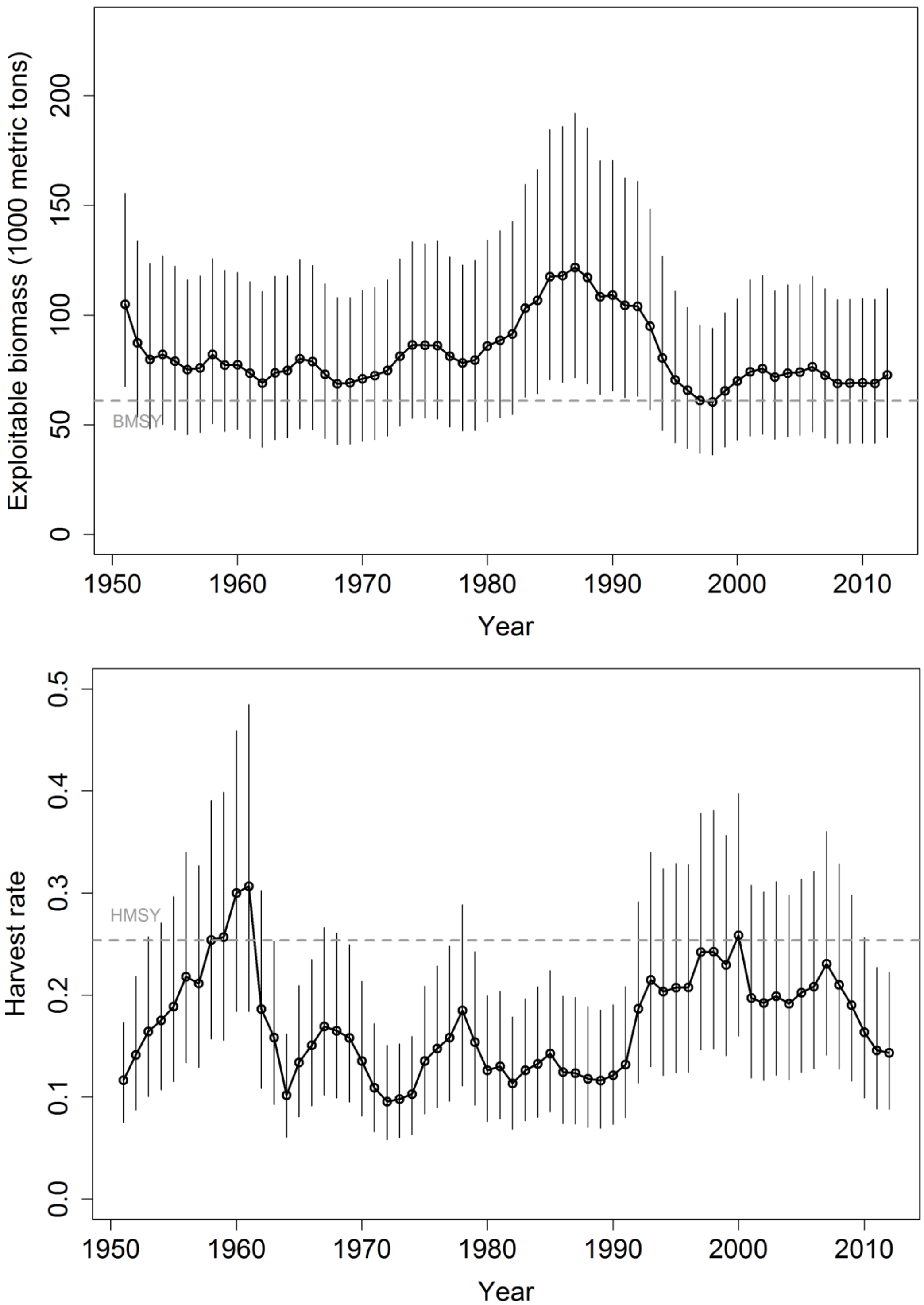


Figure 5.1. Trends in exploitable biomass (top) and harvest rate (bottom) of the Western and Central North Pacific Ocean swordfish, *Xiphias gladius*. Estimated mean values (black circles and solid line), 95% confidence interval bars, and estimated biological reference points (B_{MSY} and H_{MSY}, horizontal dashed lines) are presented.

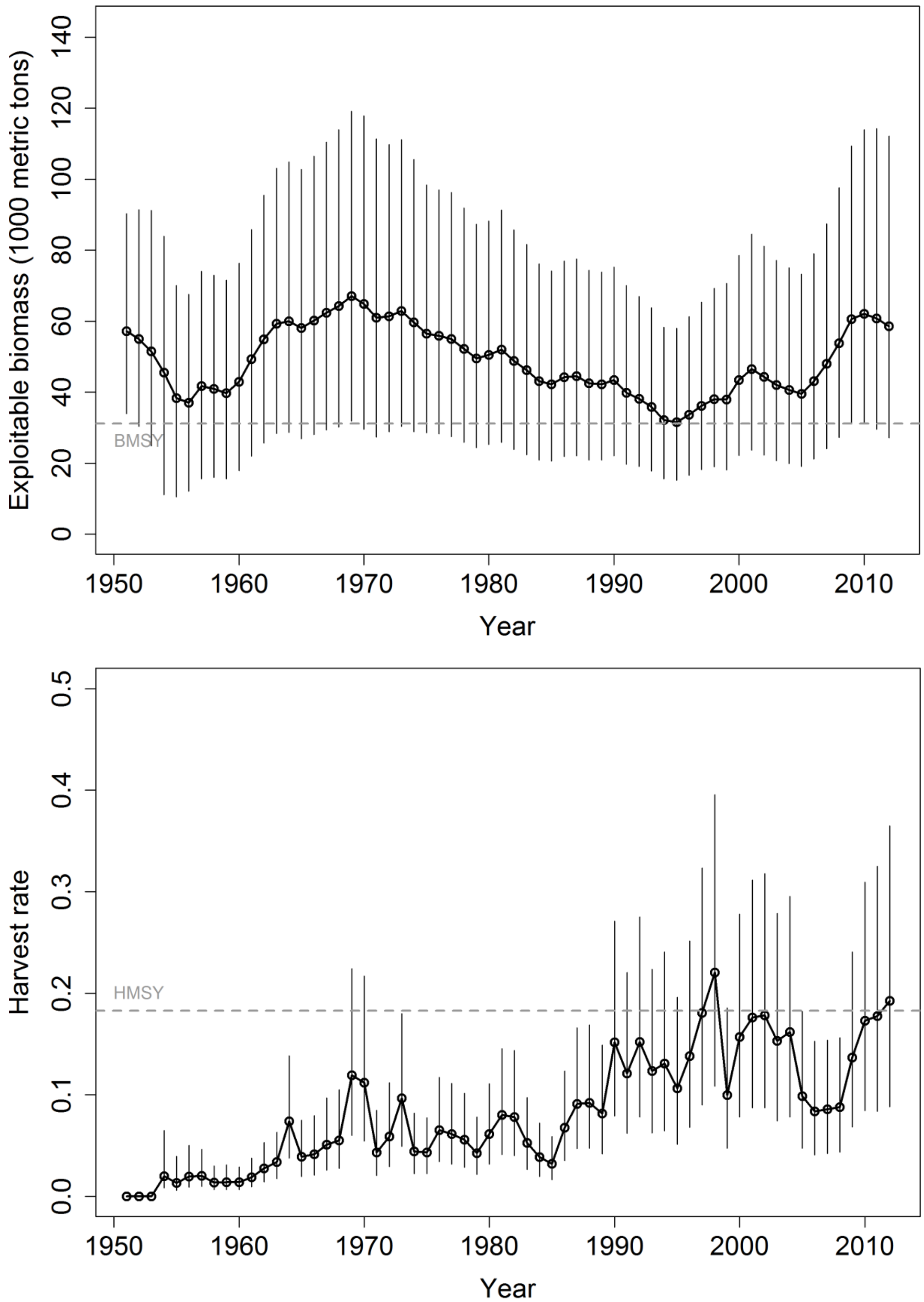


Figure 5.2. Trends in exploitable biomass (top) and harvest rate (bottom) of the Eastern Pacific Ocean swordfish, *Xiphias gladius*. Estimated mean values (black circles and solid line), 95% confidence interval bars, and estimated biological reference points (B_{MSY} and H_{MSY}, horizontal dashed lines) are presented.

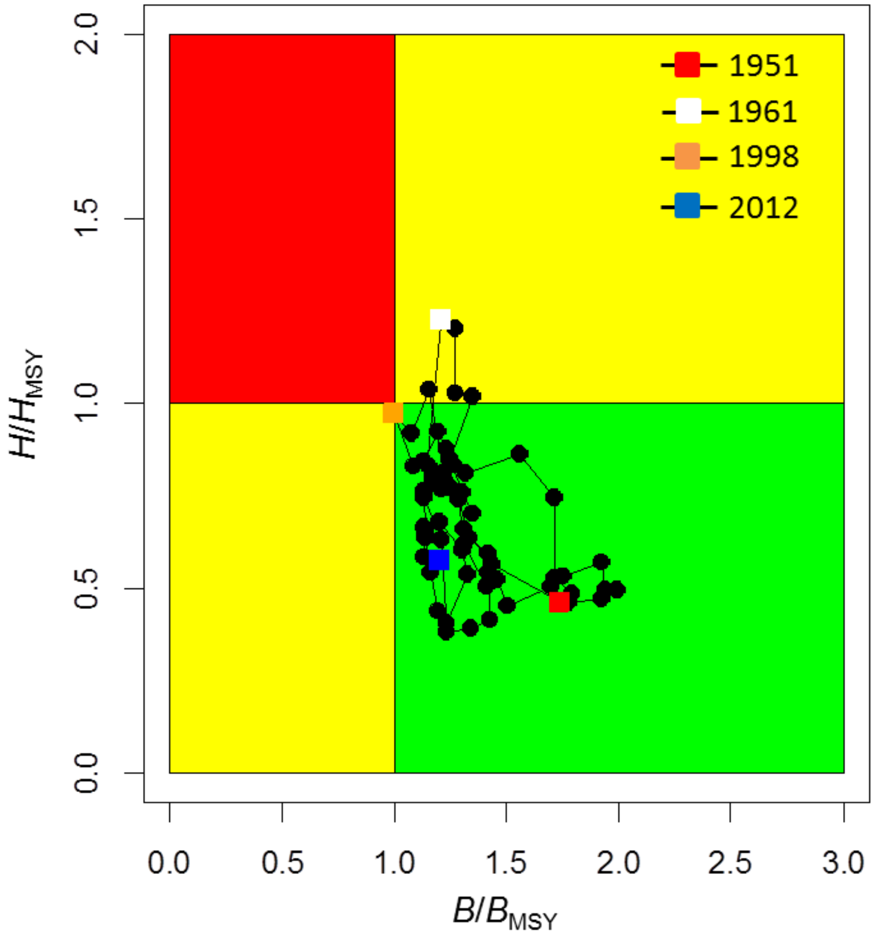


Figure 6.1. Kobe diagram shows the estimated trajectories (1951-2012) of B/B_{MSY} and H/H_{MSY} for swordfish in the Western and Central North Pacific Ocean based on the base-case model.

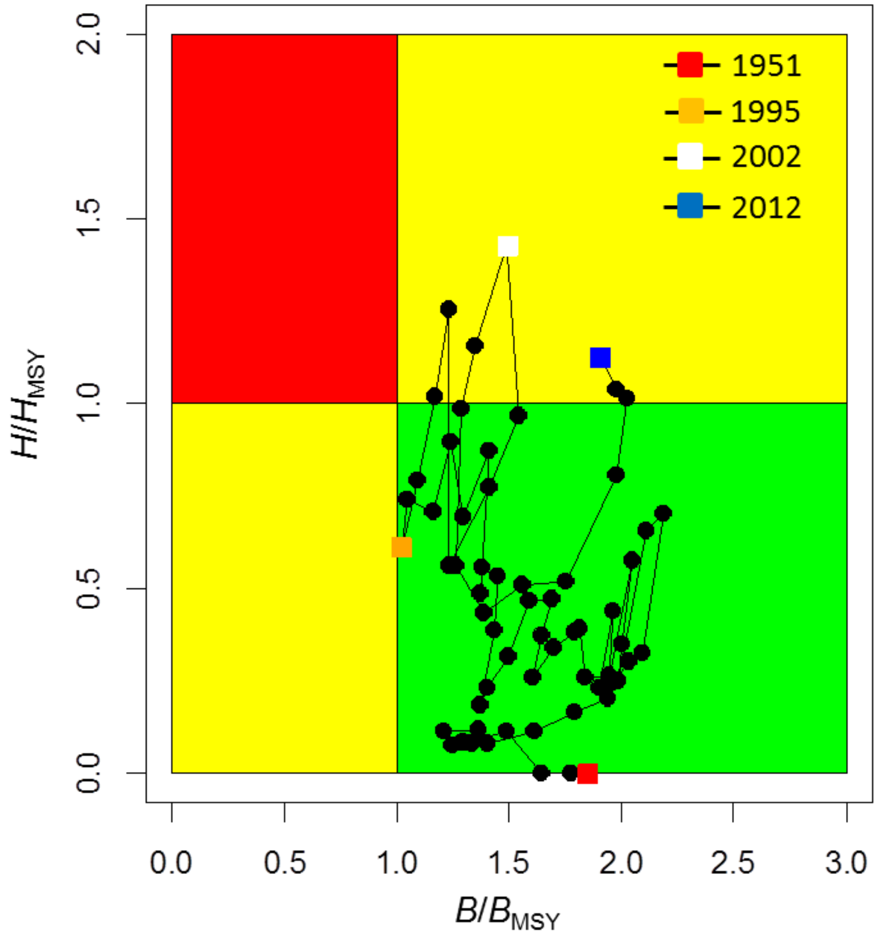


Figure 6.2. Kobe diagram shows the estimated trajectories (1951-2012) of B/B_{MSY} and H/H_{MSY} for swordfish in the Eastern Pacific Ocean based on the base-case model.

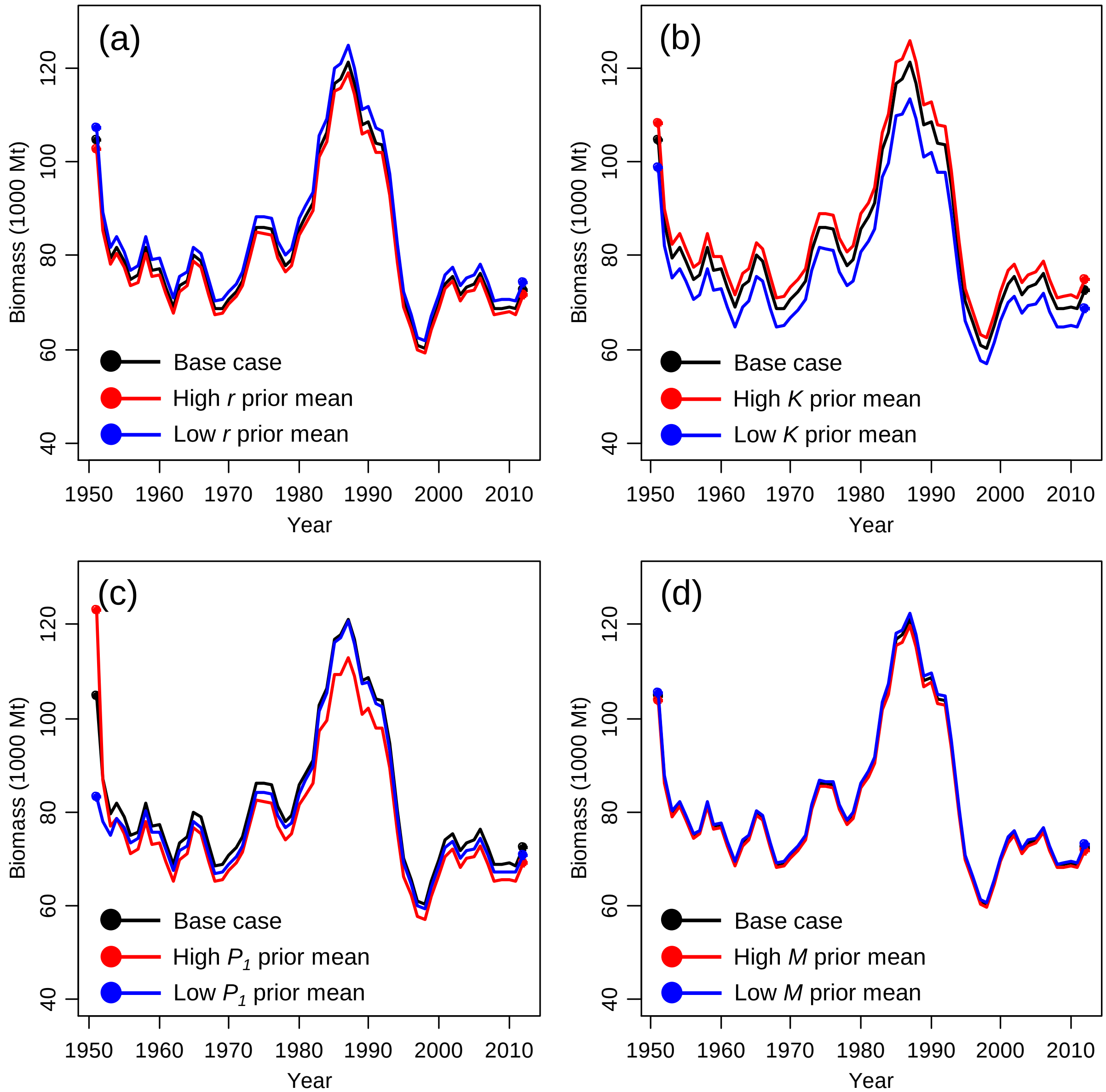


Figure 7.1.1. Comparison of time-series of biomass estimates (1000 metric tons) from the base-case model with estimates from the models of different prior assumptions of intrinsic growth rate, *r* (a), carrying capacity, *K* (b), initial condition, P_1 (c) and shape parameter, *M* (d) for the swordfish in the Western and Central Pacific Ocean.

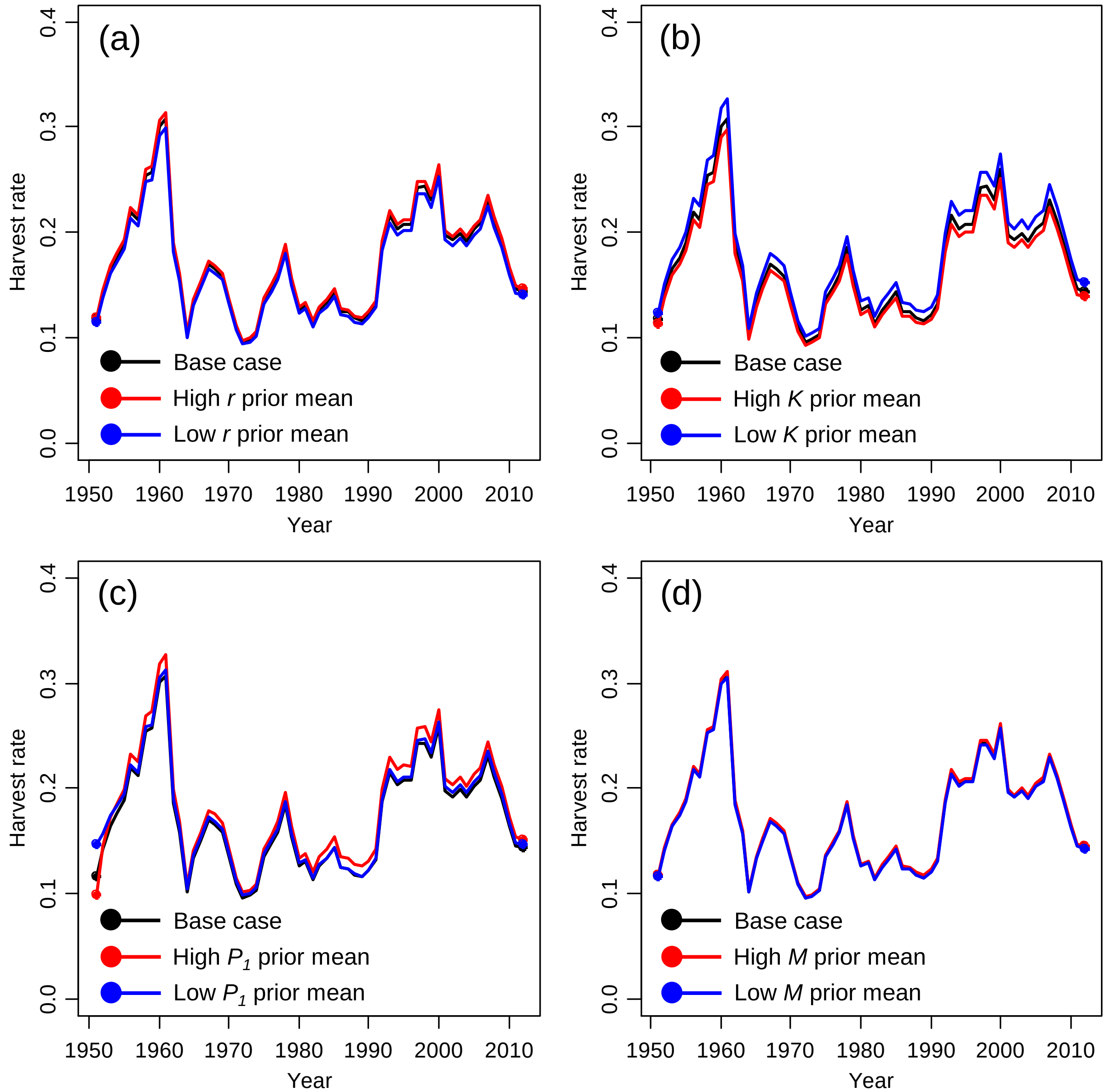


Figure 7.1.2. Comparison of time-series of harvest rates from the base-case model with estimates from the models of different prior assumptions of intrinsic growth rate, *r* (a), carrying capacity, *K* (b), initial condition, P_1 (c) and shape parameter, *M* (d) for the swordfish in the Western and Central Pacific Ocean.

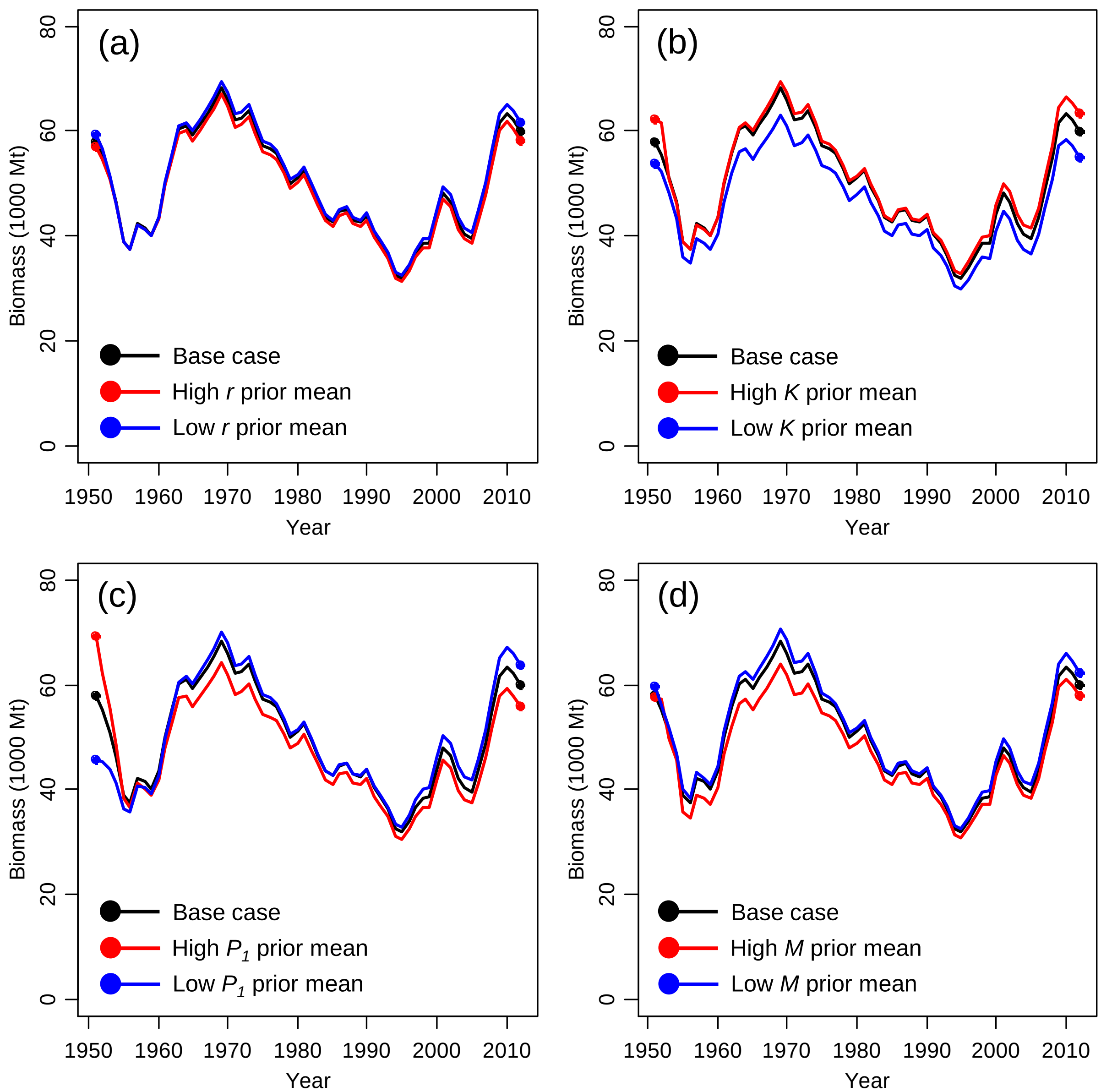


Figure 7.2.1. Comparison of time-series of biomass estimates (1000 metric tons) from the base-case model with estimates from the models of different prior assumptions of intrinsic growth rate, *r* (a), carrying capacity, *K* (b), initial condition, P_1 (c) and shape parameter, *M* (d) for the swordfish in the Eastern Pacific Ocean.

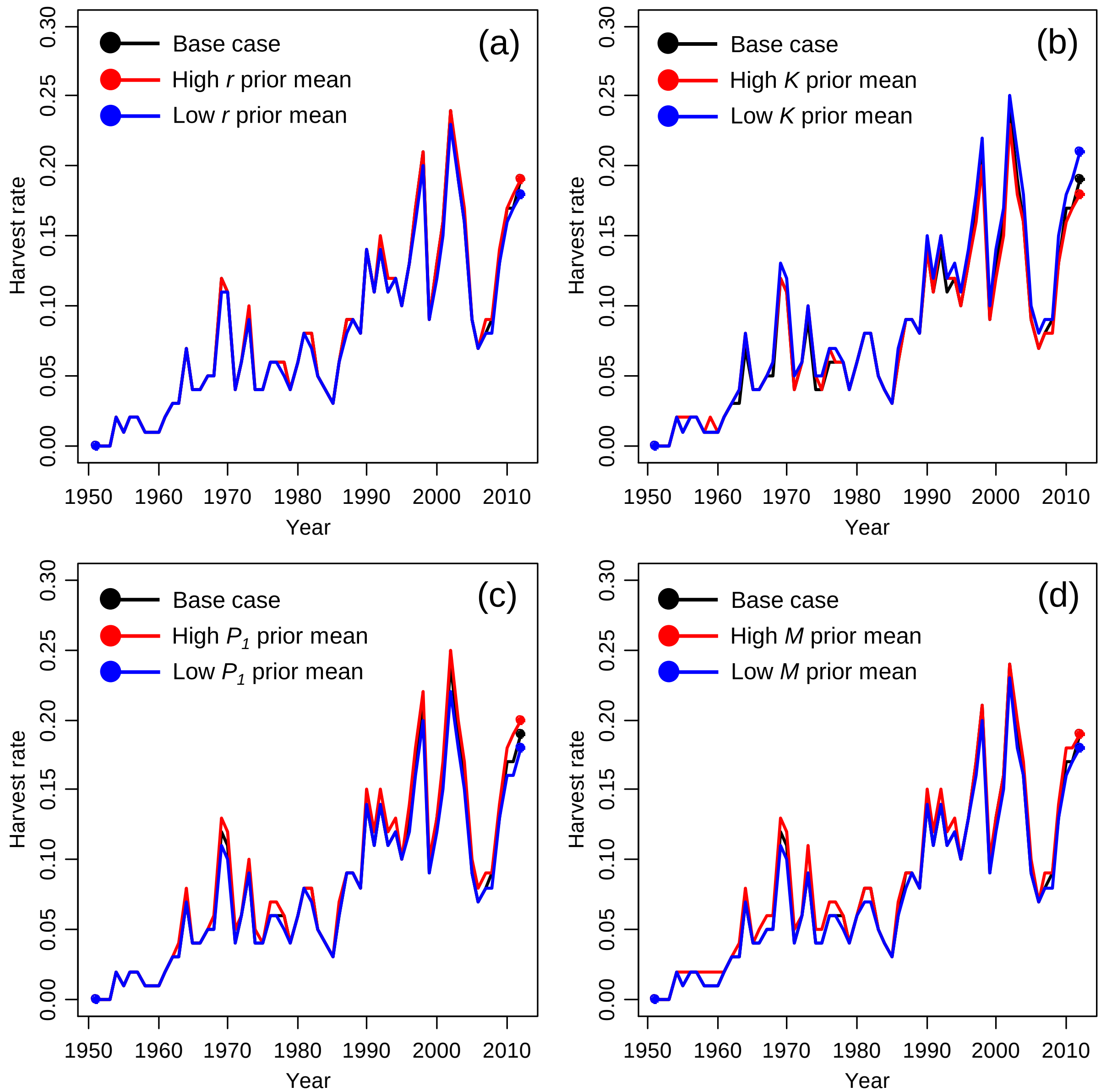


Figure 7.2.2. Comparison of time-series of harvest rates from the base-case model with estimates from the models of different prior assumptions of intrinsic growth rate, *r* (a), carrying capacity, *K* (b), initial condition, P_1 (c) and shape parameter, *M* (d) for the swordfish in the Eastern Pacific Ocean.

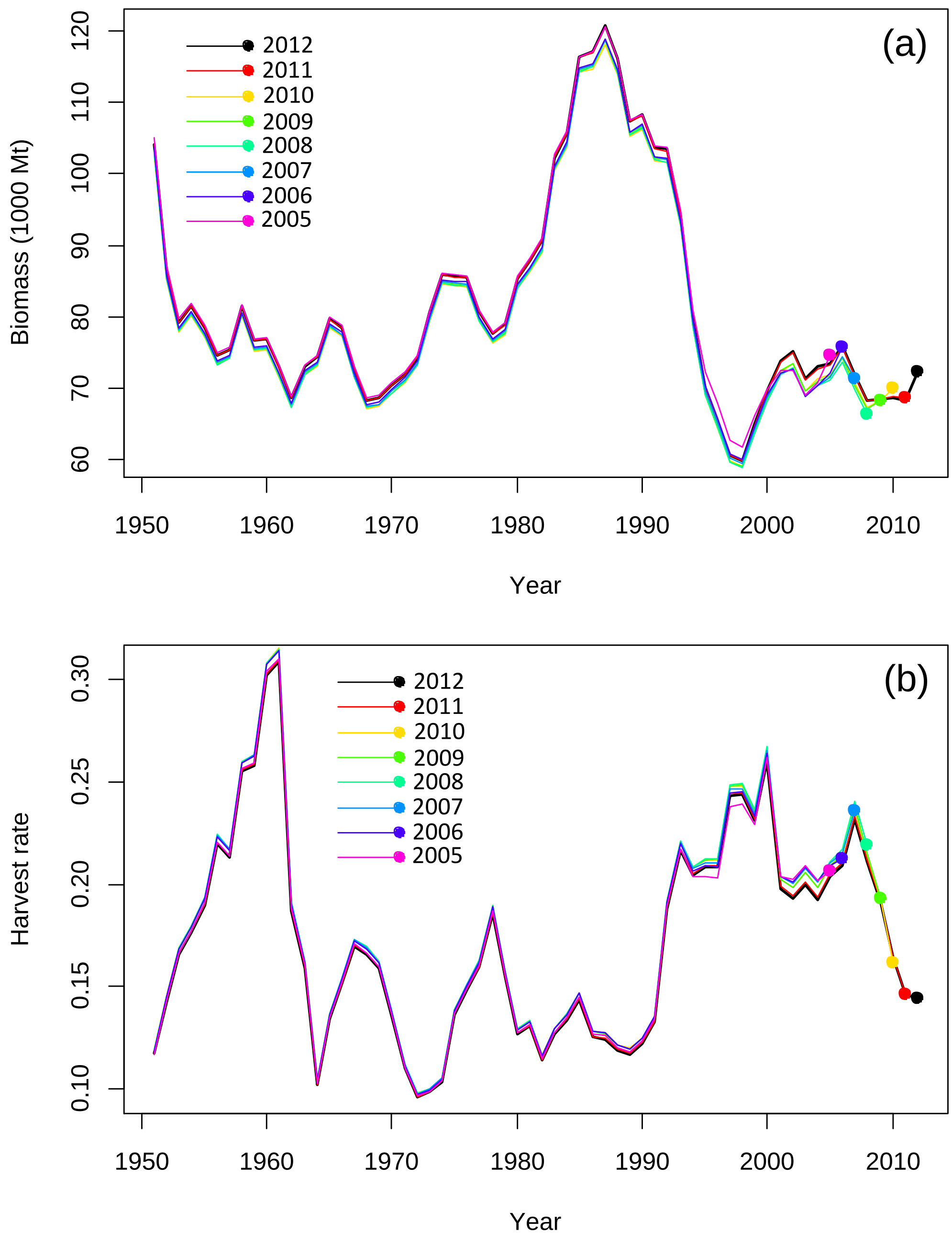


Figure 8.1. Seven years within–model retrospective plots of the absolute change in biomass (a) and harvest rate (b) for the Western and Central North Pacific swordfish based on the base-case production model.

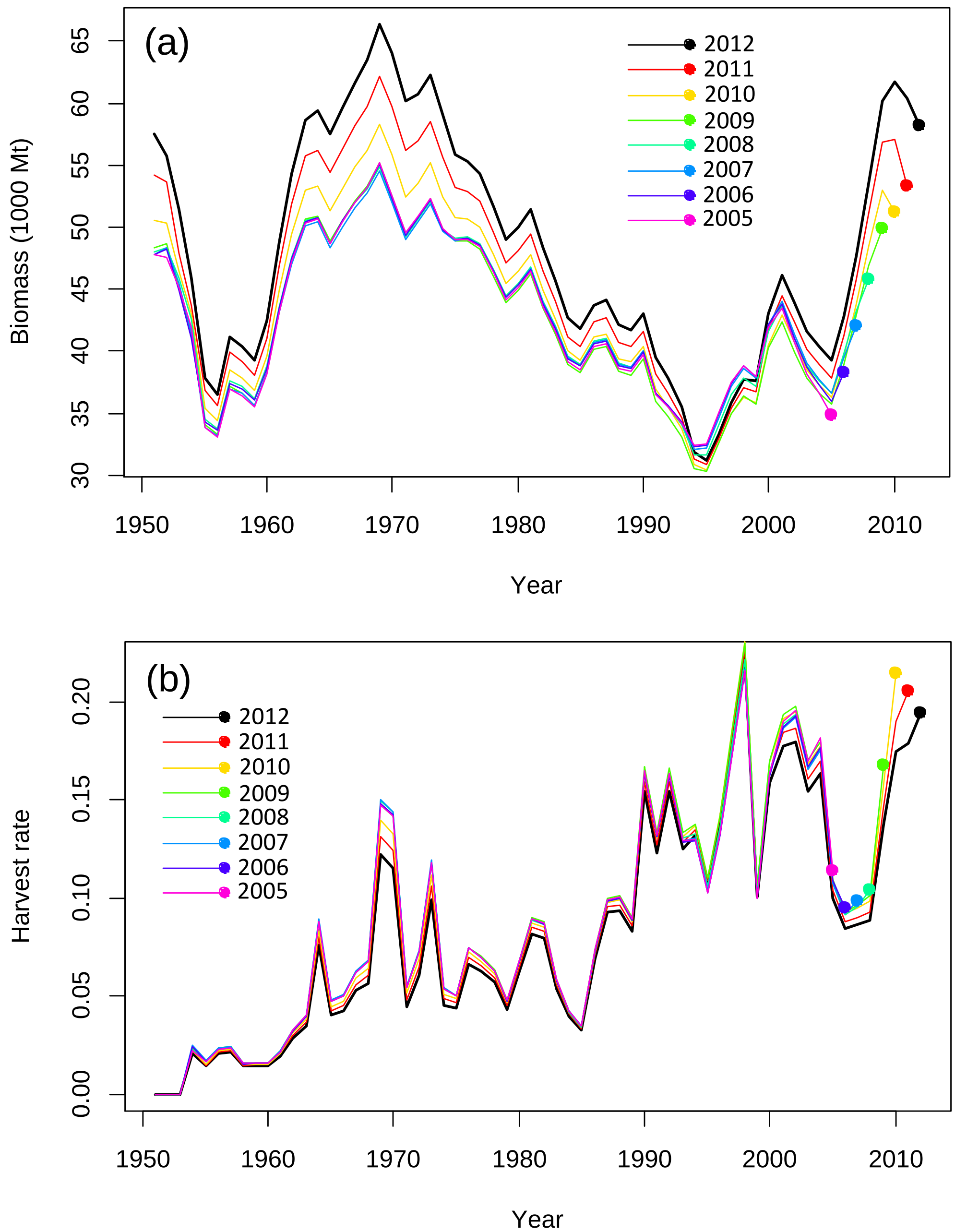


Figure 8.2. Seven years within–model retrospective plots of the absolute change in biomass (a) and harvest rate (b) for the Eastern Pacific swordfish based on the base-case production model.

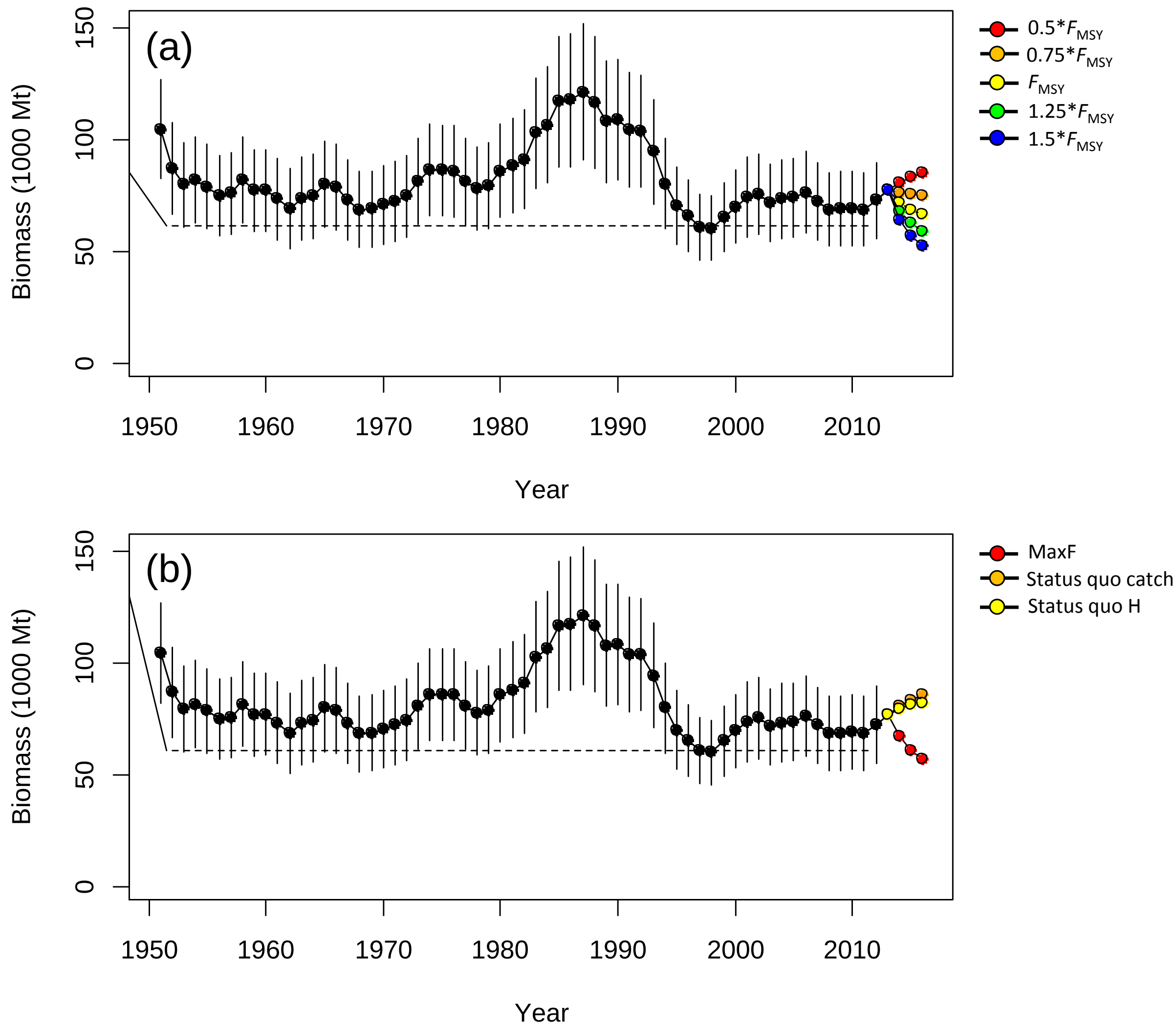


Figure 9.1.1. Historic and 4 years projected trajectories of biomass (1000 metric tons) for swordfish in the Western and Central Pacific Ocean. Upper panel are fishing mortality at 0.5, 0.75, 1.0, 1.25, and 1.5 F_{MSY}. Lower panel are status quo harvest rate from the most recent 3 years, status quo catch from the most recent 3 years and the maximum historically-observed harvest rate.

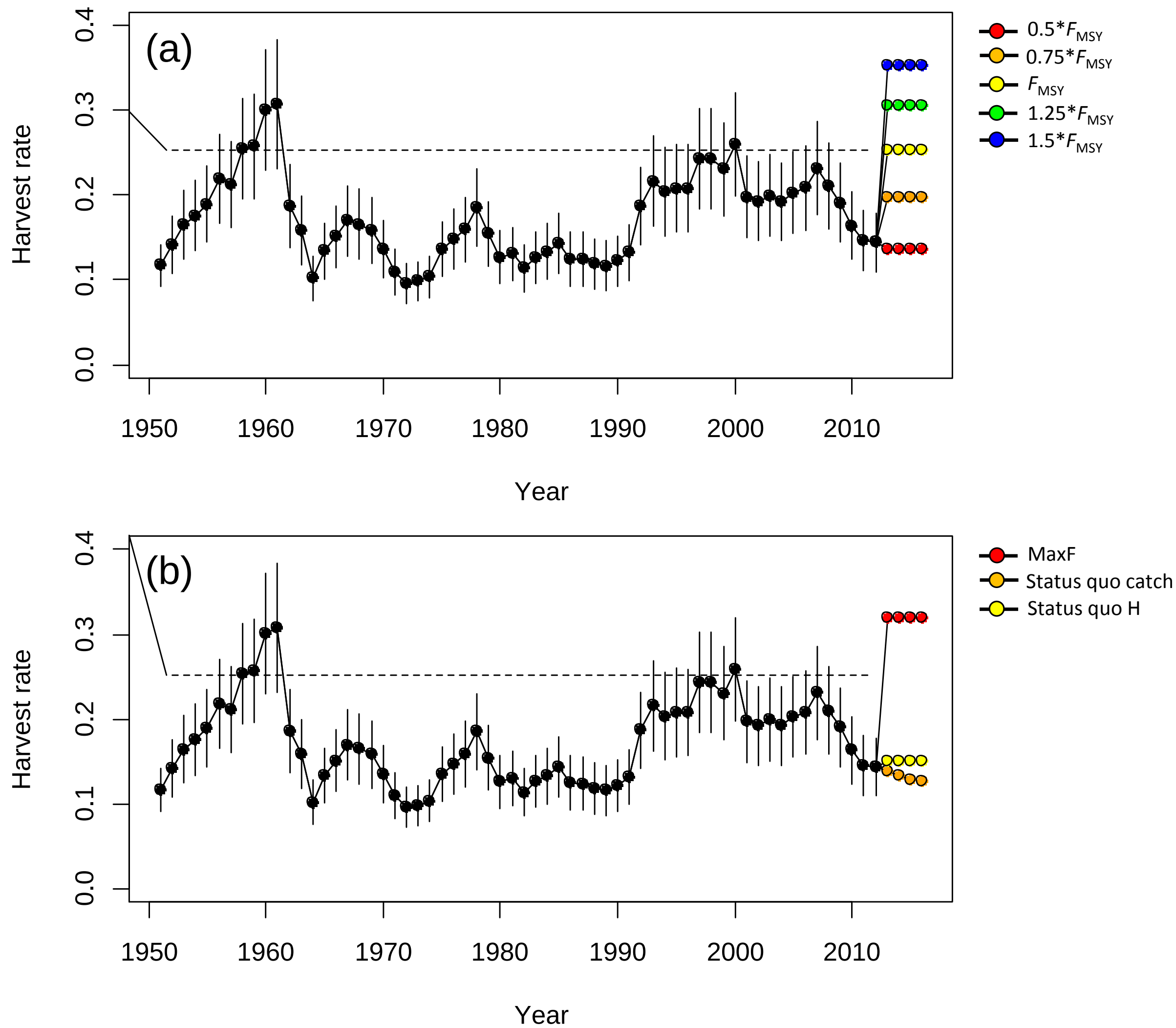


Figure 9.1.2. Historic and 4 years projected trajectories of harvest rate for swordfish in the Western and Central Pacific Ocean. Upper panel are fishing mortality at 0.5, 0.75, 1.0, 1.25, and 1.5 F_{MSY}. Lower panel are status quo harvest rate from the most recent 3 years, status quo catch from the most recent 3 years and the maximum historically-observed harvest rate.

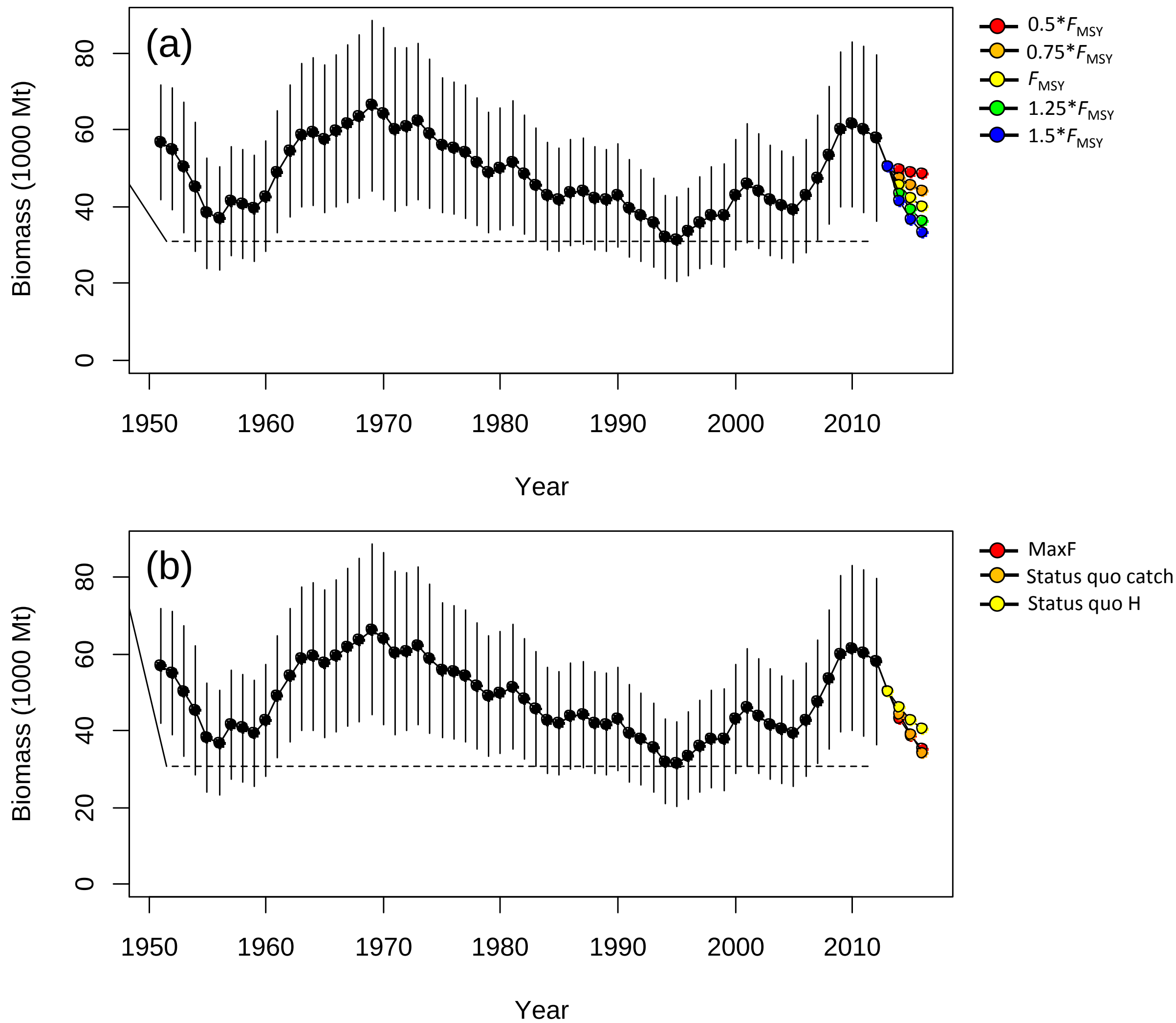


Figure 9.2.1. Historic and 4 years projected trajectories of biomass (1000 metric tons) for swordfish in the Eastern Pacific Ocean. Upper panel are fishing mortality at 0.5, 0.75, 1.0, 1.25, and 1.5 F_{MSY}. Lower panel are status quo harvest rate from the most recent 3 years, status quo catch from the most recent 3 years and the maximum historically-observed harvest rate.

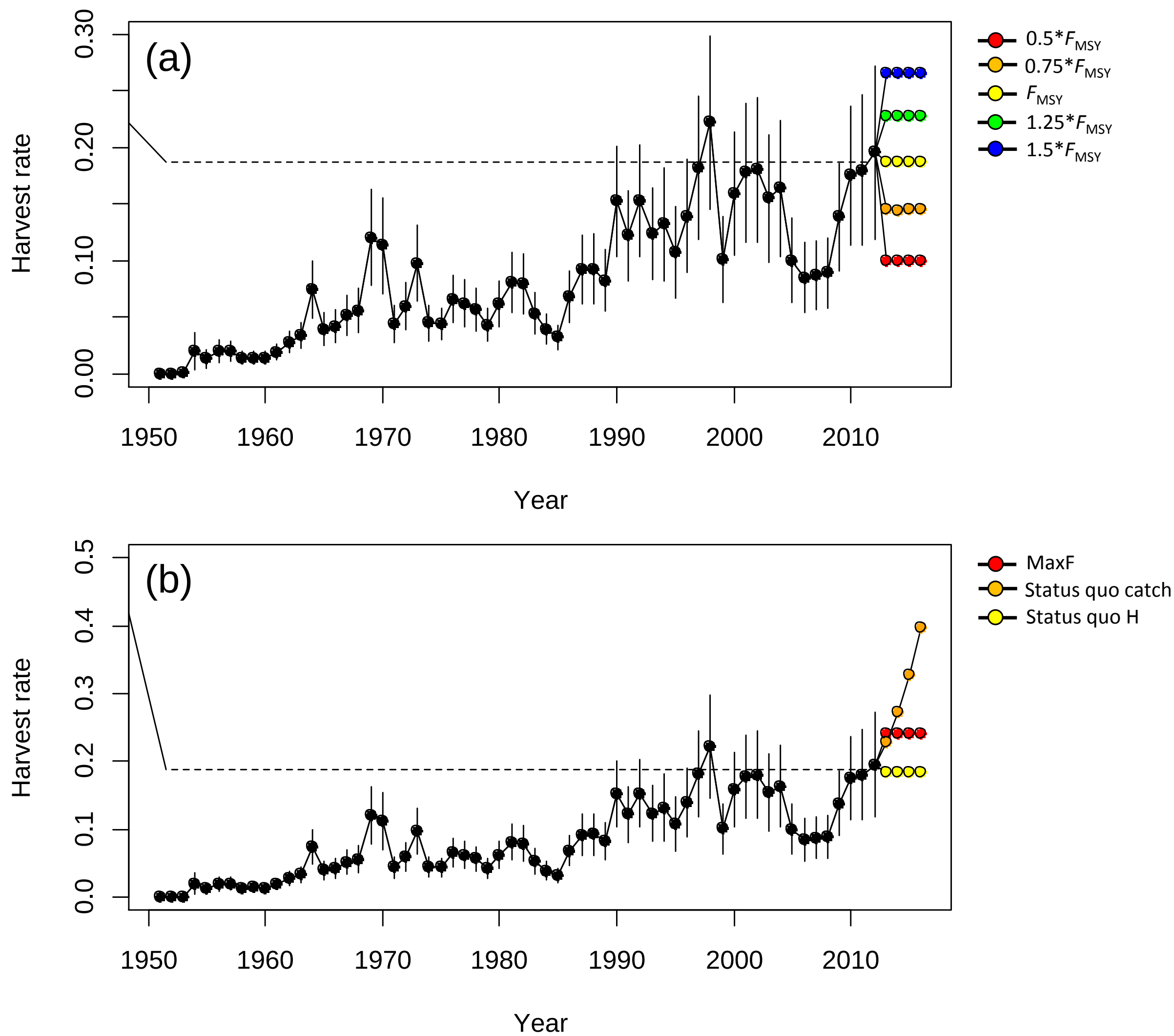


Figure 9.2.2. Historic and 4 years projected trajectories of harvest rate for swordfish in the Eastern Pacific Ocean. Upper panel are fishing mortality at 0.5, 0.75, 1.0, 1.25, and 1.5 F_{MSY}. Lower panel are status quo harvest rate from the most recent 3 years, status quo catch from the most recent 3 years and the maximum historically-observed harvest rate.

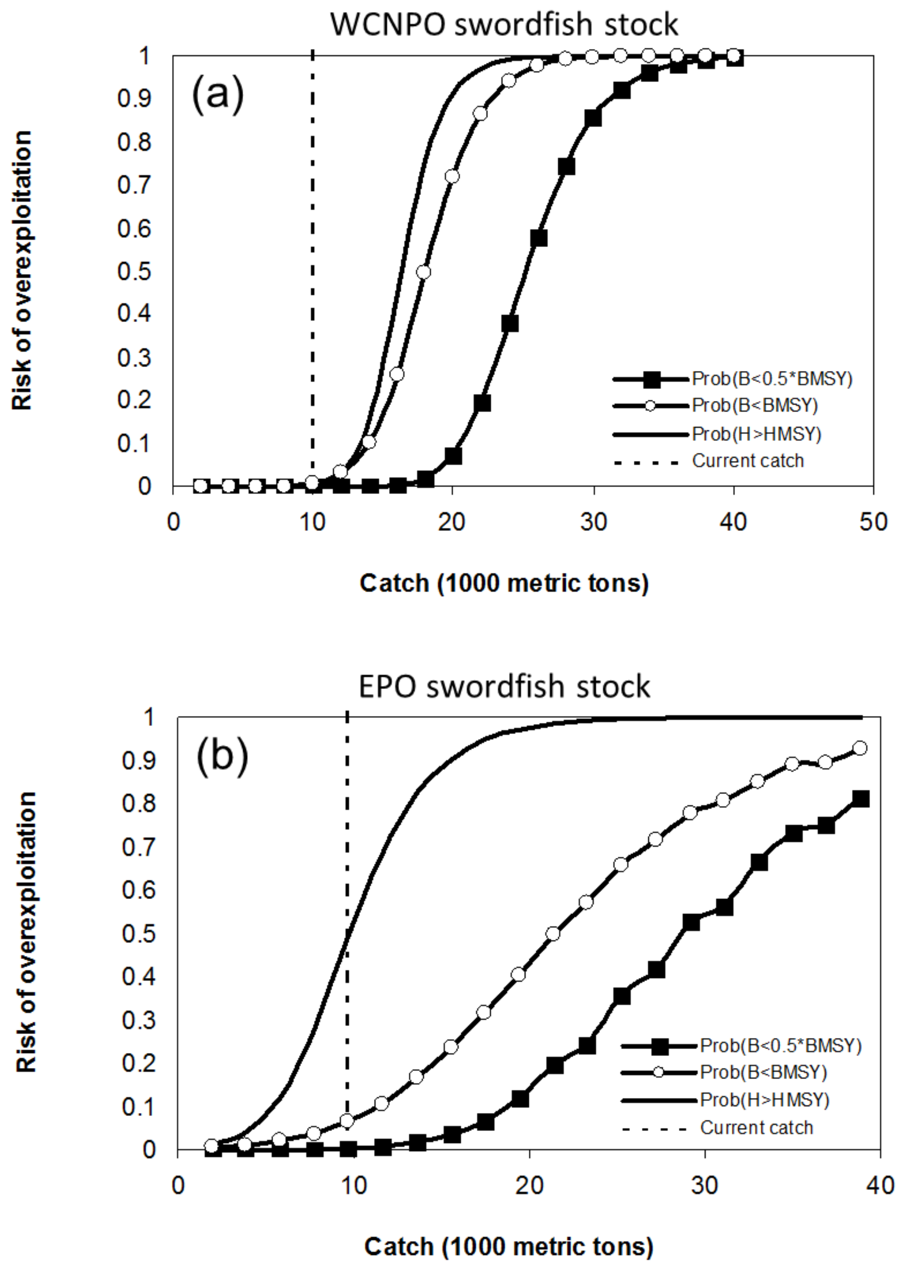


Figure 10. Probabilities of experiencing overfishing (H > H_{MSY}, solid line), of exploitable biomass falling below B_{MSY} (B < B_{MSY}, open circles), and of being overfished relative to a reference level of ½ B_{MSY} (B < 0.5* B_{MSY}, solid squares) in 2016 for swordfish in the Western and Central Pacific Ocean stock area (a) and Eastern Pacific Ocean stock area (b) based on applying a constant catch biomass (x-axis, thousand mt) in the stock projections.