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Evaluation of stock status of south Pacific albacore, bigeye, skipjack, and yellowfin tunas and southwest Pacific striped marlin against potential limit reference points

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Executive Summary

This paper is one of a suite of three pieces of work contracted to inform the WCPFC Management Objectives Workshop currently scheduled for prior to WCPFC9 in December 2012. This paper focuses on limit reference points and the other two papers focus on target reference points and harvest control rules. The presentation of this work to SC8 will provide the feedback necessary to undertake further analysis (if necessary) and refine the material that will be presented to the participants of the Workshop.

This particular paper addresses three important aspects of limit reference points:

- Background information providing context for the MOW on what reference points are, and their purpose in fisheries management;
- Supporting analysis (as requested from SC7) that may allow the Scientific Committee to recommend specific limit reference points to the Commission. This would allow us to refine the analytical material presented to the MOW; and
- Some discussion of technical issues relating to how we incorporate uncertainty into our analyses when calculating or predicting (for projections) the probability that we have exceeded a limit reference point.

This paper provides an update of SC7-MI-WP-04 specifically responding to requests made by SC7 for further analysis. The analyses were based on deterministic projections from a structural uncertainty grid (i.e., the same methodology as SC7-MI-WP-04) and covers the most recent stock assessments available at the time: the 2011 assessments reviewed by SC7 for bigeye, skipjack, and yellowfin tunas, and the 2012 assessments for south Pacific albacore and southwest Pacific striped marlin.

Tables and figures are presented expressing the uncertainty in stock status in relation to various reference points on indicators relating to fishing mortality, spawning biomass relative to equilibrium virgin levels, and spawning biomass relative to the levels predicted to exist presently in the absence of fishing. It is this latter depletion estimator that we would recommend due to the non-equilibrium conditions estimated for many WCPO stocks – especially when recent average recruitment is used for projections.

The paper also considers the recommendation by Preece et al. (2011) that only 20%SB_0 be considered for skipjack, albacore, and billfish. Based on the recently published large scale studies on growth and reproductive biology for south Pacific albacore tuna and southwest Pacific striped marlin, we are of the view that the uncertainties relating to key life-history parameters are no worse for these stocks than bigeye or yellowfin tuna, and hence that the stock assessments meet the 'exception' of Preece et al. (2011) being instances where a thorough examination of model sensitivity exists.

What are limit reference points?

Limit reference points (LRPs) are one part of the package for "reference points-based fisheries management". The key elements of this approach, and how they are linked, are provided in Figure 1.

The most relevant discussion of reference points in the international fisheries domain are provided in Annex II of the UN Fish Stocks Agreement (Anon. 1995), namely the "GUIDELINES FOR APPLICATION OF PRECAUTIONARY REFERENCE POINTS IN CONSERVATION AND MANAGEMENT OF STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS". The important concepts provided in that annex pertinent to limit reference points are repeated below (with emphasis added):

> *a) Two types of precautionary reference points should be used: <u>conservation, or limit</u>, reference points and management, or target, reference points. Limit reference points set boundaries which are intended to <u>constrain harvesting within safe biological limits</u> within which the stocks can produce maximum sustainable yield.*
>
> *b) Precautionary reference points should be stock-specific to account, inter alia, for the <u>reproductive capacity</u>, the <u>resilience of each stock</u> and the <u>characteristics of fisheries</u> exploiting the stock, as well as other sources of mortality and major sources of uncertainty.*
>
> *c) Fishery management strategies <u>shall ensure that the risk of exceeding limit reference points is very low</u>. If a stock falls below a limit reference point <u>or is at risk of falling below such a reference point</u>, conservation and management action should be initiated to facilitate stock recovery.*
>
> *d) <u>When information for determining reference points for a fishery is poor or absent, provisional reference points shall be set</u>. Provisional reference points may be established by analogy to similar and better-known stocks.*
>
> e) *<u>The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points.</u>*

Harley et al. (2009) provide some specific discussion around point (e) and we will not consider it further here.

From point (a) we make the conclusion that the primary basis for choosing LRPs should be biological, i.e., to keep the stock within safe biological limits. The biological basis for LRPs is emphasized in (c) where it states that we want to avoid falling below this level. However, point (c) also promotes the idea that the setting of LRPs is a two part process:

1. Set a biologically based LRP based on some stock size, which if fallen below, could have bad implications for the health of the population; and
2. Determine the risk or probability that you are willing to accept of falling below the LRP.

It is this second part where broader fishery management objectives and societal values would enter into the process, e.g., socioeconomic considerations common to multi-species fisheries such as those of the WCPO could be a one factor in the considerations, but of course the biological basis the limits must not be ignored or overridden by these. Values such as 5 or 10% have commonly been used in LRP-related simulation studies, but otherwise there is little guidance on the definition of "very low". This point will become more apparent in the evaluations of target reference points (Pilling et al. 2012) and harvest control rules (Berger et al. 2012), where analytical tools such as Management Strategy Evaluation become of great importance (Preece et al. 2011).

The second part of this paper, and the work of Preece et al. (2011) provide considerable discussion and analysis on the basis for choosing a particular LRP. Here we will first highlight some general issues relating to the key attributes of a LRP.

Ideally a LRP would represent some stock size that has been identified as a point below which 'bad things happen', though clearly that state will be more of a continuum than some knife edge level (Sainsbury 2008). This could represent the stock size below which significant reductions in recruitment have been identified, for example. In the absence of such data for a stock, consistent patterns seen when examining a large number of fish populations (e.g. Myers 1994, Myers et al. 1999) would be one potential way to determine an appropriate LRP level. Alternatively, for a stock which has experienced considerable fluctuations in stock status over a long period of time, the historical data might suggest some levels of stock size that would be prudent to avoid.

In conclusion, LRPs represent the place "where we don't want to go" and fit in together with target reference points which represent "where we want to be". Harvest control rules then provide the implementation framework to achieve these dual outcomes. It is the role of fishery managers to define the candidate fishery management systems (targets, levels of risk, harvest control rules). It is the role of scientists in the process to evaluate the fishery system to estimate the risk that the limits could be breached.

Further analysis to support consideration of LRPs for WCPO fisheries

The Seventh Regular Session of the Scientific Committee (SC7) reviewed candidate limit reference points for the key target species in the WCPFC (Preece et a. 2011; SC7-MI-WP-03) and evaluated stock status of bigeye, skipjack, and yellowfin tunas against those potential limit reference points (Harley and Davies 2011; SC7-MI-WP-04). The Committee recommended a hierarchical approach to identifying the key limit reference points for the key target species as follows, where levels are based upon the biological knowledge available for the stock in question:

Level	LRPs	Application
Level 1	F_{MSY} and B_{MSY}	
Level 2	$F_{X\%SPRo}$ and either $20\%SB_o$ or $20\%SB_{current,F=0}$	Bigeye and yellowfin tuna
Level 3	$20\%SB_o$ or $20\%SB_{current,F=0}$	Other key target species

The Committee further recommended that SPC-OFP undertake further analyses to evaluate the consequences through a range of limit reference points for review by the WCPFC Management Objectives Workshop (or "the Workshop"). The specific request, as outlined in paragraph 335 f) and k) of the SC7 Summary Report was to:

> *Using the most recent stock assessment models for south Pacific albacore, bigeye tuna, skipjack tuna, and yellowfin tuna, undertake further analyses to evaluate the consequences of:*
>
> *i. different levels of spawning-potential-per-recruit, x%SPRo (where x is in the range 20-50% in 10% increments) to be associated with the adopted fishing mortality-based LRP,*
> *ii. using either a x%SBo or a x%SBcurrent,F=0 biomass-based LRP (range of x of 10-40%), and*
> *iii. also adopting a spawning-potential-per-recruit-based LRP for the key target species other than yellowfin and bigeye tuna.*

This paper includes these analyses and builds on a series of reference point simulation work undertaken since SC5 (Harley et al. 2009; Davies and Harley 2010; Harley and Davies 2011). In this work we use a structural uncertainty approach to characterize uncertainty as structural uncertainty is commonly greater than the statistical uncertainty that exists within a single model run (Harley et al. 2009). The analytical work on target reference points (Pilling et al. 2012) and harvest control rules (Berger et al. 2012) will include stochastic simulations as an alternative method to determine future uncertainty.

We used the model runs contained within the structural uncertainty grid developed for the 2011 bigeye, skipjack, and yellowfin tuna assessments[2] and the 2012 south Pacific albacore and striped marlin assessments to define a range of alternative historical states of nature. These were projected forward to the year 2021 under 2010 (or 2011 for striped marlin) catch (longline fisheries and some other fisheries) and effort (most surface fisheries).

As with the grid of generic projections provided in OFP (2011), two alternative assumptions were assumed for recruitment 1) at the average of the level estimated over the last ten years of the model and 2) the levels predicted by the spawner recruitment relationship (SRR).

The reference points that stock status was evaluated against related to five important indicators:

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[2] See SC7-SA-WP-2 (bigeye), SC7-SA-WP-03 (yellowfin), SC7-SA-WP-04 (skipjack), SC8-SA-WP-04 (south Pacific albacore) and SC8-SA-WP-05 (striped marlin) for further information of the factors included in the grids.

- Spawning biomass relative to the average unfished level (SB/SB_0);
- Spawning biomass relative to the level predicted to occur through time in the absence of fishing ($SB/SB_{current,\ F=0}$);
- Spawning biomass relative to the level that will support the maximum sustainable yield (SB/SB_{MSY});
- Fishing mortality relative to the level that will support the maximum sustainable yield (F/F_{MSY});
- Fishing mortality relative to the level that would reduce the spawning biomass per recruit by a given percentage ($F/\ x\%F_{SPR}$).

For the projections based on recent average recruitment we did not assess stock status relative to SB_{MSY} due to the equilibrium assumptions used to calculate SBMSY not being compatible with the projected recruitment level (see Harley and Davies (2011) for further details).

Consistent with projections undertaken for CMM analyses, we calculated the MSY-based reference points based on the fishing mortality at age profiles in the final year of the projection. This will mean that these estimates can differ to those from the estimation period. The difference is greatest for projections that involve predominantly catch as opposed to effort, e.g., south Pacific albacore tuna.

Results

The results of the projections are presented in terms of the probability of exceeding the particular limit reference points throughout the historical and projection time periods (Figures 2-6), and in table form for 2021 only (the end of the projection period; Table 1). Boxplots representing the range of stock status levels against the various reference points are provided in Figures 6-13 within Annex 1.

Rather than describe in detail the results with respect to all the various reference points requested by SC7, we will focus on those more closely related to those originally proposed by Preece et al. (2011), i.e. those based on "20%" of unexploited spawning biomass (both SB_0 and $SB_{curr,F=0}$ variants), and $FSPR_{40\%}$.

For south Pacific albacore tuna the results were sensitive to the assumed recruitment hypothesis with low (0.05 – 0.1) probabilities of exceeding the biomass related LRPs for recent recruitment, but higher probabilities (0.26) under the other SRR recruitment scenario. Fishing mortality exceeds the FSPR LRP with moderate probabilities under both scenarios (0.34-0.45).

For bigeye tuna the results are also sensitive to the assumed recruitment hypothesis with low (0.04-0.10) probabilities of exceeding the biomass related LRPs for recent recruitment, but high probabilities (0.39-0.44) under the other SRR recruitment scenario. Fishing mortality exceeds the FSPR LRP with high probability under both scenarios (0.91 and 0.96).

For skipjack tuna, there was zero probability of falling below $20\%SB_0$ and $20\%SB_{curr,F=0}$ or exceeding $FSPR_{40\%}$ during either the historical or projection periods.

For yellowfin tuna, the results with respect to $20\%SB_0$ and $20\%SB_{curr,F=0}$ or exceeding $FSPR_{40\%}$ were similar to those for skipjack, with just a low (0.06) probability of exceeding $FSPR_{40\%}$. Perhaps more importantly, the yellowfin results changed abruptly as the reference points moved to more conservative values and reflects the low level of uncertainty in the yellowfin grid and the close proximity of the stock status to the reference point levels (see Annex figures).

The striped marlin assessment probably contained the broadest range of uncertainty in stock status. The probabilities of exceeding the LRPs increased to peak at or above 0.20 by the mid 2000s with a slight decline thereafter. The results were relatively consistent across the recruitment hypotheses with low (up to 0.1) probabilities of exceeding the biomass based reference points and moderate (0.19-0.27) probabilities of exceeding $FSPR_{40\%}$.

These results reiterate the findings from Harley and Davies (2011) that adoption of limit reference points is important for bigeye and yellowfin tuna as these stocks are at the levels (biomass and/or fishing mortality) where limit reference points are likely to impact on future fishing management strategies. South Pacific albacore is also clearly approaching these levels given the recent dramatic increases in catches and fishing mortality. For skipjack tuna, we are likely to be at a much higher level so instead the focus should be on determining management objectives and setting target reference points to maximize fishery performance while maintaining the stock away from agreed limits (see also Pilling et al., 2012; SC8-MP-WP-2). The situation for striped marlin, a new addition to the 2012 analysis, is similar to that for bigeye and yellowfin tuna.

Technical issues requiring further consideration

Methods for characterizing uncertainty

Previously we have described the different approaches that might be used for describing uncertainty in the historical and projected time periods (Harley et al. 2009; Davies and Harley 2010). In this paper we have focused on uncertainty across different structural models for both time periods as structural uncertainty is typically larger than statistical uncertainty within a model.

In using the runs from the grid we have not attempted to provide differential weight to any of the runs, i.e. they were all given equal weight. It is not necessary to make this assumption and individual model runs from the grid could be weighted either based on some prior knowledge (or expert opinion) or based on the likelihoods where these are directly comparable. It is important that such decisions be made objectively (i.e. think about the relatively plausibility of the different factors rather than the results that they give) and collectively. We have not attempted to do this in the current analysis.

Another important consideration in interpreting the results from the grid projections, is the amount of uncertainty that went into the model grid. In the case of bigeye and striped marlin the range of stock status outcomes covered by the grid is very wide when compared to those for skipjack and yellowfin tuna. This can lead to abrupt changes in probabilities from one level of a reference point to the next. It would be useful to have some common guidelines that can assist in the development of a structural uncertainty grid that ‘consistently reflects the uncertainty.

Ideally one would like to incorporate stochasticity in future conditions, uncertainty in current conditions, and uncertainty in model structure. This could be done by running stochastic projections for runs in the grid. Currently the stochastic projections, as implemented in MULTIFAN-CL, can incorporate uncertainty in future recruitment and work is progressing to incorporate uncertainty in current population state and variation in catchability in the projection period. These developments, when completed, will allow a better treatment of uncertainty in projections to determine the risk of exceeding reference points.

This critical area of how to characterize uncertainty should be the focus of some attention in the recently established joint tuna RFMO [electronic] working group on management strategy evaluation. It should also be considered at MOW; input on what the key uncertainties are will be beneficial in addition to the how to deal with them.

Finally, we must emphasize that simple simulations like the ones presented here cannot provide information on the implications for the stock of particular LRPs, rather they simply provide estimates of potential stock status outcomes based on the assumed population dynamics in the model. Overall, our level of knowledge of the population dynamics at low stock sizes of these WCPO stocks is insufficient to give precise advice on combinations of limit reference point / allowable probability of exceeding. The development of operating models that allow assessment of performance under a range of potential stock dynamics at low stock sizes, and that closely reflect the biological characteristics of our stocks (in particular variation in recruitment and stock abundance) would benefit future analyses of limit reference points and harvest control rules, but such work is not a pre-requisite to making progress on LRPs.

Consistency of biomass-based reference points with projected recruitment assumptions

We have noted earlier the difficulty in using SB/SB_{MSY} as a performance measure in projections for bigeye tuna that assume that future recruitment will be at the recent average level. This is a problem in the case of bigeye in particular because the recent average level of recruitment is considerably higher than the long-term average or the equilibrium recruitment predicted by the stock recruitment relationship. This results in projected stock sizes, which are strongly influenced by the elevated recent average recruitment, usually being well above SB_{MSY}, or some fraction of SB_0, because these reference points are typically determined as equilibrium or long-term average quantities. However, if we believe that the true stock productivity is represented by the recent average recruitment, a more consistent approach would be to use this level of recruitment to also compute SB_{MSY} and SB_0.

Appropriateness of FSPR based limit reference points

Preece et al. (2011) suggested a three-level hierarchical approach to setting limit reference points for fishing mortality, and then made specific limit reference point recommendations for the major tuna stocks and billfish. The important recommendations are provided below:

1. **If** the steepness is well estimated, then F_{MSY} and B_{MSY} are appropriate limit reference points
2. **If** the steepness is not well estimated (and essentially unknown) and **if** the relevant life-history and fishery information (natural mortality, selectivity, maturity) are both available and reliably estimated then $FSPRx\%$ and γSSB_0 are appropriate candidate F and SSB limit reference points, respectively (with an appropriately justified rationale for the selection of the fractions x and γ)
3. **If** the relevant life-history and fishery information are not reliably estimated then only use the SSB-based limit reference point, γSSB_0.

Level	LRPs	Application
Level 1	F_{MSY} and B_{MSY}	
Level 2	$F_{X\%SPR0}$ and either $20\%SB_0$ or $20\%SB_{current,F=0}$	Bigeye and yellowfin tuna
Level 3	$20\%SB_0$ or $20\%SB_{current,F=0}$	Other key target species

In making these recommendations they noted "*a review of the stock assessments of tunas and tuna like species across the tuna RFMOs highlights the difficulty in estimating or assuming a value for steepness for the majority of tuna stocks. There is commonly insufficient data on recruitment at low stock size and recovery from depletion to enable steepness to be reliably estimated in the tuna stock assessments*" which discounted Level 1 from further consideration. For skipjack they reported "*there appeared to be issues relating to the knowledge about the maturity-at-age relationship that make even the sensible and robust estimation of the SPR-type reference points difficult*. *For all fisheries where non-uniform selectivity occurs across the age classes the interaction of selectivity and maturity is a key process that can significantly affect estimation of sustainable mortality rates and overall yield*."

For other species they note "*Given the uncertainties in some of the key life-history and fishery variables required for either level 1 or level 2 in our suggested hierarchical approach, we recommend that a similar approach to skipjack be used and that level 3 (the default SSB depletion option) be used for albacore and billfish, in general, except where a thorough exploration of model sensitivity and, or, formal MSE results are available*."

In considering the recommendations for species other than yellowfin and bigeye tuna we noted that there has recently been comprehensive biological studies for South Pacific albacore (Farley et al. 2012) and southwest Pacific striped marlin (Kopf and Davie 2009). Therefore, we do not view the life-history parameters of these stocks as being any less certain than those for bigeye or yellowfin tuna, and in fact they might even be more reliable in some instances. However, both the estimated sex-specific growth differences estimated for albacore and the problems experienced in the 2012 striped marlin assessment in the estimation of selectivity – a key model parameter – do suggest some caution as suggested by Preece et al. (2011).

Our conclusion is that FSPR-based limit reference points are no less appropriate for albacore and striped marlin as long as there is balance in the issues raised above through the comprehensive exploration of model sensitivity undertaken in the assessments, and the move towards incorporating this uncertainty in the development of harvest control rules through management strategy evaluation.

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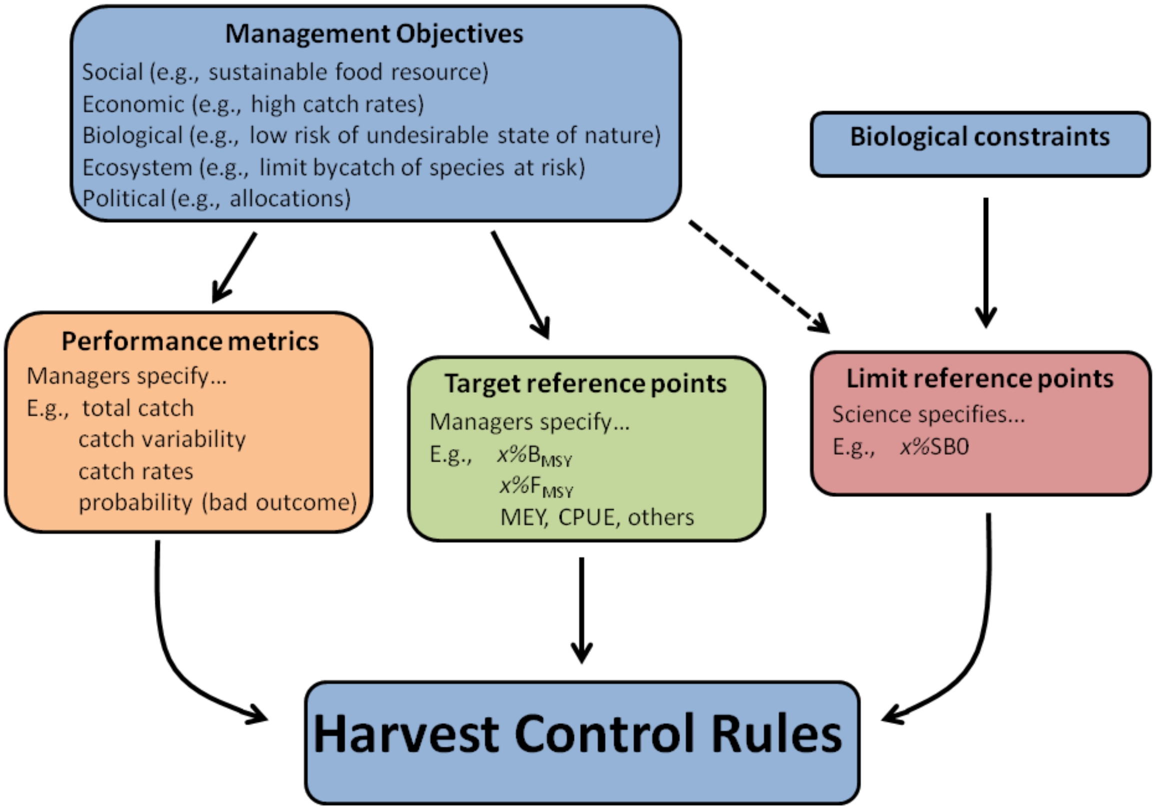


Figure 1 Conceptual model of how management objectives and biological constraints inform the development (reference points) and guide the selection (performance metrics) of harvest control rules. Abbreviations: B: biomass, SB: spawning biomass, F: fishing mortality, MSY: maximum sustainable yield, MEY: maximum economic yield, CPUE: catch-per-unit-effort.

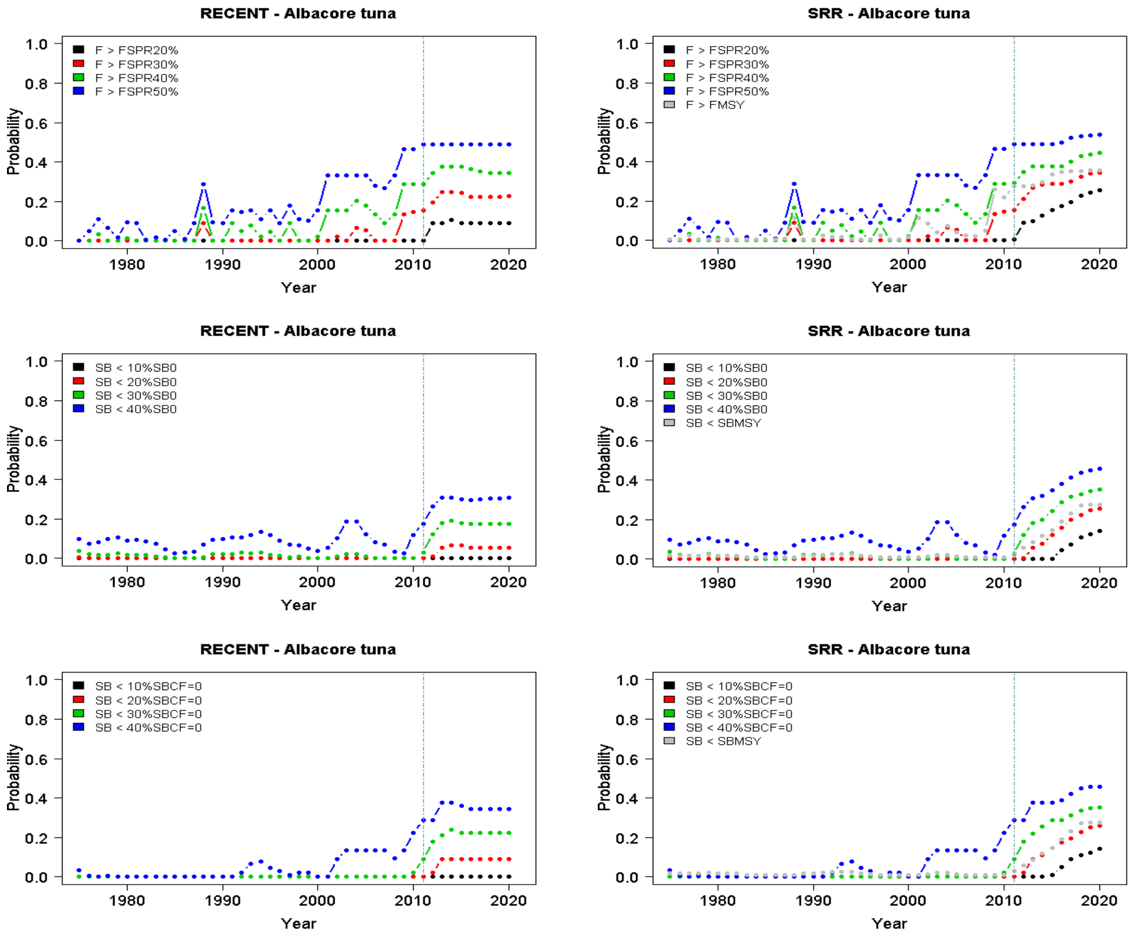


Figure 2: Probability that the south Pacific albacore tuna stock exceeds particular reference points (i.e., biomass fall below a biomass-based reference point or fishing mortality exceeds a fishing mortality-based reference point). Results are presented for projections based on recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).

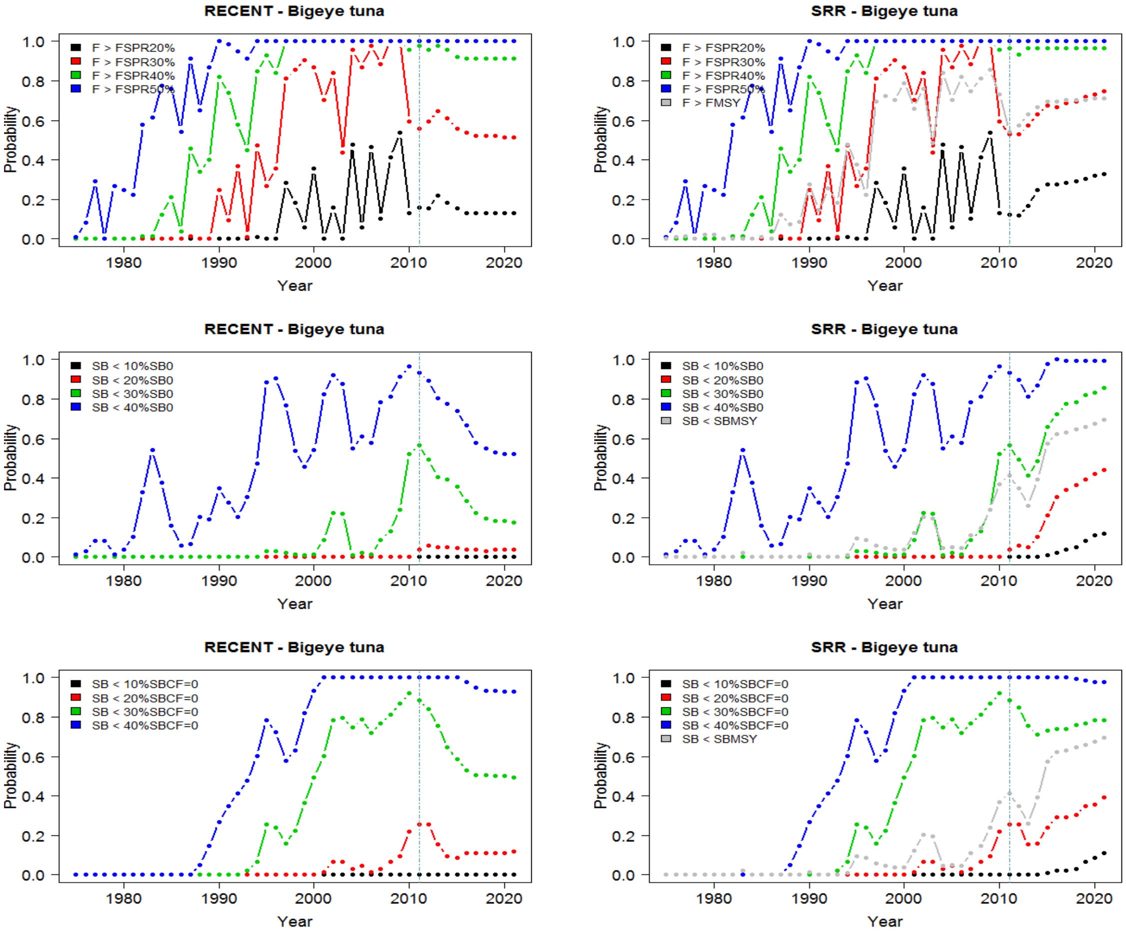


Figure 3: Probability that the bigeye tuna stock exceeds particular reference points (i.e., biomass fall below a biomass-based reference point or fishing mortality exceeds a fishing mortality-based reference point). Results are presented for projections based on recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).

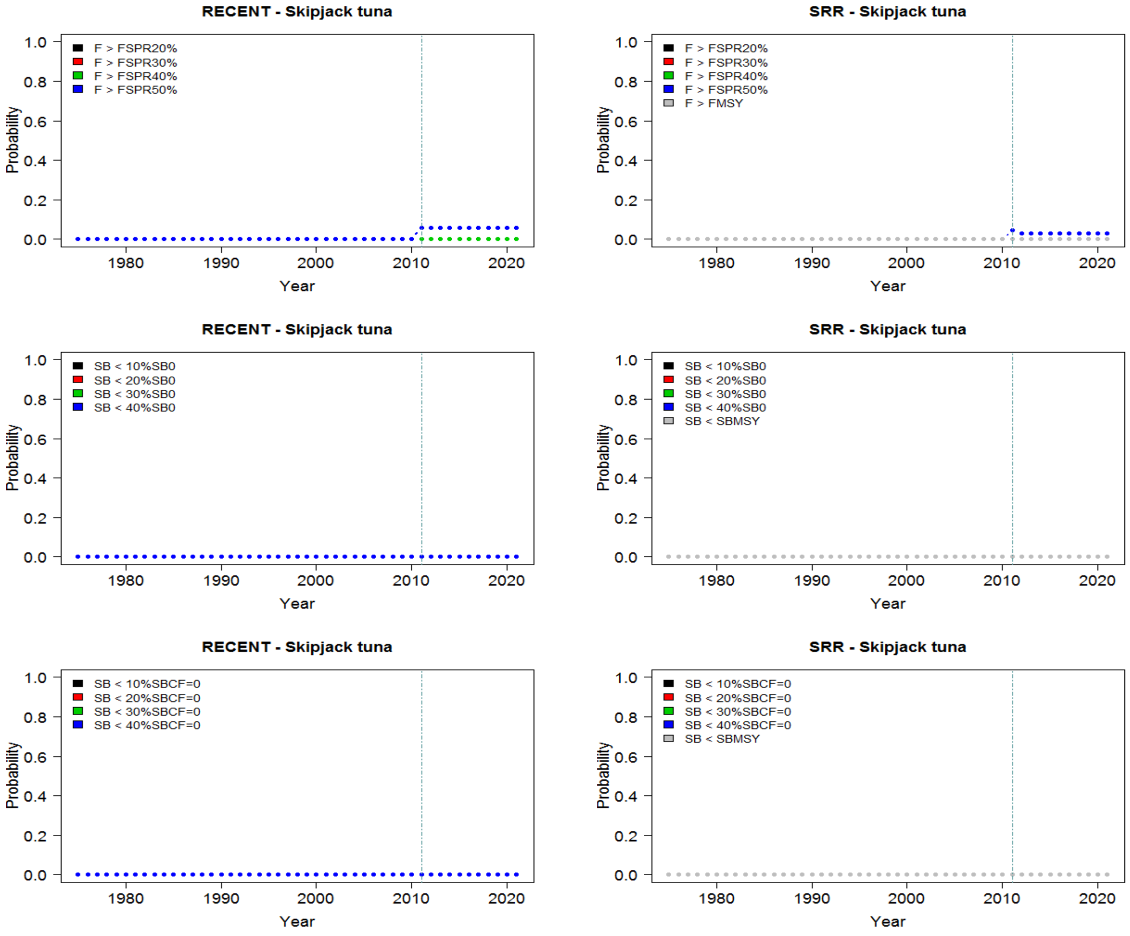


Figure 4: Probability that the skipjack tuna stock exceeds particular reference points (i.e., biomass fall below a biomass-based reference point or fishing mortality exceeds a fishing mortality-based reference point). Results are presented for projections based on recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).

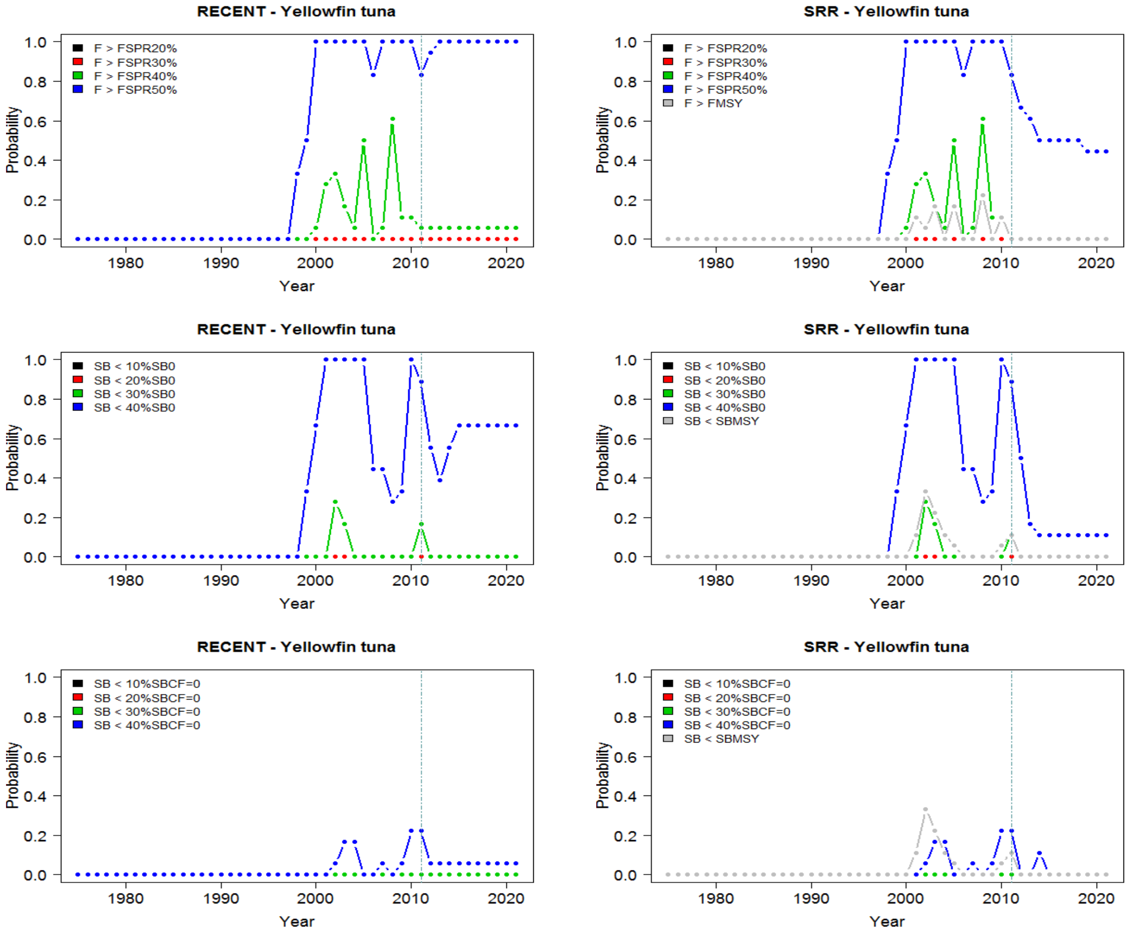


Figure 5: Probability that the yellowfin tuna stock exceeds particular reference points (i.e., biomass fall below a biomass-based reference point or fishing mortality exceeds a fishing mortality-based reference point). Results are presented for projections based on recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).

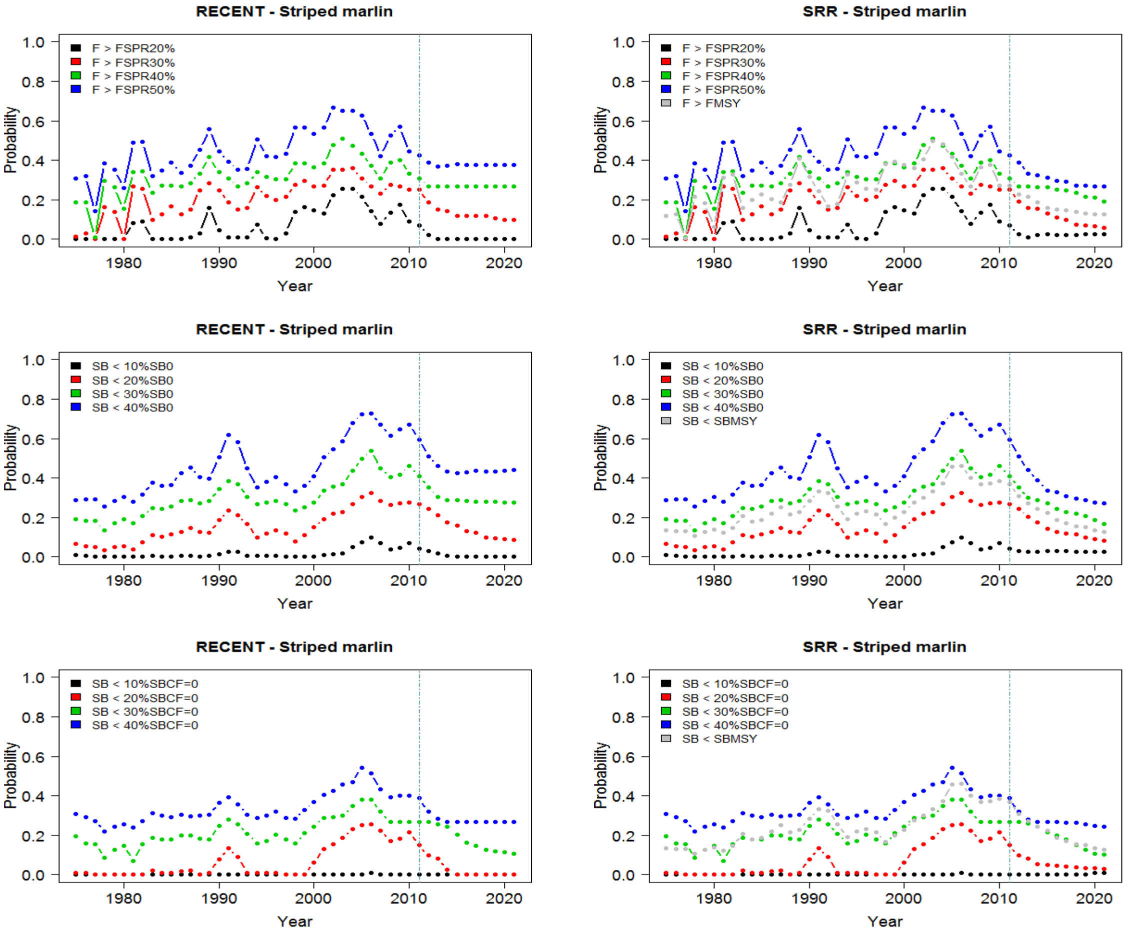


Figure 6: Probability that the striped marlin stock exceeds particular reference points (i.e., biomass fall below a biomass-based reference point or fishing mortality exceeds a fishing mortality-based reference point). Results are presented for projections based on recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).

Table 1: Probability of exceeding reference points in 2021 based on deterministic projections of status-quo conditions of structural uncertainty grid model runs for recent average recruitment (top) and recruitment predicted from the spawner recruitment relationship.

Recent average (ten years) recruitment

Indicator	Level (x)	SP ALB	BET	SKJ	YFT	STM
$SB_{2021}<xSB_0$	0.1	0.00	0.00	0.00	0.00	0.00
	0.2	0.05	0.04	0.00	0.00	0.09
	0.3	0.17	0.17	0.00	0.00	0.28
	0.4	0.31	0.52	0.00	0.67	0.44
$SB_{2021}<xSB_{2021,F=0}$	0.1	0.00	0.00	0.00	0.00	0.00
	0.2	0.09	0.12	0.00	0.00	0.00
	0.3	0.22	0.49	0.00	0.00	0.11
	0.4	0.34	0.93	0.00	0.06	0.27
$F_{2021}>FSPRx$	0.2	0.09	0.13	0.00	0.00	0.00
	0.3	0.23	0.51	0.00	0.00	0.10
	0.4	0.34	0.91	0.00	0.06	0.27
	0.5	0.49	1.00	0.06	1.00	0.38
$SB_{2021}<SB_{MSY}$						
$F_{2021}>F_{MSY}$		0.23	0.63	0.00	0.00	0.16

Spawner recruitment relationship

Indicator	Level	SP ALB	BET	SKJ	YFT	STM
$SB_{2021}<xSB_0$	0.1	0.14	0.12	0.00	0.00	0.02
	0.2	0.26	0.44	0.00	0.00	0.08
	0.3	0.35	0.86	0.00	0.00	0.17
	0.4	0.46	0.99	0.00	0.11	0.27
$SB_{2021}<xSB_{2021,F=0}$	0.1	0.14	0.11	0.00	0.00	0.01
	0.2	0.26	0.39	0.00	0.00	0.03
	0.3	0.35	0.78	0.00	0.00	0.10
	0.4	0.46	0.98	0.00	0.00	0.24
$F_{2021}>FSPRx$	0.2	0.26	0.33	0.00	0.00	0.02
	0.3	0.34	0.75	0.00	0.00	0.06
	0.4	0.45	0.96	0.00	0.00	0.19
	0.5	0.54	1.00	0.03	0.44	0.27
$SB_{2021}<SB_{MSY}$		0.27	0.70	0.00	0.00	0.13
$F_{2021}>F_{MSY}$		0.36	0.71	0.00	0.00	0.13

Annex 1: Boxplots of variation in stock status for various reference points and indicators

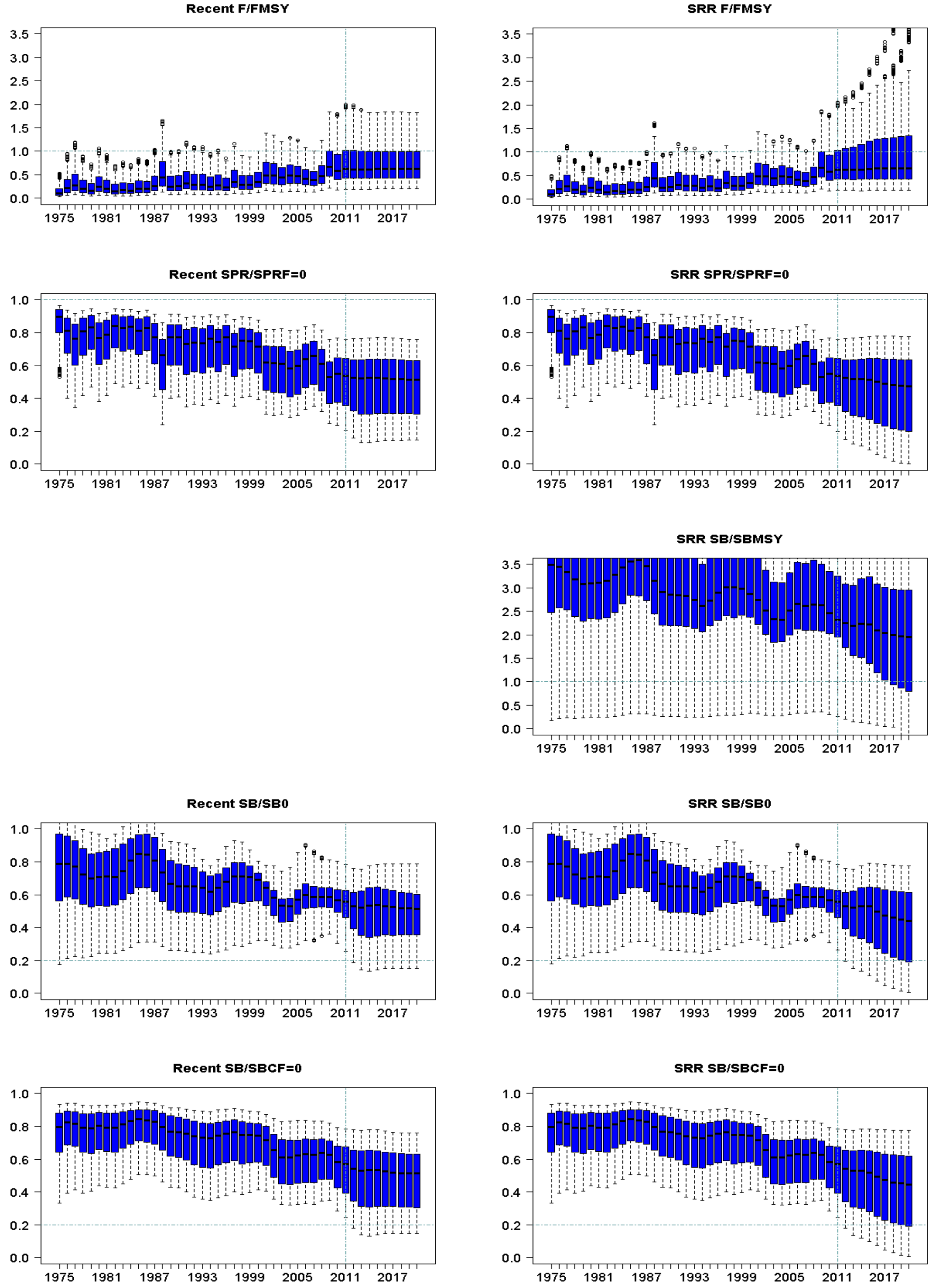


Figure 7: Boxplots of annual status of south Pacific albacore tuna against F- and S-based reference points based on the structural grid and recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).

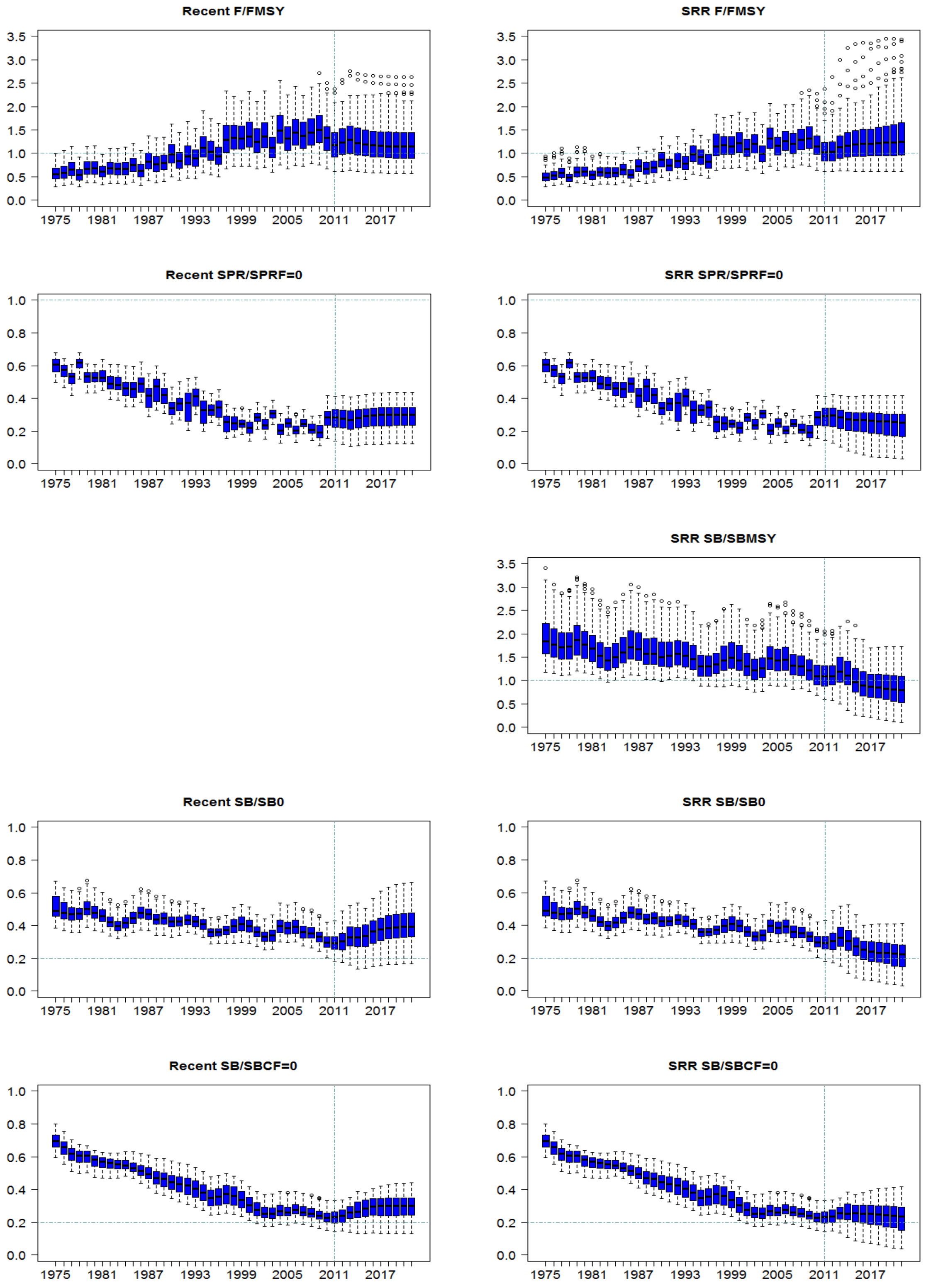
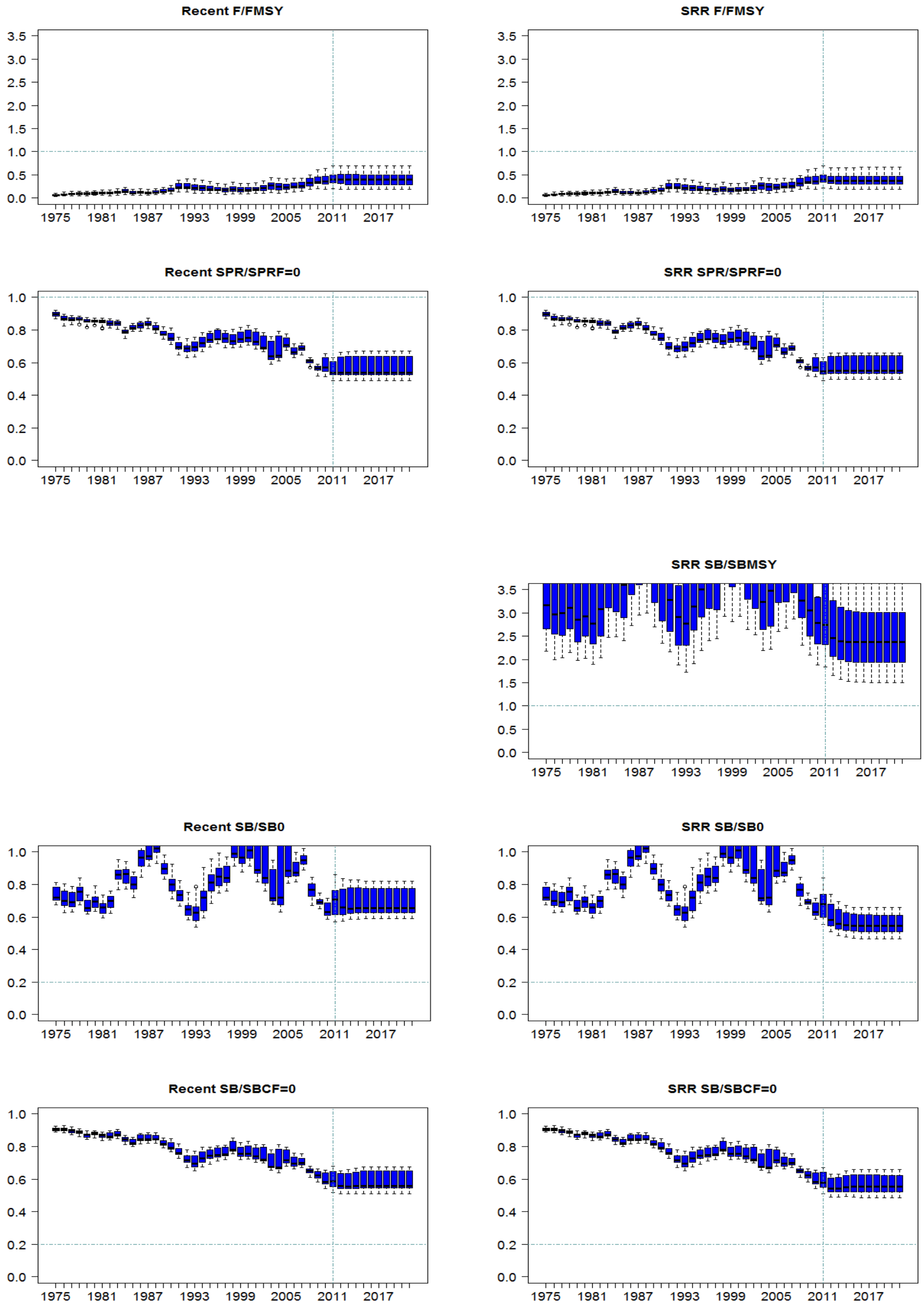


Figure 8: Boxplots of annual status of bigeye tuna against F- and S-based reference points based on the structural grid and recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).


Recent F/FMSY

SRR F/FMSY

Recent SPR/SPRF=0

SRR SPR/SPRF=0

SRR SB/SBMSY

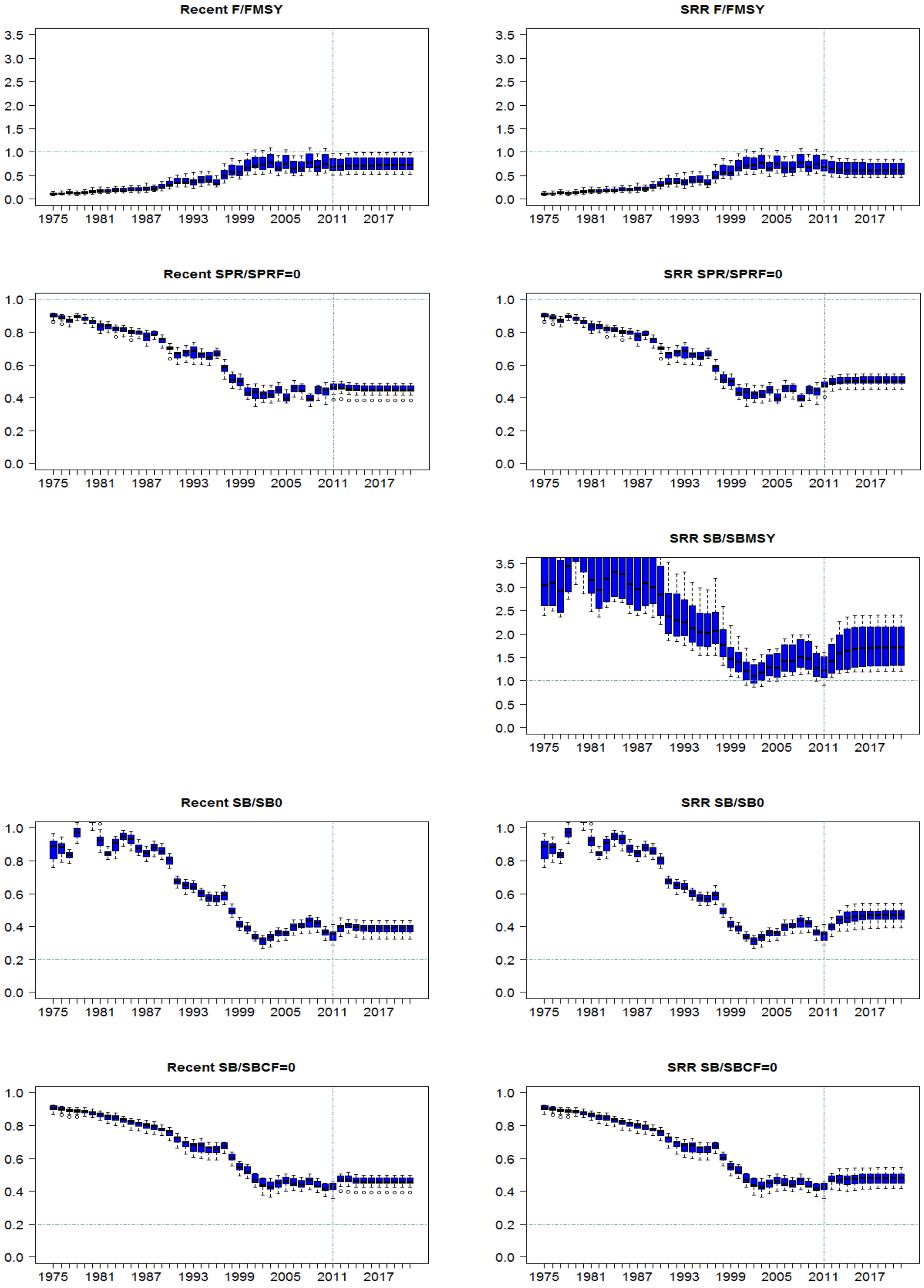
Recent SB/SB0

SRR SB/SB0

Recent SB/SBCF=0

SRR SB/SBCF=0

Figure 9: Boxplots of annual status of skipjack tuna against F- and S-based reference points on the structural grid and recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).



Recent F/FMSY

SRR F/FMSY

Recent SPR/SPRF=0

SRR SPR/SPRF=0

SRR SB/SBMSY

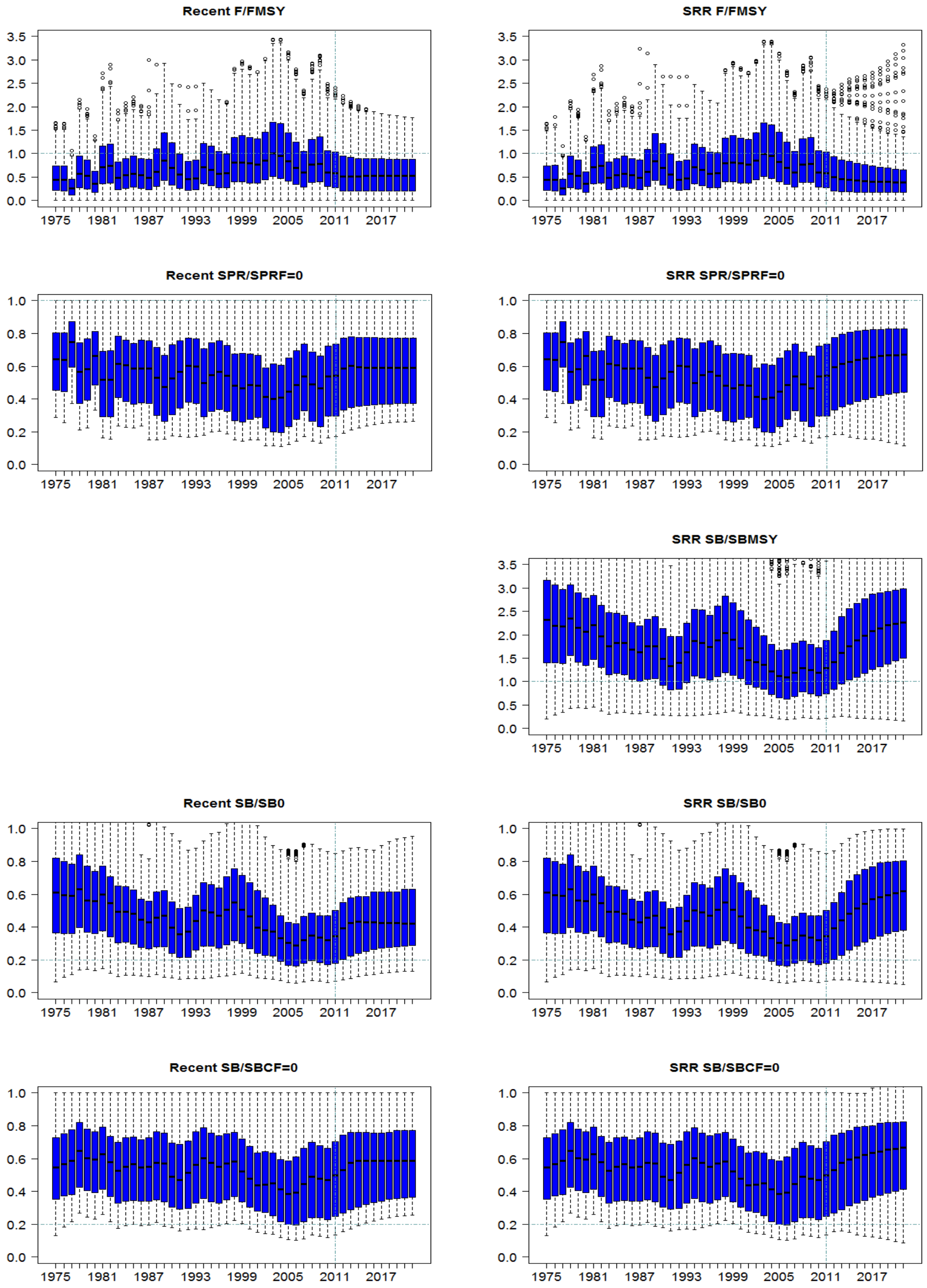
Recent SB/SB0

SRR SB/SB0

Recent SB/SBCF=0

SRR SB/SBCF=0

Figure 10: Boxplots of annual status of yellowfin tuna against F-based reference points based on the structural grid and recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).



Recent F/FMSY

SRR F/FMSY

Recent SPR/SPRF=0

SRR SPR/SPRF=0

SRR SB/SBMSY

Recent SB/SB0

SRR SB/SB0

Recent SB/SBCF=0

SRR SB/SBCF=0

Figure 11: Boxplots of annual status of southwest Pacific striped marlin against F and S-based reference points based on the structural grid and recent average recruitment (left) and spawner-recruitment relationship predicted recruitment (right).