SCIENTIFIC COMMITTEE

NINETH REGULAR SESSION

Pohnpei, Federated States of Micronesia

6-14 August 2013

Determination of appropriate time-windows for calculation of depletion-based limit reference points

WCPFC-SC9-2013/MI-WP-02

A M Berger, G M Pilling, C Kirchner, and S J Harley[1]

[1] Oceanic Fisheries Programme, SPC, B.P. D5, 98848 Noumea Cedex, New Caledonia

Definition of appropriate time-windows for calculation of depletion-based limit reference points

Executive Summary

This paper aims to further refine the definition of a biomass-based limit reference points for many WCPFC stocks (bigeye tuna, skipjack tuna, south Pacific albacore, southwest Pacific striped marlin, and yellowfin tuna)[2]. A biomass-based limit reference point signifies an 'undesirable population state' and should be avoided with high probability by appropriate management action. SC8 recommended the use of the biomass-based limit reference point $20\%SB_{F=0}$, meaning that if the adult population is depleted to 20% of unfished reference levels it is considered to be in an undesirable state (i.e., management would seek to keep the estimated absolute level of spawning biomass well above $20\%SB_{F=0}$). However, details necessary for explicitly calculating this reference point for WCPFC stocks required more discussion. SC8 requested further work on developing an appropriate time-window (t_1-t_2) over which to calculate the average unfished reference level ($SB_{F=0,\ t1\text{-}t2}$) for SC9. The time-window should cover a time period thought to best represent current and likely future average environmental and stock productivity conditions.

Several approaches to selecting an appropriate time period were examined including those based on environmental conditions (large-scale climatic cycles), species generation times (one and two generations), and indicative trends in recruitment and unfished spawning stock biomass collated from recent stock assessments used for the provision of management advice in the WCPFC. Assessment models were rerun to account for stock recruitment bias-corrections (recent update to MULTIFAN-CL) and to explore two options for calculating unfished biomass levels. Unfished biomass levels were calculated using 1) absolute recruitment levels taken directly from the estimation model (ABS) or by 2) scaling absolute estimated recruitment levels upwards according to the stock-recruitment relationship (SRR).

Analyses indicated that reference levels of unfished spawning stock biomass and the resulting depletion-based reference point ($SB_{current}/SB_{F=0,\ t1\text{-}t2}$) were generally insensitive to the time period selected across species examined, regardless of the approach used to estimate unfished biomass levels. However, one approach (ABS) consistently led to a less conservative estimate of stock status relative to the limit reference point compared to the SRR approach. The value of $20\%SB_{F=0,t1\text{-}t2}$ and the perceived risk of falling below that value will depend on the specified approach for calculating unfished biomass levels, so this will be an important consideration for defining limit reference points. The assumed value of steepness and the deviates around the stock-recruitment relationship (magnitude and temporal trends) will also influence the limit reference point.

The paper highlights key considerations for selecting an appropriate time-window and protocols for the review of the calculation time period in the future. Based upon the analyses presented, the use of a 10-year fixed time-window for WCPFC species might be adequate. Over longer time scales (i.e., 10 or more

[2] North Pacific albacore and Pacific bluefin trends were also evaluated for comparison.

years), it will be important to periodically revisit the reference time-window (t_1-t_2) to ensure that 1) the selected time period remains indicative of plausible future conditions and 2) we are not confusing a biomass driven decline as general environmental change as might be the case if steepness is lower than assumed.

Introduction

In Busan, South Korea, SC8:

1. *recommended that biomass-based limit reference points (LRPs) for BET, YFT, south Pacific ALB, SKJ, and MLS be set at 20%$SB_{recent,F=0}$; and*
2. *called for the development of an 'appropriate' time period over which to calculate a reference level for unfished spawning stock biomass.*

$SB_{recent,F=0}$ can be interpreted as the average *theoretical* level of the adult population (spawning stock) present if we had never fished over some 'recent' time period (say from t_1 to t_2). We say 'average' because prevailing environmental conditions can have a large impact on the biomass we see from year to year, so it is likely that even if we weren't fishing, the level of unfished spawning biomass would also vary over time. The calculation of $SB_{recent,F=0}$ should be based on a historical average of unfished spawning stock biomass over a time period thought to best represent current and likely future average environmental and stock productivity conditions. The representative time period may need to be adjusted to take into account major shifts in productivity (e.g., recruitment regimes).

The purpose of this paper is to aid in the selection of an 'appropriate' time period to calculate reference levels for depletion-based limit reference points for key WCPO stocks, with particular attention given to those highlighted in point 1 above. To identify an appropriate independent basis for identifying this time period, several alternative approaches were investigated. The implications of using time-windows based on environmental conditions, species generation times, and indicative trends in recruitment and unfished spawning stock biomass from recent stock assessments are explored for albacore (south and north Pacific stocks), bigeye, Pacific bluefin, skipjack, southwest Pacific striped marlin, and yellowfin in the WCPO.

Methods

Stock assessment models can provide estimates of recent trends in unfished spawning biomass that can be used to infer how stock reproductive potential would have fluctuated 'naturally' (without fishing pressure). Estimates were based on the most recent WCPO reference case stock assessment model (bigeye, skipjack, southwest Pacific striped marlin, and yellowfin) or that selected for the provision of management advice (south Pacific albacore; Table 1).[3]

In the case of SP albacore, SC8 selected the grid median as the basis for stock and management related inferences. For this work, nine models were selected that best approximated the overall grid median according to several management quantities (MSY, $F_{current}/F_{MSY}$, $SB_{current}/SB_{MSY}$, and $SB_{current}/SB_{current,F=0}$). Recent trends, generation times, and reference values presented in Table 2 were based on an average of these models.

[3] Estimates for North Pacific albacore and Pacific bluefin were kindly provided by Dr. Mikihiko Kai.

Assessment models were rerun to account for stock recruitment bias-corrections (recent update to MULTIFAN-CL) and to explore two options for calculating unfished biomass levels. Unfished biomass levels were calculated using 1) absolute recruitment (ABS) or 2) scaled recruitment according to the stock-recruitment relationship (SRR). In the ABS case, it was assumed that recruitment levels for the unfished stock were equivalent to the estimated (under fishing) recruitment levels. In the SRR case, it was assumed that recruitment levels for the unfished stock were rescaled estimates [upwards] according to the stock-recruitment relationship (i.e., the estimated recruitment deviates were added to R_0). The selection of an approach to use is a philosophical decision and should warrant further discussion at SC9.

Environmental conditions

Prevailing environmental conditions are a major driver of fish population dynamics (Bakun and Broad 2002, Stenseth et al. 2002). Recent trends in unfished spawning biomass, particularly those set apart from trending productivity regime shifts (Vert-pre et al. 2013), are perhaps the most useful indication of future environmental and potential stock productivity conditions. The selected time period over which to define recent trends should encompass the most prominent, large-scale climatic cycles that give rise to interannual variability in oceanographic conditions.

The El Niño–Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) are two such climate cycles of significance in the western and central Pacific Ocean. The ENSO refers to variations in sea surface temperature in tropical, equatorial waters of the Pacific with a complete cycle usually lasting less than a decade (typical range is from 2 to 7 years; NOAA Climate Prediction Center). The PDO refers to inter-decadal (typically 20-30 year cycles) climate variability measured by shifting sea surface temperatures in temperate waters in the Pacific Ocean. To capture environmental variability associated with a typical ENSO cycle and a typical PDO cycle, a historical time period of 10 and 25 years, respectively, from the most recent stock assessment was used to calculate average unfished spawning biomass reference levels (Table 2 and 3).

Generation time

Species generation times could be used as a minimum amount of time over which to calculate unfished spawning biomass reference levels. A single generation time indicates the length of a time interval over which biological constraints, such as total offspring production, are imposed on the population as a whole. This time-window could indicate future stock reproductive capacity if similar population structure and environmental conditions remain reasonably static through time. Multiple generation times provide additional information on how variable future reproductive capacity may be by incorporating a longer time series of environmental or stock size induced effects on cohort size (which in turn influences reproductive potential as spawning stock size changes).

Generation time was defined as the age of fish that generates maximum egg production and was calculated using estimates of natural mortality (M) and the von Bertalanffy growth parameters (t_0,L_{inf}, K) as follows (Beverton 1992).

$$G = t_0 - ln\left(1 - \frac{L_{opt}}{L_{inf}}\right) / K \qquad \text{where} \quad L_{opt} = L_{inf} * \left(3 / \left(3 + \frac{M}{K}\right)\right)$$

For each species, the resulting age that maximized egg production corresponded well with the estimated age at which 50% of the adults are sexually mature – another common approach for estimating generation time[4]. Average unfished spawning stock biomass was calculated across a range of years corresponding to one (x1) and two (x2) generation times from the most recent stock assessment (Table 2 and 3).

Recent trends

The full time series of recruitment and unfished spawning stock biomass available from each of the most recent stock assessments (Table 1) was visually inspected in an attempt to identify a representative time period that could be used to indicate plausible future levels (Figure 1). An ideal time period would occur over a recent time period and include a stable pattern in recruitment (or unfished spawning stock biomass). In contrast, a less desirable time period would occur over a more historic time period and have a trending pattern in recruitment (or unfished spawning stock biomass). We acknowledge that this approach lends itself to being more *ad hoc* and subjective than the other approaches. Nonetheless, there were relatively clear pattern distinctions in the time series for most species to allow time period selection. We also acknowledge the influence the steepness parameter (h) has on estimates of recruitment and unfished biomass. If, for example, steepness was overestimated, we could mistake biomass driven declines in recruitment as environmental impacts. In this case, using recent trends in recruitment and unfished biomass could result in a lower than expected limit reference point with impressions of risk being underestimated.

The impact of alternative recruitment and unfished spawning stock biomass time-windows were evaluated to examine how sensitive time period length was to the calculated overall average levels (Figure 1).

Results

Six approaches for defining an 'appropriate' time period over which to calculate average unfished spawning stock biomass reference levels were examined for each species (Table 2 and 3). The resulting reference $SB_{F=0,\ t1\text{-}t2}$ level is shown as is the current[5] spawning biomass relative to this reference level ($SB_{current}$ / $SB_{F=0,\ t1\text{-}t2}$) using the most recent stock assessment model (Table 1). Recall that the limit reference point under each scenario would then be $SB_{current}$ / $SB_{F=0,\ t1\text{-}t2}$ = 0.2 and anything below this level would be breaching the limit reference point.

Average unfished spawning stock biomass and recruitment levels changed depending on the time horizon over which years were averaged (Figure 1). Trends were apparent for bigeye and SWP striped marlin. However, reference levels of unfished spawning stock biomass and the resulting depletion-based reference point ($SB_{current}/SB_{F=0,\ t1\text{-}t2}$) were generally insensitive to the time period selected, regardless of the approach used to estimate unfished biomass levels (Table 2). However, one approach (ABS) consistently led to a less conservative estimate of stock status relative to the limit reference point compared to the SRR approach. The value of $20\%SB_{F=0,t1\text{-}t2}$ and the perceived risk of falling below that value will depend on the specified approach for calculating unfished biomass levels.

[4] Generation times for Pacific bluefin and NP albacore were based on the estimated age at which 50% of the adults are sexually mature.

[5] 'Current' refers to an average over the four most recent years in the stock assessment, excluding the last year.

Considerations

There are several considerations that warrant discussion at SC9.

1. Development of guidelines to select a representative reference time period given different approaches (environmental and biological). For example:
    - using a time period that sufficiently integrates at least two generation times (to capture interannual variability associated with cohort sizes and the natural time lag between recruitment and spawning biomass) and the duration of major climatic cycles (to capture interannual variability associated with environmental drivers) might be appropriate; and
    - cross reference this time period with recent indicative recruitment and unfished spawning stock biomass trends to examine if it appears representative.

Given the above guidelines and the desire for the time period to indicate 'recent' unfished reference levels, a 10-year window appears to be an adequate balance for the species examined.

Alternative approaches to choosing a reference time period may also be logical (e.g., examining temporal deviates in the stock recruitment relationship). In some cases, default reference time periods have been used such as B_0 (or SB_0), indicating the biomass during a time prior to major fishing (i.e., a virgin stock). A careful examination of the historic trends in the population and fishery can help to define a representative reference time period. For example, SB_0 would not be a good reference time period if large-scale ecosystem changes, regime shifts, or other directional changes associated with the population dynamics (e.g., major changes in productivity, predator-prey dynamics, or habitat expansion/suppression) have since occurred or if there is a lack of historic data prior to fishing.

We note that it is difficult to formally evaluate the 'appropriateness' of alternative time periods for defining $SB_{F=0,\, t1\text{-}t2}$ without doing an extensive stochastic simulation study that includes a range of different recruitment dynamics. Nonetheless, given the general insensitivity of management advice (e.g., $SB_{current}/SB_{F=0,\, t1\text{-}t2}$) to the time period selected, a pragmatic time-window definition as recommended here will likely perform just as well.

2. Consider how the reference level $SB_{F=0,\, t1\text{-}t2}$ is calculated in the future. For example:
    - should the time-window be fixed with periodic reviews to evaluate if it needs to be adjusted (i.e., fixed time-window);
    - should it be a fixed length of time that adjusts with the completion of each stock assessment (i.e., moving time-window); or
    - should the start year be fixed with the length of the window expanding with each new stock assessment (i.e., expanding time-window)?

Given the need to calculate risks associated with current stock status, potential CMMs and candidate harvest strategies, a static baseline reference level (fixed time-window) from which to gauge management advice and action would seem the most appropriate.

Over longer time scales (i.e., 10 or more years), it will be important to periodically revisit the reference time-window (t_1-t_2) to ensure that the selected time period remains indicative of plausible future conditions as irregular changes in stock or ecosystem productivity conditions (regime shifts) are common in marine environments (Vert-pre et. al. 2013). Trending or 'one-way trip' shifts in system productivity are of particular concern, potentially resulting in management reference points appearing to drift in one direction or another unexpectedly, shifting the baselines from which management decisions are made against.

3. Consider a standard approach for calculating unfished biomass levels for calculating the limit reference point. The two approaches explored were:
    - ABS – unfished levels based on estimated recruitments (under fishing); and
    - SRR – unfished levels based on scaled estimates [upwards] of recruitment according to the stock recruitment relationship.

In general, the choice of approach was insensitive to defining an appropriate time-window, but will influence the absolute value of the limit reference point, measures of risk, and the development of harvest management strategies. In addition, the assumed value of steepness and the deviates around the stock-recruitment relationship (size and temporal trends) will also influence the limit reference point. As such, temporal deviates in recruitment should be included as a standard output diagnostic in MULTIFAN-CL viewer.

References

Bakun, A. and Broad, K. (eds). 2002. Climate and fisheries: interacting paradigms, scales, and policy approaches. International Research Institute for Climate Prediction, Columbia University, Palisades, NY, 67pp.

Beverton, R.J.H. 1992. Patterns of reproductive strategy parameters in some marine teleost fishes. J. Fish Biol. 41(B):137-160.

Climate Prediction Center. "ENSO FAQ: How often do El Niño and La Niña typically occur?". National Center for Environmental Prediction. Retrieved 2012-03-22.

Davies, N., Hoyle, S., Harley, S., Langley, A., Kleiber, P., and Hampton, J. 2011. Stock assessment of bigeye tuna in the western and central Pacific Ocean. WCPFC-SC7-2011/SA-WP-02.

Davies, N. 2012. Stock assessment of striped marlin (*Kajikia audax*) in the southwest Pacific Ocean. WCPFC-SC8-2012/SA-WP-05.

Hoyle, S., Kleiber, P., Davies, N., Langley, A., and Hampton, J. 2011. Stock assessment of skipjack tuna in the western and central Pacific Ocean. WCPFC-SC7-2011/SA-WP-04.

Hoyle, S., J. Hampton and N. Davies. 2012. Stock assessment of albacore tuna in the south Pacific Ocean. WCPFC-SC8-2012/SA-WP-04-REV1.

ISC. 2011. Stock assessment of albacore tuna in the north Pacific Ocean in 2011. WCPFC-NC7-2011/IP-02.

ISC. 2012. Pacific bluefin tuna working group report. http://isc.ac.affrc.go.jp/pdf/Stock_assessment/Final_Assessment_Summary_PBF.pdf. Accessed 7 May, 2013.

Langley, A., Hoyle, S., and Hampton, J. 2011. Stock assessment of yellowfin tuna in the western and central Pacific Ocean. WCPFC-SC7-2011/SA-WP-03.

Stenseth, N.C., Mysterud, A., Ottersen, G., Hurrell, J.W., Chan, K., Lima, M. 2002. Ecological effects of climate fluctuations. Science 297: 1292-1296.

Vert-pre, K.A., Amoroso, R.O., Jensen, O.P., and Hilborn, R. 2013. Frequency and intensity of productivity regime shifts in marine fish stocks. PNAS 110 (5): 1779-1784.

Tables and Figures

Table 1. Stock assessments referred to in this paper. These were used to calculate generation times and inspect recent recruitment and unfished spawning stock biomass trends. Assessments for bigeye, skipjack, SP albacore, SWP striped marlin, and yellowfin were run again to take into account the stock recruitment bias-correction feature in updated versions of MULTIFAN-CL and to explore two options for the calculation of unfished biomass levels.

Species	Paper	Reference	Access (hyperlink)
Bigeye	WCPFC-SC7-SA-WP-02	Davies et. al. 2011	WCPFC bigeye
NP albacore	WCPFC-NC7-2011/IP-02	ISC 2011	WCPFC NP albacore
Pacific bluefin	ISC/12/PBFWG-3/08	ISC PBTWG 2012	ISC bluefin
Skipjack	WCPFC-SC7-SA-WP-04	Hoyle et al. 2011	WCPFC skipjack
SP albacore	WCPFC-SC8-SA-WP-04	Hoyle et al. 2012	WCPFC SP albacore
SWP striped marlin	WCPFC-SC8-SA-WP-05	Davies et. al. 2012	WCPFC SWP striped marlin
Yellowfin	WCPFC-SC7-SA-WP-03	Langley et. al. 2011	WCPFC yellowfin

Table 2. An examination of alternative time periods (t_1-t_2) over which an average unfished spawning biomass level ($SB_{F=0,\ t1\text{-}t2}$) could be calculated for use in defining biomass-related limit reference points (20% $SB_{F=0,t1\text{-}t2}$) for bigeye, skipjack, yellowfin, SP albacore, and SWP Striped Marlin. The unfished indicators were calculated using absolute (ABS) estimates of recruitment and estimates that were adjusted according to the spawner recruit curve (SRR). Alternative time periods where characterized by environmental (ENSO, PDO) or biological (generation time, $SB_{F=0}$ trend, recruitment trend) considerations. A single generation (x1) time-window and a two-generation (x2) time-window were explored. 'Current' refers to an average over the four most recent years in the stock assessment, excluding the last year.

Characteristic	Bigeye[1]	Skipjack[1]	Yellowfin[1]	SP Albacore[2]	SWP Striped Marlin[2]
SB_0_equilibrium	851,500	6,223,000	2,502,000	656,267	15,130
SB_{MSY}	237,800	1,661,000	693,500	175,144	4,091
El Niño–Southern Oscillation (ENSO)					
Years (#)	10	10	10	10	10
Time period (t_1-t_2)	2000-2009	2000-2009	2000-2009	2001-2010	2001-2010
$SB_{F=0,\ t1-t2}$ (mt) [ABS]	1,105,410	6,945,116	1,879,252	623,607[3]	11,701
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$ [ABS]	0.210	0.662	0.479	0.707[3]	0.299
$SB_{F=0,\ t1-t2}$ (mt) [SRR]	1,261,991	7,122,337	2,042,805	643,774[3]	13,136
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$ [SRR]	0.184	0.645	0.441	0.683[3]	0.267
Pacific Decadal Oscillation (PDO)					
Years (#)	25	25	25	25	25
Time period (t_1-t_2)	1985-2009	1985-2009	1985-2009	1986-2010	1986-2010
$SB_{F=0,\ t1-t2}$ (mt) [ABS]	920,581	6,583,130	2,069,907	622,444[3]	11,986
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$ [ABS]	0.252	0.698	0.435	0.709[3]	0.292
$SB_{F=0,\ t1-t2}$ (mt) [SRR]	1,028,020	6,727,069	2,161,085	637,975[3]	13,247
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$ [SRR]	0.226	0.683	0.416	0.690[3]	0.264
Generation Time (x1)					
Years (#)	5	2	3	5	3
Time period (t_1-t_2)	2005-2009	2008-2009	2007-2009	2006-2010	2008-2010
$SB_{F=0,\ t1-t2}$ (mt) [ABS]	1,112,670	6,868,531	2,097,950	649,650[3]	10,473
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$ [ABS]	0.209	0.669	0.429	0.677[3]	0.334
$SB_{F=0,\ t1-t2}$ (mt) [SRR]	1,278,616	7,057,733	2,304,689	672,510[3]	12,216
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$ [SRR]	0.182	0.651	0.390	0.652[3]	0.287
Generation Time (x2)					
Years (#)	9	4	6	9	6
Time period (t_1-t_2)	2001-2009	2006-2009	2004-2009	2002-2010	2005-2010
$SB_{F=0,\ t1-t2}$ (mt) [ABS]	1,109,356	7,252,144	2,001,129	627,372[3]	10,937
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$ [ABS]	0.209	0.634	0.450	0.703[3]	0.320
$SB_{F=0,\ t1-t2}$ (mt) [SRR]	1,267,701	7,457,311	2,203,702	647,919[3]	12,496
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$ [SRR]	0.183	0.616	0.408	0.679[3]	0.280
Unfished Spawning Biomass Trend					
Years (#)	9	15	38	29	21
Time period (t_1-t_2)	2001-2009	1995-2009	1972-2009	1982-2010	1990-2010

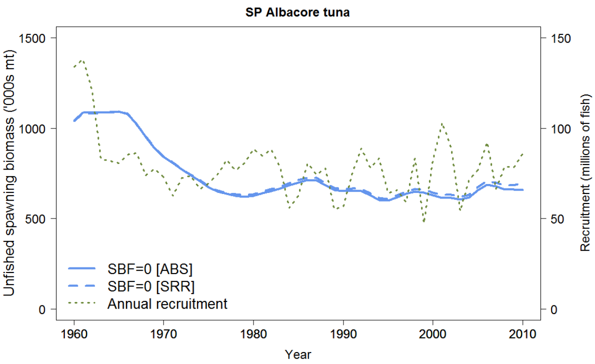
$SB_{F=0,\ t1-t2}$ (mt)	[ABS]	1,109,356	6,900,027	2,175,859	625,800[3]	12,038
$SB_{current}/SB_{F=0,\ t1-t2}$	[ABS]	0.209	0.666	0.414	0.705[3]	0.291
$SB_{F=0,\ t1-t2}$ (mt)	[SRR]	1,267,701	7,073,802	2,240,533	640,845[3]	13,377
$SB_{current}/SB_{F=0,\ t1-t2}$	[SRR]	0.183	0.650	0.402	0.687[3]	0.262
Recruitment Trend						
Years (#)		21	26	17	39	29
Time period (t_1-t_2)		1989-2009	1984-2009	1993-2009	1972-2010	1982-2010
$SB_{F=0,\ t1-t2}$ (mt)	[ABS]	970,360	6,566,997	1,913,371	629,089[3]	12,201
$SB_{current}/SB_{F=0,\ t1-t2}$	[ABS]	0.239	0.700	0.470	0.701[3]	0.287
$SB_{F=0,\ t1-t2}$ (mt)	[SRR]	1,089,003	6,708,921	2,032,710	641,896[3]	13,403
$SB_{current}/SB_{F=0,\ t1-t2}$	[SRR]	0.213	0.685	0.443	0.686[3]	0.261

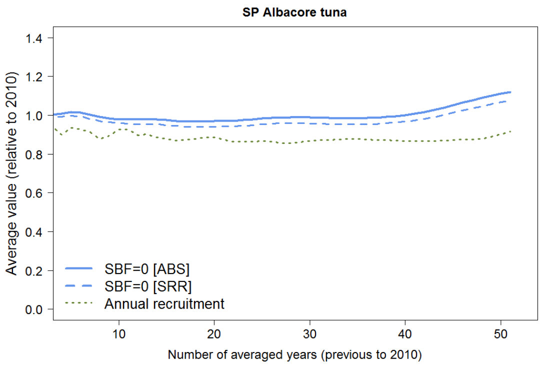
[1] Spawning biomass is expressed in quarters of a year; [2] Spawning biomass is expressed in years; [3] mean across nine selected models that best approximate the median across the full assessment uncertainty grid.

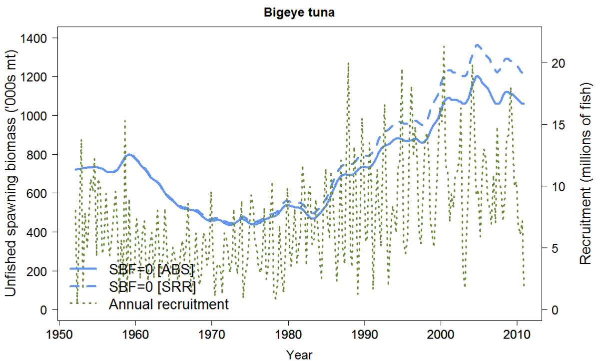
Table 3. An examination of alternative time periods (t_1-t_2) over which an average unfished spawning biomass level ($SB_{F=0,\ t1\text{-}t2}$) could be calculated for use in defining biomass-related limit reference points (20% $SB_{F=0,t1\text{-}t2}$) for Pacific bluefin and NP albacore. Alternative time periods where characterized by environmental (ENSO, PDO) or biological (generation time, $SB_{F=0}$ trend, recruitment trend) considerations. A single generation (x1) time-window and a two-generation (x2) time-window were explored.

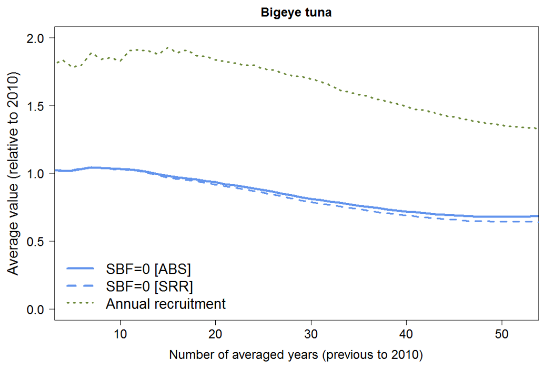
Characteristic	Pacific bluefin[1]	NP Albacore[1]
El Niño–Southern Oscillation (ENSO)		
Years (#)	10	10
Time period (t_1-t_2)	2001-2010	2000-2009
$SB_{F=0,\ t1-t2}$ (mt)	645,611	836,604
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$	0.038	0.485
Pacific Decadal Oscillation (PDO)		
Years (#)	25	25
Time period (t_1-t_2)	1986-2010	1985-2009
$SB_{F=0,\ t1-t2}$ (mt)	578,025	729,050
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$	0.043	0.557
Generation Time (x1)		
Years (#)	4	5
Time period (t_1-t_2)	2007-2010	2005-2009
$SB_{F=0,\ t1-t2}$ (mt)	662,156	835,106
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$	0.037	0.486
Generation Time (x2)		
Years (#)	8	10
Time period (t_1-t_2)	2003-2010	2000-2009
$SB_{F=0,\ t1-t2}$ (mt)	654148	836,604
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$	0.038	0.485
Unfished Spawning Biomass Trend		
Years (#)	47	12
Time period (t_1-t_2)	1964-2010	1998-2009
$SB_{F=0,\ t1-t2}$ (mt)	579,360	835,394
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$	0.043	0.486
Recruitment Trend		
Years (#)	17	22
Time period (t_1-t_2)	1994-2010	1988-2009
$SB_{F=0,\ t1-t2}$ (mt)	594,967	741,269
$SB_{current}/SB_{F=0,\ t1\text{-}t2}$	0.041	0.548

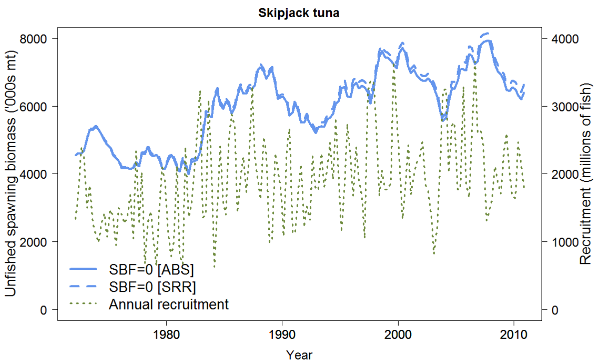
[1] Spawning biomass is expressed in years.

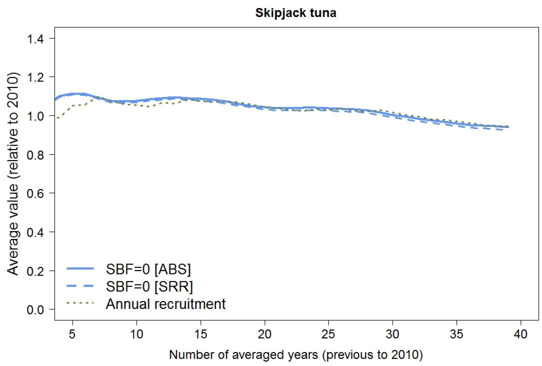

SP Albacore tuna
Unfished spawning biomass ('000s mt)
Recruitment (millions of fish)
Year
SBF=0 [ABS]
SBF=0 [SRR]
Annual recruitment

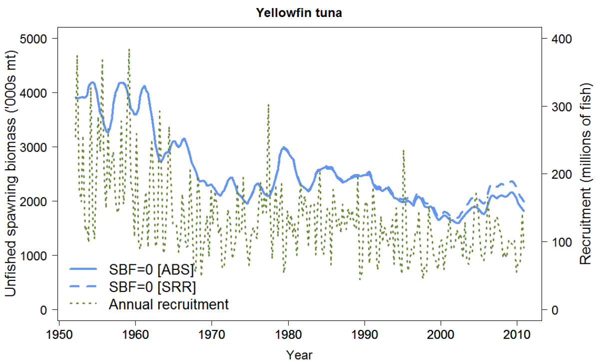

SP Albacore tuna
Average value (relative to 2010)
Number of averaged years (previous to 2010)
SBF=0 [ABS]
SBF=0 [SRR]
Annual recruitment

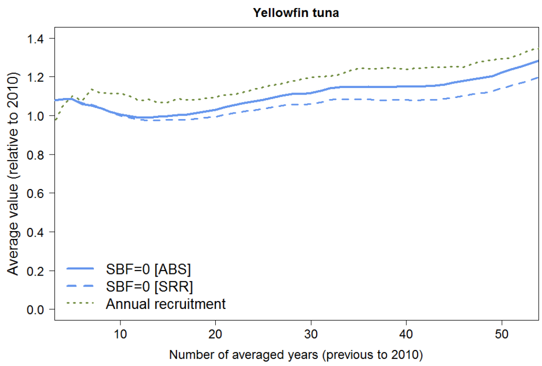

Bigeye tuna
Unfished spawning biomass ('000s mt)
Recruitment (millions of fish)
Year
SBF=0 [ABS]
SBF=0 [SRR]
Annual recruitment


Bigeye tuna
Average value (relative to 2010)
Number of averaged years (previous to 2010)
SBF=0 [ABS]
SBF=0 [SRR]
Annual recruitment


Skipjack tuna
Unfished spawning biomass ('000s mt)
Recruitment (millions of fish)
Year
SBF=0 [ABS]
SBF=0 [SRR]
Annual recruitment


Skipjack tuna
Average value (relative to 2010)
Number of averaged years (previous to 2010)
SBF=0 [ABS]
SBF=0 [SRR]
Annual recruitment


Yellowfin tuna
Unfished spawning biomass ('000s mt)
Recruitment (millions of fish)
Year
SBF=0 [ABS]
SBF=0 [SRR]
Annual recruitment


Yellowfin tuna
Average value (relative to 2010)
Number of averaged years (previous to 2010)
SBF=0 [ABS]
SBF=0 [SRR]
Annual recruitment

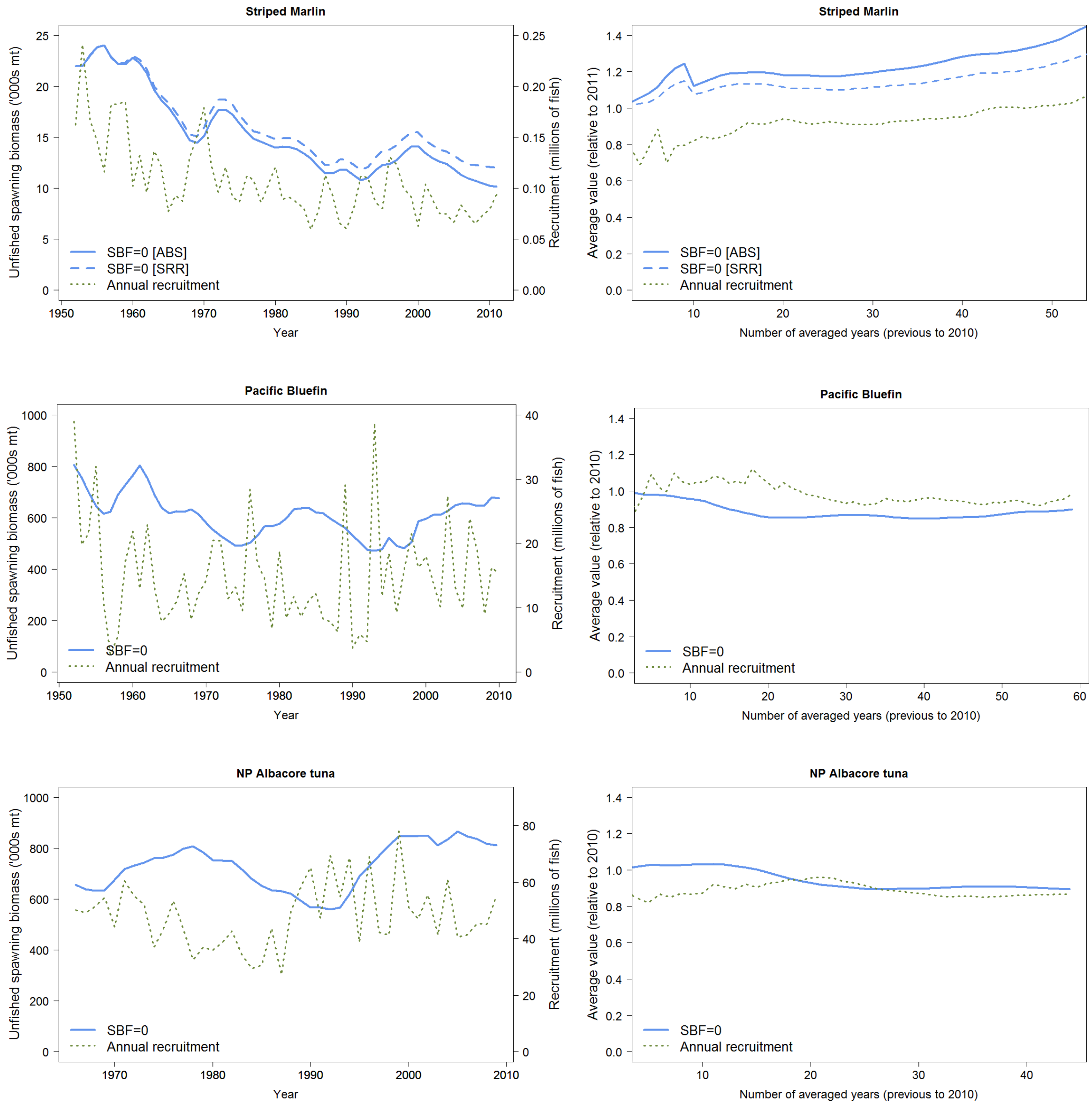


Figure 1. Unfished spawning biomass and recruitment trends (left) as estimated from the most recent stock assessment model for each species. Unfished spawning biomass was calculated using absolute (ABS) estimates of recruitment and estimates that were adjusted according to the spawner recruit curve (SRR) for bigeye, skipjack, SP albacore, SWP striped marlin, and yellowfin. Average unfished spawning stock biomass and recruitment levels change depending on the time horizon over which years were averaged (right). For SP albacore, the average of nine models identified from the 2012 structural uncertainty grid that best mimic the MSY-based SC8 provisions for management advice (i.e., the median of the uncertainty grid) is shown here.