NORTHERN COMMITTEE
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Fukuoka, Japan

Information and advice on North Pacific albacore, Western and Central Pacific Swordfish and Pacific bluefin tuna requested by the Northern Committee

WCPFC-NC9-2013/IP-03

ISC[1]

[1] International Scientific Committee for Tuna and Tuna-like species in the North Pacific Ocean

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

Information and advice on North Pacific albacore, Western and Central Pacific Swordfish and Pacific bluefin tuna requested by the Northern Committee

August
2013

INFORMATION AND ADVICE ON NORTH PACIFIC ALBACORE, WESTERN AND CENTRAL PACIFIC SWORDFISH AND PACIFIC BLUEFIN TUNA REQUESTED BY THE NORTHERN COMMITTEE

Introduction

The Northern Committee (NC) of the Western and Central Pacific Fisheries Committee (WCPFC) requested information (WCPFC/NC8 Summary report/Attachments E and F) on potential limit reference points (LRPs) for north Pacific albacore tuna (*Thunnus alalunga*) and stock projections for the Western and Central North Pacific swordfish (*Xiphias gladius*) during its Eight Regular Session (Northern Committee 2012). The ISC Plenary reviewed and endorsed the NC8 request at an intercessional Plenary in December 2012 meeting and tasked the Albacore Working Group (ALBWG) and Billfish Working Group (BILLWG) with completing the assignments and presenting the results for review at ISC13 in July 2013 (ISC 2012). During it's intercessional 2012 meeting, ISC also agreed to provide similar relevant information for Pacific bluefin tuna (*Thunnus orientalis*) pending approval from the NC, which NC provided.

The WGs discussed the requests and developed work plans and assignments to fulfill these requests at intercessional workshops in 2013 (see ISC/13/ANNEX/07/ATTACHMENT/05 and ISC/13/ANNEX/09/APPENDIX/04 and ISC/13/ANNEX/14/APPENDIX/02/APPENDIX/E). The resulting information and data were approved by ISC13 in July 2013 and are presented here, as are additional questions regarding the request for PBF.

This document is organized with the following order of information:

PART 1: NORTH PACIFIC ALBACORE

PART 2: WESTERN AND CENTRAL NORTH PACIFIC SWORDFISH

PART 3: PACIFIC BLUEFIN TUNA

Information Request to NC9 (*from ISC13 Plenary Report section 6.2*)
In addition to the information provided in the attached, the ISC also requests clarification regarding the NC request. It is assumed that NC wishes to evaluate the suitability of candidate reference points through future projection simulation. Also, it is expected NC will want analysis of the influence of the environmental variation such as regime shift and decadal change on FSPR and empirically based reference points.

The ISC PBFWG needs the NC's advice on the items listed below for its projections. Suggestions are provided by the PBFWG to promote discussion.
1. Projection years: 10 year
2. Recruitment scenarios: average (1952-2009), low (1980-1989), high (TBD by PBFWG))
3. F-level or choice of candidate F reference points (F reference points listed in *ISC/13/ANNEX/14 and ISC/10/PLENARY/04*)
4. Base F: F2007-2009, F2002-2004
5. Outputs:
    i. probability of SSB in the beginning of 2021 exceeding *SSBMIN*, SSB10%,

SSB20%, SSB30%, SSB40%
ii. Future average yield with CI or CV
iii. Other

ATTACHMENT 5

INFORMATION AND ADVICE ON BIOLOGICAL REFERENCE POINTS FOR NORTH PACIFIC ALBACORE REQUESTED BY THE NORTHERN COMMITTEE

ALBACORE WORKING GROUP

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

12-13 July 2013
Busan, Republic of Korea

1.0 INTRODUCTION

The Northern Committee (NC) of the Western and Central Pacific Fisheries Committee (WCPFC) requested information (Addendum 2) on potential limit reference points (LRPs) for north Pacific albacore tuna (*Thunnus alalunga*) during its Eight Regular Session (Northern Committee 2012). The WCPFC uses a three-level hierarchical system to evaluate and select limit reference points (LRP) for fishing mortality (F) and spawning stock biomass (SSB) based on the information richness available for the stock (Preece et al. 2011). The NC requested that the ISC provide information on the reliability and precision of key stock parameter estimates, current estimates of candidate reference point values, and the impact of climate-ocean forcing on the productivity of the north Pacific albacore stock (Addendum 2). The ISC Plenary reviewed and endorsed the NC8 request at an intercessional Plenary meeting and tasked the Albacore Working Group (ALBWG or WG) with completing the assignment and presenting the results for review at ISC13 in July 2013 (ISC 2012).

This document provides the information and advice requested by NC8. The WG discussed the requests and developed work plans and assignments to fulfill these requests at an intercessional workshop in March 2013 (ALBWG 2013). The resulting information and data were formulated into a recommended response for ISC13 and approved by the WG in July 2013. The organization of this document follows the questions posed by NC8 (Addendum 2).

2.0 KEY POPULATION AND MODEL PARAMETERS

Information was requested on key population dynamics relationships and parameter estimates. The WG discussed the stock-recruitment relationship and key biological, and fishery (selectivity) parameter estimates. This information is reported below.

2.1 Stock-recruitment Relationship and Steepness Parameter

The 2011 stock assessment assumed that a Beverton-Holt stock recruitment relationship was representative of stock-recruitment dynamics in the north Pacific albacore stock and that the value of the steepness parameter (h) in this relationship is 1.0. The h = 1.0 assumption has low biological plausibility because it implies that there will be recruitment in the absence of spawning biomass. This value was assumed in 2011 because modeling results showed that the likelihood profile of *h* was minimized at a value of 1.0, given the structure and other assumptions in the base-case model.

Steepness (*h*) is not well estimated for the north Pacific albacore stock, but the assumption of a Beverton-Holt stock-recruitment relationship is considered plausible, although the relationship may be weak. Frequency distributions of estimated steepness values provide evidence that plausible values of *h* for the north Pacific albacore stock are in the range $0.6 < h < 1.0$ (Brodziak et al. 2011; Iwata et al. 2011). Estimating credible values of the steepness parameter (*h*) is an ongoing area of research.

2.2 Maturity

The age-based maturity schedule used in the 2011 stock assessment is that 50% of albacore at age-5 are assumed to be sexually mature and all fish age-6 and older are mature. Although the WG considers this age-based maturity schedule to be reasonable, it also notes that the maturity data on which it is based are more than 40 years old (see Ueyanagi 1957), they reflect maturity in fish from the western Pacific only, and they represent the results of macroscopic techniques, which are known to be less accurate and precise in classifying gonadal development than modern microscopic approaches. Otsu and Uchida (1959) also assessed gonadal development and maturity with macroscopic techniques in the central Pacific Ocean and they along with Ueyanagi (1957) concluded that the minimum size at maturity is about 90 cm. Recently, Chen et al. (2010) reported that males and females mature at smaller sizes in the western Pacific Ocean than 90 cm on the basis of both macroscopic and microscopic examination of gonads. The WG recognizes that there is a need to develop a better description of maturity at age or length for north Pacific albacore since existing information, even the most recent information, does not capture spatial variation in maturity across the range of the adult component of this stock.

2.3 Fecundity

Ueyanagi (1957) estimated that albacore fecundity in the western Pacific Ocean was between 0.8 and 2.6 million eggs while Otsu and Uchida 1959) reported fecundity estimates ranging from 0.9 to 1.8 million eggs for albacore in Hawaiian waters. Both estimates are based on the assumption that all eggs in the most advanced developmental stage in an ovary were released. Recent batch-fecundity estimates of 21 females collected in the western Pacific Ocean ranged from 0.17 to 1.66 million eggs and was found to increase linearly with fish size (Chen et al. 2010). Recent fecundity for albacore females data in the central Pacific Ocean near Hawaii are not available. The 2011 stock assessment assumed that fecundity is proportional to weight, consistent with the findings of Chen et al. (2010).

2.4 Natural Mortality, M

Natural mortality, M, was not estimated by the 2011 assessment model. The WG fixed M at 0.3 yr^{-1} for all ages. This assumption is unchanged from previous assessments (e.g., ALBWG 2007) because new data or analyses supporting an alternative value or age-specific vector of M were not available. The assumed value was taken from assessments of Atlantic albacore (e.g., ICCAT 2010). Natural mortality of north Pacific albacore cannot be reliably estimated from existing conventional tagging data because tag return rates for adults were lower than expected, especially in the western Pacific Ocean (Bertignac et al. 1999), and estimates of M are positively correlated with tag return rates (see Ichinokawa et al. 2008). The WG has no explanation for the low adult tag returns at present.

2.5 Growth

One of the major advancements in the 2011 stock assessment was the implementation of a new growth model, which was based on length-frequency data and estimated within the base-case model. Estimating growth within the base-case model resulted in the best fit to the length data (ALBWG 2011) and the resulting growth parameter estimates were corroborated by independent estimates based on otolith age and growth data (Wells et al. 2011). Growth parameters in Wells et al. (2011) were well estimated and are based on fish aged 2 to 15 from the eastern, central and western Pacific Ocean, i.e., across the age and spatial range of the north Pacific albacore stock. The WG is confident in the new growth model parameterization and concluded that the growth curve used in previous assessments (based on Suda 1966) was not representative of growth in the north Pacific albacore stock. However, exploration of the hypothesis that there may be regional differences in growth not captured in the current assessment because it is not a spatial model has been identified as an important research need by the WG. Additional age and growth data have been collected since 2011 and were published by Wells et al. (2013). These new growth data will be used in upcoming assessment scheduled to be delivered in 2014.

2.6 Selectivity

Given the data inputs and model structure, the WG concludes that fishery selectivity for north Pacific albacore is well estimated for the eight fleets for which size composition data are available. Selectivity of fleets for which no size data were available was mirrored to one of the eight fleets based on similarities in operating characteristics.

3.0 CANDIDATE REFERENCE POINTS

3.1 Estimated Yields and Probabilities

Introduction - The NC requested advice on expected future yields and variability under low, average, and high historical recruitment scenarios over a 10-yr projection period to assist in determining the suitability of candidate reference points identified in the 2011 stock assessment. Additional information in the form of the estimated probability of breaching the Interim Management Objective (average of the 10 historical lowest years of SSB) and several biomass depletion levels for each candidate reference point harvest scenario was also requested from the ALBWG. The WG developed separate tables to provide these estimates for low, average, and high historical recruitment scenarios (Tables 1 to 3). These estimates are based on the 2011 assessment model, which includes data only through 2009, i.e., the model was not updated with 2010 and 2011 fishery data.

Methods - Biomass depletion is calculated relative to SSB_0. Since the model estimate of SSB_0 is highly uncertain, we used $SSB_{F=0}$ for the biomass depletion levels. $SSB_{F=0}$ is estimated as the mean spawning biomass ($N = 200$) at the terminal year of a 30-yr projection with F=0 and low, average, or high recruitment, i.e., the mean SSB at 2040. Thus, an average value of $SSB_{F=0}$ was calculated for each recruitment scenario and applied to the nine harvest scenarios, i.e., within a recruitment scenario a single $SSB_{F=0}$ was used for the nine harvest scenarios. Estimating $SSB_{F=0}$ was a first and separate step from the projections described below.

A second set of projections to derive estimates of future yield and probabilities that biomass will fall below depletion levels in at least one year of the projection period was performed with the R package "ssfuture" (Ichinokawa 2012,) which was also used for future projections in the 2011 stock assessment. Biological parameter values and initial population number were estimated for 2010 and recruitment was estimated by random resampling of the historical low, average, or high recruitment period data from the 2011 base case model. Projections were conducted for 27 combinations of recruitment (3 scenarios) and constant harvests strategies (9 scenarios corresponding to candidate reference points $F_{SSB\text{-}ATHL}$, F_{MAX}, $F_{0.1}$, F_{MED}, $F_{10\%}$, $F2_{0\%}$, $F_{30\%}$, $F_{40\%}$ and $F_{50\%}$). Two hundred (200) bootstrap replicates were used to estimate the mean expected yield (±CV) and the probability that SSB would fall below biomass depletion levels at a constant fishing mortality equivalent to the candidate reference points for each recruitment-harvest combination projection. Mean expected yield is calculated as average harvest at the terminal year of the projection, which is 2020 for 10-year and 2035 for the 25-year projections.

Results - Expected yield in all recruitment scenarios increased with increasing recruitment level After 10- and 25-yr projection periods and the differences are approximately 30,000-60,000 t, depending on the harvest scenario (Tables 1 to 3). The largest expected yield is obtained with the F_{MAX} harvest scenario and the lowest yield with the F_{MED} and $F_{50\%}$ harvest scenarios. There was little difference in expected yield after 10 or 25 years when fishing at $F_{SSB\text{-}ATHL}$. Yield is approximately double between the minimum and maximum values in all recruitment scenarios.

The WG notes that given the current model structure (steepness h = 1.0), F_{MAX} is theoretically equivalent to F_{MSY}. However, F_{MAX} is not well estimated by the 2011 stock assessment model since the yield curve is extremely flat, which places F_{MAX} well beyond historical or observed fishing mortality during the stock assessment time period.

Fishing at F_{MAX} has the highest probability of causing SSB to drop below various depletion levels in at least one year. Fishing at F_{MED} was the least aggressive harvest strategy, regardless of recruitment scenario.

3.2 Harvest Scenarios

Estimated F-ratios of candidate reference points to two different constant harvest scenarios ($F_{2002\text{-}2004}$, $F_{2006\text{-}2008}$) are shown in Table 4 to determine if reference point levels are exceeded. It is important to note that the WG used selectivity for $F_{2002\text{-}2004}$ and $F_{2006\text{-}2008}$, respectively, for these calculations.

$F_{2002\text{-}2004}/F_{RP}$ ratios are consistently higher than $F_{2006\text{-}2008}/F_{RP}$ ratios with a maximum difference of 16%. None of the candidate reference points are exceeded (ratio > 1.0) under an F-current ($F_{2006\text{-}2008}$) harvest scenario, although the F_{MED} and $F_{50\%}$ reference points are close to this threshold. In contrast, the F_{MED} and $F_{50\%}$ with the $F_{2002\text{-}2004}$ harvest scenario. The ratio for F_{MAX} is unrealistically low for both harvest scenarios because the yield curve for north Pacific albacore is very flat and determining the location of F_{MAX} on this curve is imprecise.

3.3 Environmental Influences on Candidate Reference Points

The north Pacific albacore stock is modeled as an environmentally-driven stock since a steepness value of 1.0 was used in the stock-recruitment relationship in the 2011 assessment (ALBWG 2011). This decision is a model-related rather than data-related because there is insufficient contrast in stock-recruit data to reject the null hypothesis that h = 1.0. Thus, although the h=1 hypothesis was accepted, the WG does not have strong evidence at present that recruitment is "environmentally driven". Kiyofuji (2013) presented a working paper that provides evidence of cyclic changes in albacore recruitment levels (high, low, average) that seems to fit regime shifts in productivity of the North Pacific Ocean in the 1970s and 1980s. Zhang et al. (2013) showed that stock productivity, when modeled with a logistic surplus production model, was positively affected by the North Pacific Gyre Oscillation (NPGO) and negatively affected by the multi-variate ENSO index (MEI) at a lag period of four years. Although it is not clear what population process is impacted by large scale climate-ocean forcing represented by the NPGO and MEI, Zhang et al. (2013) and the WG speculate that these results could be a latent recruitment effect.

A preliminary assessment of the effects of regime shifts on values of F_{SPR}s can be accomplished by comparing the results for the low and high recruitment scenarios in Tables 1 and 3. The probability of SSB breaching the Interim Management Objective and other depletion levels when harvesting at F_{MAX} was higher than the other harvests scenarios for both high and low recruitment. Probabilities were always higher in the low recruitment scenario relative to those of high recruitment scenario. In particular, for the $F_{30\%}$ to $F_{50\%}$ harvest scenarios, there was more than a 10% difference between low and high recruitment level probabilities.

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Table 1. Expected future yield at the end of the projection period (**± CV**) and estimated probabilities that SSB will be lower than several biomass depletion level thresholds in at least one year of the projection period under nine constant harvest scenarios corresponding to candidate reference points and the low historical recruitment scenario. $SSB_{F=0\ xx\%}$ refers to spawning biomass depletion relative to the unfished state. Probabilities highlighted in bold are ≥ 0.50.

Low Historical Recruitment Scenario

			Biomass Depletion Level				
Reference Point	Projection Period (yr)	Future Yield (mt)	SSB-ATHL	$SSB_{F=0\ 10\%}$	$SSB_{F=0\ 20\%}$	$SSB_{F=0\ 30\%}$	$SSB_{F=0\ 40\%}$
$F_{SSB-ATHL}$	25	75,901 (0.10)	**0.531**	0.000	0.014	0.148	0.386
$F_{SSB-ATHL}$	10	76,303 (0.09)	0.337	0.000	0.005	0.063	0.213
F_{MAX}	10	129,474 (0.23)	**0.737**	0.352	**0.518**	**0.610**	**0.684**
$F_{0.1}$	10	116,501 (0.16)	**0.613**	0.059	0.247	0.408	**0.541**
F_{MED}	10	61,133 (0.09)	0.210	0.000	0.000	0.015	0.112
$F_{10\%}$	10	118,648 (0.14)	**0.628**	0.084	0.278	0.436	**0.563**
$F_{20\%}$	10	105,537 (0.12)	**0.549**	0.014	0.127	0.295	0.456
$F_{30\%}$	10	91,264 (0.10)	0.447	0.000	0.037	0.165	0.337
$F_{40\%}$	10	79,225 (0.09)	0.350	0.000	0.008	0.068	0.228
$F_{50\%}$	10	65,026 (0.10)	0.241	0.000	0.000	0.025	0.138

Table 2. Expected future yield at the end of the projection period (± CV) and estimated probabilities that SSB will be lower than several biomass depletion level thresholds in at least one year of the projection period under nine constant harvest scenarios corresponding to candidate reference points and the average historical recruitment scenario. $SSB_{F=0\ xx\%}$ refers to spawning biomass depletion relative to the unfished state. Probabilities highlighted in bold are ≥ 0.50.

Average Historical Recruitment Scenario

			Biomass Depletion Level				
Reference Point	Projection Period (yr)	Future Yield (mt)	SSB-ATHL	$SSB_{F=0\ 10\%}$	$SSB_{F=0\ 20\%}$	$SSB_{F=0\ 30\%}$	$SSB_{F=0\ 40\%}$
$F_{SSB\text{-}ATHL}$	25	99,820 (0.11)	0.300	0.000	0.025	0.174	0.439
$F_{SSB\text{-}ATHL}$	10	101,394 (0.12)	0.221	0.000	0.015	0.118	0.356
F_{MAX}	10	174,733 (0.27)	**0.732**	0.409	**0.572**	**0.680**	**0.774**
$F_{0.1}$	10	152,885 (0.17)	**0.582**	0.081	0.305	**0.501**	**0.669**
F_{MED}	10	81,803 (0.12)	0.114	0.000	0.000	0.059	0.223
$F_{10\%}$	10	155,580 (0.18)	**0.600**	0.107	0.338	**0.528**	**0.680**
$F_{20\%}$	10	139,187 (0.16)	**0.501**	0.022	0.167	0.390	**0.595**
$F_{30\%}$	10	120,929 (0.13)	0.365	0.001	0.057	0.241	0.484
$F_{40\%}$	10	104,004 (0.12)	0.244	0.000	0.018	0.132	0.378
$F_{50\%}$	10	86,221 (0.12)	0.144	0.000	0.003	0.064	0.253

Table 3. Expected future yield at the end of the projection period (± CV) and estimated probabilities that SSB will be lower than several biomass depletion level thresholds in at least one year of the projection period under nine constant harvest scenarios corresponding to candidate reference points and the high historical recruitment scenario. $SSB_{F=0\ xx\%}$ refers to spawning biomass depletion relative to the unfished state. Probabilities highlighted in bold are ≥ 0.50.

High Historical Recruitment Scenario

			Biomass Depletion Level				
Reference Point	Projection Period (yr)	Future Yield (mt)	SSB-ATHL	$SSB_{F=0\ 10\%}$	$SSB_{F=0\ 20\%}$	$SSB_{F=0\ 30\%}$	$SSB_{F=0\ 40\%}$
$F_{SSB-ATHL}$	25	112,561 (0.11)	0.234	0.000	0.030	0.206	0.467
$F_{SSB-ATHL}$	10	113,447 (0.10)	0.182	0.000	0.022	0.162	0.422
F_{MAX}	10	191,925 (0.27)	**0.729**	0.428	**0.595**	**0.711**	**0.815**
$F_{0.1}$	10	172,289 (0.17)	**0.568**	0.097	0.337	**0.548**	**0.721**
F_{MED}	10	90,113 (0.10)	0.097	0.000	0.003	0.085	0.313
$F_{10\%}$	10	178,653 (0.16)	**0.590**	0.123	0.367	**0.571**	**0.736**
$F_{20\%}$	10	156,192 (0.14)	0.468	0.028	0.194	0.444	**0.651**
$F_{30\%}$	10	136,104 (0.12)	0.320	0.002	0.075	0.287	**0.566**
$F_{40\%}$	10	116,402 (0.10)	0.210	0.000	0.023	0.184	0.438
$F_{50\%}$	10	96,250 (0.10)	0.105	0.000	0.002	0.092	0.338

Table 4. Potential reference points and estimated F-ratios using Fcurrent ($F_{2006\text{-}2008}$) and $F_{2002\text{-}2004}$ (current F in the 2011 assessment). Ratios ≥ 1.0 are highlighted in bold.

Reference Point	$F_{2006\text{-}2008}/F_{RP}$	$F_{2002\text{-}2004}/F_{RP}$
$F_{SSB\text{-}ATHL}$	0.71	0.78
F_{MAX}	0.14	0.18
$F_{0.1}$	0.29	0.35
F_{MED}	0.99	**1.15**
$F_{10\%}$	0.27	0.31
$F_{20\%}$	0.38	0.45
$F_{30\%}$	0.52	0.61
$F_{40\%}$	0.68	0.80
$F_{50\%}$	0.91	**1.06**

ATTACHMENT 5

ADDENDUM 2

Attachment E

The Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean

Northern Committee
Eighth Regular Session

Nagasaki, Japan
3–6 September 2012

North Pacific Albacore Reference Points
Requests to the ISC

1. For the purposes of determining potential limit reference points for a precautionary approach management framework for North Pacific albacore, Northern Committee (NC) requests advice from the ISC on the following:
   i) Is the stock-recruitment relationship known, and in particular a reliable estimate of the steepness parameter (h) for the stock?
   ii) Are the key biological (natural mortality, maturity) and fishery (selectivity) variables reasonably well estimated?

2. To determine the suitability of candidate reference points identified by the ALBWG in its 2011 stock assessment, NC8 further requests that the ISC provide advice with respect to the following:
   a) For each of the following levels of F, expected yields, with measures of variability of these expected yields, under high, low and historical average recruitment scenarios, over the course of 10 years projections (and, in addition, 25 year projections for $F_{SSB\text{-}ATHL}$), the probabilities of breaching (in at least 1 year of the projection period) the Interim Management Objective (average of the 10 historical lowest years of SSB) and each of the depletion levels $SB_{10\%}$, $SB_{20\%}$, $SB_{30\%}$ and $SB_{40\%}$:
      i) $F_{SSB\text{-}ATHL}$
      ii) F_{MAX}
      iii) $F_{0.1}$
      iv) F_{MED}
      v) $F_{10\%}$, $F_{20\%}$, $F_{30\%}$, $F_{40\%}$, $F_{50\%}$
   b) A determination of whether or not under different levels of fishing mortality (average $F_{2006\text{-}2008}$, average $F_{2002\text{-}2004}$) that the above candidate reference points will be exceeded.
   c) To provide the influence of the environmental variation such as regime shift and decadal change on F_{SPR} and empirical based reference points.

Appendix 4. Western and Central North Pacific swordfish stock projections.

ISC/13/BILLWG-3/2

Projections for the Western and Central North Pacific Swordfish Stock Under Alternative Harvest Rates and Reference Points

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ABSTRACT

This working paper addresses a request of the Northern Committee (NC) of the Western and Central Pacific Fisheries Commission to the ISC Billfish Working Group to conduct stock projections for the Western and Central North Pacific (WCPO) swordfish stock. The requested projections included information on expected yields and their variability under alternative harvest rates and biological reference points. Updated catch information for WCPO swordfish through 2012 was gathered from ISC member countries and all other available sources. . The potential limit reference points to set the harvest rate scenarios for the NC request included three scenarios: (1) the most recent 3-year average harvest rate (scenario 1), (2) the harvest rate set at fractions of HMSY ranging from 0.5 to 1.5 in multiples of 0.25 (scenarios 2.1 to 2.5), and (3) the harvest rate set at the maximum historic harvest rate during 1951-2012 (scenario 3). Parameters of the WCPO production model were reevaluated using the updated catch data during 2007-2012 (Figure 1.1). Revised estimates of biological reference points were virtually identical to those

from the 2009 stock assessment: MSY = 14.4 thousand mt, BMSY = 57.3 thousand mt, and HMSY = 0.26. Estimates of the exploitable biomass of WCPO swordfish showed the same trends as in the 2010 stock assessment (Figure 1.2). Exploitable biomass in 2012 was estimated to be 80.8 thousand mt (±26.4), or 41% above BMSY. Similarly, estimates of the harvest rate of WCPO swordfish also exhibited the same trends as in the 2010 stock assessment (Figure 1.3). The harvest rate in 2012 was estimated to be 12% (±5%), or about 54% below HMSY. Overall, the updated stock status information indicated that the WCPO swordfish stock was not overfished or experiencing overfishing in 2012 relative to MSY-based reference points. Projection results indicated that expected WCPO yields would increase under most of the alternative harvest rate scenarios and that expected WCPO biomass would be reduced to below BMSY in 2017 (Table 3 and Figure 2.2) under some of the harvest rate scenarios. Projection results for the probabilities of breaching biomass depletion reference points indicated that the there was a high probability that exploited biomass would be reduced to below BMSY in 2017 for some of the higher harvest rate scenarios.

MATERIALS AND METHODS

This working paper addresses the request of the Northern Committee (NC) of the Western and Central Pacific Fisheries Commission to the ISC Billfish Working Group to conduct stock projections for the Western and Central North Pacific (WCPO) swordfish stock. The NC request was made at the 8th regular session of the Northern Committee and was listed in Attachment F of the summary report of that meeting (available at http://www.wcpfc.int/node/4588) and states that

For the purpose of the NC's consideration of biological reference points for swordfish in the northwest Pacific Ocean, the NC requests information and advice from the ISC on the following:

"1. If a production model is used to assess the status of the stock:

a. Is there an adequately precise estimate of intrinsic growth rate available?

2. If an age-structured model is used to assess the status of the stock:

a. Is there an adequately precise estimate of steepness available?

b. Are the key biological (natural mortality, maturity) and fishery (selectivity) variables reasonably well estimated?

3. For the purpose of evaluating the suitability of specific candidate limit reference points:

a. For each of the following levels of F, expected yields, with measures of variability of those expected yields, over the course of 15-year projections, the probabilities of breaching (in at least one year of the projection period) each of the depletion levels SB10%, SB20%, SB30%, and SB40%:

i) Most recent 3-year average F

ii) 0.5FMSY, 0.75FMSY, FMSY, 1.25FMSY, 1.5FMSY

iii) Maximum historically observed single-year F

4. The implications, with respect to any limit reference points that may have been adopted while using a production model, of changing to the use of an age-structured model."

The last assessment of the North Pacific swordfish population was conducted by the BILLWG in 2009 (BILLWG 2009) using catch data through 2006. This assessment was conducted for two stocks: the WCPO and the Eastern North Pacific swordfish stock using Bayesian production models (BILLWG 2009, Brodziak and Ishimura 2010a). The EPO swordfish assessment was updated in 2010 to account for additional information on swordfish catches (BILLWG 2010). The results of the 2009 WCPO assessment indicated that estimates of intrinsic growth rate were adequately precise to conduct stock projections ($r = 0.58 \pm 0.21$) for item 1 of the NC request. Biological reference points for the WCPO swordfish stock were summarized by Brodziak and Ishimura (2010b): maximum sustainable yield (MSY) was MSY = 14.4 thousand mt, biomass to produce MSY (BMSY) was BMSY = 57.3 thousand mt, and harvest rate to produce MSY (HMSY) was HMSY = 0.25. Point estimates of these reference points were updated using the updated information on swordfish catches during 2007-2012 for the projection analyses described below.

Updated catch information for WCPO swordfish through 2012 was gathered from ISC member countries and all other available sources (Table 1.1). Catch information for the WCPO swordfish stock area was not available for 2007-2008 and 2012 for the Inter-American Tropical Tuna Commission and other sources. These missing catches were estimated using the average proportion of IATTC and other sources catches of the total WCPO swordfish catch during the period 2009-2011; this proportion was 0.21% (Table 1.2). Catch information for the WCPO swordfish area was also not available for Taiwanese longline and other fleets in 2012 (Table 1.1). The missing Taiwanese catch biomass in 2012 was estimated from the ratio of the Taiwanese to Japanese catch in 2011 times the Japanese catch in 2012 (Table 1.2). This estimator was used to account for recent changes in the ratio of Taiwanese to Japanese swordfish catches in 2011 given the impact of the March 11, 2011 earthquake on the effective effort of the Japanese fishing fleet targeting WCPO swordfish.

Parameters of the WCPO production model were reevaluated using the updated catch data during 2007-2012 (Figure 1.1). Revised estimates of biological reference points were virtually identical to those from the 2009 stock assessment: MSY = 14.4 thousand mt, BMSY = 57.3 thousand mt, and HMSY = 0.26. Estimates of the exploitable biomass of WCPO swordfish showed the same trends as in the 2010 stock assessment (Figure 1.2). Exploitable biomass in 2012 was estimated to be 80.8 thousand mt (±26.4), or 41% above BMSY. Similarly, estimates of the harvest rate of WCPO swordfish also exhibited the same trends as in the 2010 stock assessment (Figure 1.3). The harvest rate in 2012 was estimated to be 12% (±5%), or about 54% below HMSY. Overall, the updated stock status information indicated that the WCPO swordfish stock was not overfished or experiencing overfishing in 2012 relative to MSY-based reference points.

Performance measures for the NC request included the expected yields of WCPO swordfish and the probabilities of breaching (falling below in at least one year of the projection period) the biomass depletion levels of 10% (B10), 20% (B20), 30% (B30), and 40% (B40) of the estimated carrying capacity. The potential limit reference points to set the harvest rate scenarios for the NC request included three scenarios: (1) the most recent 3-year average harvest rate (scenario 1), (2) the harvest rate set at fractions of HMSY ranging from 0.5 to 1.5 in multiples of 0.25 (scenarios 2.1 to 2.5), and (3) the harvest rate set at the maximum historic harvest rate during 1951-2012 (scenario 3). The values of these reference points were tabulated (Table 2.1) and applied in stochastic projections to assess the projected performance measures for each scenario. A total of 3 Markov Chain Monte Carlo chains were simulated for each scenario using a total of 31000 simulations for each chain using a burnin of 1000 simulations and a thinning rate of 3, numerical values that were similar to those used in the 2010 WCPO stock assessment.

Projection results indicated that expected WCPO yields would increase under most of the alternative harvest rate scenarios (Table 3). Expected yields would be higher than recent average yields under the higher harvest rate scenarios (HMSY, 125% of HMSY, 150% of HMSY, and Maximum historic H). Expected yields would slightly increase under the 75% of HMSY scenario and would decrease under the 50% of HMSY and recent 3-year average scenarios (Figure 2.1). In this context, note that the 50% of HMSY and recent 3-year average H scenarios were virtually identical.

Projection results for exploited biomass indicated that the expected WCPO biomass would be reduced to below BMSY in 2017 (Table 3 and Figure 2.2) under some of the harvest rate scenarios (125% of HMSY, 150% of HMSY, and Maximum historic H). Fishing at the

HMSY level would lead to an expected biomass near BMSY in 2017 as expected, while the lower harvest rate scenarios would maintain expected biomasses above BMSY (75% of HMSY, 50% of HMSY, and recent 3-year average H scenarios).

Projection results for the probabilities of breaching biomass depletion reference points indicated that the there was a high probability that exploited biomass would be reduced to below BMSY in 2017 (Table 3 and Figure 2.3) for some of the higher harvest rate scenarios (125% of HMSY, 150% of HMSY, and Maximum historic H). In contrast, for the lower harvest rate scenarios (75% of HMSY, 50% of HMSY, and recent 3-year average H scenarios) there were relatively low probabilities of breaching any of the potential biomass depletion reference points (Table 3 and Figure 2.3). For the 10% and 20% biomass depletion levels, it was very unlikely that these depletion levels would be breached by 2017 given current WCPO stock conditions. We also note that the corresponding annual probabilities of breaching the biomass depletion reference points have been tabulated along with other simulation results and that this additional information will be provided upon written request to the author.

With respect to item 4, changing to the use of an age-structured model will have limited effect on the interpretation of production model reference points based on MSY. When moving to an age-structured model from a production model it is important to note that the stock-recruitment steepness and natural mortality rate will effectively determine the fraction of unfished spawning biomass that produces MSY (Mangel et al. 2013). In the production model, the fraction of unfished biomass to produce MSY is effectively determined by the shape parameter M. Thus, there is an analogous interpretation of MSY-based reference points for a general age-structured model and production model but different parameters determine the biomass to produce MSY. For reference points based on spawning potential ratio (SPR), there is an analogous interpretation of the fraction of unfished spawning biomass per recruit as an analogue of a fraction of unfished exploitable biomass, again with the recognition that the scaling of spawning biomass to produce a specific fraction of SPR will differ from the biomass scale of an equivalent fraction of unfished exploitable biomass. One other major point to note is that while changing to an age-structured model will change the scale of estimates of biomass, it should be emphasized that it is the value of ratio biomass to the reference point that is important for stock status determination.

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Table 1.1. Updated estimates of WCPO swordfish catch biomass (thousand mt) by source during 2007-2012.

Year	ISC 2013 Subarea1 Swordfish Catch Biomass Estimates (1000 mt)	USA Subarea1 Swordfish Catch (1000 mt)	Japan Subarea1 Swordfish Catch (1000 mt)	IATTC and Other Sources Subarea1 Swordfish Catch (1000 mt)	Taiwan Subarea1 Swordfish Catch (1000 mt)
2007		1.735	9.131		3.935
2008		1.980	6.766		3.605
2009	11.403	1.818	6.200	0.003	3.382
2010	9.811	1.671	5.467	0.058	2.615
2011	8.872	1.625	3.726	0.001	3.520
2012		0.904	3.989		

Table 1.2. Estimates of WCPO swordfish catch biomass (thousand mt) by source during 2007-2012 used for conducting stock projections under alternative harvest rates and reference points.

Year	ISC 2013 Subarea1 Swordfish Catch Biomass Estimates	USA Subarea1 Swordfish Catch (1000 mt)	Japan Subarea1 Swordfish Catch (1000 mt)	IATTC and Other Sources Subarea1 Swordfish Catch	Taiwan Subarea1 Swordfish Catch (1000 mt)
2007	14.832	1.735	9.131	0.031	3.935
2008	12.377	1.980	6.766	0.026	3.605
2009	11.403	1.818	6.200	0.003	3.382
2010	9.811	1.671	5.467	0.058	2.615
2011	8.872	1.625	3.726	0.001	3.520
2012	8.680	0.904	3.989	0.001	3.769

Table 2.1. The three scenarios of potential limit reference points to set the harvest rate for WCPO swordfish projections in the NC request.

SCENARIO 1: 3-YEAR AVERAGE HARVEST RATE FOR 2010-2012

Variable	mean	sd	CV	PRECISION
H[60]	0.144	0.052	0.364	364.9
H[61]	0.127	0.049	0.385	418.2
H[62]	0.121	0.051	0.424	383.4
3-YEAR AVERAGE HARVEST RATE	0.130	0.051	0.389	387.9

SCENARIO 2: MULTIPLES OF HMSY HARVEST RATE

Variable	mean	sd	CV	PRECISION
0.5*HMSY	0.130	0.031	0.237	1047.7
0.75*HMSY	0.196	0.046	0.237	465.6
HMSY	0.261	0.062	0.237	261.9
1.25*HMSY	0.326	0.077	0.237	167.6
1.5*HMSY	0.391	0.093	0.237	116.4

SCENARIO 3: MAXIMUM OBSERVED HARVEST RATE

Variable	mean	sd	CV	PRECISION
MAX H	0.326	0.082	0.253	147.4

Table 3. WCPO swordfish projection results by harvest scenario for expected catch biomass (Mean, thousand mt) and its standard deviation (Stdev), expected exploitable biomass (Mean, thousand mt) and its standard deviation (Stdev), and the probability of breaching biomass depletion reference points of B10, B20, B30, B40, and BMSY.

	Scenario S1		Scenario S2.1		Scenario S2.2		Scenario S2.3		Scenario S2.4		Scenario S2.5		Scenario S3	
Variable	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
Catch 2013	10.68	5.367	10.68	4.098	16.1	6.166	21.44	8.215	26.78	10.26	32.12	12.31	26.78	10.56
Catch 2014	10.64	4.989	10.64	3.629	14.98	5.093	18.56	6.339	21.44	7.405	23.63	8.329	21.44	7.697
Catch 2015	10.66	4.838	10.67	3.414	14.4	4.595	17.07	5.493	18.83	6.164	19.76	6.658	18.82	6.442
Catch 2016	10.67	4.737	10.69	3.275	14.03	4.278	16.13	4.973	17.2	5.437	17.39	5.731	17.19	5.701
Catch 2017	10.71	4.689	10.73	3.192	13.81	4.08	15.52	4.655	16.12	5.008	15.82	5.208	16.11	5.261
Biomass 2013	82.15	23.85	82.15	23.85	82.15	23.85	82.15	23.85	82.15	23.85	82.15	23.85	82.15	23.85
Biomass 2014	81.87	19.86	81.87	19.57	76.45	18.26	71.11	17.11	65.77	16.15	60.43	15.4	65.77	16.33
Biomass 2015	82.01	17.5	82.07	17.04	73.46	15.25	65.4	13.79	57.75	12.62	50.53	11.71	57.73	12.84
Biomass 2016	82.25	15.93	82.35	15.37	71.66	13.33	61.86	11.8	52.82	10.67	44.53	9.84	52.78	10.9
Biomass 2017	82.49	14.91	82.62	14.29	70.5	12.08	59.5	10.6	49.48	9.623	40.49	8.96	49.43	9.866
Pr(Breach B10)	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.03	0.00	0.04	0.00	0.03
Pr(Breach B20)	0.00	0.05	0.00	0.05	0.00	0.05	0.00	0.06	0.01	0.09	0.04	0.19	0.01	0.09
Pr(Breach B30)	0.01	0.10	0.01	0.10	0.01	0.11	0.02	0.14	0.08	0.27	0.28	0.45	0.08	0.28
Pr(Breach B40)	0.03	0.18	0.03	0.18	0.04	0.20	0.11	0.32	0.36	0.48	0.70	0.46	0.38	0.48
Pr(Breach BMSY)	0.09	0.29	0.09	0.28	0.13	0.34	0.40	0.49	0.77	0.42	0.94	0.23	0.77	0.42

Figure 1.1. Estimates of catch biomass of WCPO swordfish during 1951-2012 used for stock projections.

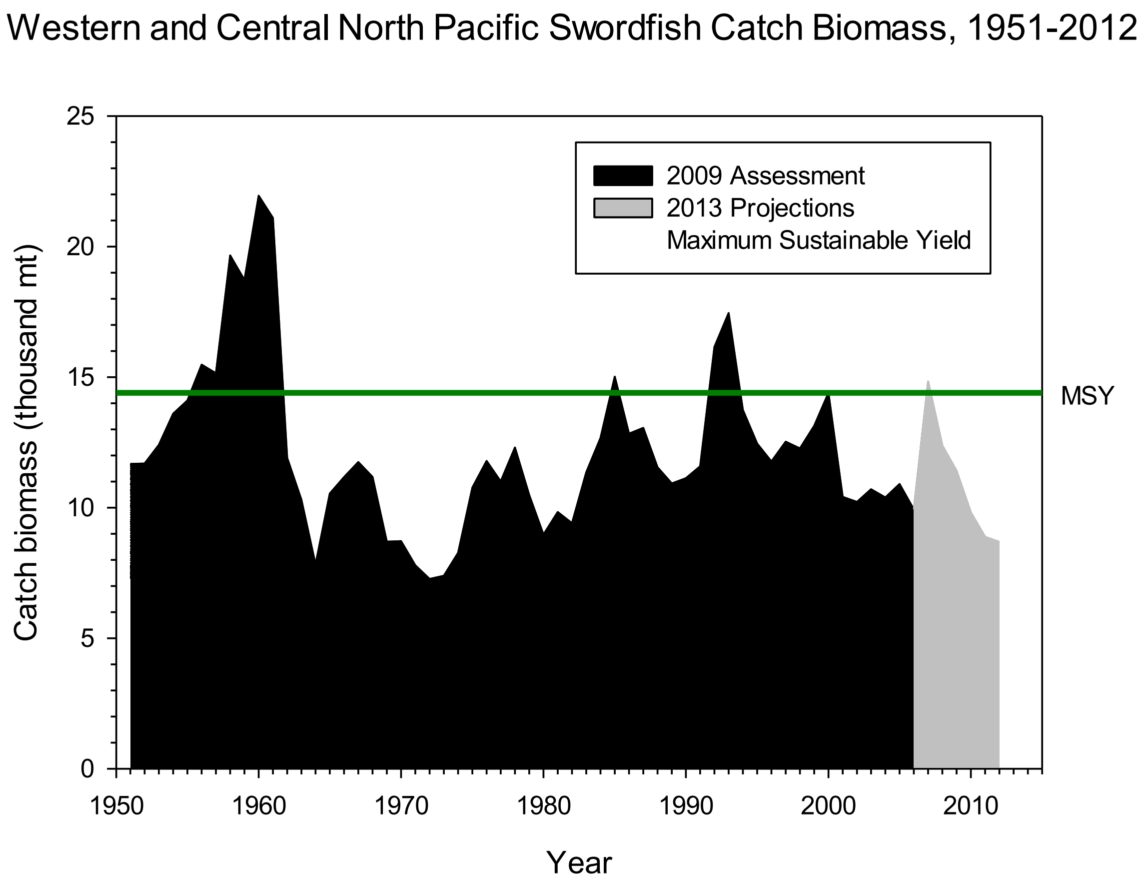
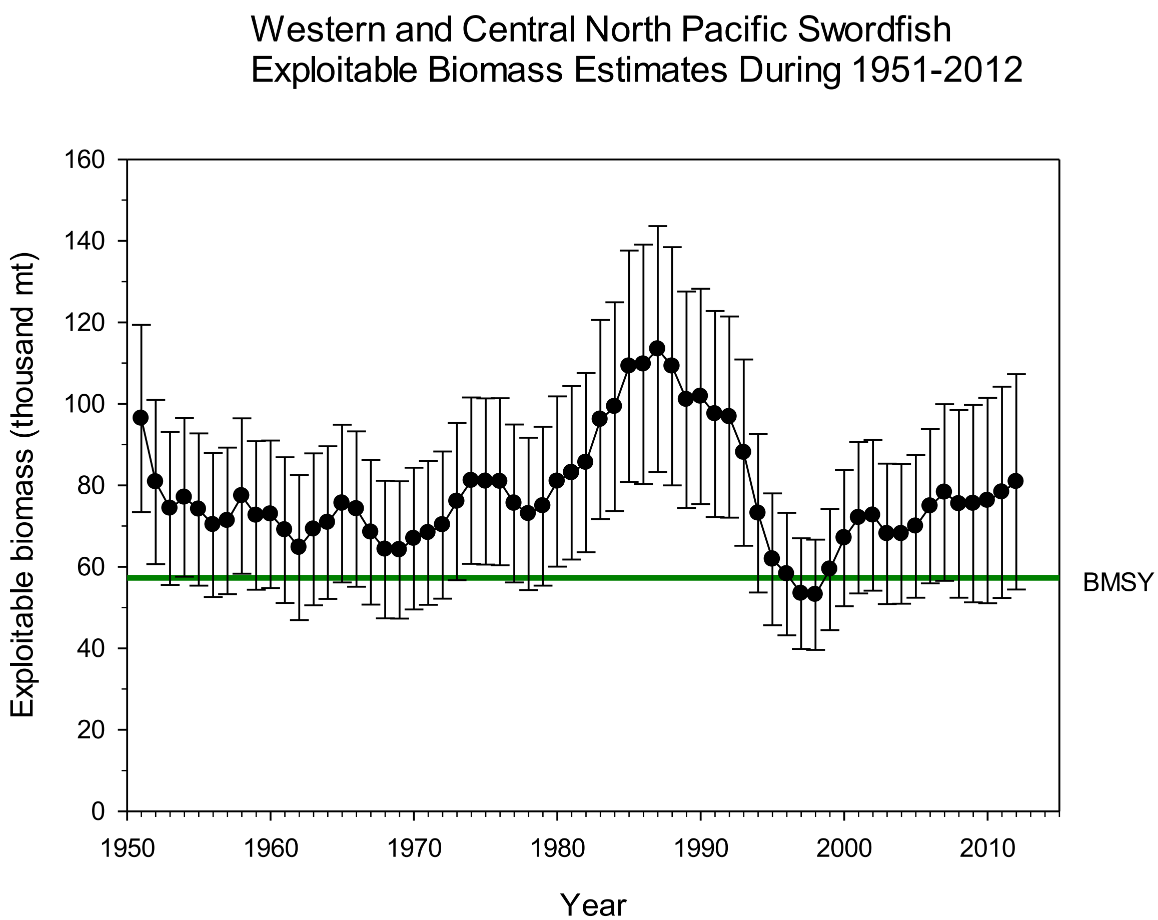


Figure 1.2. Estimates of exploitable biomass for WCPO swordfish (± 1 standard error) during 1951-2012 used for stock projections.



From: SC/13/ANNEX/09/APPENDIX/04

Figure 1.3. Estimates of harvest rates for WCPO swordfish (± 1 standard error) during 1951-2012 used for stock projections.

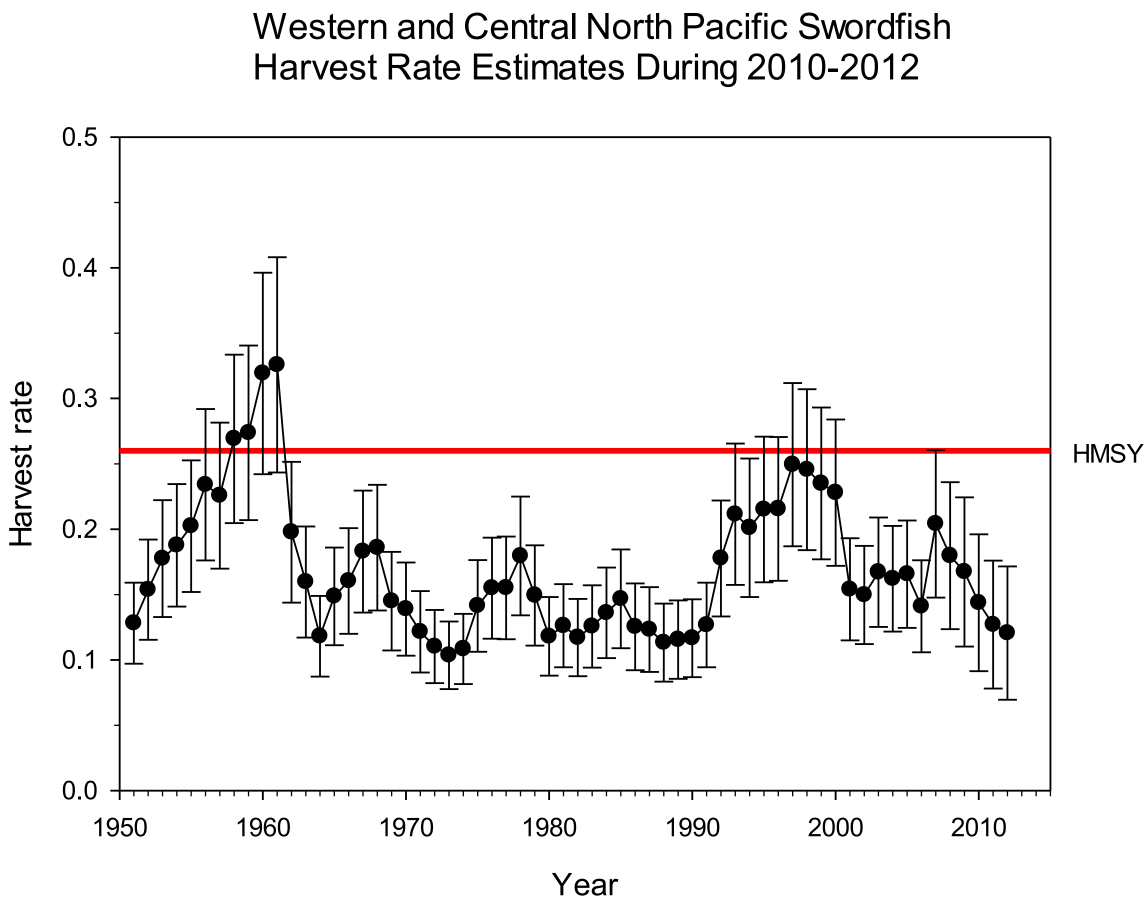


Figure 2.1. Projections of expected catch biomasses of WCPO swordfish during 2013-2017 under alternative harvest scenarios.

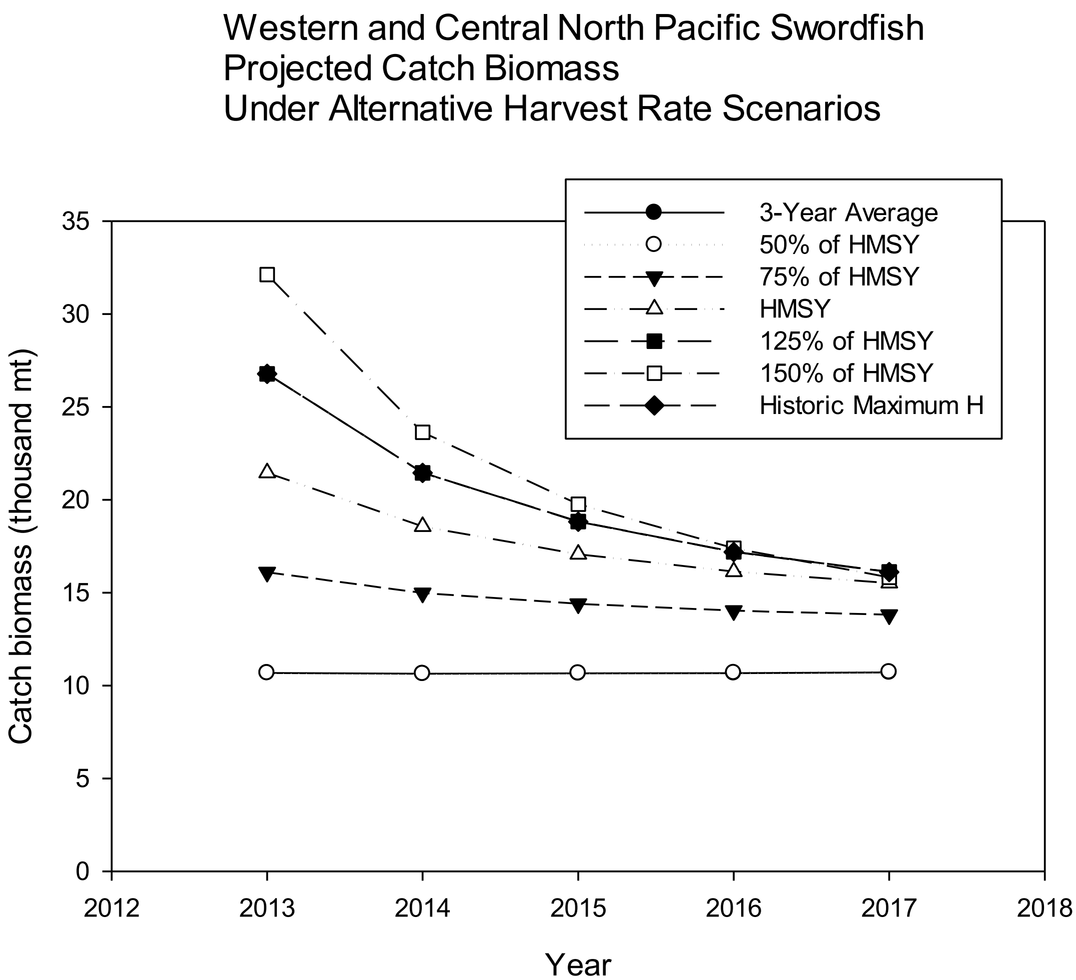


Figure 2.2. Projections of expected exploitable biomasses of WCPO swordfish during 2013-2017 under alternative harvest scenarios.

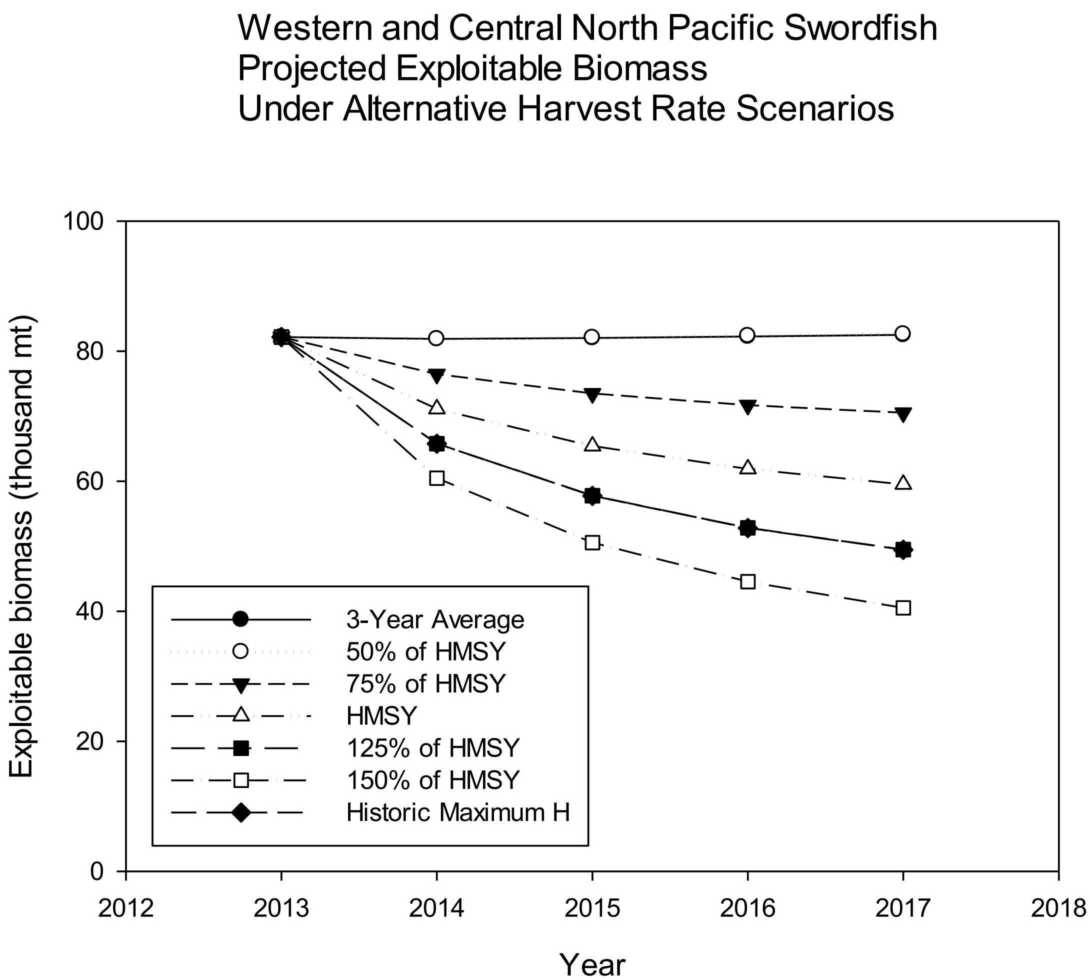
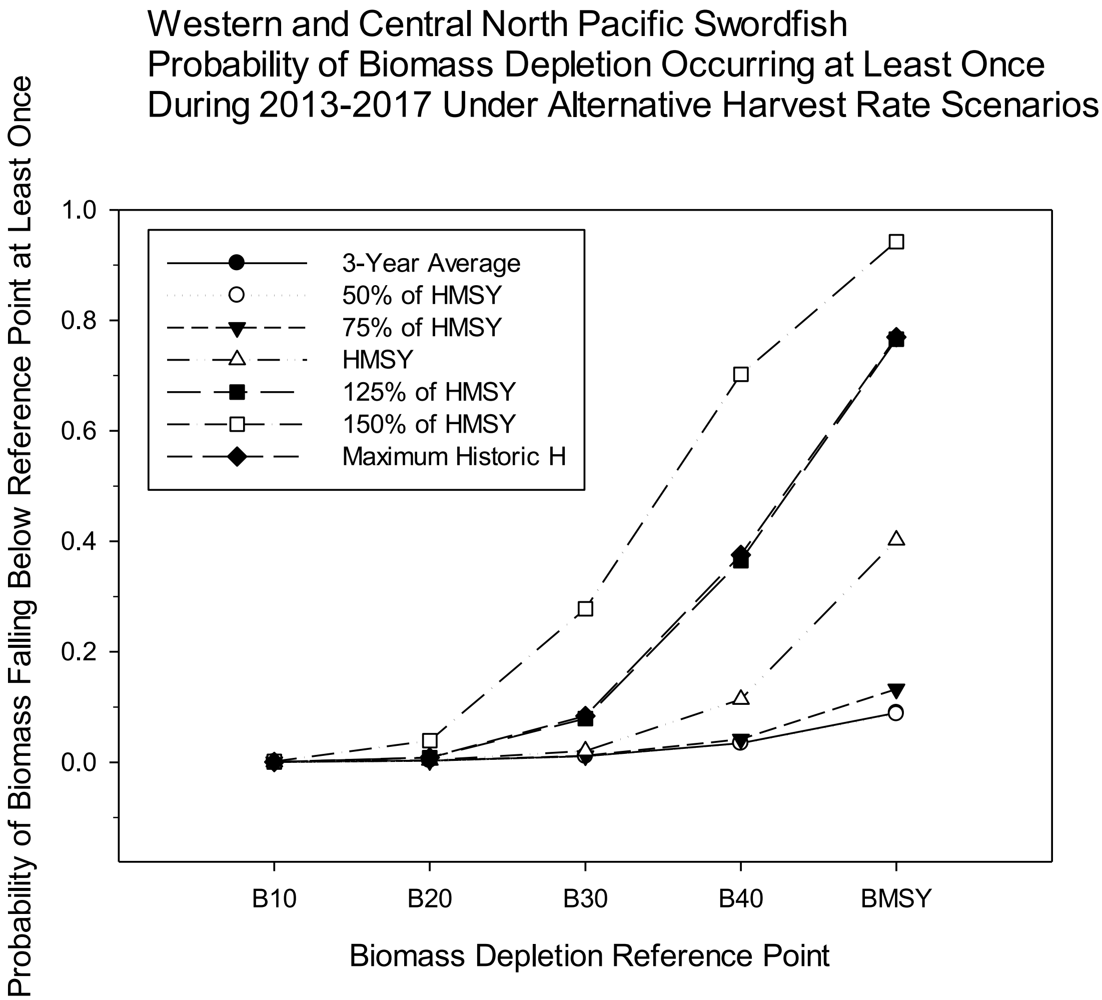


Figure 2.3. Projected probabilities of breaching biomass depletion levels for WCPO swordfish during 2013-2017 under alternative harvest scenarios.



Appendix E

The description about some of the key biological and fishery variables

For the purpose of determining potential limit reference points, the ISC Chairman directed PBFWG to develop the description about some of the key biological (Stock recruitment and steepness, maturity and fecundity, natural mortality, growth) and fishery (selectivity) variables whether those variables were reasonably well estimated or not.

1. Stock-Recruitment and Steepness

- Beverton and Holt stock recruitment relationship with fixed steepness (h) of 0.999 was assumed in 2012 stock assessment, because preliminary runs estimated the parameter to be approximately equal to 1, and a sensitivity run to fix the parameter as 0.8 did not converge.
- Some studies estimated h outside of the stock assessment model. Mangel et al. (2010) estimated the parameter using early life-history parameters near from those of PBF. In addition, Iwata et al. (2012; 2012b) followed the analysis with growth parameters exactly same as those used in the actual stock assessment of PBF. Those studies found that mean h was estimated approximately as 0.999. The WG noted in the 2012 stock assessment report that the estimates were highly uncertain due to the lack of information on early life history stages and other parameters such as 'weight-length-key'. Estimating the steepness parameter is an ongoing area of research;

2. Maturity and Fecundity

- A recent histological study (Tanaka 2006) showed that 80% of the fish of about 30 kg (corresponding to age-3) caught in the Sea of Japan from July to August were mature. Almost all the fish caught off the Ryukyu Islands and east of Taiwan were above 60 kg (over 150 cm fork length [FL], corresponding to age 5+) and mature. However, there is not enough information about the maturity of age 3-5 PBF except in the Sea of Japan. In the current stock assessment model, the age-specific proportion of mature fish were fixed as 0.2 at age-3, 0.5 at age-4 and 1.0 at age-5+. Further researches are necessary about the migration pattern and maturity of PBF especially between age 3 to 5 to understand the actual age-specific proportion of mature fish and its distribution in each spawning area.
- Current stock assessment is based on the constant fecundity depending on the weight of the matured fish, as a standard practice of fish stock assessment, when available information is not enough.
- Chen et al. (2006) showed the correlation between the batch fecundity and the fork length. On the other hand, a recent study showed a possibility of the regionally independent relationships between the gonad weight and the body weight around Japan (Pers. Comm.).
- There is a need to develop the comparative information about a potential for

reproduction in each age/size class.

3. Natural mortality

- Age-specific estimates of M were fixed in the SS model as 1.6 year-1 for age 0, 0.386 year-1 for age 1, and 0.25 year-1 for age 2+. Because of the absence of direct estimates of M for PBF beyond age-0, the WG discussed the setting of natural mortality based on the natural mortalities of the other tuna species in the 2008 stock assessment and 2012 data preparation. Then the WG reached a consensus about the natural mortality for PBF that the current value of M vector is appropriate. The natural mortality estimate for age-0 fish was based on results obtained from a conventional tagging study (Takeuchi and Takahashi 2006; Iwata et al. 2012a). For age 1-2 fish, natural mortality was based on length-adjusted M estimates from southern bluefin tuna (Thunnus maccoyii) conventional tagging studies (Polacheck et al. 1997, PBFWG 2008). Natural mortality of older fish (age 3+) was estimated as 0.25 per year using the Pauly's equation. WG also confirmed that the possible M scenario of age 3+ fish from many different methods, including Pauly, Hoenig and others, ranged about 0.17 to 0.41 (PBFWG 2011).
- The WG recommended a seasonal natural mortality for Age-0 in the future assessment, because M likely changes with size based on tagging studies, and age-0 PBF are growing very rapidly.
- A recent published paper (Whitlock et al., 2012) showed lower natural mortality (0.15 year-1) for age 2+ PBF. However, the WG noted several issue on the data bias for EPO and the bias for young fish (very few older fish on which to base an estimates of M5+) in the 2012 data preparatory report.

4. Growth

- Current stock assessment is based on the growth curve proposed by Shimose et al. (2009). However, this growth curve underestimates the size of age 0 fish from the commercial catch taken during summer. Therefore, the WG adjusted the expected length at age of fish at age 0.125 to a higher value (21.54 cm FL from 15.47 cm FL).
- The PBFWG recommended continuing research to further improve the growth curve before the next stock assessment.

5. Selectivity

- Given data available for estimating the selectivity of each fleet, WG notes on quality of input size composition data for each fleet in 2012 stock assessment report.
- Eight fleets on 14 fleets were judged to be better than good, and most of the selectivity parameters were relatively well estimated.
- The rest of the fleets were judged to be fair. Some of those for which no reliable size data were available were mirrored to one of the above mentioned eight fleets based on similarities in operating characteristics. The selectivity of a fleet which contains the miscellaneous fisheries (Fleet 14; others), was fixed with parameters estimated by a

preliminary run with lambda=0.1. Due to the fixed parameters, the composition data were not fit in the final model. The selectivity of two purse seine fleets (Fleet 4 and Fleet 12), which contained no reliable size data depend on the time period, was estimated based on the size composition data of reliable time period.

- Thus, several issues about the ways to estimate the selectivity of each fleet were still on the discussion table (i.e., seasonal selectivity, time-varying selectivity, relative weighting of the data), the selectivity should be improved further.

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